

Natural Language Inference

Entailment Relations

Marc Schulder

Saarland University

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- 1** Entailment Relations
 - ▶ Introduce entailment relations
 - ▶ Joining multiple relations
- 2** Compositional Entailment
 - ▶ Monotonicity
 - ▶ Projectivity
 - ▶ Implicature
- 3** NatLog
 - ▶ Entailment System
 - ▶ Evaluation

Entailment

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NatLog

What is entailment?

- ▶ Entailment is one type of inference.
- ▶ Premise p entails hypothesis h
iff p cannot be true unless h is true

Example

p Stimpny is a cat.

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Example

- p Stimpy is a cat.
- h_1 Stimpy is a mammal.

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Example

- p Stimpy is a cat.
- h_1 Stimpy is a mammal.
- h_2 Stimpy is not a dog.

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- ▶ Entailment is one type of inference.
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iff p cannot be true unless h is true

Example

- p Stimpy is a cat.
- h_1 Stimpy is a mammal.
- h_2 Stimpy is not a dog.
- h_3 **Stimpy is hungry.**

Approaches to Entailment

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Two-way classification

- 1 Entailment ($p \models h$)
- 2 Non-Entailment ($p \not\models h$)

Not modelled: Equivalence, contradiction

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Three-way classification

- 1 Entailment ($p \models h$)
- 2 Contradiction ($p \models \neg h$)
- 3 Compatibility ($p \not\models h \wedge p \not\models \neg h$)

Not modelled: Equivalence

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Three-way classification

- 1 Entailment ($p \models h$)
- 2 Contradiction ($p \models \neg h$)
- 3 Compatibility ($p \not\models h \wedge p \not\models \neg h$)

Not modelled: Equivalence

Containment classification

- 1 \equiv Equivalence ($p \models h \wedge h \models p$)
- 2 \sqsubset Forward Entailment ($p \models h \wedge h \not\models p$)
- 3 \sqsupset Reverse Entailment ($p \not\models h \wedge h \models p$)
- 4 No Containment ($p \not\models h \wedge h \not\models p$)

Not modelled: Contradiction

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	2-way	3-way	containment
p. X is a couch h. X is a sofa	entailment	entailment	$p \equiv h$
p. X is a crow h. X is a bird			$p \sqsubset h$
p. X is a fish h. X is a carp	non-entailm.	compatibility	$p \sqsupset h$
p. X is a hippo h. X is hungry			no-containm.
p. X is a cat h. X is a dog		contradiction	

The best of both worlds

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Requirements to new approach

- ▶ Keep semantic containment relations
- ▶ Add relations for semantic exclusion
- ▶ Completeness
- ▶ Mutual exclusion

⇒ Computation of new relations would require an excursion into set theory.

See MacCartney's dissertation for details.

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Symbol	Name	Example	Set Theoretic Definition
$x \equiv y$	equivalence	couch \equiv sofa	$x = y$
$x \sqsubset y$	forward entailment	crow \sqsubset bird	$x \subset y$
$x \supset y$	reverse entailment	bird \supset crow	$x \supset y$
$x \wedge y$	negation	able \wedge unable	$x \cap y = \emptyset \wedge x \cup y = U$
$x y$	alternation	cat dog	$x \cap y = \emptyset \wedge x \cup y \neq U$
$x \smile y$	cover	animal \smile non-ape	$x \cap y \neq \emptyset \wedge x \cup y = U$
$x \# y$	independence	hungry $\#$ hippo	(all other cases)

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Given Entailment relation R holds between x and y .
Entailment relation S holds between y and z .
 \Rightarrow What entailment relation holds between x and z ?

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Given Entailment relation R holds between x and y .

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1 $\sqsubset \bowtie \sqsubset = \sqsubset$

▶ $\text{crow} \sqsubset \text{bird} \bowtie \text{bird} \sqsubset \text{animal} = \text{crow} \sqsubset \text{animal}$

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▶ $\text{crow} \sqsubset \text{bird} \bowtie \text{bird} \sqsubset \text{animal} = \text{crow} \sqsubset \text{animal}$

2 $\wedge \bowtie \wedge = \equiv$

▶ $\text{happy} \wedge \text{unhappy} \bowtie \text{unhappy} \wedge \text{jolly} = \text{happy} \equiv \text{jolly}$

Joining Entailment Relations

Given Entailment relation R holds between x and y .

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\Rightarrow What entailment relation holds between x and z ?

1 $\sqsubset \bowtie \sqsubset = \sqsubset$

▶ $\text{crow} \sqsubset \text{bird} \bowtie \text{bird} \sqsubset \text{animal} = \text{crow} \sqsubset \text{animal}$

2 $\wedge \bowtie \wedge = \equiv$

▶ $\text{happy} \wedge \text{unhappy} \bowtie \text{unhappy} \wedge \text{jolly} = \text{happy} \equiv \text{jolly}$

3 $| \bowtie \wedge = \sqsubset$

▶ $\text{fish} | \text{human} \bowtie \text{human} \wedge \text{nonhuman} = \text{fish} \sqsubset \text{nonhuman}$

Joining Entailment Relations

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	\boxtimes	\equiv	\sqsubset	\sqsupset	\wedge	\mid	\cup	$\#$
Marc Schulder	\equiv	\equiv	\sqsubset	\sqsupset	\wedge	\mid	\cup	$\#$
Entailment Relations	\sqsubset	\sqsubset	\sqsubset		\mid	\mid		
Background Entailment Relations	\sqsupset	\sqsupset		\sqsupset	\cup		\cup	
Joining Relations	\wedge	\wedge	\cup	\mid	\equiv	\sqsupset	\sqsubset	$\#$
Compositional Entailment	\mid	\mid		\mid	\sqsubset		\sqsubset	
NatLog	\cup	\cup	\cup		\sqsupset	\sqsupset		
	$\#$	$\#$			$\#$			

Nondeterministic joins

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$| \bowtie | = ?$

1 gasoline|water \bowtie water|petrol = gasoline \equiv petrol

Nondeterministic joins

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| \bowtie | = ?

