

A Formal Account of Contracts for Web Services

Samuele Carpineti, Giuseppe Castagna, Cosimo Laneve, Luca Padovani

University of Bologna, University of Urbino, École Normale Supérieure de Paris

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Summary

Part I

- Contracts and technologies for Web Services
- A language of contracts
- Desirable properties of the subcontract relation

Part II

- Subcontract relation and contract compliance
- Contract synthesis and process compliance
- Contract compliance \Rightarrow process compliance

Concluding remarks

Reasoning about compatibility of behavior

Why is it important to formalize the contract of a client or of a service?

Use:

- dynamic discovery
- dynamic composition
- type checking
- debugging
- automatic code generation
- run-time analysis

Focus:

- communication between two parties (no choreography)

Contracts in WSDL

Focus on the static interface:

- Interface = set of operations
- Operation = name + **message exchange pattern** (MEP)

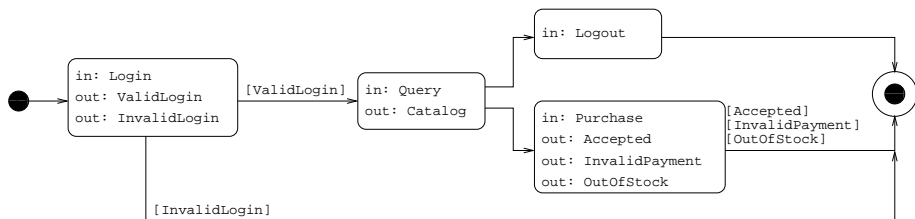
```
<operation name="A"  
  pattern="http://www.w3.org/2006/01/wsdl/in-only">  
  <input messageLabel="In"/>  
</operation>
```

```
<operation name="B"  
  pattern="http://www.w3.org/2006/01/wsdl/robust-in-only">  
  <input messageLabel="In"/>  
  <outfault messageLabel="Fault"/>  
</operation>
```

Contracts in WSCL

Focus on the dynamic interface:

- Conversation = Interactions + Transitions
- Interaction = Types of exchanged messages



- + distinction between internal and external choice
- + possibly cyclic patterns

