QoS-Aware Management of Monotonic Service Orchestrations

A 5 years project, jointly developed with A. Benveniste and 2 PhDs at IRISA/INRIA, in collaboration with Misra's group in Austin UT

June 22, 2012

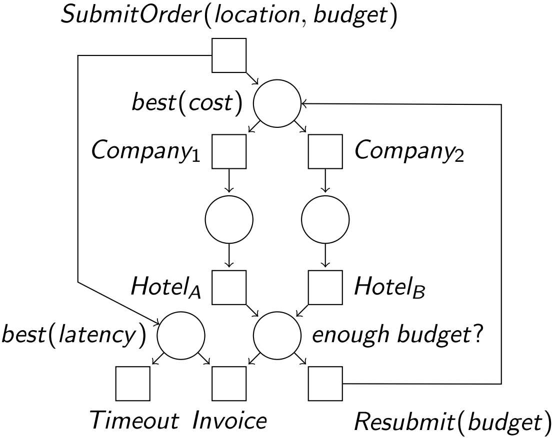
Wide-area computing

- Services are building blocks for creating open distributed applications
- Services may be composed together to form new services (orchestrations, choreographies)
- Importance of contracts in an open world (SLAs), including non functional aspects (latency, security, cost, ...)
- Managing business processes over a Web infrastructure
- The example of ORC programming language (J. Misra, Austin), as an clean alternative of BPEL

Typical example

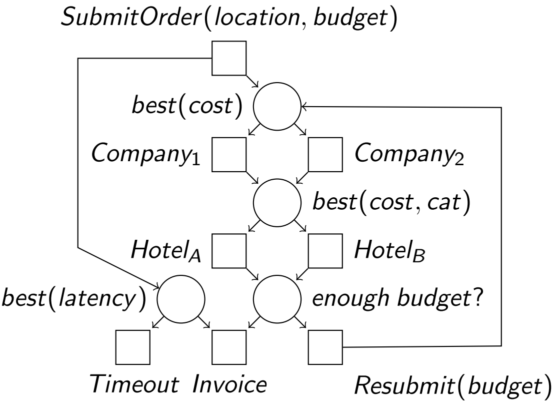
- A typical example alike travel services: a service is composed by reusing existing services exposed by other providers seen as sub-contractors.
- Garantees must be offered:
  - Functional: the composed service shall offer what it is supposed to
  - QoS: with some agreed security and performance (SLA)

Small example in a Petri net style



- Data-dependent workflow
- Multi-dimensional QoS

Small example in a Petri net style



- Data-dependent workflow
- Multi-dimensional QoS

QoS analysis (quite different from networks)

- Combining transactional Web services
  - Seen as "black-" or "grey-boxes", exposed through their semantically rich interface (WSDL++,WSLA++, ...)
  - Infrastructure-agnostic (SOAP, REST)
- Semi-open world
  - Typically professional
  - Extranet, E-enterprise, E-business
  - Business management
  - Good balance btw fubnctionality, security, safety/correctness, and QoS
- Tangency with automation management, and, to a lesser extent, manufacturing systems design
- a world of **contracts**

Outline

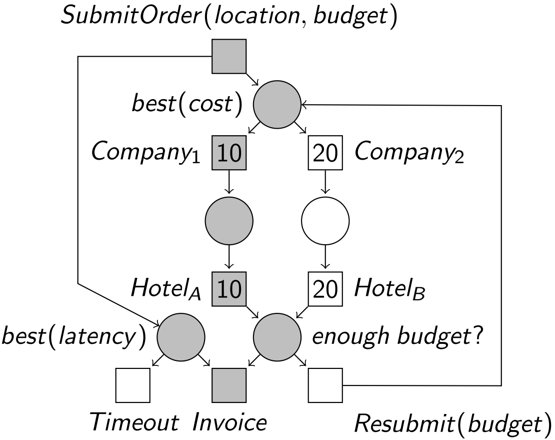
Monotonicity

Implicit assumption in contract-based management:

QoS improvements in component services can only be better for the composite service.

