Compositional Specification of Commercial Contracts

Jesper Andersen, Ebbe Elsborg, Fritz Henglein, Jakob Grue Simonsen, and Christian Stefansen
{jespera,elsborg,henglein,simonsen,cstef}@diku.dk

DIKU
Department of Computer Science
University of Copenhagen
A major French investment bank has costs of about 50 mio. Euro per year with about half due to legal costs in connection with contract disputes and the other half due to malexecution of financial contracts.

(Estimate by Eber, 2002)
Informal Contract Handling Must Be Replaced

Current informal contract handling is labor-intensive and problem-ridden.
The General Idea of Formal Contracts

**Agreement to Sell Goods**
Section 1. Seller shall sell and deliver to buyer (description of goods) no later than (date).
Section 2. In consideration hereof, buyer shall pay (amount in dollars) in cash on delivery.
The General Idea of Formal Contracts

Agreement to Sell Goods
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\[
\text{sale} \left( \text{seller}, \text{buyer}, \text{goods}, \text{payment}, t_1, t_2 \right) = \\
\text{transmit} \left( \text{seller}, \text{buyer}, \text{goods}, T \mid T < t_1 \right) \\
\| \text{transmit} \left( \text{buyer}, \text{seller}, \text{payment}, T \mid T < t_2 \right)
\]
Contributions

We designed a declarative, compositional specification language for the basis of a contract life-cycle management system.
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Let’s consider contracts in the language in terms of:

1. Specification
2. Semantics
3. Execution
4. Analysis (future work!)
We Analyzed 15 Real-Life Contracts

How does one specify contracts?

To answer this we analyzed these commercial contracts:

<table>
<thead>
<tr>
<th>Agreement to Sell Goods</th>
<th>Sale with Installment Payment</th>
</tr>
</thead>
<tbody>
<tr>
<td>General Contract</td>
<td>Agreement to Sell</td>
</tr>
<tr>
<td>Balloon Note</td>
<td>Contractor Agreement</td>
</tr>
<tr>
<td><strong>Legal Services Agreement</strong></td>
<td>The Danish Trade Law</td>
</tr>
<tr>
<td>Website Development Contract</td>
<td>Lease Contract</td>
</tr>
<tr>
<td>Loan and Security Agreement</td>
<td>License Agreement</td>
</tr>
<tr>
<td>Operating Agreement</td>
<td>Supply Agreement</td>
</tr>
<tr>
<td>Manufacturing Agreement</td>
<td></td>
</tr>
</tbody>
</table>
Agreement to Provide Legal Services
Section 1. The attorney shall provide, on a non-exclusive basis, legal services up to (n) hours per month, and furthermore provide services in excess of (n) hours upon agreement.
Section 2. In consideration hereof, the company shall pay a monthly fee of (amount in dollars) before the 8th day of the following month and (rate) per hour for any services in excess of (n) hours 40 days after the receipt of an invoice.
Section 3. This contract is valid 1/1-12/31, 2004.
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Data:
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Data:
- Agents
- Resource
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- Events

Structure:
- Sequence
- Parallel
- Choice
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**Data:**
- Agents
- Resource
- Time
- Events

**Structure:**
- Sequence
- Parallel
- Choice
- Repetition
Syntax for Contract Specification

Success/Failure

The succeeded/failed contract with no commitments.

\textbf{transmit}(A_1, A_2, R, T|P).c

The commitment of agent \(A_1\) to transmit resource \(R\) to agent \(A_2\) at time \(T\) subject to predicate \(P\) (afterwards do contract \(c\)).

\[c_1 ; c_1\]

A sequence of two contracts. The first contract must be reduced to Success before the second can begin.

\[c_1 \parallel c_2\]

Parallel, independent execution of two contracts.

\[c_1 + c_2\]

(Non-deterministic) choice between two contracts.

\[f(\vec{a})\]

Expansion to body of contract \(f\) with arguments \(\vec{a}\).

\[\text{letrec } f_i[\vec{X}_i] = c_i \text{ in } c\]

Contract \(c\) with named contracts \(f_i\) with formal arguments \(X_i\) bound to \(c_i\).
Legal Services Revisited

letrec
  legal (att, comp, hours, payment, extraprice, end, n) =
    transmit (att, comp, H, T | n <= T and T < n + 30 d and T <= end).
    (transmit (att, comp, invoice, T1 | hours < #(H, number, n + 30d)
       and #(invoice,total,T1) = (#(H,number,n) - hours) * extraprice).
       transmit(comp, att, #(invoice,total,T1), T2 | T2 <= T1+45)
       + Success)
  || (legal (att, comp, hours, payment, extraprice, end, n + 30 d)
       + Success)
  || transmit (comp, att, payment, T | T <= n + 40 d)
in
Specification

Semantics

Execution

Analysis
What Is the Meaning of a Contract?

