Multifarious Uncertainty in Ontologies

Where we are and where we might go

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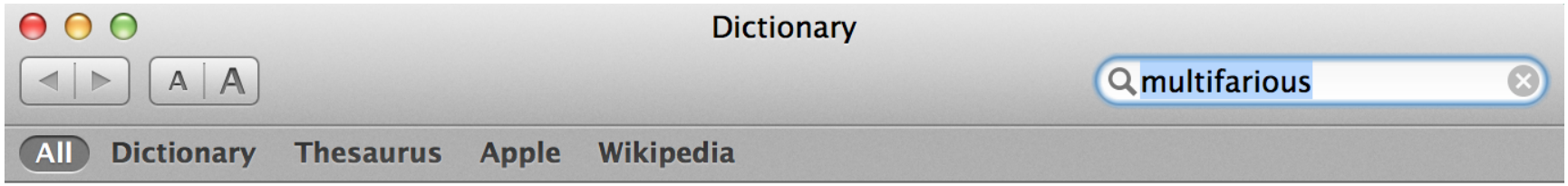


Dictionary

multifarious | ˌməlt(ə)ˈfe(ə)rēəs |

adjective
many and of various types: *multifarious activities*.
• having many varied parts or aspects: *a vast multifarious organization*.

DERIVATIVES
multifariously adverb .
multifariousness noun

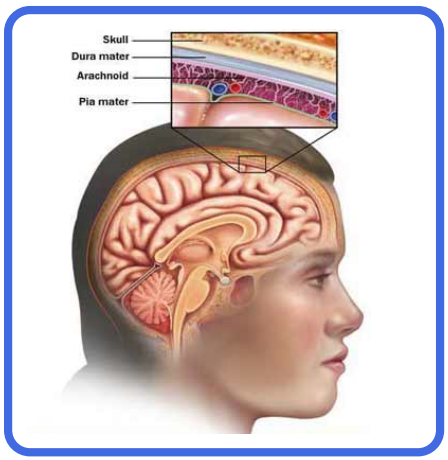
ORIGIN late 16th cent.: from Latin ***multifarius*** + **-OUS**.

Thesaurus

multifarious

adjective
our multifarious ethnic traditions: DIVERSE, many, numerous, various, varied, diversified, multiple, multitudinous, multiplex, manifold, multifaceted, different, heterogeneous, miscellaneous, assorted; literary myriad, divers. ANTONYMS homogeneous.

Motivation



Medical terminology

- Viral meningitis is a type of meningitis
- Bacterial meningitis is a type of meningitis
- Meningitis is either viral or bacterial

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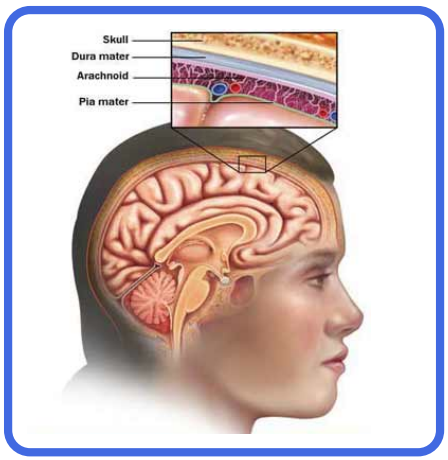

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- *Meningitis* is usually *not fatal*
- *Meningitis* and *caused by bacteria* is usually *fatal*
- *Meningitis* affects most of *skull*, *Dura mater* is mostly made of *fibre*
- *B. menin.* is similar to *v. menin.*, *Pia mater* is analogous to *dura mater*
- Cases of *B. meningitis* can be treated with *antibiotics*
- But *Mary* has *meningitis* and is *pregnant*

Uncertainty in Ontologies

Several nuances

- Exceptions: special cases, overriding of properties

  meningitis, bact. meningitis

- Similarity or analogy: focus on relevant aspects, tolerance

  pia mater, dura mater

- Vagueness: notions of 'generally', 'rarely', 'most'

  meningitis rarely kills

- Incomplete information: take chances, be venturous

  give antibiotics to cases of meningitis

- Dynamicity: incorporate new information, backtracking

  not during pregnancy

- Others

Uncertainty in Ontologies

Various takes

- Quantitative: probabilistic, statistical
- Qualitative: logical
- Combinations thereof