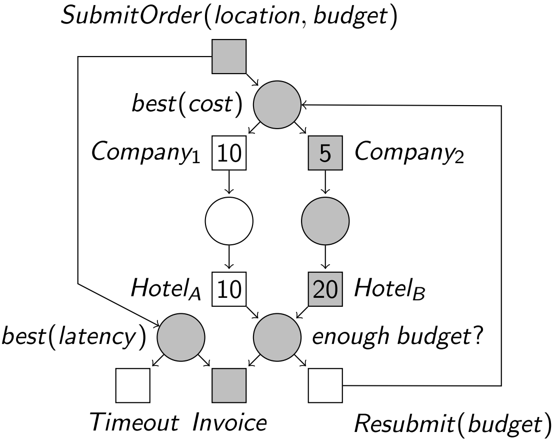
- Can be false...

Non monotonicity



- End-to-end cost = 20

Non monotonicity



- Cost of *Company*$_2$ has been improved to 5
- End-to-end cost = 25 is worse!

Theorems

- Loose monotonicity: considering maximum QoS for all possible branching choices ensures monotonicity. May lead in practice to very pessiministic QoS estimations.
- Computing branching cells (by unfolding) allows for detection of non monotonicity. Monotonicity is undecidable in general.
- A syntactical sufficient condition for monotonicity is that, each time branching has occurred in net N, a join occurs right after.

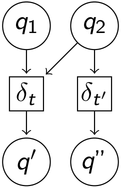
QoS domain

- Partially ordered domain $\mathbf{Q} = (\mathbf{D}, \leq, \oplus, \triangleleft)$ that is a complete upper lattice (the least upper bound operator $\vee$ meaning taking the "worst" QoS and is used during synchronization)
- Operator $\oplus : \mathbf{D} \times \mathbf{D} \rightarrow \mathbf{D}$ captures how a transition increments the QoS value. $\oplus$ must be monotonic w.r.t. $\leq$
- Competition function $\triangleleft : \mathbf{D} \times \mathbf{D}^* \rightarrow \mathbf{D}$ (must be also monotonic)

Examples of QoS domains

- Latency: $\mathbf{Q} = (\mathbf{R}^+, \leq, +, \lhd)$ where $d_1 \lhd d_2 = d_1$ (the winner is the first arrived)
- Security: $\mathbf{Q} = (\{\text{low,high}\}, \text{high} \leq \text{low}, \vee, \lhd)$
- Cost: $\mathbf{Q} = (\{1\} \rightarrow \mathbf{N}, \subseteq, +, \lhd)$
- Composite QoS (product): $\mathbf{Q} = ((\mathbf{D}_1, \mathbf{D}_1), \leq_1 \times \leq_2, +, (\lhd_1, \lhd_2))$
- Composite QoS (priority): suppose $\mathbf{Q_1}$ is security and $\mathbf{Q_2}$ is latency.
  - $\leq$ is the lexicographic order from $(\leq_1, \leq_2)$
  - $(s, d) \lhd (s', d') =$ if $d \leq d'$ and $s = \mathit{low}$ then (s, d') else (s, d) (wait is needed to decide who wins the competition)

QoS computation



- Tokens bring the QoS information
- If $((q_1 \vee q_2) \oplus \delta_t) \leq (q_2 \oplus \delta_{t'})$ then t fires and $q' = ((q_1 \vee q_2) \oplus \delta_t) \triangleleft (q_2 \oplus \delta_{t'})$
- If $((q_1 \vee q_2) \oplus \delta_t) \geq (q_2 \oplus \delta_{t'})$ then t' fires and $q" = (q_2 \oplus \delta_{t'}) \triangleleft ((q_1 \vee q_2) \oplus \delta_t)$
- Else choose non deterministically to fire t or t'

ORC (Misra's group at Austin UT)

- **Sites:** the fundamental unit of computation. Similar to functions but may be remote and therefore unreliable. Publishes the value returned by the site.
- **Combinators:** only four:
  - do f and g in parallel: $f \mid g$
  - for all x from f do g (sequential composition): $f >x> g$
  - for some x from g do f (pruning): $f <x< g$
  - if f completes without publishing do g (otherwise): f **;** g
- functions
- a lot of built-in sites

Symmetric composition $f \mid g$

- Evaluate f and g independently
- Publish all values from both
- No direct communication of interaction between f and g. They can communicate only through sites.
- **Example:**

$$CNN(d) \mid BBC(d)$$

returns $0, 1$ or 2 values.

