Specification and Analysis of Contracts

Tutorial

Gerardo Schneider

gerardo@ifi.uio.no

http://folk.uio.no/gerardo/

Department of Informatics,
University of Oslo
What Is This Tutorial About?

- Specification and analysis of contracts for Services
- Many of the material is state-of-the-art and on-going research
- It is not an exhaustive exposition of
  - Service-Oriented Architecture (SOA)
  - Components
- We will see how to use (a special kind of) contracts in the context of Services and Components
What Is This Tutorial About?

- Contracts and Service-Oriented Computing (SOC)
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- Contracts and Components
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The tutorial covers topics such as:
- Static Analysis Testing/Simulation (Maude)
- Compatibility/Conflict-free
- Conformance

The diagram illustrates the relationships between these concepts.
What Is This Tutorial About?

We will see:

- A bit of formal methods
- SOC and components
- Deontic logic
- A formal language for writing contracts
- How to analyze contracts using *model checking*
Lesson 1: Introduction
- Formal Methods
- Contracts ‘and’ Informatics

Lesson 2: Components, Services and Contracts
- Components
- Service-Oriented Computing

Lesson 3: Deontic Logic
- Deontic Logic
- Paradoxes in Deontic Logic

Lesson 4: Specification and Analysis of Contracts
- The Contract Language CL
- Properties of the Language
- Verification of Contracts
Outline

1. **Lesson 1: Introduction**
   - Formal Methods
   - Contracts ‘and’ Informatics

2. **Lesson 2: Components, Services and Contracts**
   - Components
   - Service-Oriented Computing

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   - Paradoxes in Deontic Logic

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   - The Contract Language $\mathcal{CL}$
   - Properties of the Language
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   - The Contract Language $\mathcal{CL}$
   - Properties of the Language
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How to Guarantee Correctness?
Is it possible at all?

- How to show a system is correct?
  - It is not enough to show that it can meet its requirement
  - We should show that a system cannot fail to meet its requirement
  - By testing? Dijkstra wrote (1972): “Program testing can be used to show the presence of bugs, but never to show their absence”
  - By other kind of “proof”? Dijkstra again (1965): “One can never guarantee that a proof is correct, the best one can say is: ‘I have not discovered any mistakes’”
  - What about automatic proof? It is impossible to construct a general proof procedure for arbitrary programs\(^1\)

- Any hope?

\(^1\)Undecidability of the halting problem, by Turing.
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- Any hope? In some cases it is possible to mechanically verify correctness; in other cases... we try to do our best

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A system is **correct** if it meets its design requirements.

A deadly embrace is entered when two processes obtain access to two mutually dependent shared resources and each decide to wait indefinitely for the other. Saying 'a program is correct' is only meaningful w.r.t. a given specification!
A system is correct if it meets its design requirements

**Example**

- **System**: A telephone system
  - **Requirement**: If user A wants to call user B, then eventually (s)he will manage to establish a connection

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- **System:** A contract for Internet services  
  **Requirement:** Signatory A will never be obliged to pay more than a certain amount of money.

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What is Validation?

- In general, **validation** is the process of checking if something satisfies a certain criterion.
- Do not confuse validation with **verification**

Validation: "Are we building the right product?", i.e., does the product do what the user really requires.

Verification: "Are we building the product right?", i.e., does the product conform to the specifications.
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**Remark**

Some authors define verification as a validation technique, others talk about V & V –Validation & Verification– as being complementary techniques. In this tutorial I consider verification as a validation technique.
Usual Approaches for Validation

The following techniques are used in industry for validation:

- **Testing**
  - Check the actual system rather than a model
  - Focused on sampling executions according to some coverage criteria – Not exhaustive
  - It is usually informal, though there are some formal approaches

- **Simulation**
  - A model of the system is written in a PL, which is run with different inputs – Not exhaustive

- **Verification**
  - “Is the process of applying a manual or automatic technique for establishing whether a given system satisfies a given property or behaves in accordance to some abstract description (specification) of the system”\(^2\)

\(^2\)From Peled’s book “Software reliability methods”. 
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What are Formal Methods?

- “Formal methods are a collection of notations and techniques for describing and analyzing systems”

- **Formal** means the methods used are based on mathematical theories, such as logic, automata, graph or set theory

- **Formal specification** techniques are used to unambiguously describe the system itself or its properties

- **Formal analysis/verification** techniques serve to verify that a system satisfies its specification (or to help finding out why it is not the case)

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The term **verification** is used in different ways

- Sometimes used only to refer the process of obtaining the formal correctness proof of a system (deductive verification)
- In other cases, used to describe any action taken for finding errors in a program (including model checking and testing)
- Sometimes testing is not considered to be a verification technique
What are Formal Methods?

