Specification and Analysis of Electronic Contracts

Gerardo Schneider

gerardo@ifi.uio.no

PMA group
Department of Informatics,
University of Oslo

Joint work with
Cristian Prisacariu (cristi@ifi.uio.no) and Gordon Pace
(gordon.pace@um.edu.mt)

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Contracts and Informatics

1. Conventional contracts
   - Traditional commercial and judicial domain
2. "Programming by contract" or "Design by contract" (e.g., Eiffel)
   - Relation between pre- and post-conditions of routines, method calls, invariants, temporal dependencies, etc
3. In the context of web services
   - Service-Level Agreement, usually written in an XML-like language (e.g. WSLA)
4. Behavioral interfaces
   - Specify the sequence of interactions between different participants. The allowed interactions are captured by legal (sets of) traces
5. Contractual protocols
   - To specify the interaction between communicating entities
6. "Deontic e-contracts": representing Obligations, Permissions, Prohibitions, Power, etc
   - Inspired from a conventional contract
   - Written directly in a formal specification language
7. "Social contracts": Multi-agent systems

Contracts

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This deed of **Agreement** is made between:
1. **[name]**, from now on referred to as **Provider** and
2. the **Client**.

INTRODUCTION

3. The **Provider** is obliged to provide the **Internet Services** as stipulated in this **Agreement**.
4. DEFINITIONS

a) **Internet traffic** may be measured by both **Client** and **Provider** by means of Equipment and may take the two values **high** and **normal**.

OPERATIVE PART

1. The **Client** shall not 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**.

Contracts

- We call the above a *conventional contract*
- An e-contract is a machine-readable contract

Two scenarios:

1. Obtain an e-contract from a conventional contract
   - Context: legal (e.g. financial) contracts
2. Write the e-contract directly in a formal language
   - Context: web services, components, OO, etc

Definition

A contract is a document which engages several parties in a transaction and stipulates their (conditional) obligations, rights, and prohibitions, as well as penalties in case of contract violations.

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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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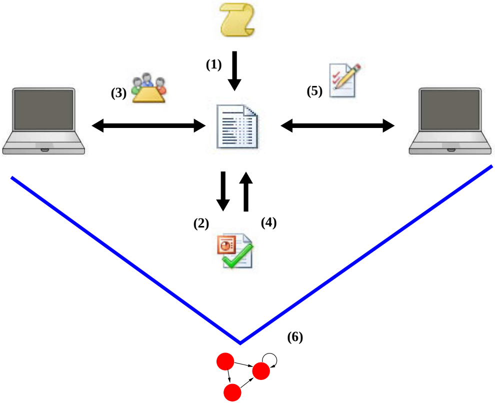
Aim and Motivation
COSoDIS



- COSoDIS: "Contract-Oriented Software Development for Internet Services" –A Nordunet3 project (http://www.ifi.uio.no/cosodis/)

A Formal Language for Contracts

- A precise and concise syntax and a formal semantics
- Expressive enough as to capture natural contract clauses
- Restrictive enough to avoid (deontic) paradoxes and be amenable to formal analysis
    - Model checking
    - Deductive verification
- Allow representation of complex clauses: conditional obligations, permissions, and prohibitions
- Allow specification of (nested) contrary-to-duty (CTD) and contrary-to-prohibition (CTP)
    - CTD: when an obligation is not fulfilled
    - CTP: when a prohibition is violated
- We want to combine
    - The logical approach (e.g., dynamic, temporal, deontic logic)
    - The automata-like approach (labelled Kripke structures)

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(Standard) Deontic Logic
Few Words

- Concerned with moral and normative notions
  - *obligation*, *permission*, *prohibition*, *optionality*, *power*, *indifference*, *immunity*, etc
- Focus on
  - The logical consistency of the above notions
  - The faithful representation of their intuitive meaning in law, moral systems, business organisations and security systems
- Difficult to avoid *puzzles* and *paradoxes*
  - Logical paradoxes, where we can deduce contradictory actions
  - "Practical oddities", where we can get counterintuitive conclusions
- Approaches
  - ought-to-do: expressions consider *names of actions*
    - "The Internet Provider *must send* a password to the Client"
  - ought-to-be: expressions consider state of affairs (results of actions)
    - "The average bandwidth *must be* more than 20kb/s"
- We'll only consider obligation, permission and prohibition over actions
  - Assertions define the "state of affairs"

