Embedded implicatures as pragmatic inferences under compositional lexical uncertainty

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Paper, code, data: https://github.com/cgpotts/pypragmods


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Conversational implicature

Definition

Speaker S saying U to listener L conversationally implicates q iff

1. S and L mutually, publicly presume that S is cooperative.
2. To maintain 1 given U, it must be supposed that S thinks q.
3. S thinks that both S and L mutually, publicly presume that L is willing and able to work out that 2 holds.

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Example

Ann: What city does Paul live in?

Bob: Hmm . . . he lives in California.

(A) Assume Bob is cooperative.

(B) Bob supplied less information than was required, seemingly contradicting (A).

(C) Assume Bob does not know which city Paul lives in.

(D) Then Bob's answer is optimal given his evidence.

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Implicature as social, interactional

Implicatures are inferences that listeners make to reconcile the speaker's linguistic behavior with the assumption that the speaker is cooperative.

Implicatures and cognitive complexity

The speaker must believe that the listener will infer that the speaker believes the implicature.

Two strands of inquiry

Interactional models

- Embrace the social nature of implicatures.
- Derive implicatures from nested belief models with cooperative structure.
- Focus on contextual variability and uncertainty.

Grammar models

- Limit interaction to semantic interpretation.
- Derive implicatures without nested beliefs or cooperativity.
- Place variability and uncertainty outside the theory of implicature.

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My goal

Despite divisive rhetoric, the two sides in this debate are not in opposition, but rather offer complementary insights.

Plan for today

1. Scalar implicature
2. Grammar-driven models of implicature
3. The compositional lexical uncertainty model
4. Experiment: scalars under quantifiers
5. Model assessment

Scalar implicature calculation

Example

A: Sandy's work this term was satisfactory.
Implicature: Sandy's work was not excellent ($= \neg q$)

1. *Contextual premise*: the speaker *A* intends to exhaustively answer 'What was the quality of Sandy's work this term?'
2. *Contextual premise*: *A* has complete knowledge of Sandy's work for the term (say, *A* assigned all the grades for the class).
3. Assume *A* is cooperative in the Gricean sense.
4. The proposition q that Sandy's work was excellent is more informative than p, the content of *A*'s utterance.
5. q is as polite and easy to express in this context as p.
6. By 1, q is more relevant than p.
7. By 3–6, *A* must lack sufficient evidence to assert q.
8. By 2, *A* must lack evidence for q because q is false.

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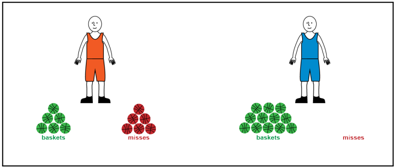
Simplified scalar implicature reasoning

Context: the speaker is a sportscaster who fully observed the outcomes and intends a complete and accurate report:

Player A hit some of his shots.



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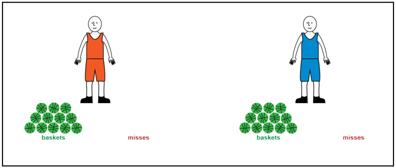

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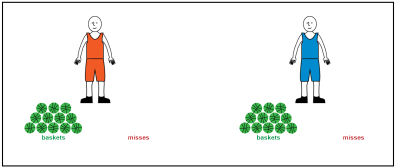
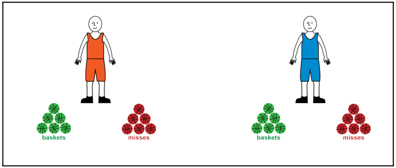


a.	Worlds:	`NN NS NA SN SS SA AN AS AA`	
b.	Literal:	`SN SS SA AN AS AA`	'at least some'
c.	Implicature:	`NN NS NA SN SS SA`	'not all'
d.	Communicated:	`SN SS SA`	'only some'

Scalar implicatures under universal quantifiers

Every player hit some of his shots.