Contracts denote sets of finite traces. A trace is a finite sequence of events:

\[ s ::= \langle \rangle \mid \text{transmit}(a_1, a_2, r, t) \ s \]

So contracts classify a given trace as performing or nonperforming. Formally, \( C[c]^D;\delta = \{ s : s \vdash_D^\delta c \} \)
The Satisfaction Relation

\[ \delta \models P[a_1/A_1, a_2/A_2, r/R, t/T] \quad s \vdash_{\delta}^{D} c[a_1/A_1, a_2/A_2, r/R, t/T] \]

\[ \text{transmit}(a_1, a_2, r, t) s \vdash_{\delta}^{D} \text{transmit}((A_1, A_2, R, T|P)).c \]
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$$\text{transmit}(a_1, a_2, r, t) \models^\delta \text{transmit}((A_1, A_2, R, T|P)).c$$

$$\langle \rangle \models^\delta \text{Success}$$
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transmit\((a_1, a_2, r, t)\) \(s \vdash^\delta_{D} \) transmit\(((A_1, A_2, R, T|P))\).\(c\)

\[\langle \rangle \vdash^\delta_{D} \text{Success} \]

\[s_1 \vdash^\delta_{D} c_1 \quad s_2 \vdash^\delta_{D} c_2 \quad (s_1, s_2) \rightsquigarrow s \]

\[s \vdash^\delta_{D} c_1 \parallel c_2\]
The Satisfaction Relation

\[ \delta \vdash P[a_1/A_1, a_2/A_2, r/R, t/T] \quad s \vdash^\delta c[a_1/A_1, a_2/A_2, r/R, t/T] \]

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What is \( C[\text{Failure}]^D;\delta \)?
The Satisfaction Relation

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transmit\((a_1, a_2, r, t)\) \(s \vdash^\delta_{\text{D}}\) transmit\(((A_1, A_2, R, T|P))\).\(c\)

\[ \langle \rangle \vdash^\delta_{\text{D}} \text{Success} \]

\[ s_1 \vdash^\delta_{\text{D}} c_1 \quad s_2 \vdash^\delta_{\text{D}} c_2 \quad (s_1, s_2) \leadsto s \]

\[ s \vdash^\delta_{\text{D}} c_1 \parallel c_2 \]

What is \(C[\text{Failure}]^\text{D};\delta\)?

The data model and the predicate language are orthogonal to the contract language. Plug in your own favorites!

To be general we just say \(\text{transmit}(\vec{X})\).
Specification

Semantics

Execution

Analysis
We Need a Representation of Residual Contracts

Define the *residuation function*:

\[ S/e = \{ s' \mid \exists s \in S : es' = s \} \]
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It is not a priori clear whether \( S_C/e \) is denotable by a contract \( c' \).

Luckily, this is the case if we impose one tiny contraint...
Only Consider Guarded Contracts

Consider the contract

\[ f[\vec{X}] = (\text{transmit}(Y|P) + \text{Success}) \parallel f[\vec{X}] \].
Only Consider Guarded Contracts

Consider the contract

\[ f[\tilde{X}] = (\text{transmit}(Y|P) + \text{Success}) \parallel f[\tilde{X}]. \]

We introduce \textit{guardedness}:

- To avoid the runtime system chasing around infinitely in this or arbitrarily complex other contracts that potentially denote the empty trace set.
- To thus make sure that every contract has a residual contract under any event.
Guarded Contracts

Intuitively, a contract is guarded if (mutual) recursions are prefixed by a transmit.

\[ D \vdash \text{Success guarded} \quad D \vdash \text{Failure guarded} \]

\[ D \vdash \text{transmit}(\vec{X} \mid P).c \text{ guarded} \]

\[ D \vdash c \text{ guarded} \quad D \vdash c' \text{ guarded} \]

\[ D \vdash c + c' \text{ guarded} \]

\[ D \vdash \text{c guarded} \quad (f[\vec{X}] = c) \in D \]

\[ D \vdash f(\vec{a}) \text{ guarded} \]

\[ D \vdash \text{c guarded} \quad D \vdash c' \text{ guarded} \]

\[ D \vdash c \mid c' \text{ guarded} \]

\[ D \not\vdash \text{c nullable} \quad D \vdash c \text{ guarded} \]

\[ D \vdash c; c' \text{ guarded} \]

\[ D \not\vdash c \text{ nullable} \quad D \vdash c \text{ guarded} \quad D \vdash c' \text{ guarded} \]

\[ D \vdash c; c' \text{ guarded} \]
Deterministic Reduction Thru Delayed Matching