Some Terminology

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We will use the following definition (reminder):

**Definition**

Formal verification is the process of applying a manual or automatic *formal* technique for establishing whether a given system satisfies a given property or behaves in accordance to some abstract description (*formal* specification) of the system
Limitations

- Software verification methods do not guarantee, in general, the correctness of the code itself but rather of an abstract model of it.
- It cannot identify fabrication faults (e.g., in digital circuits).
- If the specification is incomplete or wrong, the verification result will also be wrong.
- The implementation of verification tools may be faulty.
- The bigger the system (number of possible states) more difficult is to analyze it (state explosion problem).
Any advantage?

OF COURSE!

Formal methods are not intended to guarantee absolute reliability but to increase the confidence on system reliability. They help minimizing the number of errors and in many cases allow to find errors impossible to find manually.
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Formal methods are not intended to guarantee absolute reliability but to *increase* the confidence on system reliability. They help minimizing the number of errors and in many cases allow to find errors impossible to find manually.
Formal methods are used in different stages of the development process, giving a classification of formal methods.

1. We describe the system giving a formal specification.
2. We can then prove some properties about the specification (formal verification).
3. We can proceed by:
   - Deriving a program from its specification (formal synthesis).
   - Verifying the specification w.r.t. implementation (formal verification).
Formal Specification

- A specification formalism must be unambiguous: it should have a precise syntax and semantics (e.g., natural languages are not suitable).
- A trade-off must be found between expressiveness and analysis feasibility: more expressive the specification formalism more difficult its analysis (if possible at all).

Do not confuse the specification of the system itself with the specification of some of its properties.
- Both kinds of specifications may use the same formalism but not necessarily.
- For example:
  - The system specification can be given as a program or as a state machine.
  - System properties can be formalized using some logic.
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To gain confidence about the correctness of a specification it is useful to:

- Prove some properties of the specification to check that it really means what it is supposed to
- Prove the equivalence of different specifications

Example:
\[ a(0) \land a(1) \land \forall t \cdot a(t+1) = \neg a(t) \]

INCORRECT! - The error may be found when trying to prove some properties

Correct specification:
\[ a(0) \land a(1) \land \forall t \geq 0 \cdot a(t+3) = \neg a(t+2) \]
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- $a$ should be true for the first two points of time, and then oscillates
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- In the last lesson we will see how to verify contracts
Formal synthesis

- It would be helpful to automatically obtain an implementation from the specification of a system.
- Difficult since most specifications are *declarative* and not *constructive*.
  - They usually describe **what** the system should do; not **how** it can be achieved.

Example 1

Specify the operational semantics of a programming language in a constructive logic (Calculus of Constructions).

Example 2

Prove the correctness of a given property w.r.t. the operational semantics in Coq.

Example 3

Extract an OCAML code from the correctness proof (using Coq's extraction mechanism).
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3. Extract an OCAML code from the correctness proof (using Coq’s extraction mechanism).
There are mainly two approaches:

- **Deductive approach** (automated theorem proving)
  - Describe the specification $\Phi_{\text{spec}}$ in a formal model (logic)
  - Describe the system’s model $\Phi_{\text{imp}}$ in the same formal model
  - Prove that $\Phi_{\text{imp}} \implies \Phi_{\text{spec}}$

- **Algorithmic approach**
  - Describe the specification $\Phi_{\text{spec}}$ as a formula of a logic
  - Describe the system as an interpretation $M_{\text{imp}}$ of the given logic (e.g. as a finite automaton)
  - Prove that $M_{\text{imp}}$ is a “model” (in the logical sense) of $\Phi_{\text{spec}}$
Verifying Specifications w.r.t. Implementations

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**Remark**

The same technique may be used to prove properties about the specification
When and Which Formal Method to Use?

- It depends on the problem, the underlying system and the property we want to prove.
  Examples:
  - Digital circuits ... (BDDs, model checking)
  - Communication protocol with unbounded number of processes.... (verification of infinite-state systems)
  - Overflow in programs (static analysis and abstract interpretation)
  - ...

- Open distributed concurrent systems with unbounded number of processes interacting through shared variables and with real-time constraints $\Rightarrow$ VERY DIFFICULT!!
  Need the combination of different techniques.
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Remark

In this tutorial: Specification and verification of contracts using logics and model checking techniques
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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.