Sequential composition $f \; {>}x{>} \; g$

- For all values published by f do g
- Publish only the values from g
- **Example:**

$$CNN(d) \; {>}x{>} \; Email(address, x)$$

- **Example:**

$$(CNN(d) \mid BBC(d)) \; {>}x{>} \; Email(address, x)$$

may call *Email* twice.

Pruning $f <x< g$

- Evaluate f and g in parallel. Site calls that need x are suspended.
- **Example:**

$$(M() \mid N(x)) <x< g$$

- When g returns a (first) value, bind the value to x, terminate g and resume suspended calls.
- **Example:**

$$Email(address, x) <x< (CNN(d) \mid BBC(d))$$

sends at most one email.

Fork-join parallelism

- Call M and N in parallel
- Return their values as a tuple after both respond
- **Example:**

$$((u, v) < u < M()) < v < N()$$

Otherwise f ; g

Do f. If f completes without publishing then do g.

- An expression completes if its execution can take no more steps, and all called sites have either responded, or will never respond.
- All library sites in ORC are helpful (indicate if they halt).
- **Example:**

$$(h >x> println(x) \gg ift(false)) \;;\; "done"$$

- **Example:** print all publications of h. When h completes, publish "done".

Concurrent function calls

$$\textbf{def}\ \mathit{Metronome}() = \mathit{signal} \mid (\mathit{Rwait}(1000) \gg \mathit{Metronome}())$$

$$(\mathit{Metronome}() \gg \text{"}\mathit{tick}\text{"}) \mid (\mathit{Rwait}(500) \gg \mathit{Metronome}() \gg \text{"}\mathit{tock}\text{"})$$

Causality and QoS

Goal:

- Specified as an ORC program transformation: $P \rightarrow P'$
- P' behaves as P, but produces extra information about causality and QoS

Approach:

- Events in ORC are site calls (and returns) and publications (including intermediate ones)
- The idea is to instrument each event e with causal and QoS additional information: $(e, pre(e), q(e))$

Causality tracking as a basis for QoS computation

Original program P

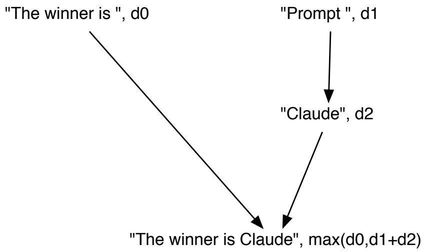
```
("The winner is " + x) <x< (Prompt("?") | Prompt("?"))
```

Transformed program P'

```
(x>(vx,_)>
("The winner is " + vx,("The winner is ",[]):[x]))
     <x< ((("Prompt",[])>u1>Prompt("?")>w1>(w1,[u1])) |
          (("Prompt",[])>u2>Prompt("?")>w2>(w2,[u2])))
```

Example of response times

```
("The winner is Claude", [("The winner is ", []),
("Claude", [("Prompt", [])])])
```



The ORC calculus

$$
\begin{array}{llll}
v & \in & \text{Value} & \\
x, x_1, \ldots, x_n & \in & \text{Variable} & \\
f, g & \in & \text{Expression} & ::= \; v \mathbin{\textbf{|}} x \mathbin{\textbf{|}} x(x_1, \ldots, x_n) \mathbin{\textbf{|}} f \mid g \mathbin{\textbf{|}} \\
 & & & \quad f > x > g \mathbin{\textbf{|}} f < x < g \mathbin{\textbf{|}} f \; \textbf{;} \; g \mathbin{\textbf{|}} \\
 & & & \quad \textbf{def } x(x_1, \ldots, x_n) = fg
\end{array}
$$

