Consistency and Completeness of Regulations

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Objectives

Modelling regulations

Completing an incomplete regulation

Examples

Discussion
Regulation: set of statements expressing what is obligatory, permitted, forbidden... *smoking is forbidden in any public area except specific places where smoking is permitted*
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Consistency:

- (Cholvy, ICAIL 1999) a regulation is consistent if there exists no possible situation which leads an agent to *contradictions* (a given behaviour is prescribed and not prescribed, or prohibited and not prohibited) or *dilemmas* (two incompatible behaviours are prescribed)
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Completeness:
- (Bieber, Cuppens, DEON 1991) Confidentiality policies: *for each piece of information, the user must have either the permission to know it or the prohibition to know it*
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- (Cholvy, Roussel, ECSQARU 2007) Completeness of information exchange policies: *for each piece of information he receives, an agent must know “what to do with it”*
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**Objectives**: Extending this work to “general” regulations.
Outline

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Modelling regulations

Completing an incomplete regulation

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Discussion
Requirements for a formal language

- Reasoning with deontic notions $\implies$ modal deontic logic?
- Complexity of the rules $\implies$ first order logic?
- Temporal notions $\implies$ temporal logic?


A typed first order language + three unary predicate symbols

\[ \forall x \text{ car}(x) \land \text{light}(\text{red}) \rightarrow \text{F}(\text{pass}(x)) \]
\[ \forall x \text{ car}(x) \land \text{light}(\text{green}) \rightarrow \text{O}(\text{pass}(x)) \]

Relations between these predicates:

\[ \forall x \lnot \text{O}(\text{not}(x)) \rightarrow \lnot \text{O}(x) \]
\[ \forall x \text{F}(x) \iff \lnot \text{O}(\text{not}(x)) \]
\[ \forall x \text{P}(x) \iff \lnot \text{O}(\text{not}(x)) \land \lnot \text{O}(x) \]
\[ \forall x \text{O}(\text{not}(2x)) \iff \text{O}(x) \]

A
Requirements for a formal language

- Reasoning with deontic notions \(\Rightarrow\) modal deontic logic?
- Complexity of the rules \(\Rightarrow\) first order logic?
- Temporal notions \(\Rightarrow\) temporal logic?


- A typed first order language + three unary predicate symbols represent the deontic notions O, F, P.
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- Reasoning with deontic notions $\implies$ modal deontic logic?
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\[
\begin{align*}
\forall x \quad & \text{car}(x) \land \text{light}(\text{red}) \rightarrow F(\text{pass}(x)) \\
\forall x \quad & \text{car}(x) \land \text{light}(\text{green}) \rightarrow O(\text{pass}(x))
\end{align*}
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Requirements for a formal language

- Reasoning with deontic notions $\implies$ modal deontic logic?
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- $\forall x \ car(x) \land light(red) \implies F(pass(x))$
- $\forall x \ car(x) \land light(green) \implies O(pass(x))$

- Relations between these predicates:
  - $\forall x \ O(not(x)) \implies \neg O(x)$
  - $\forall x \ F(x) \iff O(not(x))$
  - $\forall x \ P(x) \iff \neg O(not(x)) \land \neg O(x)$
  - $\forall x \ O(not^2(x)) \iff O(x)$
Requirements for a formal language

- Reasoning with deontic notions $\Rightarrow$ modal deontic logic?
- Complexity of the rules $\Rightarrow$ first order logic?
- Temporal notions $\Rightarrow$ temporal logic?


- A typed first order language $+$ three unary predicate symbols represent the deontic notions O, F, P.

\[
\begin{align*}
\forall x \ (\text{car}(x) \land \text{light}(\text{red})) & \rightarrow F(\text{pass}(x)) \\
\forall x \ (\text{car}(x) \land \text{light}(\text{green})) & \rightarrow O(\text{pass}(x))
\end{align*}
\]

- Relations between these predicates:
  \[
  \begin{align*}
  &\forall x \ O(\text{not}(x)) \rightarrow \neg O(x) \\
  &\forall x \ F(x) \leftrightarrow O(\text{not}(x)) \\
  &\forall x \ P(x) \leftrightarrow \neg O(\text{not}(x)) \land \neg O(x) \\
  &\forall x \ O(\text{not}^2(x)) \leftrightarrow O(x)
  \end{align*}
  \]

\[\{ A \} \]
Definition (World)

A world $W$ is a complete set of p-literals.
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Definition (Consistency in a world)
Let $R$ be a regulation and $W$ a world consistent with some domain constraints $Dom$.
$R$ is consistent in $W$ (given $Dom$) iff $W \land R \land A$ is consistent
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Let $\mathcal{R}$ be a regulation and $W$ a world consistent with some domain constraints $Dom$.