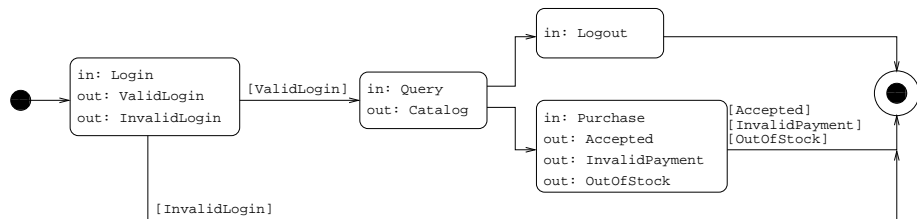
Encoding MEPs into contracts

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</operation>
```

$$\begin{array}{l} A \stackrel{\text{def}}{=} \text{In}.\overline{\text{End}} \\ B \stackrel{\text{def}}{=} \text{In}.\overline{(\text{End} \oplus \text{Fault}.\overline{\text{End}})} \end{array}$$

Encoding WSCL into contracts



$\text{Login.}(\overline{\text{InvalidLogin.End}} \oplus \overline{\text{ValidLogin.Query.Catalog.}}(\text{Logout.End} + \text{Purchase.}(\overline{\text{Accepted.End}} \oplus \overline{\text{InvalidPayment.End}} \oplus \overline{\text{OutOfStock.End}})))$

A formal contract language

contracts $\sigma ::=$

- $\mathbf{0}$ (*void*)
- $\alpha.\sigma$ (*action prefix*)
- $\sigma + \sigma$ (*external choice*)
- $\sigma \oplus \sigma$ (*internal choice*)

actions $\alpha ::=$

- a (*name*)
- \bar{a} (*co-name*)

Names represent **types, operations, ...**

c.f. De Nicola, Hennessy, "CCS without τ 's", 1984

Comparing contracts: the **subcontract** relation \preceq

σ is a subcontract of σ' if σ' is *more deterministic* than σ

$$a \oplus b \preceq a \qquad a \oplus b \preceq a + b$$

$$\text{In.}(\overline{\text{End}} \oplus \overline{\text{Fault.}}\overline{\text{End}}) \preceq \text{In.}\overline{\text{End}}$$

(c.f. *must pre-order*)

σ is a subcontract of σ' if σ' has *more interacting capabilities* than σ

$$a \preceq a.b \qquad a \preceq a + b \qquad \mathbf{0} \preceq \sigma$$

$$\text{Logout} + \text{Purchase} \preceq \text{Logout} + \text{Purchase} + \text{BuyLater}$$

(\preceq is different from testing, must, may, ...)

Summary of the technical part

- 1 define contract transition and ready sets
- 2 define subcontract \preceq and contract compliance \ll
- 3 synthesize contracts out of processes
- 4 define process compliance as “successful interaction”
- 5 prove that contract compliance implies process compliance

Contracts: transition relation

Interacting party's point of view:

$$a.b + a.c \xrightarrow{a} b \oplus c$$

$$\alpha.\sigma \xrightarrow{\alpha} \sigma$$

$$\frac{\sigma_1 \xrightarrow{\alpha} \sigma'_1 \quad \sigma_2 \xrightarrow{\alpha} \sigma'_2}{\sigma_1 + \sigma_2 \xrightarrow{\alpha} \sigma'_1 \oplus \sigma'_2}$$

$$\frac{\sigma_1 \xrightarrow{\alpha} \sigma'_1 \quad \sigma_2 \xrightarrow{\alpha} \sigma'_2}{\sigma_1 + \sigma_2 \xrightarrow{\alpha} \sigma'_1}$$

$$\frac{\sigma_1 \xrightarrow{\alpha} \sigma'_1 \quad \sigma_2 \xrightarrow{\alpha} \sigma'_2}{\sigma_1 \oplus \sigma_2 \xrightarrow{\alpha} \sigma'_1 \oplus \sigma'_2}$$

$$\frac{\sigma_1 \xrightarrow{\alpha} \sigma'_1 \quad \sigma_2 \xrightarrow{\alpha} \sigma'_2}{\sigma_1 \oplus \sigma_2 \xrightarrow{\alpha} \sigma'_1}$$

Contracts: ready sets

$\sigma \Downarrow R$: the service **can be** in a state where the actions in R are allowed

$$\mathbf{0} \Downarrow \emptyset$$

$$\alpha.\sigma \Downarrow \{\alpha\}$$

$$(\sigma + \sigma') \Downarrow R \cup R' \quad \text{if } \sigma \Downarrow R \text{ and } \sigma' \Downarrow R'$$

$$(\sigma \oplus \sigma') \Downarrow R \quad \text{if either } \sigma \Downarrow R \text{ or } \sigma' \Downarrow R$$

Example of internal choice:

$$a \oplus b \Downarrow \{a\}$$

$$a \oplus b \Downarrow \{b\}$$

Example of external choice:

$$a + b \Downarrow \{a, b\}$$

Subcontract relation

\preceq is the largest relation such that $\sigma_1 \preceq \sigma_2$ implies:

- 1 if $\sigma_2 \Downarrow R_2$ then $\sigma_1 \Downarrow R_1$ with $R_1 \subseteq R_2$
- 2 if $\sigma_1 \xrightarrow{\alpha} \sigma'_1$ and $\sigma_2 \xrightarrow{\alpha} \sigma'_2$ then $\sigma'_1 \preceq \sigma'_2$

Key:

- 1 σ_2 has no more internal states than σ_1 has:

$$a \oplus b \preceq a \qquad a \oplus b \preceq b$$

and they all allow more capabilities than those in σ_1 :

$$a \oplus b \preceq a + b \qquad a \preceq a + b$$

- 2 if σ_1 and σ_2 share a common action, the continuations are in the subcontract relation:

$$\mathbf{0} \preceq \sigma \qquad a.b \preceq a.b + c$$

Client/service duality and contract compliance

If a client P has contract σ , what is the “cheapest” contract that a service should expose to interact successfully with P ?

$$\begin{aligned} a \oplus b &\Rightarrow \bar{a} + \bar{b} \\ a + b &\Rightarrow \bar{a} \oplus \bar{b} && \text{also } \bar{a} \dots \\ a.b + a.c &\Rightarrow \bar{a}.\bar{b} \oplus \bar{a}.\bar{c} && \text{NO!} \\ a.b + a.c &\Rightarrow \bar{a}.\overline{(b + c)} \end{aligned}$$