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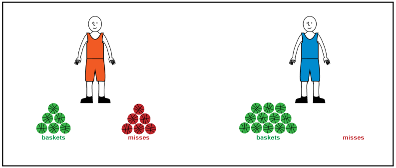

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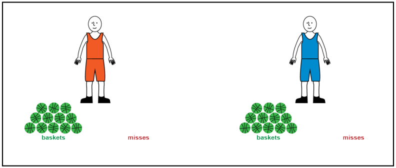

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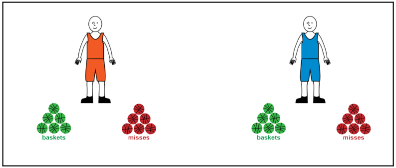
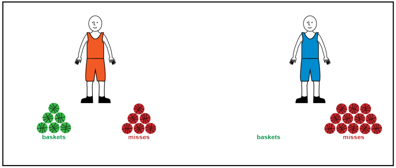


a.	Worlds:	NN	NS	NA	SN	SS	SA	AN	AS	AA	
b.	Literal:					SS	SA		AS	AA	‘all hit at least some’
c.	Implicature:	NN	NS	NA	SN	SS	SA	AN	AS		‘not all hit all’
d.	Result:					SS	SA		AS		‘all hit some; not all hit all’
e.	Aux. premise:	NN				SS				AA	‘uniform outcomes’
f.	Communicated:					SS					‘all hit only some’

Scalar implicatures under non-monotone quantifiers

Exactly one player hit some of his shots.



a. Worlds:	NN	NS	NA	SN	SS	SA	AN	AS	AA	
b. Literal:		NS	NA	SN			AN			‘exactly one hit at least some’
c. Local:		NS		SN		SA		AS		‘exactly one hit only some’

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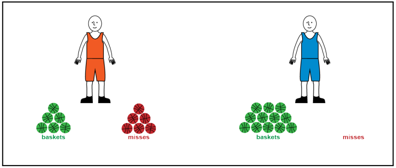

a. Worlds:	`NN`	`NS`	`NA`	`SN`	`SS`	`SA`	`AN`	`AS`	`AA`	
b. Literal:		`NS`	`NA`	`SN`			`AN`			'exactly one hit at least some'
c. Local:		`NS`		`SN`		`SA`		`AS`		'exactly one hit only some'

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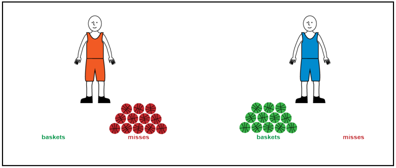
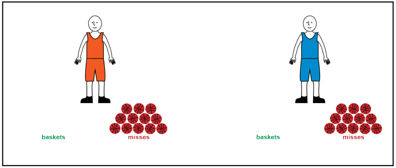


a.	Worlds:	NN NS NA SN SS SA AN AS AA	
b.	Literal:	NS NA SN AN	‘exactly one hit at least some’
c.	Local:	NS SN SA AS	‘exactly one hit only some’

Scalar implicatures under downward-entailing quantifiers

No player hit some of his shots.



a. Worlds: NN NS NA SN SS SA AN AS AA

b. Literal: NN ‘none hit some’

c. Local: NN NA AN AA ‘none hit only some’

Scalar implicatures under downward-entailing quantifiers

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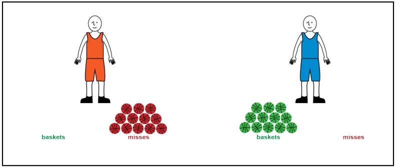

a. Worlds: NN NS NA SN SS SA AN AS AA

b. Literal: NN ‘none hit some’

c. Local: NN NA AN AA ‘none hit only some’

Grammar-driven models

Grammar models

Gennaro Chierchia, Danny Fox, and Benjamin Spector (2012), 'The grammatical view of scalar implicatures'

"More specifically, the facts suggest that SIs are not pragmatic in nature but arise, instead, as a consequence of semantic or syntactic mechanisms, which we've characterized with the operator, O. This operator, although inspired by Gricean reasoning, must be incorporated into the theory of syntax or semantics, so that — like the overt operator *only* — it will find its way to embedded positions."

Exhaustification

Definition (Exhaustification operator)

$$O_{ALT}(\varphi) = [\![\varphi]\!] \sqcap \bigsqcap \{-q : q \in ALT(\varphi) \wedge [\![\varphi]\!] \not\sqsubseteq q\}$$

the exhaustified meaning is **the literal meaning** plus **the negation of all stronger alternatives**