DEFINITIONS
4. 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.
Conventional contracts

- Traditional commercial and judicial domain
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“Programming by contract” or “Design by contract” (e.g., Eiffel)
- Relation between pre- and post-conditions of routines, method calls, invariants, temporal dependencies, etc

In the context of web services
- Service-Level Agreement, usually written in an XML-like language (e.g., WSLA)

Behavioral interfaces
- Specify the sequence of interactions between different participants. The allowed interactions are captured by legal (sets of) traces

Contractual protocols
- To specify the interaction between communicating entities

“Social contracts”: Multi-agent systems

“Deontic e-contracts”: representing Obligations, Permissions, Prohibitions, Power, etc
- Inspired from a conventional contract
- Written directly in a formal specification language
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   - 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. “Social contracts”: Multi-agent systems
7. “Deontic e-contracts”: representing Obligations, Permissions, Prohibitions, Power, etc
   - Inspired from a conventional contract
   - Written directly in a formal specification language
In this tutorial: ‘deontic’ e-contracts

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
Contracts

- In this tutorial: ‘deontic’ e-contracts

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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.
Introduction to Formal Methods: See first lecture of the course “Specification and verification of parallel systems” (INF5140) and references therein: http://www.uio.no/studier/emner/matnat/ifi/INF5140/v07/undervisningsmateriale/1-formal-methods.pdf
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1. Lesson 1: Introduction
   - Formal Methods
   - Contracts ‘and’ Informatics

2. Lesson 2: Components, Services and Contracts
   - Components
   - Service-Oriented Computing

3. Lesson 3: Deontic Logic
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   - Paradoxes in Deontic Logic

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   - The Contract Language $\mathcal{CL}$
   - Properties of the Language
   - Verification of Contracts
What is a Component?

- We will concentrate only on *software components*

- A component has to be a *unit of deployment*
  - It has to be an executable deliverable for a (virtual) machine

- A component has to be a *unit of versioning and replacement*
  - It has to remain invariant in different contexts
  - It lives at the level of packages, modules, or classes, and not at the level of objects

- It is useful to see software components as a collection of modules and resources
1. **Acquisition** is the process of obtaining a software component.

2. **Deployment** is the process of readying the component for installation in a specific environment.

3. **Installation** is the process of making the component available in the specific environment.

4. **Loading** is the process of enabling an installed component in a particular runtime context.

- Deployment is not a development activity: it does not happen at the supplier’s site.
Components Vs. Objects

1. **Components** are supposed to be self-contained units, platform independent, and independently deployable.

   - Objects are usually not executable by themselves.
Components Vs. Objects

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   - If an object creates another object inside a component, this new object is not visible from the outside unless explicitly allowed by the interface.
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4. **Components** are static entities representing the main elements of the run-time structure.
   - Classes can be instantiated dynamically in any number.
   - A purely class-oriented program does not identify the main elements of a system.
Why Components?

Four main “levels” of reasons:

1. “Make and buy”
   - Balance between purpose-built software and standard software
2. Reuse partial design and implementation fragments across multiple solutions or products
3. Use components from multiple sources, and integrate them on site (i.e., not part of the software build process)
   - The integration is called deployment
   - The matching components are called deployable components
4. Achieve highly dynamic servicing, upgrading, extension, and integration of deployed systems
Challenges

- Practical use of components stop in the third reason above
  - Truly dynamic components needs to address correctness, robustness and efficiency
- Components can be combined in many ways
  - No possibility to perform exhaustive and final integration tests at the component supplier’s site
  - Verification of component properties are crucial
  - A compositional reasoning at all levels is required
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Remark

A correct component is 100% reliable
A component with a very slight defect is 100% unreliable!
In “traditional” component-based development, contracts are understood as specification attached to interfaces

- **Behavioral interfaces** instead of static interfaces
In “traditional” component-based development, contracts are understood as specification attached to interfaces.

- **Behavioral interfaces** instead of static interfaces

**Observation**

We propose the use of ‘deontic’ e-contracts to help verification of and reasoning about components.
Components and Contracts II

Development (Creol)

Static Analysis

Testing/Simulation (Maude)

Conformance

Compatibiltiy/Conflict-free

Co1
Cc1
Con
Ccn
CcnCc1
Co1
Cc1
Con
Ccn
Pre-execution Analysis

Executing Platform

Monitor

 Gerardo Schneider (UiO)  Specification and Analysis of Contracts  November 2007  35 / 88
What is a Service?