$\mathcal{R}$ is consistent in $W$ (given $Dom$) iff $W \land \mathcal{R} \land A$ is consistent

Example

$Dom = \emptyset$

\[
\begin{align*}
\forall x & \quad car(x) \land light(red) \rightarrow F(pass(x)) \\
\forall x & \quad car(x) \land light(green) \rightarrow O(pass(x)) \\
\quad car(jag), light(red), light(green) & \quad \} W_0
\end{align*}
\]

$W_0 \land \mathcal{R}_0 \land A$ is not consistent $\implies \mathcal{R}_0$ is not consistent in $W_0$. 


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$\{ \mathcal{R}_0 \}$

$\{ W_0 \}$

$W_0 \land \mathcal{R}_0 \land A$ is not consistent $\implies \mathcal{R}_0$ is not consistent in $W_0$.

Definition (Consistency)

$\mathcal{R}$ is consistent iff it is consistent in any world.
Definition (Completeness in a world)

\( \mathcal{R} \) is complete in \( W \) for \( \vdash, \phi(X) \) and \( \psi(X) \) iff

\[
\begin{align*}
W \land \mathcal{R} \land A & \vdash O(\psi(X)) \text{ or } \\
W \vdash \phi(X) & \implies \\
W \land \mathcal{R} \land A & \vdash P(\psi(X)) \text{ or } \\
W \land \mathcal{R} \land A & \vdash F(\psi(X))
\end{align*}
\]

Example

\[
\forall x \ car(x) \land light(red(x)) \rightarrow F(pass(x))
\]

\[
\forall x \ car(x) \land light(green(x)) \rightarrow O(pass(x))
\]

\[
\mathcal{R}_0 = car(jag), light(orange) \}
\]

\[
W_0 = \phi(jag) \land \psi(jag)
\]
Definition (Completeness in a world)

\[ \mathcal{R} \text{ is complete in } W \text{ for } \vdash, \phi(X) \text{ and } \psi(X) \text{ iff } \]

\[ W \land \mathcal{R} \land A \vdash O(\psi(X)) \text{ or } \]

\[ W \vdash \phi(X) \implies \left\{ \begin{array}{l}
W \land \mathcal{R} \land A \vdash P(\psi(X)) \text{ or } \\
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\end{array} \right. \]

Example

\[ \forall x \text{ car}(x) \land \text{light(red)} \rightarrow F(\text{pass}(x)) \]
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\]

Example

\[
\forall x \ with \ car(x) \land light(red) \rightarrow F(pass(x)) \quad \mathcal{R}_0
\]

\[
\forall x \ with \ car(x) \land light(green) \rightarrow O(pass(x)) \quad \mathcal{R}_0
\]

\[
\text{car(jag), light(orange)} \quad W_0
\]
Definition (Completeness in a world)

\( R \) is complete in \( W \) for \( \vdash, \phi(X) \) and \( \psi(X) \) iff

\[
W \land R \land \mathcal{A} \vdash O(\psi(X)) \text{ or } W \land R \land \mathcal{A} \vdash P(\psi(X)) \text{ or } W \land R \land \mathcal{A} \vdash F(\psi(X))
\]

Example

\[
\begin{align*}
\forall x \; & car(x) \land light(red) \rightarrow F(pass(x)) \\
\forall x \; & car(x) \land light(green) \rightarrow O(pass(x)) \\
& car(jag), light(orange) \quad \mathcal{R}_0 \\
\phi(x) = & \; car(x) \land light(orange) \quad \text{and} \quad \psi(x) = pass(x) \\
\end{align*}
\]

\( W_0 \)
Definition (Completeness in a world)

$\mathcal{R}$ is complete in $W$ for $\vdash$, $\phi(X)$ and $\psi(X)$ iff

$$
W \land R \land \mathcal{A} \vdash O(\psi(X)) \text{ or } \\
W \vdash \phi(X) \implies \\
W \land R \land \mathcal{A} \vdash P(\psi(X)) \text{ or } \\
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$$

Example

$$
\forall x \ car(x) \land \text{light(red)} \rightarrow F(\text{pass}(x)) \\
\forall x \ car(x) \land \text{light(green)} \rightarrow O(\text{pass}(x)) \\
\text{car(jag), light(orange)}
$$

$W_0$ is not complete in $W_0$ for $\vdash$, $\phi(x)$ and $\psi(x)$

$$
W_0 \vdash \phi(jag) \text{ but } \\
W_0 \land R_0 \land \mathcal{A} \not\vdash O(\psi(jag)) \\
W_0 \land R_0 \land \mathcal{A} \not\vdash P(\psi(jag)) \\
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W \vdash \phi(X) \implies \\
\left\{ \\
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W \land \mathcal{R} \land A \vdash F(\psi(X)) \\
\right\}
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Example