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Outline

1. The Contract Language $\mathcal{CL}$
2. Properties of the Language
3. Verification of Contracts
4. Final Remarks

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The Contract Specification Language $\mathcal{CL}$

$$
\begin{array}{rcl}
\mathcal{C}ontract & := & \mathcal{D}\ ;\ \mathcal{C} \\
\mathcal{C} & := & \mathcal{C}_O \mid \mathcal{C}_P \mid \mathcal{C}_F \mid \mathcal{C} \wedge \mathcal{C} \mid [\alpha]\mathcal{C} \mid \langle\alpha\rangle\mathcal{C} \mid \mathcal{C}\,\mathcal{U}\,\mathcal{C} \mid \bigcirc\,\mathcal{C} \mid \Box\mathcal{C} \\
\mathcal{C}_O & := & O(\alpha) \mid \mathcal{C}_O \oplus \mathcal{C}_O \\
\mathcal{C}_P & := & P(\alpha) \mid \mathcal{C}_P \oplus \mathcal{C}_P \\
\mathcal{C}_F & := & F(\alpha) \mid \mathcal{C}_F \vee [\alpha]\mathcal{C}_F
\end{array}
$$

- $O(\alpha)$, $P(\alpha)$, $F(\alpha)$ specify obligation, permission (rights), and prohibition (forbidden) over actions
- 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
- $[\alpha]$ and $\langle\alpha\rangle$ are the action parameterized modalities of dynamic logic
- $\mathcal{U}$, $\bigcirc$, and $\Box$ correspond to temporal logic operators

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- Tests as actions: $\phi?$
  - The behaviour of a test is like a *guard*; e.g. $\varphi? \cdot a$ *if the test succeeds then action a is performed*
  - Tests are used to model conditions: $[\varphi?]\mathcal{C}$ is the same as $\varphi \Rightarrow \mathcal{C}$
- Action negation $\overline{\alpha}$
  - It represents all immediate traces that take us outside the trace of α
  - Involves the use of a *canonic form* of actions
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- $a\&b$
- "The client must pay immediately, or the client must notify the service provider by sending an e-mail specifying that he delays the payment"

$$O(p) \oplus O(d\&n)$$

- $O(d\&n) \equiv O(d) \wedge O(n)$
- Action algebra enriched with a conflict relation to represent incompatible actions
  - $a =$ "increase Internet traffic" and $b =$ "decrease Internet traffic"
    - $a \#_{\mathcal{C}} b$
    - $O(a) \wedge O(b)$ gives an inconsistency

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- Expressing contrary-to-duty (CTD)

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Example

"[...] the client must immediately lower the Internet traffic to the *low* level, and pay later twice. If the client does not lower the Internet traffic immediately, then the client will have to pay three times the price"

In $\mathcal{CL}$: $\square(O_{\mathcal{C}}(l) \wedge [l]\lozenge(O(p\&p)))$

where $\mathcal{C} = \lozenge O(p\&p\&p)$

- 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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- Obligation

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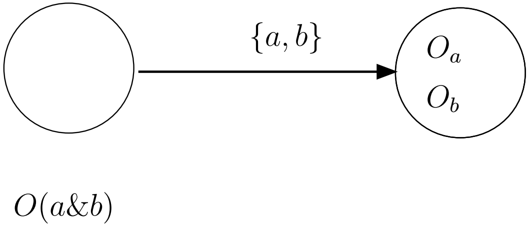

Very recent work:

- “The” semantics of the language
  - Branching semantics
- For monitoring purposes
  - Trace semantics

Outline

Ross's paradox

1. It is obligatory that one mails the letter
2. It is obligatory that one mails the letter or one destroys the letter

In Standard Deontic Logic (SDL) these are expressed as:

1. $O(p)$
2. $O(p \vee q)$

Problem: in SDL one can infer that $O(p) \Rightarrow O(p \vee q)$

Avoided in $\mathcal{CL}$ –Proof Sketch:

- $f^{\mathcal{T}}(O(a)) = \langle a \rangle O_a$
- $O(a + b) \equiv O(a) \oplus O(b) \stackrel{f^{\mathcal{T}}}{=} \langle a \rangle O_a \wedge \langle b \rangle O_b$
- $\langle a \rangle O_a \not\Rightarrow \langle a \rangle O_a \wedge \langle b \rangle O_b$

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- $\langle a \rangle O_a \not\Rightarrow \langle a \rangle O_a \wedge \langle b \rangle O_b$

Properties of the contract language

Theorem

The following paradoxes are avoided in $\mathcal{CL}$:

- *Ross's paradox*
- *The Free Choice Permission paradox*
- *Sartre's dilemma*
- *The Good Samaritan paradox*
- *Chisholm's paradox*
- *The Gentle Murderer paradox*

Properties of the contract language (II)

Theorem

The following hold in $\mathcal{CL}$:

- $P(\alpha) \equiv \neg F(\alpha)$
- $O(\alpha) \Rightarrow P(\alpha)$
- $P(a) \not\Rightarrow P(a\&b)$
- $F(a) \not\Rightarrow F(a\&b)$
- $F(a\&b) \not\Rightarrow F(a)$
- $P(a\&b) \not\Rightarrow P(a)$

Outline

Model Checking in a Nutshell

A model checker is a software tool that given:

- A model M (usually a *Kripke model*)
- A property ϕ (usually a *temporal logic formula*)

It decides whether

$$M \models \phi$$

- It returns YES if the property is satisfied,
- Otherwise returns NO and provides a counterexample

It is completely automatic!

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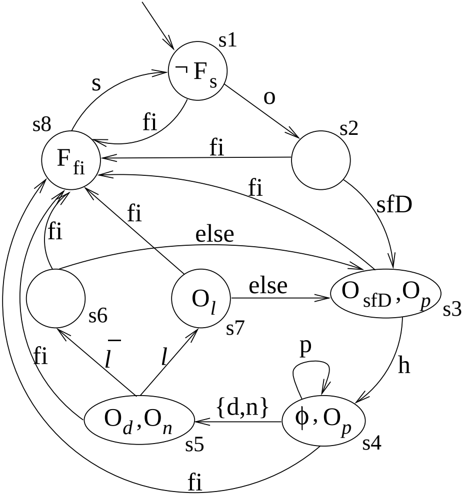
$$
\begin{aligned}
\phi &= \text{the Internet traffic is high} \\
fi &= \text{client supplies false information} \\
& \text{to Client Relations Department} \\
h &= \text{client increases Internet traffic} \\
& \text{to } \textit{high} \text{ level} \\
p &= \text{client pays [price]} \\
d &= \text{client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

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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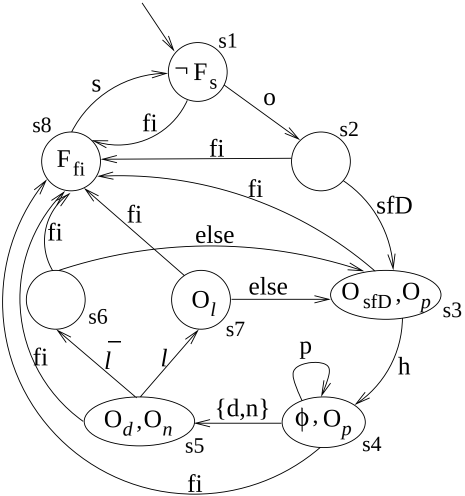
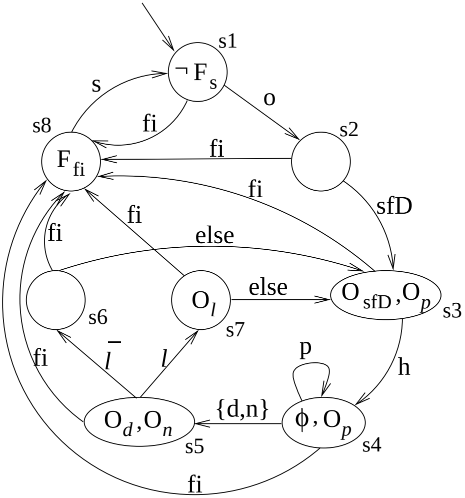
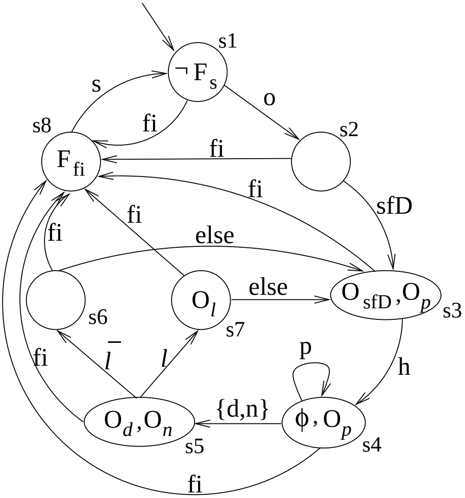