- A service is a self-describing, platform-independent computational element
  - It supports rapid, low-cost composition of distributed applications
  - It allows organizations to offer their core competences over intra-nets or the Internet using standard languages (e.g., XML-based) and protocols
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- Services must be
  - Technology neutral: Invocation mechanisms should comply with standards
  - Loosely coupled: Not require any knowledge, internal structure, nor context at the client or service side
  - Locally transparent: Have their definition and local information stored in repositories accessible independent of their location
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- Services may be
  - Simple
  - Composite
Service-Oriented Computing

Definition

“Service-Oriented Computing (SOC) is the computing paradigm that utilizes services as fundamental elements for developing applications / solutions.
To build the service model, SOC relies on the Service-Oriented Architecture (SOA), which is a way of reorganizing software applications and infrastructure into a set of interacting services.”

(*) From “Service-Oriented Computing: Concepts, Characteristics and Directions”, by Mike P. Papazoglou
What is a Web Service?

- Def. 1: A **web service** is a web site to be used by software instead of by humans
- Def. 2: A **web service** is a specific kind of service identified by a URI (Uniform Resource Indicator), that:
  - It is exposed over Internet using standard languages and protocols
  - It can be implemented via a self-describing interface based on open Internet standards (e.g. XML)

- Web services require special consideration since they use a public, insecure, low-fidelity mechanism for inter-service interactions
- Service descriptions are usually expressed using WSDL (Web Services Description Language)
- UDDI (Universal Description, Discovery and Integration)
  - Providing registry and repository services for storing and retrieving web service interfaces
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Services vs. Components

- Payment of services is on execution basis *(per-use value)* for the delivery of the service
  - In components, there is a one-time payment for the implementation of the software
- Services may be a non-component implementation
  - A deployed component may offer one or more services
In web services, a service contract is usually understood as a service-level agreement (SLA).

Example: how much the client might pay for the service; guarantees from the provider: minimal performance, capacity, etc.
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Challenges:

- How to reason about service contracts
- How to address (automatic) negotiation
- How to enforce the fulfillment of the contract
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**Observation**

We propose the use of **'deontic' e-contracts** to help verification of and reasoning about services.

Such contracts may also be useful in the negotiation process.
M. Papazoglou. **Service-Oriented Computing: Concepts, Characteristics and Directions**

E. Newcomer. **Understanding Web Services**

C. Szyperski. **Component Technology - What, Where, and How?**

O. Owe, G. Schneider and M. Steffen. **Objects, Components and Contracts**

COSoDIS project: [http://www.ifi.uio.no/cosodis](http://www.ifi.uio.no/cosodis)
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Why Deontic Logic?

- We propose the use of ‘deontic’ e-contracts in the context of Service-Oriented Computing and Components
- We need then some knowledge of deontic logic
  - Though we only get inspiration from deontic logic and not build upon its standard formalization
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 organizations 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”
(Standard) Deontic Logic
In One Slide

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A Bit of Prehistory

Since Aristotle (384 BC–322 BC) there were some philosophers’ writing on obligation, permission and prohibition.

Leibniz (1646–1716) related obligation, permission and prohibition with logical modalities of necessity, possibility and impossibility.

Ernst Mally (1926) used the term deontik for his “Logic of the Will”:
- Also called it: The logic of what ought to be
- No mention of Leibniz nor of relation between modal and normative notions

A lot of discussions in the late 1930s and early 1940s:
- Jørgen Jørgensen and Alf Ross
The Beginnings

- It is accepted that the deontic logic was born as discipline from the following (independent) works
  - G.H. von Wright published the paper “Deontic Logic” (1951)
  - O. Becker (1952, in German)
  - J. Kalinowski (1953, in French)
- All 3 authors explored the analogy between normative and modal concepts
  - von Wright (1951)
    - Started by exploring the formal analogy between the modalities “possible”, “impossible” and “necessary” with the quantifiers “some”, “no” and “all”
    - Extended his study to the analogy with the normative notions (the 1951 paper)
  - A. Prior (1954) criticized von Wright’s paper
    - How to obtain derived obligations, i.e. conditional obligations?
    - von Wright’s answer by adding relative permission: $P(p/q)$: “it is permitted that $p$ on the condition that $q$”
- Much more followed...
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Ought-to-do vs. Ought-to-be

- **Ought-to-do**: expressions consider *names of actions*
  - “One ought to close the window”
- **Ought-to-be**: expressions consider *state of affairs* (results of actions)
  - “The window ought to be closed”

Why is this so important?