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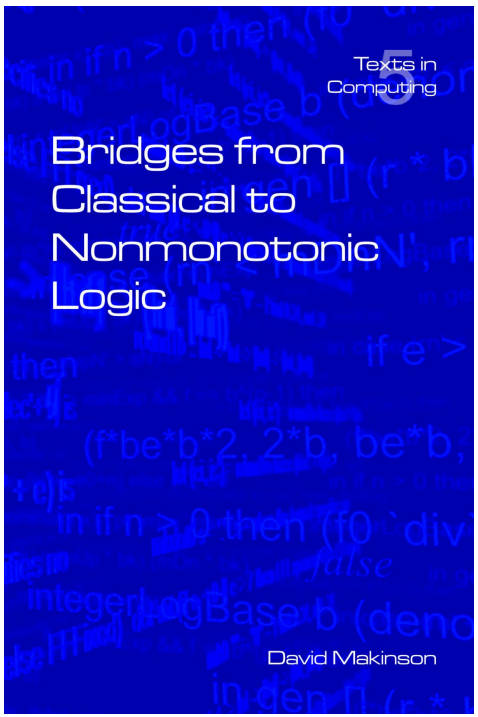
Logical approaches

- Qualitative analysis of uncertainty in reasoning
- a.k.a. nonmonotonic reasoning
- Broader than the usual understanding of NMR



Outline

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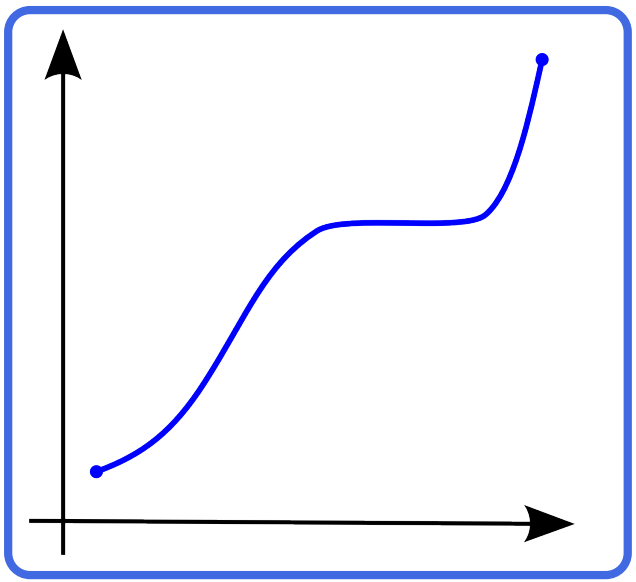
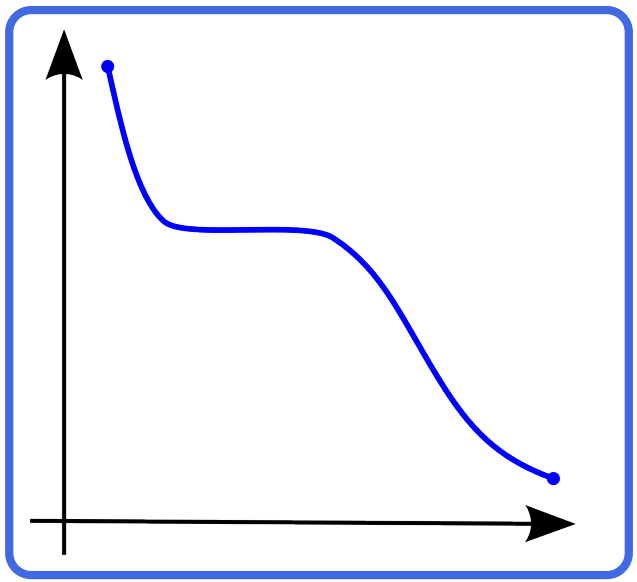
Monotonicity





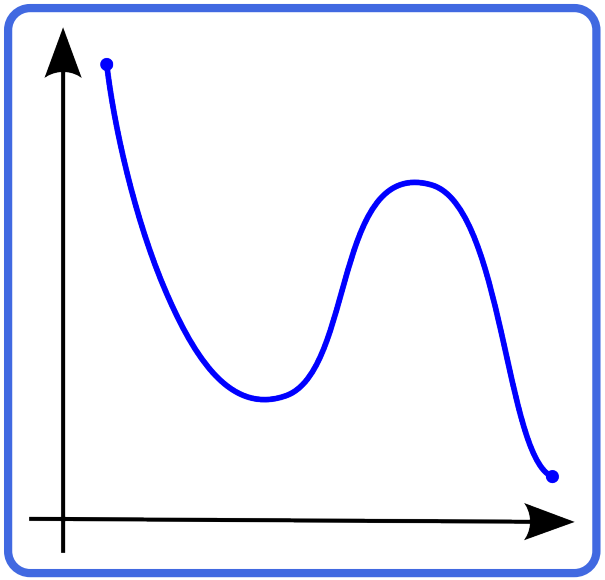
$Cn(\alpha) \subseteq Cn(\alpha \wedge \beta)$