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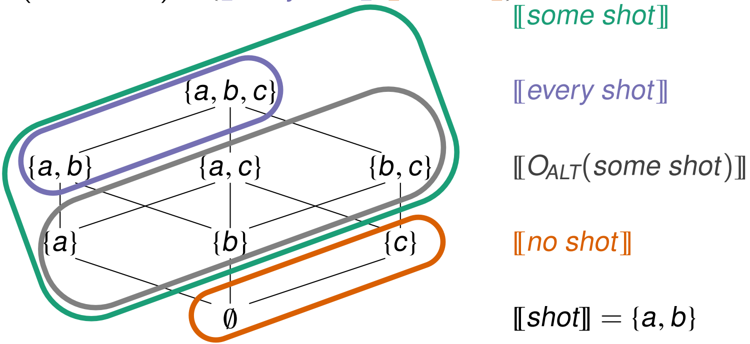
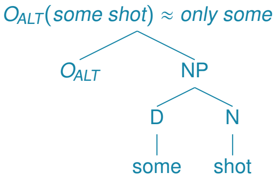
the exhaustified meaning is **the literal meaning** plus **the negation of all stronger alternatives**

$ALT(\textit{some shot}) = \{[\![\textit{every shot}]\!], [\![\textit{no shot}]\!]\}$



Scalar implicatures in logical forms



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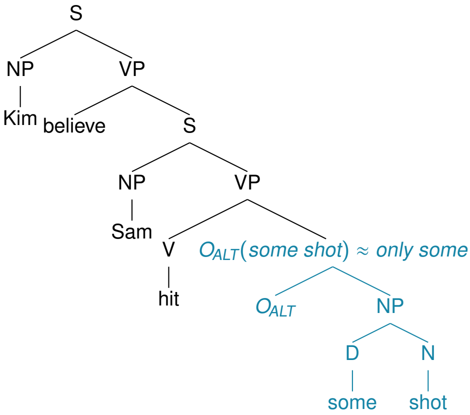

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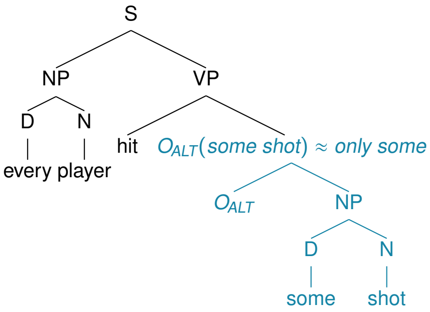

Implicit interactionality

Chierchia et al.

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Resolving underspecification pragmatically

The grammatical system specifies a one-to-many mapping from surface forms to logical forms. Only a pragmatic theory can explain how discourse participants coordinate on these LFs.

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Chierchia et al.

"one can capture the correlation with various contextual considerations, under the standard assumption [. . .] that such considerations enter into the choice between competing representations (those that contain the operator and those that do not)."

Coordinating on a logical form in context

Example

A: Sandy's work this term was satisfactory.
Potential implicature: Sandy's work was not excellent

Available logical forms:

Sandy's work was

1. $[\![\mathit{satisfactory}]\!]$
2. $O_{ALT([\![\mathit{satisfactory}]\!])=\{[\![\mathit{excellent}]\!]\}}([\![\mathit{satisfactory}]\!])$
3. $O_{ALT([\![\mathit{satisfactory}]\!])=\{[\![\mathit{good}]\!],[\![\mathit{excellent}]\!]\}}([\![\mathit{satisfactory}]\!])$

The compositional lexical uncertainty model

Agents

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Definition (Literal listener)

$$l_0(world \mid msg, Lex) \propto Lex(msg, world)P(world)$$

Agents

Definition (Pragmatic speaker)

$$s_1(msg \mid world, Lex) \propto \exp \lambda \left(\log l_0(world \mid msg, Lex) - C(msg)\right)$$

Definition (Literal listener)

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Agents

Definition (Lexical uncertainty listener)

$$L(world \mid msg) \propto \sum_{Lex \in \mathbf{L}} P_{\mathbf{L}}(Lex) s_1(msg \mid world, Lex) P(world)$$

Definition (Pragmatic speaker)

$$s_1(msg \mid world, Lex) \propto \exp \lambda \left(\log l_0(world \mid msg, Lex) - C(msg)\right)$$

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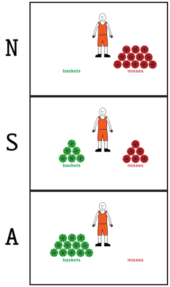
The Rational Speech Acts (RSA) model



(a) Possible worlds

	N	S	A
A scored	0	1	1
A aced	0	0	1
0	1	1	1

(b) *M*

N	.33
S	.33
A	.33

(c) Prior

scored	0
aced	0
0	5

(d) Costs

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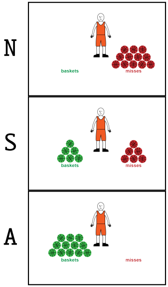

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(d) Costs

	N	S	A
A scored	0	.5	.5
A aced	0	0	1
0	.33	.33	.33

(a) l_0

	A scored	*A aced*	**0**
N	0	0	1
S	.99	0	.01
A	.5	.5	0

(b) s_1

	N	S	A
A scored	0	.67	.33
A aced	0	0	1
0	.99	.01	0

(c) *L*

Lexical uncertainty

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1. It's a sofa, not a couch.