Some things are easier to represent in one approach and others in the other.

"The average bandwidth must be more than 20kb/s"

Sergot's example on the "strict University code"

The logical system may have some nicer properties in one or the other approach

Paradoxes...
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  - Sergot’s example on the “strict University code”
- The logical system may have some nicer properties in one or the other approach
  - Paradoxes...
Why Is This All So Complicated?

- **Norms** as prescriptions for conduct, are not **true** or **false**
  - If norms have no truth-value, how can we reason about them and detect contradictions and define logical consequence?
- According to von Wright: norms and valuations are still subject to logical view
- Consequence: Logic has a wider reach than truth!
- **Prescriptive vs. descriptive view**
- Conditional norms
- Meta-norms
- How to represent what happens when an obligation is not fulfilled or a prohibition is violated?
- Paradoxes
- A lot more...
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Standard Deontic Logic

- Takes different modal logics and makes analogies between “necessity” and “possibility”, with “obligation” and “permission”
- It turns out to be difficult!
  - Many of the rules in modal logic do not extrapolate to deontic logic

Example

In modal logic:

- If $p$ then $♦ p$ (if $p$ is true, then it is possible)

The deontic analogs:

- If $O(p)$ then $p$ (if it is obligatory that $p$, then $p$ is true)
- If $p$ then $P(p)$ (if $p$ is true, then it is permissible)
Standard Deontic Logic

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Example

In modal logic:
- If $\square p$ then $p$ (if it is necessary that $p$, then $p$ is true)
- If $p$ then $\Diamond p$ (if $p$ is true, then it is possible)

The deontic analogs:
- If $O(p)$ then $p$ (if it is obligatory that $p$, then $p$ is true)
- If $p$ then $P(p)$ (if $p$ is true, then it is permissible)
Paradoxes and Practical Oddities

- **Deontic paradoxes.** A paradox is an apparently true statement that leads to a contradiction, or a situation which is counter-intuitive.
  
  - *The Gentle Murderer Paradox*
    
    1. It is obligatory that John does not kill his mother;
    2. If John does kill his mother, then it is obligatory that John kills her gently;
    3. John does kill his mother.

    It could be possible to infer that John is obliged to kill his mother (contradicting 1 above)

- **Practical oddities.** A situation where you can infer two assertions which are contradictory from the intuitive practical point of view, though they might not represent a logical contradiction

  Assume you have the following norms and facts:

  1. Keep your promise;
  2. If you haven’t kept your promise, apologize;
  3. You haven’t kept your promise.

  It could be possible to deduce that you are both obliged to keep your promise and to apologize for not keeping it
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  It could be possible to deduce that you are both obliged to keep your promise and to apologize for not keeping it
It is obligatory that one mails the letter

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. $O(p \lor q)$

Problem: in SDL one can infer that $O(p) \rightarrow O(p \lor q)$
You may either sleep on the sofa or sleep on the bed.  
You may sleep on the sofa and you may sleep on the bed.

In SDL this is:
1. $P(p \lor q)$
2. $P(p) \land P(q)$

- The natural intuition tells that $P(p \lor q) \Rightarrow P(p) \land P(q)$
- In SDL this would lead to $P(p) \Rightarrow P(p \lor q)$ which is $P(p) \Rightarrow P(p) \land P(q)$,
- so $P(p) \Rightarrow P(q)$
- Thus: *If one is permitted something, then one is permitted anything.*
1. It is obligatory I now meet Jones (as promised to Jones).
2. It is obligatory I now do not meet Jones (as promised to Smith).

In SDL this is:

1. $O(p)$
2. $O(\neg p)$

- The problem is that in the natural language the two obligations are intuitive and often happen.
- But the logical formulae are inconsistent when put together (in conjunction) in SDL.
- (In SDL, $O(p) \implies \neg O(\neg p)$ and we get a contradiction.)
Paradoxes

The Good Samaritan Paradox

1. It ought to be the case that Jones helps Smith who has been robbed.
2. It ought to be the case that Smith has been robbed.

And one naturally infers that:

Jones helps Smith who has been robbed if and only if Jones helps Smith and Smith has been robbed.