$Mod(\alpha \wedge \beta) \subseteq Mod(\alpha)$

In reasoning

- It means knowledge is always *incremental*
- Not suitable when facing uncertainty

Reasoning under Uncertainty



In the logic landscape

- Shares aims of non-classical logics
- But does not reject classical reasoning
- Builds on classical logic, extending it

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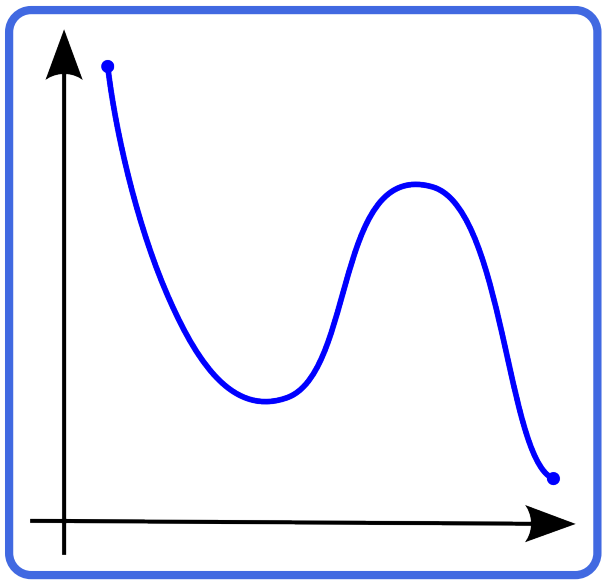

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Two fundamental aspects

- *Ampliativeness* and *defeasibility*

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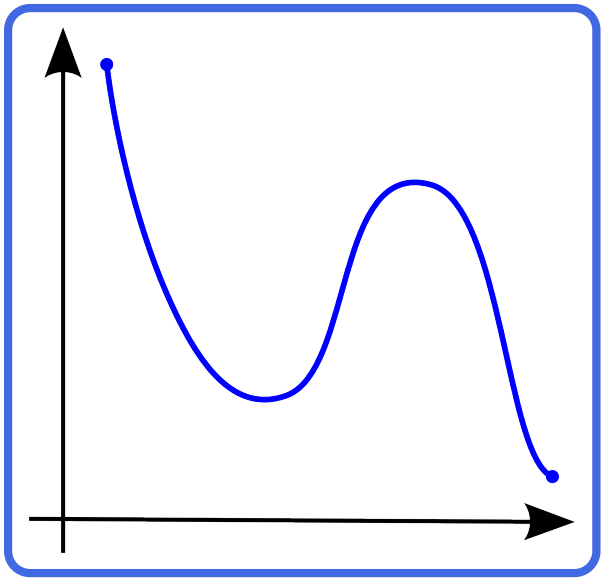

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Happens at three levels (at least)

- *Object*, *entailment* and *meta-reasoning* levels

Ampliative Aspect of Uncertainty

Allowing more conclusions by venturing beyond what is known

Default reasoning

- Jumping to conclusions: $\mathcal{T} \not\models \neg\alpha, \ \therefore \mathcal{T} \cup \{\alpha\}$ OK
- E.g.: negation as failure, closed-world assumption

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Abductive reasoning

- Finding tentative explanations: $\mathcal{T} \not\models \alpha, \quad \mathcal{T} \cup ? \models \alpha$
- E.g.: diagnosis, forensics

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Inductive reasoning

- Making generalizations: $P(a), P(b), P(c), \ldots, \therefore \forall x.P(x)$ OK
- E.g.: physical laws, stereotypes

Defeasible Aspect of Uncertainty

Allowing less conclusions by disregarding or blocking some of them

Retractive reasoning

- Withdrawing conclusions already derived

$$\alpha \in Cn(\mathcal{T}) \quad \blacksquare \quad \alpha \notin Cn(\mathcal{T})$$

