Specification and Analysis of Electronic Contracts

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Contracts and Informatics

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   - Traditional commercial and judicial domain
2. "Programming by contract" or "Design by contract" (e.g., Eiffel)
   - Pre- and post-conditions, invariants, temporal dependencies, etc
3. Behavioral interfaces
   - The allowed interactions are captured by legal (sets of) traces
4. In the context of web services (SOA)
   - Service-Level Agreement, an XML-like language (e.g. WSLA)
5. Contractual protocols
   - To specify the interaction between communicating entities
6. "Social contracts": Multi-agent systems

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6. "Social contracts": Multi-agent systems
7. "Deontic e-contracts": representing Obligations, Permissions, Prohibitions

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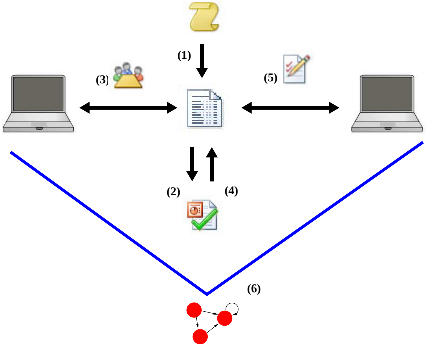

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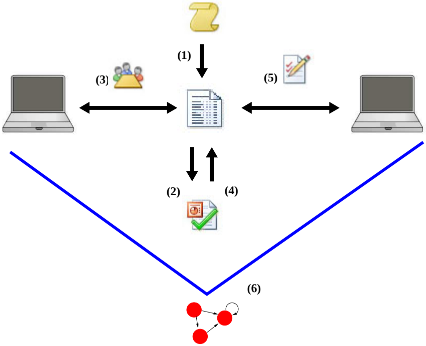

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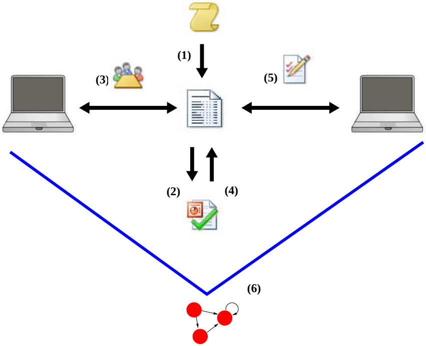

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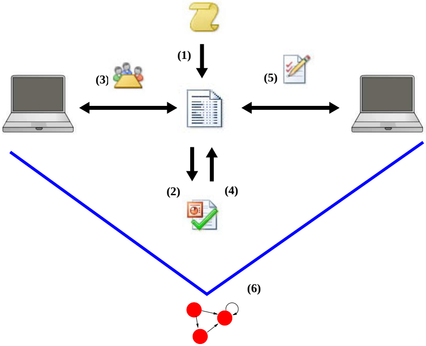

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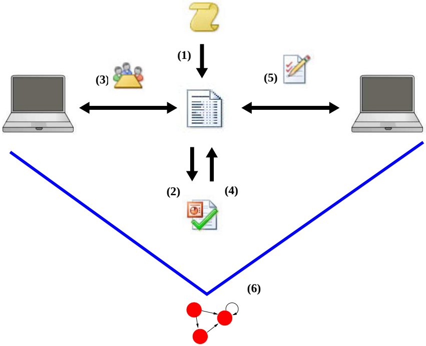

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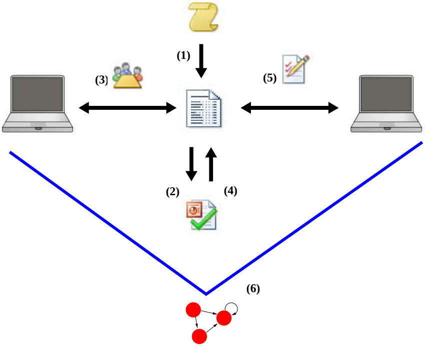
6. Monitor/enforce contract fulfillment