1 gasoline|water \bowtie water|petrol = gasoline \equiv petrol

2 pistol|knife \bowtie knife|gun = pistol \sqsubset gun

Nondeterministic joins

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$| \bowtie | = ?$

- 1 gasoline|water \bowtie water|petrol = gasoline \equiv petrol
- 2 pistol|knife \bowtie knife|gun = pistol \sqsubset gun
- 3 gun|knife \bowtie knife|pistol = gun \sqsubset pistol

Nondeterministic joins

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$| \bowtie | = ?$

- 1 gasoline|water \bowtie water|petrol = gasoline \equiv petrol
- 2 pistol|knife \bowtie knife|gun = pistol \sqsubset gun
- 3 gun|knife \bowtie knife|pistol = gun \sqsupset pistol
- 4 rose|orchid \bowtie orchid|daisy = rose|daisy

Nondeterministic joins

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| \bowtie | = ?

- 1 gasoline|water \bowtie water|petrol = gasoline \equiv petrol
- 2 pistol|knife \bowtie knife|gun = pistol \sqsubset gun
- 3 gun|knife \bowtie knife|pistol = gun \sqsupset pistol
- 4 rose|orchid \bowtie orchid|daisy = rose|daisy
- 5 woman|frog \bowtie frog|Eskimo = woman#Eskimo

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	\boxtimes	\equiv	\sqsubset	\sqsupset	\wedge	\vee	\cup	$\#$
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Entailment Relations	\sqsubset	\sqsubset	\sqsubset		\vee	\vee		
Background Entailment Relations	\sqsupset	\sqsupset		\sqsupset	\cup		\cup	
Joining Relations	\wedge	\wedge	\cup	\vee	\equiv	\sqsupset	\sqsubset	$\#$
Compositional Entailment	\vee	\vee		\vee	\sqsubset		\sqsubset	
NatLog	\cup	\cup	\cup		\sqsupset	\sqsupset		
	$\#$	$\#$			$\#$			

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	\boxtimes	\equiv	\sqsubset	\sqsupset	\wedge	\vee	\cup	$\#$
Marc Schulder	\equiv	\equiv	\sqsubset	\sqsupset	\wedge	\vee	\cup	$\#$
Entailment Relations	\sqsubset	\sqsubset	\sqsubset	$\equiv \sqsubset \sqsupset \mid \#$	\mid	\mid	$\sqsubset \wedge \mid \cup \#$	$\sqsubset \mid \#$
Background Entailment Relations	\sqsupset	\sqsupset	$\equiv \sqsubset \sqsupset \cup \#$	\sqsupset	\cup	$\sqsupset \wedge \mid \cup \#$	\cup	$\sqsupset \cup \#$
Joining Relations	\wedge	\wedge	\cup	\mid	\equiv	\sqsupset	\sqsubset	$\#$
Compositional Entailment	\mid	\mid	$\sqsubset \wedge \mid \cup \#$	\mid	\sqsubset	$\equiv \sqsubset \sqsupset \mid \#$	\sqsubset	$\sqsubset \mid \#$
NatLog	\cup	\cup	\cup	$\sqsupset \wedge \mid \cup \#$	\sqsupset	\sqsupset	$\equiv \sqsubset \sqsupset \cup \#$	$\sqsupset \cup \#$
	$\#$	$\#$	$\sqsubset \cup \#$	$\sqsupset \mid \#$	$\#$	$\sqsupset \mid \#$	$\sqsubset \cup \#$	$\equiv \sqsubset \sqsupset \wedge \mid \cup \#$

Now on to Compositional Entailment

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Elementary Set Relations

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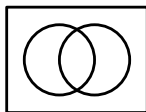
Background

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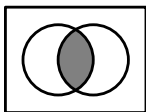
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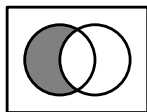
NatLog



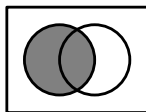
R_{0000}



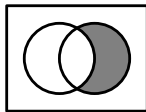
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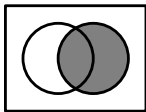
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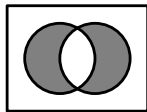
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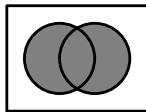
R_{0100}



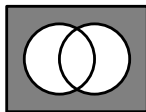
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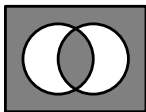
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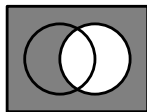
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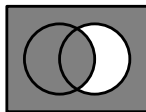
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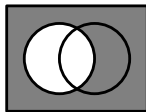
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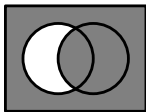
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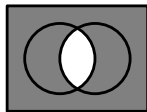
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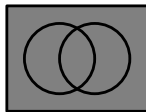
R_{1100}



R_{1101}



R_{1110}



R_{1111}