- Ex.: ontology change, dialectics

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Preemptive reasoning

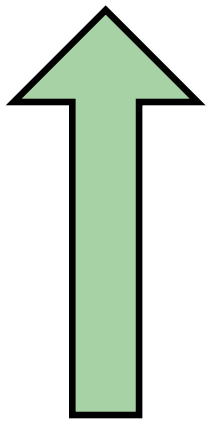
- Preventing the derivation of some conclusion

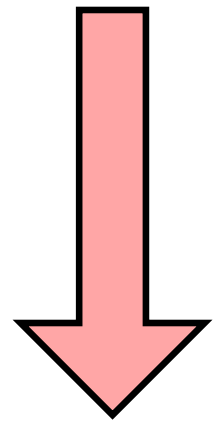
$$\gamma \rightarrow \alpha, \quad \alpha \rightarrow \beta, \quad \textit{not} \quad (\gamma \rightarrow \beta)$$

- Ex.: special cases in taxonomies, exceptions in regulations

Central Research Question in Uncertainty

How to sanction more conclusions and how to sanction fewer of them





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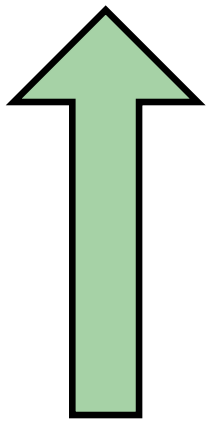

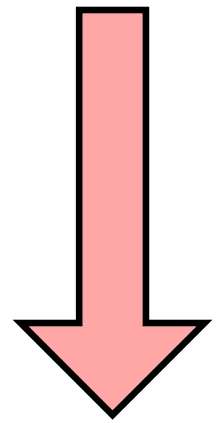

Uncertainty at the Object Level

Logical symbols of the language

- Connectives can behave nonmonotonically

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Nonmonotonic version of material implication '$\rightsquigarrow$'

- Ampliative aspect: $\alpha \rightsquigarrow \beta$ holds even if $\alpha \rightarrow \beta$ doesn't

$$\textit{meningitis} \rightsquigarrow \neg \textit{fatal}$$

- Defeasible (preemptive) aspect: $\alpha \rightsquigarrow \beta$ is the case but $\alpha \wedge \gamma \rightsquigarrow \beta$ not

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Negation in logic programming

- Ampliative and retractive

Uncertainty at the Entailment Level

Sanctioned inferences or reasoning

- Entailment $\models$ behaves nonmonotonically

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Nonmonotonic version of $\models$

- Historically the most extensively studied
- Ampliative aspect: we may have $\{\alpha\} \not\models \beta$ even if $\{\alpha\} \models \beta$

$$\{\mathit{hasMeningitis}(\text{mary})\} \not\models \mathit{AntiBioOK}$$

- Defeasible (retractive) aspect: $\{\alpha\} \not\models \beta$ is the case but $\{\alpha, \gamma\} \models \beta$

$$\{\mathit{hasMeningitis}(\text{mary}), \mathit{pregnant}(\text{mary})\} \not\models \mathit{AntiBioOK}$$

Uncertainty at the Meta-reasoning Level

Reasoning about sanctioned inferences

- Nonmonotonicity happens 'outside' the logic

Theory change

- Theory expansion: make sure $\alpha \in Cn(\mathcal{T})$
- Theory contraction: make sure $\alpha \notin Cn(\mathcal{T})$

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Ampliative aspect

- Usually more 'conservative': primacy of new information
- Even when not conservative, not venturous enough: minimal change
- New information must follow classically from the new theory

Outline

Standard Logical Frameworks for Uncertainty

- Conditional logics
- Default logic
- Circumscription
- Autoepistemic logic
- AGM belief revision
- Ontology evolution
- Abstract argumentation frameworks
- Dynamic epistemic logic
- Adaptive logics
- Preferential logics
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Default Logic

Motivation

- Account of conclusions by default (based on absence of knowledge)
- Default rules of the form

$$\frac{\alpha : \beta, \neg\gamma}{\beta} \qquad \frac{\mathit{hasMeningitis}(\mathsf{mary}) : \mathit{AntiBioOK}, \neg \mathit{pregnant}(\mathsf{mary})}{\mathit{AntiBioOK}}$$

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- Only at the entailment level

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- Minimize the extension of predicates (different policies)
- Look at some models of the premises
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- E.g. minimize extension of *pregnant* to infer *AntiBioOK*

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Approaches and construction methods

- *Belief bases* and *belief sets*
- *Partial-meet*, *kernels*, *system of spheres*, etc.