Aim and Motivation

- Use deontic e-contracts to ‘rule’ services exchange

1. Give a formal language for specifying/writing contracts
2. Analyze contracts “internally”
   - Detect contradictions/inconsistencies statically
   - Determine the obligations (permissions, prohibitions) of a signatory
   - Detect superfluous contract clauses
3. Develop a theory of contracts
   - Contract composition
   - Subcontracting
   - Conformance between a contract and the governing policies
   - *Meta-contracts* (policies)
4. Monitor contracts
   - Run-time system to ensure the contract is respected
   - In case of contract violations, act accordingly

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Outline

The Contract Specification Language $\mathcal{CL}$

Definition ($\mathcal{CL}$ Syntax)

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\begin{array}{rcl}
\mathcal{C}ontract & := & \mathcal{D} \; ; \; \mathcal{C} \\
\mathcal{C} & := & \mathcal{C}_O \mid \mathcal{C}_P \mid \mathcal{C}_F \mid \mathcal{C} \wedge \mathcal{C} \mid [\alpha]\mathcal{C} \mid \langle\alpha\rangle\mathcal{C} \mid \mathcal{C} \, \mathcal{U} \, \mathcal{C} \mid \bigcirc \mathcal{C} \mid \Box\mathcal{C} \\
\mathcal{C}_O & := & O(\alpha) \mid \mathcal{C}_O \oplus \mathcal{C}_O \\
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\end{array}
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- $O(\alpha)$, $P(\alpha)$, $F(\alpha)$: obligations, permissions, and prohibitions
- α are actions given in the definition part $\mathcal{D}$
  - $+$ choice
  - $\cdot$ concatenation (sequencing)
  - $\&$ concurrency
  - $\phi?$ test
- $\wedge$, $\vee$, and $\oplus$ are conjunction, disjunction, and exclusive disjunction
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More on the Contract Language
CTD and CTP

- We want to handle violations (*CTDs*, *CTPs*)
  - A contrary-to-duty (CTD) expresses what happen when an obligation is not fulfilled
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Example

CTD: You must send an acknowledgment immediately after receiving the message. If you don't do that, you must pay double.

CTP: You are forbidden to send a message before having acknowledged the reception of the previous answer. If you do that, I am allowed to cancel the contract.

More on the Contract Language
CTD and CTP

- Expressing contrary-to-duty (CTD)

$$O_{\mathcal{C}}(\alpha) = O(\alpha) \wedge [\overline{\alpha}]\mathcal{C}$$

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- Expressing contrary-to-prohibition (CTP)

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$\mathcal{CL}$ Semantics

$\mathcal{C}\mu$ – A variant of the modal μ-calculus

- Translation into a variant of μ-calculus ($\mathcal{C}\mu$)
- The syntax of the $\mathcal{C}\mu$ logic
  $\varphi \;:=\; P \mid Z \mid P_c \mid \top \mid \neg\varphi \mid \varphi \wedge \varphi \mid [\gamma]\varphi \mid \mu Z.\varphi(Z)$

Main differences with respect to the classical μ-calculus:

1. P_c is set of propositional constants O_a and $\mathcal{F}_a$, one for each basic action a
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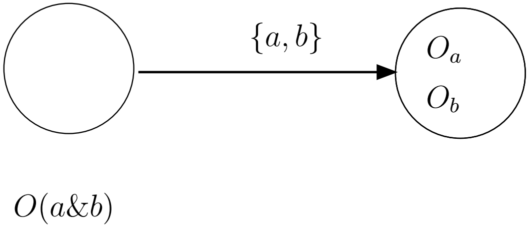

Model Checking Contracts

1. Model the conventional contract (in English) as a $\mathcal{CL}$ expression
2. Translate the $\mathcal{CL}$ specification into $\mathcal{C}\mu$
3. Obtain a Kripke-like model (LTS) from the $\mathcal{C}\mu$ formulas
4. Translate the LTS into the input language of NuSMV
5. Perform model checking using NuSMV
   - Check the model is 'good'
   - Check some properties about the client and the provider
6. In case of a counter-example given by NuSMV, interpret it as a $\mathcal{CL}$ clause and repeat the model checking process until the property is satisfied
7. In some cases rephrase the original contract