The **dual contract** of σ is defined on σ 's normal form:

$$\begin{aligned} \sigma &\simeq \bigoplus_{\sigma \Downarrow_{\mathbb{R}}} \sum_{\sigma \xrightarrow{\alpha} \sigma', \alpha \in \mathbb{R}} \alpha.\sigma' \\ \bar{\sigma} &\stackrel{\text{def}}{=} \sum_{\sigma \Downarrow_{\mathbb{R}, \mathbb{R} \neq \emptyset}} \bigoplus_{\sigma \xrightarrow{\alpha} \sigma', \alpha \in \mathbb{R}} \bar{\alpha}.\bar{\sigma}' \end{aligned}$$

Contract compliance:

$$\sigma \ll \sigma' \stackrel{\text{def}}{=} \bar{\sigma} \preceq \bar{\sigma}'$$

Simple processes: finite CCS without choice

Syntax:

$$P ::= \mathbf{0} \mid a.P \mid \bar{a}.P \mid P \setminus a \mid P \mid P$$

Transition relation:

$$\text{(IN)} \quad a.P \xrightarrow{a} P$$

$$\text{(OUT)} \quad \bar{a}.P \xrightarrow{\bar{a}} P$$

$$\text{(RES)} \quad \frac{P \xrightarrow{\mu} Q \quad \mu \notin \{a, \bar{a}\}}{P \setminus a \xrightarrow{\mu} Q \setminus a}$$

$$\text{(PAR)} \quad \frac{P \xrightarrow{\mu} Q}{P \mid R \xrightarrow{\mu} Q \mid R}$$

$$\text{(COM)} \quad \frac{P \xrightarrow{\alpha} P' \quad Q \xrightarrow{\bar{\alpha}} Q'}{P \mid Q \xrightarrow{\tau} P' \mid Q'}$$

How do we characterize a “successful interaction” of a **system** $P \parallel Q$?

System transition:

- if $P \xrightarrow{\tau} P'$ then $P \parallel Q \longrightarrow P' \parallel Q$;
- if $Q \xrightarrow{\tau} Q'$ then $P \parallel Q \longrightarrow P \parallel Q'$;
- if $P \xrightarrow{\alpha} P'$ and $Q \xrightarrow{\bar{\alpha}} Q'$ then $P \parallel Q \longrightarrow P' \parallel Q'$.

P is **compliant with** Q , notation $P \ll Q$, if either

- 1 $P \xrightarrow{\alpha} \rightarrow$, or
- 2 $P \parallel Q \longrightarrow P' \parallel Q'$ implies $P' \ll Q'$

Synthesizing contracts from processes

The **type system**:

$$\vdash \mathbf{0} : \mathbf{0} \quad \frac{\vdash P : \sigma}{\vdash \alpha.P : \alpha.\sigma} \quad \frac{\vdash P : \sigma}{\vdash P \setminus a : \sigma \setminus a} \quad \frac{\vdash P : \sigma \quad \vdash Q : \sigma'}{\vdash P | Q : \sigma | \sigma'}$$

The \setminus meta-operator behaves like the laws for \setminus in the axiomatization of must/testing pre-orders:

$$\begin{aligned} a.\sigma \setminus a &= \mathbf{0} \\ b.\sigma \setminus a &= b.(\sigma \setminus a) \quad a \neq b \end{aligned}$$

The $|$ meta-operator is just the **expansion law** (in the testing equivalence):

$$\begin{aligned} a | b &= a.b + b.a \\ a | \bar{a}.b &= (a.\bar{a}.b + \bar{a}.(a | b) + b) \oplus b \end{aligned}$$

Contract compliance implies process compliance

Theorem

If $\vdash P : \sigma_1$, $\vdash Q : \sigma_2$, and $\sigma_1 \ll \sigma_2$ then $P \ll Q$

Proof (idea)

- if $P \xrightarrow{\alpha}$ we are done
- if $P \xrightarrow{\alpha}$ implies $Q \xrightarrow{\bar{\alpha}}$ we have a contradiction: every ready set of $\bar{\sigma}_1$ is not empty hence from $\bar{\sigma}_1 \preceq \sigma_2$ we have that P and Q can communicate through a name
- if $P \parallel Q \longrightarrow P' \parallel Q'$ and $\vdash P' : \sigma'_1$ and $\vdash Q' : \sigma'_2$ then $\sigma'_1 \ll \sigma'_2$

Open issues

- is \preceq the **right** compatibility relation?

- ▶ \preceq is *not* transitive

$$a \oplus b.c \preceq a \quad a \preceq a + b \quad \text{however} \quad a \oplus b.c \not\preceq a + b$$

- ▶ \preceq is *not* a pre-congruence w.r.t. $|$

\preceq is “good” for searching, not for typing (subsumption)

- \ll is **sufficient** but not necessary:

$$P \equiv x \mid \bar{x} \quad Q \equiv \mathbf{0} \quad P \ll Q \quad \text{however} \quad (x.\bar{x} + \bar{x}.x) \oplus \mathbf{0} \not\ll \mathbf{0}$$

Is $x \mid \bar{x}$ a “meaningful” contract? Is it possible to capture the ability of a client to complete autonomously?

- experiment the effectiveness of contracts in PiDuce

Future work

- **Recursive** contracts

$$\mu x.(a.x + b.x)$$

How do we infer contracts from processes? **Syntactic restrictions** over processes or **regular approximations**?

- **Name passing**:

$$a(x).\bar{x} \quad \bar{a}(x).x$$

- Adapting \preceq to **asynchronous communication**
- Relationship with **linear logic** and **denotational semantics** of contracts
- Contract **isomorphisms** and automatic generation of adapters:

$$a.b \iff b.a$$