Transformation rules for causality

$$
\begin{array}{rcl}
[\![v]\!]_c & \rightarrow & (v, c) \\
[\![x]\!]_c & \rightarrow & (v, \{x\} \cup c) <(v, \_)< x \ \{\text{- } v \text{ fresh -}\} \\
\text{– function call} & & \{\text{- } v_1, c_1, \ldots, v_n, c_n \text{ fresh -}\} \\
[\![x(x_1, \ldots, x_n)]\!]_c & \rightarrow & x((v_1, c_1 \cup c) < (v_1, c_1) < x_1, \ldots, \\
 & & (v_n, c_n \cup c) < (v_n, c_n) < x_n) \\
\text{– site call} & & \{\text{- } v_1, c_1, \ldots, v_n, c_n, Y, u, v' \text{ fresh -}\} \\
[\![x(x_1, \ldots, x_n)]\!]_c & \rightarrow & ((x, \bigcup_{1 \leq i \leq n} c_i \cup c) >u> x(v_1, \ldots, v_n) \\
 & & >(v', Y)> (v', Y \cup \{u\})) \\
 & & <(v_1, c_1)< x_1 \ldots \ <(v_n, c_n)< x_n \\
[\![f \mid g]\!]_c & \rightarrow & [\![f]\!]_c \mid [\![g]\!]_c \\
[\![f >x> g]\!]_c & \rightarrow & [\![f]\!]_c >x> [\![g]\!]_{\{x\}} \\
[\![f <x< g]\!]_c & \rightarrow & [\![f]\!]_c <x< [\![g]\!]_c \\
[\![\textbf{def } x(x_1, \ldots, x_n) = fg]\!]_c & \rightarrow & \textbf{def } x(x_1, \ldots, x_n) = [\![f]\!]_c [\![g]\!]_c
\end{array}
$$

The otherwise operator: tracking halts

All events inside the scope of the $f; g$ operator are recorded in a buffer. When f halts, they form the causes of the halting event h, cause of g.

$$
\begin{array}{l}
\text{val trace} = \text{Buffer}() \\
\quad \textbf{def } max([], u) = trace.put(u) \\
\quad \textbf{def } max(m : ms, (x, px)) = \text{ if member}(m, px) \text{ then signal} \\
\qquad\quad \text{else } trace.put(m)) \gg \text{ max}(ms, (x, px)) \\
\textbf{def } record(u) = trace.getAll() >ms> \text{max}(ms, u) \\
\textbf{def } track(u) = (u, record(u)) > (y, \_) > y
\end{array}
$$

$$
\llbracket f \text{ ; } g \rrbracket_c \quad \rightarrow \quad \llbracket f \rrbracket_c \text{ ; } track(("h", trace.getAll())) >x> \llbracket g \rrbracket_{\{x\}}
$$
$$
-x \text{ fresh}
$$

Extension with QoS

Consider the general case of composite QoS domain, which is partially ordered

$$\mathbb{Q} = (\mathbb{D}_q, \leq_q, \oplus_q)$$

- Each event is equipped with a QoS increment value

$$e = ((v, q, Q), pre(e))$$

- The associated QoS may be recursively computed using the causal past

$$Q(e) \quad = \quad \underbrace{\left(\bigvee_{e' \in pre(e)} Q(e') \right)}_{\text{synchronizing the causes}} \quad \oplus \quad \underbrace{q(e)}_{\text{increment}}$$

Extending ORC with a best QoS pruning operator: solving conflicts by QoS competition

New pruning operator Demands in general to wait for all the first publications of g

$$f \ {<}x{<_{\mathbf{q}}}\ g$$

$$\mathbb{Q} = (\mathbb{D}_q, \leq_q, \oplus_q, \lhd_q)$$

- Direct conflicts are recorded with the event

$$e = ((v, q, Q)pre(e), directconflicts(e))$$

- Used in the QoS computation

$$Q(e) \ = \ \left(\left(\bigvee_{e' \in pre(e)} Q(e')\right) \oplus_q q(e)\right) \lhd \left(Q(e') \mid e' \in \#(e)\right)$$

Implementation: the principles

- Separate description of the composite QoS domain and its related algebra
- The original ORC program is then weaved (instrumented) with the QoS description
- Publications of the weaved program contain the QoS information
- Use of XML/OIL intermediate form
  - This form is parsed and printed using SCALA functions
  - Rules are implemented using ORC expressions and sites implemented in SCALA
  - The ORC engine executes the transformed OIL program