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Example

$$\mathcal{K} = \{\ldots, \exists \mathsf{hasDisease.Menin(mary)}, \ldots\} \models \exists \mathsf{hasDisease.}\neg\mathsf{Fatal(mary)}$$

Revise $\mathcal{K}$ with $\exists \mathsf{hasDisease.BacMenin(mary)}$

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- Logic of (group) knowledge change
- Information flows via informative events:

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- Epistemic possibilities held by multiple agents
- Model transformations: $\mathscr{M}_E \otimes \mathscr{M}_A \Rightarrow \mathscr{M}'_E$

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Aspects and levels

- Only defeasible (retractive): $\neg K\alpha \rightarrow [\alpha!]\neg K\alpha$ not valid
- Only at the object level

Preferential Logics and Rational Closure (KLM)

Motivation

- Nonmonotonic conditional $\leadsto$ satisfying rationality properties:

(Ref) $\alpha \leadsto \alpha$ (LLE) $\dfrac{\alpha \equiv \beta, \quad \alpha \leadsto \gamma}{\beta \leadsto \gamma}$ (And) $\dfrac{\alpha \leadsto \beta, \quad \alpha \leadsto \gamma}{\alpha \leadsto \beta \wedge \gamma}$ (Or) $\dfrac{\alpha \leadsto \gamma, \quad \beta \leadsto \gamma}{\alpha \vee \beta \leadsto \gamma}$

(RW) $\dfrac{\alpha \leadsto \beta, \quad \models \beta \rightarrow \gamma}{\alpha \leadsto \gamma}$ (CM) $\dfrac{\alpha \leadsto \beta, \quad \alpha \leadsto \gamma}{\alpha \wedge \gamma \leadsto \beta}$ (RM) $\dfrac{\alpha \leadsto \beta, \quad \alpha \not\leadsto \neg \gamma}{\alpha \wedge \gamma \leadsto \beta}$

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- Notion of *minimal entailment* *à la* circumscription
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- Only at the object and entailment levels

Preferential DLs

Defeasible subsumption

- E.g. Menin $\sqsubseteq \neg$Fatal, BacMenin $\sqsubseteq$ Fatal
- Properties

(Cons) $\top \not\sqsubseteq \bot$ (Ref) $C \sqsubseteq C$ (LLE) $\dfrac{C \equiv D, \quad C \sqsubseteq E}{D \sqsubseteq E}$

(And) $\dfrac{C \sqsubseteq D, \quad C \sqsubseteq E}{C \sqsubseteq D \sqcap E}$ (Or) $\dfrac{C \sqsubseteq E, \quad D \sqsubseteq E}{C \sqcup D \sqsubseteq E}$ (RW) $\dfrac{C \sqsubseteq D, \quad D \sqsubseteq E}{C \sqsubseteq E}$

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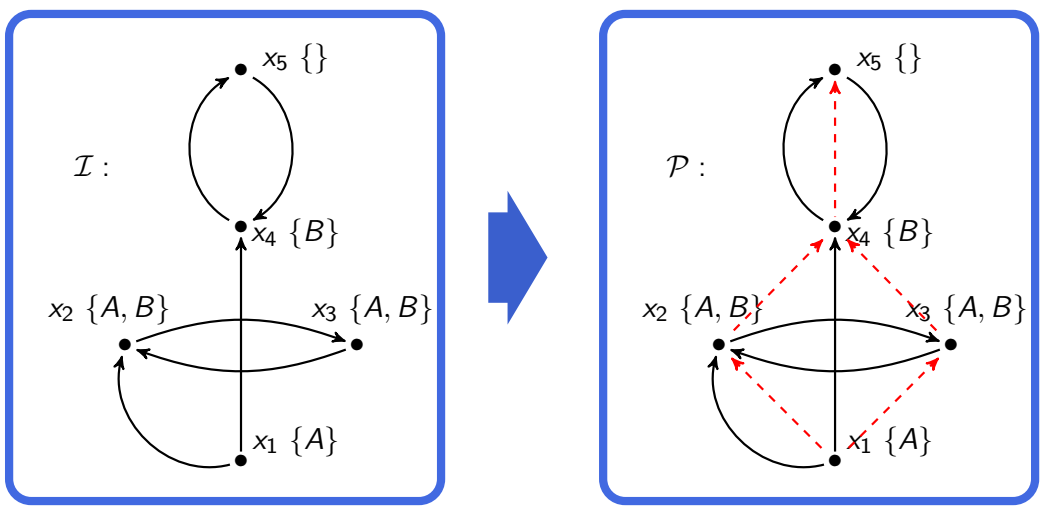
Typicality operator