Let’s consider some rules from one of the possible reduction semantics:

\[
\delta \models P[\bar{a}/\bar{X}]
\]

\[
\text{D, } \delta \vdash_D \text{transmit}(\bar{X}|P). \ c \xrightarrow{\text{transmit}(\bar{a})} c[\bar{a}/\bar{X}] 
\]
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D, \delta \vdash_D \text{transmit}(\bar{X}|P).c \xrightarrow{\text{transmit}(\bar{a})} c[\bar{a}/\bar{X}] \\
\hline
D, \delta \vdash_D c \xrightarrow{e} d \quad D, \delta \vdash_D c' \xrightarrow{e} d' \\
\hline
D, \delta \vdash_D c + c' \xrightarrow{e} d + d'
\]
Deterministic Reduction Thru Delayed Matching

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\[ D, \delta \vdash_D \text{transmit}(\bar{X} | P). c \xrightarrow{\text{transmit}(\bar{a})} c[\bar{a}/\bar{X}] \]

\[ D, \delta \vdash_D c \xrightarrow{e} d \quad D, \delta \vdash_D c' \xrightarrow{e} d' \]

\[ D, \delta \vdash_D c + c' \xrightarrow{e} d + d' \]

\[ D, \delta \vdash_D c || c' \xrightarrow{e} c || d' + d || c' \]
Guarded Subject Reduction:

**Theorem** If \( c \in C^P \) is guarded then for each event \( e \) there exists a unique \( c' \in C^P \) such that \( D, \delta \vdash_D c \xrightarrow{e} c' \). Furthermore, we have that \( c' \) is guarded and \( D, \delta \models c/e = c' \), which means \( C[c]^{D;\delta}/e = C[c']^{D;\delta} \). △
Guarded Subject Reduction:

**Theorem** If $c \in C^P$ is guarded then for each event $e$ there exists a unique $c' \in C^P$ such that $D, \delta \vdash_D c \xrightarrow{e} c'$. Furthermore, we have that $c'$ is guarded and $D, \delta \models c/e = c'$, which means $C[c]^{D;\delta}/e = C[c']^{D;\delta}$. ▶

Immediate payoff: Contracts can be used to represent trace sets. All functions on “original” contracts extend to residual contracts.
Specification
↓
Semantics
↓
Execution
↓
Analysis
Contract Analysis Is Also Compositional

Future work!

Questions we would like to answer:

- What is my next order of business?
- What is this contract worth?
- What will this contract demand in terms of inventory/labor hours the next week/month?
- Is this contract consistent?
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...enter financial engineering and stochastic programming!
Computing a Task List Is Easy!
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D, δ, a, t ⊢ Success : []

\[ \models a \neq a_1 \quad X = (a_1, A, R, T) \]

\[ \models t \notin [x; y] \]

D, δ, a, t ⊢ transmit(\(\vec{X} \mid [x; y]\)). c : do []

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D, δ, a, t ⊢ transmit(\(\vec{X} \mid [x; y]\)). c : do []

\[ \models a = a_1 \quad X = (a_1, A, R, T) \quad t \in [x; y] \]

D, δ, a, t ⊢ transmit(\(\vec{X} \mid [x; y]\)) : do [transmit(\(\vec{X} \mid [x; y]\))]

D, δ, a, t ⊢ c_1 : l_1 \quad D, δ, a, t ⊢ c_2 : l_2

D, δ, a, t ⊢ c_1 + c_2 : choose[l_1, l_2]

D ⊢ c_1 nullable \quad D, δ, a, t ⊢ c_1 : l_1 \quad D, δ, a, t ⊢ c_2 : l_2

D, δ, a, t ⊢ c_1; c_2 : choose[l_1, l_2]

D ⊢ c_1 nullable \quad D, δ, a, t ⊢ c_1 : l_1

D, δ, a, t ⊢ c_1; c_2 : l_1

D, δ, a, t ⊢ c_1 || c_2 : l_1 \ @ l_2

D, δ, a, t ⊢ c_1 : l_1 \quad D, δ, a, t ⊢ c_2 : l_2

D, δ, a, t ⊢ c_1; c_2 : l_1

D, δ, a, t ⊢ c_1 || c_2 : l_1 \ @ l_2
Related Work

- Compositional Contracts (Peyton Jones, Eber, Seward, 2001)
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- Compositional Contracts (Peyton Jones, Eber, Seward, 2001)
- CSP (Communicating Sequential Processes) (C.A.R. Hoare, 1985)
Review

Specification – Semantics – Execution – Analysis
Review

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- The compositional approach is viable!
Review

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Review

Specification – Semantics – Execution – Analysis

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- Business systems will be the next heyday for theoretical computer science.
Review

Specification – Semantics – Execution – Analysis

- The compositional approach is viable!
- Contract handling has been broken for a while now.
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Thank you!
More Information

Read the technical report at:
http://topps.diku.dk/next/contracts/

Visit our homepage:
http://www.it.edu/next

Write an email:
cstef@diku.dk