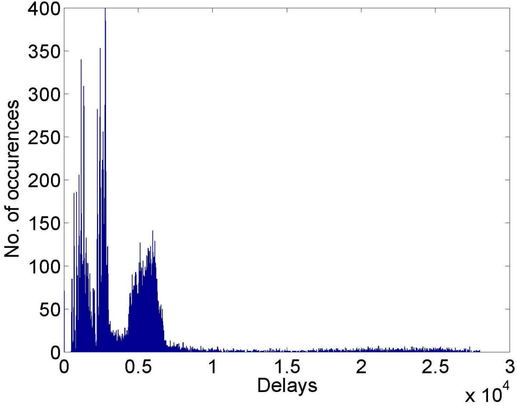
SLA description in ORC

```
def bestQoS(comparer, publisher) = head(sortBy(comparer, publisher))
def class InterQueryTime()=
   def QoS(sitex) =
   val s = {. r = Ref(0), c = Channel() .}
   val curTime = Rclock().time()
   s.r? >p> (s.c.put(curTime-p) | s.r:=(curTime)) >>
            Dictionary() >sitex> sitex.InterQueryTime := s
   def QoSCompare(it1,it2) = it1 >= it2
   def QoSCompete(it1,it2) = bestQoS(QoSCompare,[it1,it2])
stop

def class ResponseTime() =
   def QoS(sitex,d) = Rclock().time()-d + 100 >q> q
   def QoSOplus(rt1,rt2) = rt1+rt2
   def QoSCompare(rt1,rt2) = rt1 <= rt2
   def QoSCompete(rt1,rt2) = bestQoS(QoSCompare,[rt1,rt2])
   def QoSVee(rt1,rt2) = max(rt1,rt2)
stop

def class Cost() =
   def QoS(sitex,c)=
   val s = Ref([])
   s? >x> QoSOplus(x,[]) >q> s:= q >> Dictionary() >sitex> sitex.Cost := s
   def QoSOplus(c1,c2) =
   def Oplus([],[]) = []
      def Oplus(x:xs,y:ys) = (x+y):Oplus(xs,ys)
   Oplus(c1,c2)
   def QoSCompare(c1,c2) =
      def Compare([],[]) = true
      def Compare(x:xs,y:ys) = (x <= y) && Compare(xs,ys)
      Compare(c1,c2)
   def QoSCompete(c1,c2) = bestQoS(QoSCompare,[c1,c2])
   def QoSVee(c1,c2) =
   def Vee([],[]) = []
   def Vee(x:xs,y:ys) = max(x,y):Vee(xs,ys)
   Vee(c1,c2)
stop
```

QoS contracts cannot rely on hard bounds

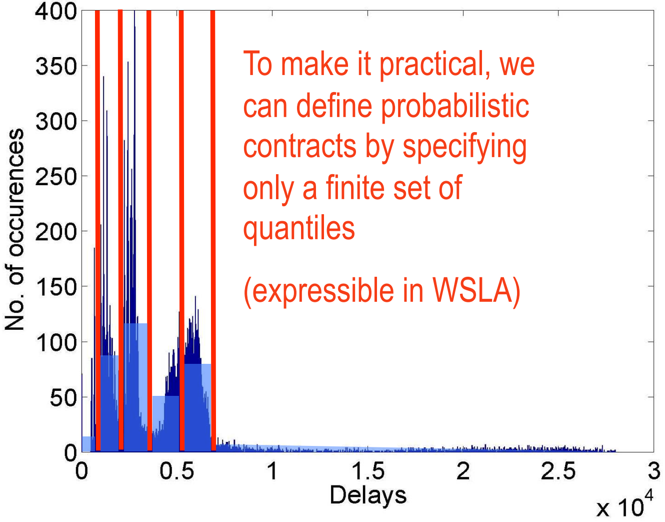


- Why not a soft bound, covering 95% of the cases?
- Unfortunately, such contracts do not compose
- Idea: a contract is a probability distribution