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\begin{align*}
\forall x & \ car(x) \land light(red) \rightarrow F(pass(x)) \quad \{ \mathcal{R}_0 \\
\forall x & \ car(x) \land light(green) \rightarrow O(pass(x)) \quad \} \\
\text{car(jag), light(orange)} & \quad \{ W_0 \\
\phi(x) = car(x) \land light(orange) \quad \text{and} \quad \psi(x) = pass(x) \\
W_0 \vdash \phi(jag) & \quad \text{but} \quad \\
W_0 \land \mathcal{R}_0 \land A & \not\vdash O(\psi(jag)) \\
W_0 \land \mathcal{R}_0 \land A & \not\vdash P(\psi(jag)) \\
W_0 \land \mathcal{R}_0 \land A & \not\vdash F(\psi(jag)) \\
\implies & \mathcal{R}_0 \text{ is not complete in } W_0 \text{ for } \vdash, \phi(jag) \text{ and } \psi(jag)
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\]

\( \implies \mathcal{R}_0 \) is not complete in \( W_0 \) for \( \vdash, \phi(jag) \) and \( \psi(jag) \)

Definition (Completeness)

\( \mathcal{R} \) is complete for \( \vdash, \phi(X) \) and \( \psi(X) \) iff for all world \( W \) consistent with \( Dom \), \( \mathcal{R} \) is complete for \( \vdash, \phi(X) \) and \( \psi(X) \) in \( W \).
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Discussion
Completion Rules

- **Idea**: Adapt Reiter’s CWA (Closed World Assumption) defined for incomplete databases in order to complete them.
  - (CWA) If a literal $l$ is not deduced (from the database) then it is assumed that its negation is deduced.
  - Motivation underlying CWA: In the real world, whether $l$ is true or $l$ is false i.e., $|\models l \otimes \neg l|$
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- Here we have: $\mathcal{A} \models O(l) \otimes F(l) \otimes P(l)$. 
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  - Here we have: \( \mathcal{A} \models O(l) \otimes F(l) \otimes P(l) \).
  - This leads to several completion rules

Notation:

\[ \mathcal{R} \text{ incomplete for } X \text{ in } W \left\{ \begin{array}{c}
W \vdash \phi(X) \\
W \land \mathcal{R} \land \mathcal{A} \not\vdash O(\psi(X)) \\
W \land \mathcal{R} \land \mathcal{A} \not\vdash P(\psi(X)) \\
W \land \mathcal{R} \land \mathcal{A} \not\vdash F(\psi(X))
\end{array} \right. \]
Definition (Completion rules)

In order to be as general as possible, we parametrize the completion rules by some conditions $E_0, E_P, E_F$.

$$(R_{E_0})$$

\[ \frac{\mathcal{P} \text{ incomplete for } X \text{ in } W \quad W \vdash E_O(X)}{O(\psi(X))} \]

$$(R_{E_F})$$

\[ \frac{\mathcal{P} \text{ incomplete for } X, \text{ in } W \quad W \vdash E_F(X)}{F(\psi(X))} \]

$$(R_{E_P})$$

\[ \frac{\mathcal{P} \text{ incomplete for } X, \text{ in } W \quad W \vdash E_P(X)}{P(\psi(X))} \]

Let $\vdash_*$ denotes the inference defined by $\vdash + R_{E_F} + R_{E_P} + R_{E_0}$.
Main result (necessary and sufficient condition)
\( \mathcal{R} \) is complete and consistent for \( \vdash \) in \( W \) iff for any \( X \) so that \( \mathcal{R} \) is incomplete for \( X \) in \( W \), we have:

\[
W \vdash E_F(X) \otimes E_T(X) \otimes E_O(X)
\]
Main result (necessary and sufficient condition)
\( \mathcal{R} \) is complete and consistent for \( \vdash * \) in \( W \) iff for any \( X \) so that \( \mathcal{R} \) is incomplete for \( X \) in \( W \), we have:

\[ W \vdash E_F(X) \otimes E_T(X) \otimes E_O(X) \]

Weaker result (sufficient condition)
If for any \( X \) we have:
\[ W \vdash \phi(X) \rightarrow E_F(X) \otimes E_P(X) \otimes E_O(X) \]
then \( \mathcal{R} \) is complete and consistent for \( \vdash * \) in \( W \)
Main result (necessary and sufficient condition)
\( \mathcal{R} \) is complete and consistent for \( \vdash^* \) in \( W \) iff for any \( X \) so that \( \mathcal{R} \) is incomplete for \( X \) in \( W \), we have:

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W \vdash E_F(X) \otimes E_T(X) \otimes E_O(X)
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Weaker result (sufficient condition)
If for any \( X \) we have:

\[
W \vdash \phi(X) \rightarrow E_F(X) \otimes E_P(X) \otimes E_O(X)
\]
then \( \mathcal{R} \) is complete and consistent for \( \vdash^* \) in \( W \).