In SDL the first two are expressed as:

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

The problem is that in SDL one can derive that $O(p \land q) \Rightarrow O(q)$ which is counter intuitive in the natural language.
Paradoxes
Chisholm’s Paradox

1. John ought to go to the party.
2. If John goes to the party then he ought to tell them he is coming.
3. If John does not go to the party then he ought not to tell them he is coming.
4. John does not go to the party.

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

1. $O(p)$
2. $O(p \Rightarrow q)$
3. $\neg p \Rightarrow O(\neg q)$
4. $\neg p$

• The problem is that in SDL one can infer $O(q) \land O(\neg q)$ (due to statement 2)
Paradoxes
The Gentle Murderer Paradox

1. It is obligatory that John does not kill his mother.
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3. John does kill his mother.

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

1. $O(\neg p)$
2. $p \Rightarrow O(q)$
3. $p$

- The problem is that when adding a natural inference like $q \Rightarrow p$, one can infer that $O(p)$ (contradicting 1 above)
Reminder

- We want to use **deontic e-contracts** to specify and reason about contracts in Internet services.
- We need a formal system to relate the normative notions of obligation, permission and prohibition.
- We want to represent (nested) “exceptions”: Can we represent and reason about what happens when an obligation is not fulfilled or a prohibition is violated?
- We want to avoid the philosophical problems of deontic logic (restrict its use to our application domain).
Links and Papers

- P. McNamara. Deontic Logic. See the entry at the Stanford Encyclopedia of Philosophy (http://plato.stanford.edu/entries/logic-deontic)
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Aim and Motivation

- Use **deontic e-contracts** to ‘rule’ services exchange (e.g., web services and component-based development)

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. Tackle the **negotiation** process (automatically?)
4. Develop a **theory of contracts**
   - Contract composition
   - Subcontracting
   - Conformance between a contract and the governing policies
   - *Meta-contracts* (policies)
5. Monitor contracts
   - Run-time system to ensure the contract is respected
   - In case of contract violations, act accordingly
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- Use deontic e-contracts to ‘rule’ services exchange (e.g., web services and component-based development)

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. Tackle the negotiation process (automatically?)
4. Develop a theory of contracts
   - Contract composition
   - Subcontracting
   - Conformance between a contract and the governing policies
   - Meta-contracts (policies)
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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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The Contract Specification Language $\mathcal{CL}$

**Definition ($\mathcal{CL}$)**

$Contract := \mathcal{D} ; \mathcal{C}$

$\mathcal{C} := \mathcal{C}_O \mid \mathcal{C}_P \mid \mathcal{C}_F \mid \mathcal{C} \land \mathcal{C} \mid [\alpha] \mathcal{C} \mid \langle \alpha \rangle \mathcal{C} \mid \mathcal{C} \cup \mathcal{C} \mid \bigcirc \mathcal{C} \mid \Box \mathcal{C}$

$\mathcal{C}_O := O(\alpha) \mid \mathcal{C}_O \oplus \mathcal{C}_O$

$\mathcal{C}_P := P(\alpha) \mid \mathcal{C}_P \oplus \mathcal{C}_P$

$\mathcal{C}_F := F(\alpha) \mid \mathcal{C}_F \lor [\alpha] \mathcal{C}_F$

- $O(\alpha), P(\alpha), F(\alpha)$ specify obligation, permission (rights), and prohibition (forbidden) over actions.
- $\alpha$ are actions given in the definition part $\mathcal{D}$.
- $\mathcal{D}$ includes choice, concatenation (sequencing), concurrency, and test.
- $\land, \lor, \text{and } \oplus$ 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.
The Contract Specification Language $\mathcal{CL}$

### Definition ($\mathcal{CL}$)

**Contract** := $D \; ; \; C$

$C$ := $C_O \; | \; C_P \; | \; C_F \; | \; C \; \land \; C \; | \; [\alpha]C \; | \; \langle \alpha \rangle C \; | \; C \; \cup \; C \; | \; \bigcirc C \; | \; \Box C$

$C_O$ := $O(\alpha) \; | \; C_O \; \oplus \; C_O$

$C_P$ := $P(\alpha) \; | \; C_P \; \oplus \; C_P$

$C_F$ := $F(\alpha) \; | \; C_F \; \vee \; [\alpha]C_F$

- $O(\alpha), P(\alpha), F(\alpha)$ specify obligation, permission (rights), and prohibition (forbidden) over actions
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  - · concatenation (sequencing)
  - & concurrency
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- $\text{Contract} := D ; C$
- $C := CO | CP | CF | C \land C | [\alpha]C | \langle \alpha \rangle C | C U C | \bigcirc C | \square C$
- $CO := O(\alpha) | CO \oplus CO$
- $CP := P(\alpha) | CP \oplus CP$
- $CF := F(\alpha) | CF \lor [\alpha]CF$