- "It is always the case that whenever the Internet traffic is high, if the clients pays immediately, then the client is *not* obliged to pay again immediately afterward"



- "It is always the case that whenever the Internet traffic is high, if the clients pays immediately, then the client is *not* obliged to pay again immediately afterward"
- It fails!



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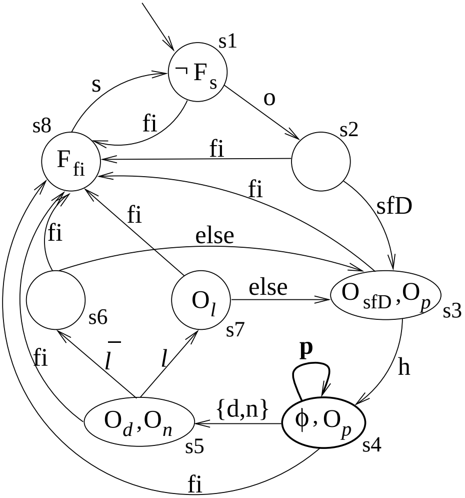
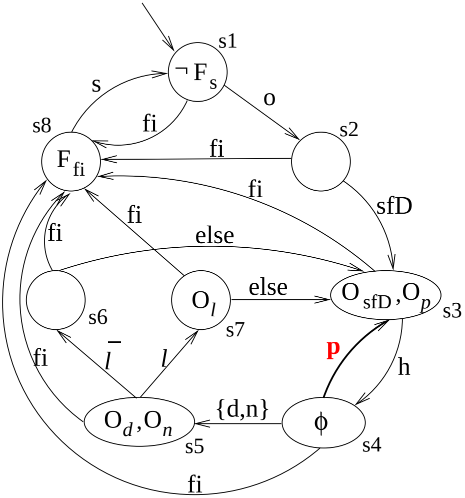
- We get a counter-example –Problem: state *s*4



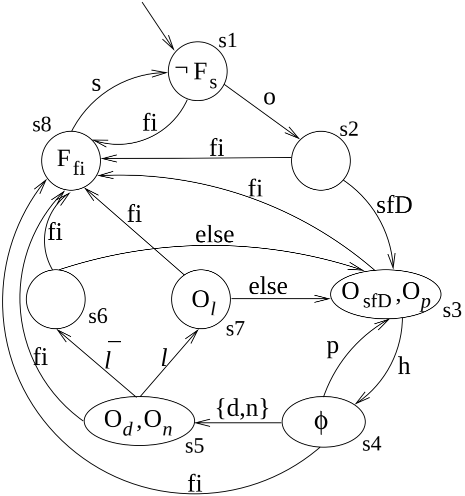
- "It is always the case that whenever the Internet traffic is high, if the clients pays immediately, then the client is *not* obliged to pay again immediately afterward"
- It fails!
- We get a counter-example –Problem: state $s4$
- We modify the original contract to capture the above more precisely



Case Study

Verifying a property about payment in case of increasing Internet traffic

- "It is always the case that whenever Internet traffic is high, if the client delays payment and notifies, and afterward lowers the Internet traffic, then the client is forbidden to increase Internet traffic until he pays twice"



