COMP4418: Knowledge Representation and Reasoning

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Nonmonotonic Reasoning

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Nonmonotonic Reasoning

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- Suppose you are told “Tweety is a bird”
- What conclusions would you draw?
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- What conclusions would you draw now? Do they differ from the conclusions that you would dr information? In what way(s)?

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- Nonmonotonic reasoning is an attem *commonsense* reasoning

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Nonmonotonic Reasoning

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- In classical logic the more facts (premises) we have, the more conclusions we can draw
- This property is known as *Monotonicity*

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(where *Cn* denotes classical consequence)

- However, the previous example sho reason in this manner

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- Might a nonmonotonic logic—one th Monotonicity property—provide a more effective way of reasoning?

Why Nonmonotonicity?

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- Problems with the classical approach to consequence
  - It is usually not possible to write down all we would like to
    ge

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  - Sometimes we would like to represe
    something that is not *entirely* t
    knowledge

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- Nonmonotonic reasoning is concerned with getting around these shortcomings

Makinson's Classification

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Makinson has suggested the following classification of non

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- Additional rules

David Makinson, *Bridges from Classic Logic*, Texts in Computing, Volume 5, King's Publications, 2005.

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Nonmonotonicity

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- Classical logic satisfies the following property
- Monotonicity: If $\Delta \subseteq \Gamma$, then $Cn(\Delta) \subseteq Cn(\Gamma)$
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- More information can lead us to retract p conclusions

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- We shall adopt the following notation
  - $\vdash$ classical consequence relation
  - $\mid\!\sim$ nonmonotonic consequence relation

Consequence Operation *Cn*

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Other properties of consequence operation *Cn*:

Inclusion $\Delta \subseteq Cn(\Delta)$

Cum ... $Cn(\Delta)$

Com ... such

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Disjunction in the Premises

$Cn(\Delta \cup \{a\}) \cap Cn(\Delta \cup \{$ ...

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Note: $\Delta \vdash \phi$ iff $\phi \in Cn(\Delta)$

alternatively: $Cn(\Delta) = \{\phi : \Delta \vdash \phi\}$

Example

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Suppose I tell you ‘Tweety is a bird’

You

I then t

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You

$bird(Tweety) \mid\!\sim flies(Tweety)$

$bird(Tweety) \land emu(Tweety) \mid\!\sim \neg flie$

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The Closed World Assumption

- A *complete* theory is one in which for every ground atom in the language, either the atom or its negation appears in the theory
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  base
- In other words, if we have no evidence as t (ground atom) P, we assume that it is f
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- Given a base set of formulae Δ *assumption* set
  $\neg P \in \Delta_{asm}$ iff for ground atom P, $\Delta \nvdash P$
- $CWA(\Delta) \; = \; Cn\{\Delta \cup \Delta_{asm}\}$

Example

$$\Delta = \{P(a), P(b), P(a) \rightarrow Q(a)\}$$
$$\Delta_{asm} = \{\neg Q(b)\}$$

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Theorem: The CWA applied to a consistent set of formulae Δ is inconsistent iff there are positive ground literals $L, \ldots, L_n$ such

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language could contain other consta
the *Domain Closure Assumption*

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- Another common assumption is the *Assumption* (UNA).

If two ground terms can't be proved equal, assume that they are not.

Predicate Completion

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Idea: The only objects that satisfy a predicate are those that must

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- Can add the *only if* part:

  $\forall x.\ P(x) \rightarrow x = a$

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- Giving:

  $\forall x.\ P(x) \leftrightarrow x = a$

Predicate Completion

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- **Definition:** A clause is *solitary* in a predicate P if

  P, it

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  P

  $Q(a) \vee R(a) \vee P(b)$ is solitary i

- Completion of a predicate is only define
  clauses solitary in that predicate

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Predicate Completion

- Each clause can be written:
  $\forall y.\ Q_1 \wedge \ldots \wedge Q_m \rightarrow P(t)$ (P not contained in Q_i)
  $\forall y.\ \forall x.\ (x = t) \wedge Q_1 \wedge \ldots \wedge Q_m \rightarrow P(x)$

  m of

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  $\forall x.\ E_1 \rightarrow P(x)$
  $\vdots$
  $\forall x.\ E_n \rightarrow P(x)$

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- Grouping these together we get:
  $\forall x.\ E_1 \vee \ldots \vee E_n \rightarrow P(x)$
- Completion becomes: $\forall x.\ P(x) \leftrightarrow E_1 \vee \ldots \vee E_n$
  and we can add this to the original set of formulae