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Tests as actions: $\phi$?
- The behaviour of a test is like a guard; e.g. $\phi? \cdot a$ if the test succeeds then action $a$ is performed
- Tests are used to model implication: $[\phi?]C$ is the same as $\phi \Rightarrow C$

Action negation $\overline{\alpha}$
- It represents all immediate traces that take us outside the trace of $\alpha$
- Involves the use of a canonic form of actions
- E.g.: consider two atomic actions $a$ and $b$ then $a \cdot b$ is $b + a \cdot a$
**Actions**

**Test and Negation**

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Actions
Concurrent actions

- \( a \& b \)
- “The client must pay immediately, or the client must notify the service provider by sending an e-mail specifying that he delays the payment”

\[
O(p) \oplus O(d \& n)
\]

- \( O(d \& n) \equiv O(d) \land O(n) \)

Action algebra enriched with a conflict relation to represent incompatible actions

- \( a = "\text{increase Internet traffic}" \) and \( b = "\text{decrease Internet traffic}" \)
  - \( a \not\#_c b \)
  - \( O(a) \land O(b) \) gives an inconsistency
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More on the Contract Language
CTD and CTP

- Expressing *contrary-to-duty* (CTD)

\[ O_C(\alpha) = O(\alpha) \land \lbrack \overline{\alpha}\rbrack C \]

Example

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

In CL:

\[ \Box (O_C(l) \land \lbrack \overline{l}\rbrack \Box (O(p \& p \& p))) \]

where \( C = \Box O(p \& p \& p) \)
More on the Contract Language
CTD and CTP

- Expressing **contrary-to-duty** (CTD)
  \[ O_C(\alpha) = O(\alpha) \land [\overline{\alpha}]C \]

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In \( CL \):
\[ \Box (O_C(l) \land [l]\Diamond (O(p&p))) \]

where
\[ C = \Diamond O(p&p&p) \]
Translation into a variant of $\mu$-calculus ($C\mu$)

The syntax of the $C\mu$ logic

$$\varphi := P \mid Z \mid P_c \mid \top \mid \neg \varphi \mid \varphi \land \varphi \mid [\gamma] \varphi \mid \mu Z. \varphi(Z)$$

Main differences with respect to the classical $\mu$-calculus:

1. $P_c$ is set of propositional constants $O_a$ and $F_a$, one for each basic action $a$
2. Multisets of basic actions: i.e. $\gamma = \{a, a, b\}$ is a label
Translation into a variant of $\mu$-calculus ($C_\mu$)

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Obligation

\[ f^T(O(a \& b)) = \langle \{a, b\} \rangle (O_a \land O_b) \]
Obligation

\[ f^T (O(a \& b)) = \langle \{a, b\}\rangle (O_a \land O_b) \]

\[ O(a \& b) \]
Outline

1. Lesson 1: Introduction
   - Formal Methods
   - Contracts ‘and’ Informatics

2. Lesson 2: Components, Services and Contracts
   - Components
   - Service-Oriented Computing

3. Lesson 3: Deontic Logic
   - Deontic Logic
   - Paradoxes in Deontic Logic

4. Lesson 4: Specification and Analysis of Contracts
   - The Contract Language $CL$
   - Properties of the Language
   - Verification of Contracts
Theorem

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

- $P(\alpha) \equiv \neg F(\alpha)$
- $O(\alpha) \Rightarrow P(\alpha)$
- $P(a) \not\Rightarrow P(a \& b)$
- $F(a) \not\Rightarrow F(a \& b)$
- $F(a \& b) \not\Rightarrow F(a)$
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A model checker is a software tool that given:

- A model $M$ (usually a *Kripke model*)
- A property $\phi$ (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!
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It is completely automatic!
1 Model the conventional contract (in English) as a $CL$ expression
2 Translate the $CL$ specification into $C\mu$
3 Obtain a Kripke-like model (LTS) from the $C\mu$ 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 $CL$ clause and repeat the model checking process until the property is satisfied
7 In some cases rephrase the original contract
Model Checking Contracts

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Case Study
A Contract Example

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 \[\text{price}\] 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 \((2 \times \text{price})\).
4. If the Client does not lower the Internet traffic immediately, then the Client will have to pay \(3 \times \text{price}\).
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:
   a) Suspend Internet Services immediately if Client is in breach of Clause 1;
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 \((2 \times [price])\).
4. If the **Client** does not lower the Internet traffic immediately, then the **Client** will have to pay \(3 \times [price]\).
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:
   a) Suspend Internet Services immediately if **Client** is in breach of Clause 1;
1. $\square F(f_i)$

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 ($2 \times [price]$).