Weaker result (sufficient condition)
If \( \vdash Dom \rightarrow E_F(X) \otimes E_P(X) \otimes E_O(X) \) then \( \mathcal{R} \) is complete and consistent for \( \vdash^* \).
Some basic $E_i$

- $E_F = True$, $E_P = False$ et $E_O = False \Rightarrow$
  Everything which is not explicitly obligatory nor permitted is forbidden
  This applies to regulations which regulate highly secured systems where any action has to be explicitly permitted before being performed.

- $E_F = False$, $E_P = True$ et $E_O = False \Rightarrow$
  Everything which is not explicitly forbidden nor obligatory is permitted.
  This applies to “tolerant” regulations which regulate dimmed weakly secured system where, unless contrary, anything is permitted.

- $E_F = False$, $E_P = False$ et $E_O = True \Rightarrow$
  This means that any action which is not explicitly forbidden nor permitted is obligatory.
  This applies for instance to mail servers which must let pass every mail except spams.
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Information exchange policies

$$\phi(x, i, y) = \text{Receives}(x, i) \land \text{Agent}(y) \land \neg(x = y)$$

$$\psi(x, i, y) = \text{tell}(x, i, y)$$
Security policies

\[ \phi_1(x, y) = User(x) \land Permanent(x) \land File(y) \]

\[ \phi_2(x, y) = User(x) \land Temporary(x) \land File(y) \]

\[ \psi_1(x, y) = read(x, y) \]

\[ \psi_2(x, y) = write(x, y) \]

A security policy may be complete (in a world \( W \)) for \( \phi_1(x, y) \) and \( \psi_1(x, y) \), \( \phi_1(x, y) \) and \( \psi_2(x, y) \) but may be incomplete for \( \phi_2(x, y) \) and \( \psi_1(x, y) \), \( \phi_2(x, y) \) and \( \psi_2(x, y) \).

This means that the policy completely prescribes the behaviour of permanent users regarding reading and writing files, but is incomplete as for temporary users and reading or writing files.
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Study of consistency and completeness:
- definitions
- method to consistently complete an incomplete regulation
Study of consistency and completeness:
  ▶ definitions
  ▶ method to consistently complete an incomplete regulation
  ▶ Relation with Reiter’s defaults

\[
\begin{align*}
(d_F) & \quad \frac{\phi(X) \land E_F(X) : F(\psi(X))}{F(\psi(X))} \\
(d_P) & \quad \frac{\phi(X) \land E_P(X) : P(\psi(X))}{P(\psi(X)))} \\
(d_O) & \quad \frac{\phi(X) \land E_O(X) : O(\psi(X))}{O(\psi(X))}
\end{align*}
\]
Study of consistency and completeness:
- definitions
- method to consistently complete an incomplete regulation
- Relation with Reiter’s defaults

\[
\begin{align*}
(d_F) & \quad \phi(X) \land E_F(X) : F(\psi(X)) \\
& \quad \frac{F(\psi(X))}{\phi(X) \land E_F(X) : F(\psi(X))} \\
(d_P) & \quad \phi(X) \land E_P(X) : P(\psi(X)) \\
& \quad \frac{P(\psi(X))}{\phi(X) \land E_P(X) : P(\psi(X))} \\
(d_O) & \quad \phi(X) \land E_O(X) : O(\psi(X)) \\
& \quad \frac{O(\psi(X))}{\phi(X) \land E_O(X) : O(\psi(X))}
\end{align*}
\]

“Local completeness” (cf databases: for any employee, the database should know its phone number)
Study of consistency and completeness:
  - definitions
  - method to consistently complete an incomplete regulation

Relation with Reiter’s defaults

\[
(d_F) \quad \frac{\phi(X) \land E_F(X) : F(\psi(X))}{F(\psi(X))}
\]

\[
(d_P) \quad \frac{\phi(X) \land E_P(X) : P(\psi(X))}{P(\psi(X))}
\]

\[
(d_O) \quad \frac{\phi(X) \land E_O(X) : O(\psi(X))}{O(\psi(X))}
\]

“Local completeness” (cf databases: for any employee, the database should know its phone number)

Extensions:
  - Modal logic
  - Time