Example

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- Suppose $\Delta = \{\forall x.\ Emu(x) \rightarrow Bird(x),$

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- $$\forall x.\ (Emu(x) \vee x = Tweety)$$

- Predicate completion of P in Δ

  $$\Delta \cup \{\forall x.\ Bird(x) \rightarrow Emu(x$$

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Circumscription

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- **Idea:** Make extension of predicate as small as possible
- Example:

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- Want to be able to conclude *Flie*
  $\neg Flies(Sam)$

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- Accept interpretations where *Ab*
  possible
- That is, we *minimise abnormality*

Circumscription

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- Given interpretations $\mathbf{I}_1 = \langle D, I_1 \rangle$, $\mathbf{I}_2 = \langle D, I_2 \rangle$, $\mathbf{I}_1 \leq \mathbf{I}_2$ iff for every predicate $P \in \mathbf{P}$, $I_1[P] \subseteq I_2[P]$.
- , either

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-
- Now consider

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$$\forall x.Bird(x) \wedge \neg Ab(x)$$
$$\forall x.Emu(x) \rightarrow Bird(x)$$
$$Bird(Tweety)$$

Reiter's Default Logic (1980)

- Add default rules of the form $\frac{\alpha:\beta}{\gamma}$
  - "If α can be proven and consistent to assume β, then conclude γ"
- $\frac{\alpha:\beta}{}$
-
-

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D – set of defaults; W – set of facts

- *Extension* of default theory contains
  conclusions as possible and must be c
  closed under classical consequenc

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- Concluding whether formula ϕ follows from $\langle D, W\rangle$
  - Sceptical inference: ϕ occurs in *every* extension of $\langle D, W\rangle$
    Credulous inference: ϕ occurs in *some* extension of $\langle D, W\rangle$

Examples

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- $W = \{\}$; $D = \{\frac{:p}{\neg p}\}$ – no extensions
- $W = \{p \vee r\}$; $D = \{\frac{p:q}{q}, \frac{r:q}{q}\}$ – one extension $\{p \vee r\}$
-
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  $D = \{\frac{bird(x):flies(x)}{flies(x)}\}$ – one extensio
- What if we add $\frac{emu(x):\neg flies(x)}{\neg flies(x)}$?

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- Poole (1988) achieves a similar effect (
  general) by changing the way the underlying logic is used rather than introducing a new element into the syntax

Default Theories—Properties

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Observation: Every normal default theory (default rules are all normal) has an extension

Observation: If a normal default theory has several exte

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Obs

D is i

Theorem: (Semi-monotonicity)

Given two normal default theories $\langle D$

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that $D \subseteq D'$ then, for any extension $\mathcal{E}$

extension $\mathcal{E}(D', W)$ where $\mathcal{E}(D, W)$

(The addition of normal default rules does not lead to the retraction of consequences.)

Nonmonotonic Consequence

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- Abstract study and analysis of nonmonotonic consequence relation $\mid\!\sim$ in terms of general properties Kraus, Lehmann
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  Left Logical Equivalence If $\vdash \phi$ $\mid\!\sim \chi$

  Right Weakening If $\vdash \psi \rightarrow \chi$ an

  And If $\phi \mid\!\sim \psi$ and $\phi \mid\!\sim \chi$, t

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- Plus many more!

KLM Systems

- Kraus, Lehman and Magidor (1991) study various classes of nonmonotonic consequence relations

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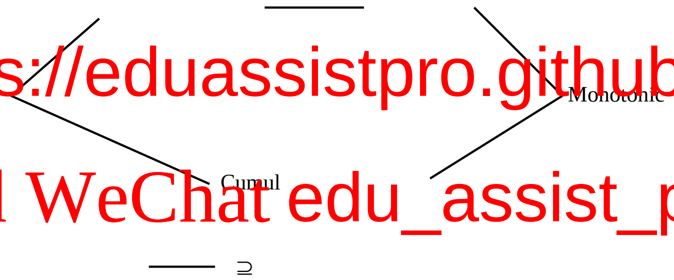

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- This has been extended since. A good reference for this line of work is Schlechta (1997)

Summary

- Nonmonotonic reasoning attempts to capture a form of commonsense reasoning
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- Nonmonotonic reasoning often deals with inferences
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- Can introduce abstract study of nonm consequence relations in same way a consequence relations
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- Similar links exist with conditionals
- One area where nonmonotonic reasoning is important is reasoning about action (dynamic systems)