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Translating into $\mathcal{CL}$ syntax

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Translating into $\mathcal{CL}$ syntax

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Case Study

Translating into $CL$ syntax

1. $\Box F_{P(s)}(fi)$

2. $\Box [h](\phi \Rightarrow O(p + (d\&n)))$

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Translating into $CL$ syntax

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3. $\square([d\&n](O(l) \land [l]\diamond O(p\&p)))$

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4. $\square([d&n \cdot \neg l]\diamond O(p&p&p))$

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4. $\Box ([d\&n \cdot \bar{l}]\Diamond O(p\&p\&p))$

5. $\Box ([o]O(sfD))$
Case Study
Handcrafting the model

\( \phi = \) 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)
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\( sfD = \) client sends the Personal Data Form to Client Relations Department
\( o = \) provider activates the Internet Service (it becomes operative)
\( s = \) provider suspends service
1. $\square F_{P(s)}(fi)$
2. $\square [h](\phi \Rightarrow O(p + (d \& n)))$
3. $\square ([d \& n](O(1) \land [l] O(p \& p)))$
4. $\square ([d \& n \cdot \bar{1}] O(p \& p \& p))$
5. $\square ([o] O(sfD))$

1, 2, and 4: OK
3 and 5: FAIL!
Case Study
Checking the contract on the model

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

1, 2, and 4: OK

$\neg F_s$

$\neg F_s$

$\neg F_s$

$\neg F_s$

$\neg F_s$
Case Study
Checking the contract on the model

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

1, 2, and 4: OK
3 and 5: FAIL!
Failure of 3. It fails since there is a dependency with clause 2

- We need to combine clauses 2 and 3: it model checks!
Failure of 3. It fails since there is a dependency with clause 2

- We need to combine clauses 2 and 3: it model checks!

Failure on our formalization in $CL$!
Failure of 3. It fails since there is a dependency with clause 2

- We need to combine clauses 2 and 3: it model checks!

Failure on our formalization in $\mathcal{CL}$!

Failure of 5. $\Box([o]O(sfD)))$

- The system should become operative only once
Failure of 3. It fails since there is a dependency with clause 2

- We need to combine clauses 2 and 3: it model checks!

Failure on our formalization in $CL$!

Failure of 5. $(\square([o]O(sfD)))$

- The system should become operative only once

1. We rewrite the original contract
2. This is formulated in $CL$, written in NuSMV, and it model checks!
Failure of 3. It fails since there is a dependency with clause 2

- We need to combine clauses 2 and 3: it model checks!

Failure on our formalization in $\mathcal{CL}$!

Failure of 5. $(\square([o]O(sfD)))$

- The system should become operative only once

1. We rewrite the original contract
2. This is formulated in $\mathcal{CL}$, written in NuSMV, and it model checks!

’Failure’ on the original contract!
“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”
Case Study
Verifying a property about client obligations

“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!
“It is always the case that whenever the Internet traffic is high, if the client pays immediately, then the client is not obliged to pay again immediately afterward”

- It fails!
- We get a counter-example –Problem: state s4
“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
“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”
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”

• It fails!
“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”

It fails!

Counter-example: From $s_4$ ($\phi$ holds), after $d \& n \cdot l$, it is possible to increase Internet traffic in state $s_7$, so neither $F(h)$ nor $\text{done}_{p \& p}$ hold.
Case Study
Verifying a property about payment in case of increasing Internet traffic

“\text{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}”

It fails!

Counter-example: From \( s_4 \) (\( \phi \) holds), after \( d \& n \cdot l \), it is possible to increase Internet traffic in state \( s_7 \), so neither \( F(h) \) nor \( \text{done}_{p \& p} \) hold.

Add to the original contract the clause above!
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


Research Topics

- Improve the language/logic $\mathcal{CL}$ for contracts
- Develop a proof system for $\mathcal{CL}$
- Develop a theory of contracts
- Case studies
- Find other application domains to use contracts (e.g., financial)
- Implement algorithms for model checking
- Implement web services/components including contracts as presented in this tutorial
Thank you!