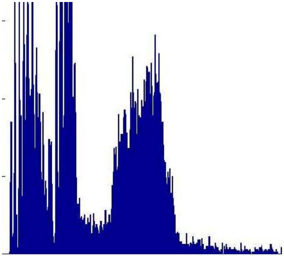
Probabilistic contracts

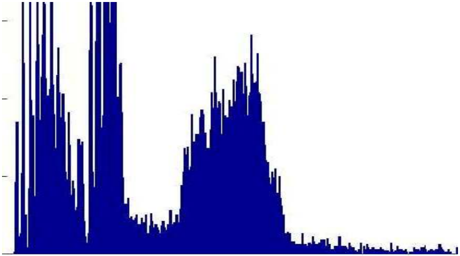
- The contract consists of a probability distribution
- Probas compose well:
  - use Max-Plus probabilistic algebra if the control is deterministic
  - otherwise run Monte-Carlo simulations
- QoS distributions can result
  - from contracts
  - from measurements

Probabilistic contracts in practice



Statistical monitoring

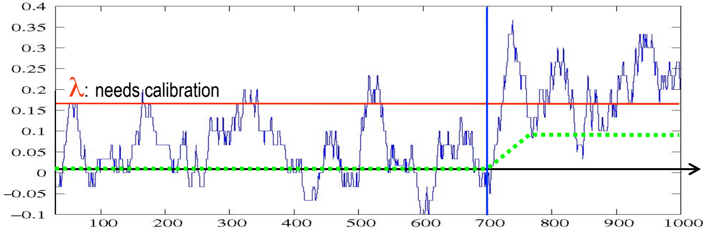




- The specified contract $F(x) = Pr(\delta \leq x)$ (probability density)
- A distribution $G(x)$ breaching the contract, meaning that
  - $\neg(G \geq_S F)$, where $\geq_S$ denotes stochastic dominance ($\forall x, G(x) \geq F(x)$)
  - G is unknown: it is observed. How to perform on-line detection of the contract violation?

On-line detection

- Actual test running with t: $sup_x[F(x) - G_{[t,t+N]}(x)] \geq \lambda$
- $G_{[t,t+N]}(x)$ empirical distribution function based on $[t, t+N]$



- Calibration is performed by bootstrapping:
  1. Build large training data set (Monte-Carlo simulation of contract distribution)
  2. Resample it many times by selecting $N-$size trials
  3. Tune λ so that 95% of trials are accepted

Conclusion

Web services orchestrations or choreographies are a world of contracts

- SLA: function & QoS jointly
- The paradigm of contracts (composition, monitoring, reconfiguration)
- Novel issues
  - Function: workflow & data
  - QoS: monotonicity
  - QoS: soft contracts

Conclusion

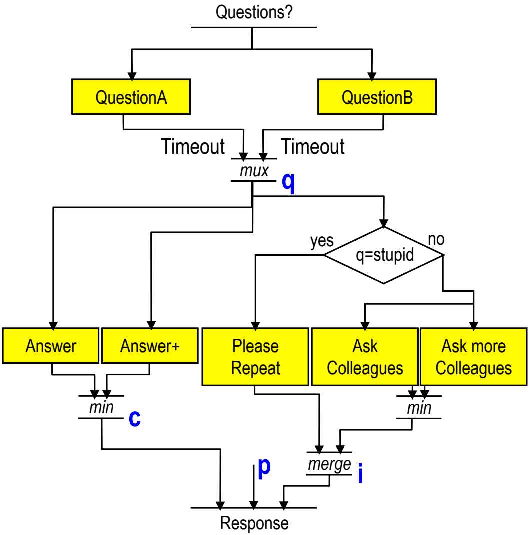
We have propose a comprehensive approach

- QoS algebra
- Probabilistic soft contracts
- Contract composition
- Statistical contract monitoring
- Reconfiguration?

A mix of techniques

- Formal concurrent models for orchestrations (ORC, Petri nets)
- Monte-Carlo simulation
- Bootstrap methods from statistics

Thank you


Questions?
QuestionA
QuestionB
Timeout
Timeout
mux
q
yes
q=stupid
no
Answer
Answer+
Please Repeat
Ask Colleagues
Ask more Colleagues
min
c
min
p
merge
i
Response

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