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1. The **Client** shall not:
a) supply false information to the Client Relations Department of the **Provider**.
2. Whenever the Internet Traffic is **high** then the **Client** must pay [*price*] immediately, or the **Client** must notify the **Provider** by sending an e-mail specifying that he will pay later.
3. If the **Client** delays the payment as stipulated in 2, after notification he must immediately lower the Internet traffic to the **normal** level, and pay later twice $(2 * [price])$.
4. If the **Client** does not lower the Internet traffic immediately, then the **Client** will have to pay $3 * [price]$.
5. The **Client** shall, as soon as the Internet Service becomes operative, submit within seven (7) days the Personal Data Form from his account on the **Provider**'s web page to the Client Relations Department of the **Provider**.
6. **Provider** may, at its sole discretion, without notice or giving any reason or incurring any liability for doing so:
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4. $\Box([d\&n \cdot \bar{l}\,]\Diamond O(p\&p\&p))$
5. The **Client** shall, as soon as the Internet Service becomes operative, submit within seven (7) days the Personal Data Form from his account on the **Provider**'s web page to the Client Relations Department of the **Provider**.

Case Study

Translating into $\mathcal{CL}$ syntax

1. $\Box F_{P(s)}(fi)$
2. $\Box[h](\phi \Rightarrow O(p + (d\&n)))$
3. $\Box([d\&n](O(l) \wedge [l]\Diamond O(p\&p)))$
4. $\Box([d\&n \cdot \bar{l}\,]\Diamond O(p\&p\&p))$
5. $\Box([o]O(sfD))$

Case Study

Handcrafting the model

ϕ = the Internet traffic is high
fi = client supplies false information to Client Relations Department
h = client increases Internet traffic to *high* level
p = client pays [price]
d = client delays payment
n = client notifies by e-mail
l = client lowers the Int. traffic
sfD = client sends the Personal Data Form to Client Relations Department
o = provider activates the Internet Service (it becomes operative)
s = provider suspends service

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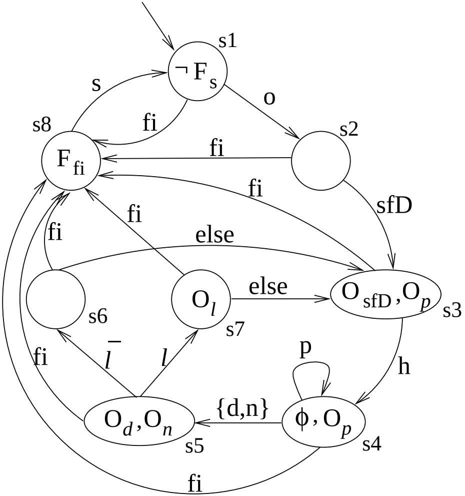

Use of model checking for reasoning about contracts:

1. We use model checking to increase our confidence in the correctness of the model with respect to the original natural language contract
2. By finding errors in the model, we identify problems in the original natural language contract or its interpretation in $\mathcal{CL}$
3. We enable the signatories to safeguard their interests by ensuring certain desirable properties hold (and certain undesirable ones do not)

- Counter-examples
  - Problems on the $\mathcal{CL}$ formula and on the original contract in English

Final Remarks

- A formal specification language for contracts with semantics based on a variant of μ-calculus
- Initial ideas on how to model check contracts

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Currently:

- Redesign $\mathcal{CL}$
- Kripke semantics for $\mathcal{CL}$
  - Development of an action algebra
- Automatic monitor extraction

Future Work

- Develop a proof system for (an improved) $\mathcal{CL}$
- Internal vs external operations
- Add time
- Automate the model checking process
- Develop a theory of contracts
- Programming languages and contracts
    - Embedded language
    - Contract-as-types
- Combination with operational models (e.g. process algebra)
- Case studies and other applications:
    - Fault tolerant systems
    - Long transactions
    - Component-based development
    - Legal contracts (?)

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What We Have Done So Far...

- C. Prisacariu and G. Schneider. **A formal language for electronic contracts.** In FMOODS'07, LNCS.
- G. Pace, C. Prisacariu and G. Schneider. **Model Checking Contracts –A case study.** In ATVA'07, LNCS.
- M. Kyas, C. Prisacariu, and G. Schneider. **Runtime Monitoring of Electronic Contracts.** In ATVA'08, LNCS.
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Tomorrow Gordon will present part of Stephen's master thesis:

- S. Fenech. **Conflict analysis of deontic contracts.** M.Sc. thesis. University of Malta, November 2008.