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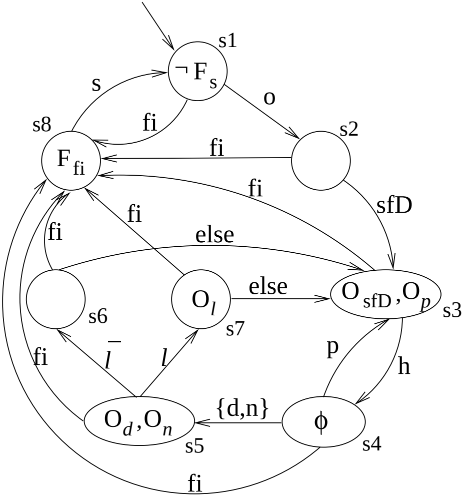

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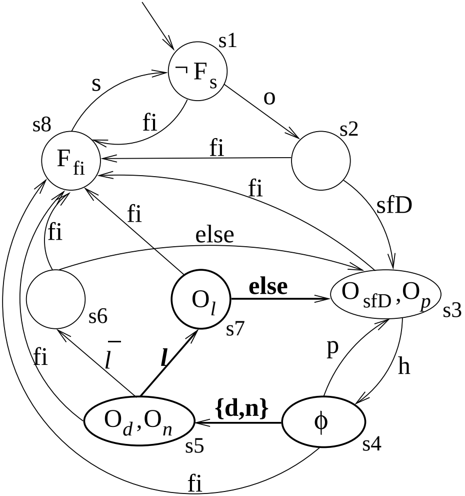

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- It fails!
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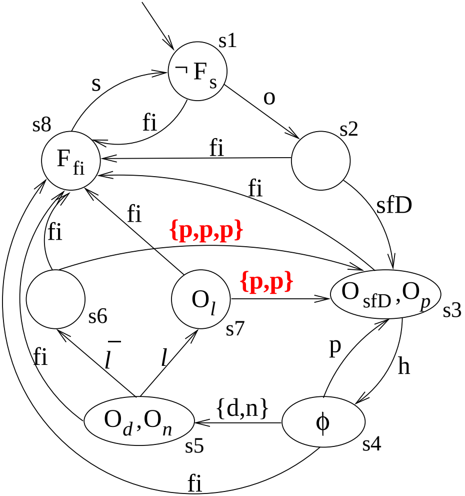
- Add to the original contract the clause above!



Outline

A Language for Deontic e-Contracts

- A formal specification language for contracts with semantics based on a variant of μ-calculus

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Use of model checking for reasoning about contracts:

1. Model checking to increase confidence in the correctness of the model wrt the original natural language contract
2. We identify problems in the original natural language contract or its interpretation in $\mathcal{CL}$
3. We ensure certain desirable properties hold (and certain undesirable ones do not) for the signatories

Current and Further Work

Recent work

- Redesign $\mathcal{CL}$ (changes going fast!) [C. Prisacariu]
- Branching semantics [C. Prisacariu]
- Trace semantics (run-time monitoring) [C. Prisacariu & M. Kyas]
- Case study (CoCoME) [S. Fenech & G. Pace]

On-going work

- Automate the model checking process [...]
- Encoding into LTL to check inconsistencies [S. Fenech & G. Pace]

Current and Further Work

Further work

- "Normative" automata
- Develop a proof system
- Internal vs external operations
  - Obligation on sequences vs sequence of obligations
  - Kleene star vs Until
  - $+$ vs $\oplus$
- Add time
  - Timed $\mu-$calculus, TCTL, ...? Associated with actions or formulae?
  - Durations, time stamps, beginning and end, dates, ...?
- Negotiation
  - Maude
- Applications (besides SOA)
  - Component-based development
  - Fault-tolerant systems
  - Compensable transactions

Links and Papers

- COSoDIS: "Contract-Oriented Software Development for Internet Services" –A Nordunet3 project (`http://www.ifi.uio.no/cosodis/`)

- FLACOS'07 – 1st Workshop on Formal Languages and Analysis of Contract-Oriented Software (`http://www.ifi.uio.no/flacos07/`)
  - Oslo, 9-10 October 2007

- C. Prisacariu and G. Schneider. A formal language for electronic contracts. In FMOODS'07, vol. 4468 of LNCS, pages 174-189, Cyprus. June 2007
- Gordon Pace, Cristian Prisacariu, and Gerardo Schneider. Model checking contracts -a case study. In ATVA'07, vol. 4762 of LNCS, pages 82-97, Tokyo, Japan. October 2007.

Thank you!