- E.g. $\mathbf{T}$(Menin) $\sqsubseteq \neg$Fatal, $\mathbf{T}$(BacMenin) $\sqsubseteq$ Fatal

Preferential DLs

Semantics

- Enriched DL Interpretations $\mathcal{P} := \langle \Delta^{\mathcal{I}}, \cdot^{\mathcal{I}}, \prec \rangle$
- $\Delta^{\mathcal{I}}$ and $\cdot^{\mathcal{I}}$ as before
- $\prec$ is a *preference (or normality) relation*



$\mathcal{P} \Vdash C \sqsubseteq D$ iff $\min_{\prec} C^{\mathcal{P}} \subseteq D^{\mathcal{P}}$

$(\mathbf{T}(C))^{\mathcal{P}} = \min_{\prec} C^{\mathcal{P}}$

Representation results: soundness and completeness of postulates

Existing Frameworks: Summary

	Amp.	Def.	Obj.	Ent.	Meta.
Conditional logics	✓	✓	✓		
Default logics	✓	✓		✓	
Circumscription	✓	✓		✓	
Autoepistemic logic	✓	✓		✓	
AGM belief change		✓			✓
Ontology evolution		✓			✓
Argumentation		✓			✓
DEL		✓	✓		
Adaptive logics	✓	✓		✓	✓
Preferential	✓	✓	✓	✓	

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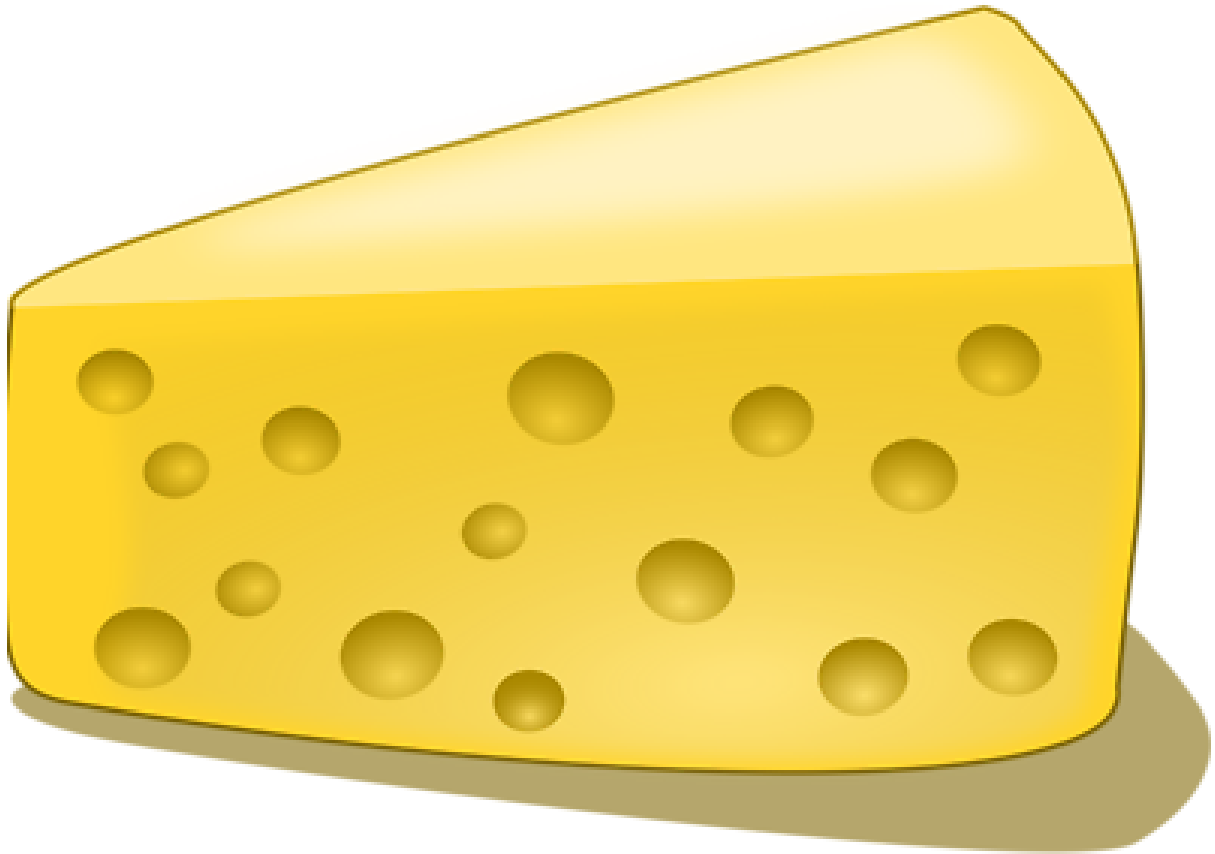

Not all **levels** and **aspects** have been dealt with!

Outline

The Need for Multifarious Uncertainty

Other nonmonotonic logical symbols

- Nonmonotonic connectives
- Nonmonotonic modalities and quantifiers

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New nonmonotonic consequence relations

- Levels of venturousness
- Links with abduction, induction and other forms of reasoning

The Need for Multifarious Uncertainty

Other nonmonotonic logical symbols

- Nonmonotonic connectives
- Nonmonotonic modalities and quantifiers

New nonmonotonic consequence relations

- Levels of venturousness
- Links with abduction, induction and other forms of reasoning

More powerful accounts of theory change

- Languages that are more expressive
- With nonmonotonic connectives

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New and more general theories of uncertainty are called for

Uncertainty in Concept Constructors

Defeasible disjointness

- Normally mutually exclusive

$$\text{BacMenin} \sqsubseteq \neg\text{ViralMen} \text{ 'OR' } \text{ViralMen} \sqsubseteq \neg\text{BacMenin}$$

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Other layers of typicality

- Talk about other levels

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Typicality for roles

- Some relations are more normal than others

$$\mathbf{T}(\mathsf{infectedBy}),\ \mathbf{T}(\mathsf{marriedTo})$$

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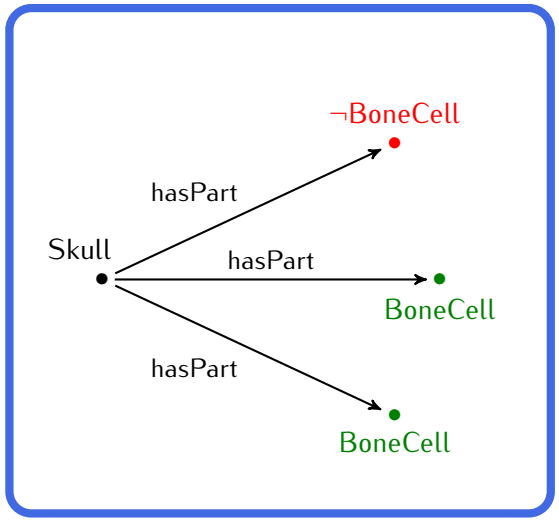
Nonmonotonic role restrictions

- Normal role fillers

$$\mathsf{Skull} \equiv \forall \mathsf{madeOf}.\mathsf{Bone}$$



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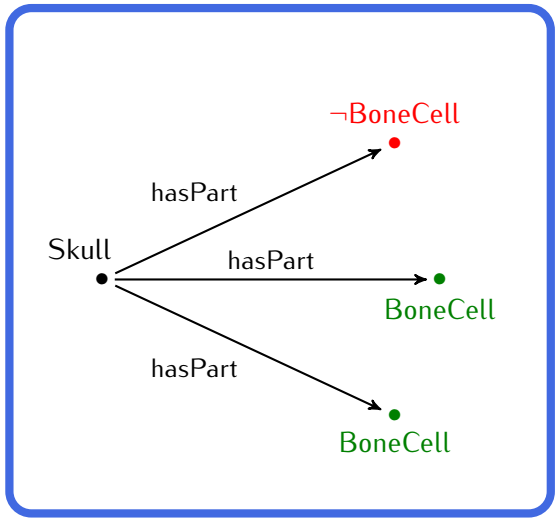

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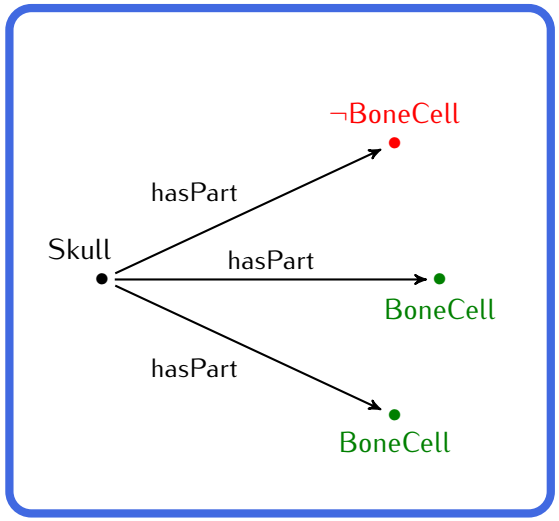

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Defeasible role properties

- Holding in the most normal cases

$$\mathsf{marriedTo} : \textit{usually functional}, \quad \mathsf{partOf} : \textit{usually transitive}$$

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- Further semantic constraints
- (Naïve) Existential Restriction Introduction

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✓ $$\frac{\mathsf{BacMenin} \mathrel{\sqsubseteq\!\!\!\sim} \mathsf{Fatal}}{\exists \mathsf{hasDisease}.\mathsf{BacMenin} \mathrel{\sqsubseteq\!\!\!\sim} \exists \mathsf{hasDisease}.\mathsf{Fatal}}$$

✗ $$\frac{\mathsf{Menin} \mathrel{\sqsubseteq\!\!\!\sim} \neg\mathsf{Fatal}}{\exists \mathsf{dieOf}.\mathsf{Menin} \mathrel{\sqsubseteq\!\!\!\sim} \exists \mathsf{dieOf}.\neg\mathsf{Fatal}}$$

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- Value Restriction Introduction

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- Rational Existential Monotonicity

$$\text{(REM)}\quad \frac{\exists r.C \sqsubseteq_{\sim} \exists r.D, \quad \exists r.C \not\sqsubseteq_{\sim} \neg \mathbf{T}(\exists r.E)}{\exists r.(C \sqcap E) \sqsubseteq_{\sim} \exists r.D}$$

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Uncertainty in Entailment

Instance-level ampliative and defeasible reasoning

- Let the TBox

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- If we learn $\mathsf{hasDisease.Menin(mary)}$ ...

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- ...allowing for retracting it if we learn $\mathsf{hasDisease.BacMenin(mary)}$

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Different levels of 'venturousness'

- Skeptical, credulous, and in between

Uncertainty in Entailment

Standard constructions

- Usually: Strengthening the premises or relaxing the conclusions

$$\mathcal{K} \mid\!\approx \alpha \text{ iff } \downarrow Mod(\mathcal{K}) \subseteq Mod(\alpha)$$

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Beyond standard constructions

- Go beyond the dichotomy "preferred v. non-preferred"
- Look for other notions of preferences and minimality
- New forms of reasoning beyond induction and abduction?

Enhanced Theory Change

Beyond propositional languages

- Modal logics, description logics, ...

$$\mathcal{T} \star \Box\alpha \; ?, \quad \mathcal{T} \star (C \sqsubseteq D) \; ?, \quad \mathcal{T} - r(a, b) \; ?$$

- Also fragments thereof (Horn, $\mathcal{EL}$, etc.)

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Beyond classical constructors

- Makes sense for languages with nonmonotonic connectives
- A whole family of AGM-like new postulates
- Links with various $\not\approx$

Desiderata for a General Framework

Remember

- The two aspects and the three levels

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- accounts for languages of various expressive power
- has good balance between expressivity and computational complexity
- is general yet elegant
- can serve as a core formalism for further extensions
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Principle

- Not to diverge from existing approaches, rather build on them

What to Use as a Springboard?

Several frameworks available

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Why?

- Provides a general proof-theoretic characterization of $\rightsquigarrow$ (and $\sqsubset$)
- Basis for nonmonotonic entailment $\mid\!\approx$, e.g. *rational closure*
- Links with AGM belief revision (inter-definability)
- Simple and elegant (cf. our desiderata)
- Recently extended to modal and description logics

Outline

Conclusion

What we have seen

- Uncertainty has two aspects: ampliative and defeasible
- It happens at three levels: object, entailment, and meta-reasoning
- There are still many open issues not fully addressed
- There is a need for more general theories
- We saw some possible directions to pursue

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Thank you!