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1. It's a sofa, not a couch.
2. synagogues and other churches

Lexical uncertainty

1. It's a sofa, not a couch.
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3. superb but not outstanding

Lexical uncertainty

1. It's a sofa, not a couch.
2. synagogues and other churches
3. superb but not outstanding
4. some . . .

Lexical uncertainty

Definition (Refinement)

1. Let φ be a set-denoting expression. X is a **refinement** of φ iff $X \neq \emptyset$ and $X \subseteq [\![\varphi]\!]$.
2. $\mathcal{R}_c(\varphi)$, the set of refinements for φ in context c, is constrained so that $[\![\varphi]\!] \in \mathcal{R}_c(\varphi)$ and $\mathcal{R}_c(\varphi) \subseteq \wp([\![\varphi]\!]) - \emptyset$

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Example

1. $D = \{a, b\}$
2. $$\begin{aligned}[\![\textit{Player A}]\!] &= \{Y \subseteq D : \mathrm{a} \in Y\} \\ &= \{\{a, b\}, \{a\}\}\end{aligned}$$
3. $$\mathcal{R}_c(\textit{Player A}) = \left\{ \begin{array}{l} \{\{a, b\}, \{a\}\} \\ \{\{a, b\}\} \\ \{\{a\}\} \end{array} \right\}$$

Compositional semantics under lexical uncertainty

Refinements	Lexica	Semantic composition
$\mathcal{R}_c(\textit{Player A}) = \begin{Bmatrix} \{\{a,b\},\{a\}\} \\ \{\{a,b\}\} \\ \{\{a\}\} \end{Bmatrix}$	$[\![\textit{Player A}]\!] = \{\{a,b\},\{a\}\}$ $[\![\textit{scored}]\!] = \{a,b\}$	$[\![\textit{Player A}]\!]([\![\textit{scored}]\!]) = 1$
	$[\![\textit{Player A}]\!] = \{\{a,b\},\{a\}\}$ $[\![\textit{scored}]\!] = \{a\}$	$[\![\textit{Player A}]\!]([\![\textit{scored}]\!]) = 1$
$\mathcal{R}_c(\textit{scored}) = \begin{Bmatrix} \{a,b\} \\ \{a\} \\ \{b\} \end{Bmatrix}$	$[\![\textit{Player A}]\!] = \{\{a,b\},\{a\}\}$ $[\![\textit{scored}]\!] = \{b\}$	$[\![\textit{Player A}]\!]([\![\textit{scored}]\!]) = 0$
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Simple scalar implicature

L

	N	S	A
A scored	0	.71	.29
A aced	0	0	1
0	.75	.25	0

s_1

	A scored	*A aced*	**0**
N	0	0	1
S	.99	0	.01
A	.33	.67	0

l_0

	N	S	A
A scored	0	.5	.5
A aced	0	0	1
0	.33	.33	.33

M

	N	S	A
A scored	0	1	1
A aced	0	0	1
0	1	1	1

$\mathcal{L}$

$[\![scored]\!] = \{\langle \mathtt{S}, \mathtt{a}\rangle, \langle \mathtt{A}, \mathtt{a}\rangle\}$

$[\![aced]\!] = \{\langle \mathtt{A}, \mathtt{a}\rangle\}$

s_1

	A scored	*A aced*	**0**
N	0	0	1
S	.99	0	.01
A	0	.99	.01

l_0

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$\mathcal{L}$

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$\mathcal{L}$

$[\![scored]\!] = \{\langle \mathtt{A}, \mathtt{a}\rangle\}$

$[\![aced]\!] = \{\langle \mathtt{A}, \mathtt{a}\rangle\}$

Embedded implicatures with unconstrained refinement

	NN	NS	NA	SN	SS	SA	AN	AS	AA
Player A scored	0.0	0.0	0.0	0.24	0.19	0.16	0.18	0.16	0.07
Player A aced	0.0	0.0	0.0	0.0	0.0	0.0	0.36	0.3	0.34
Player B scored	0.0	0.24	0.18	0.0	0.19	0.16	0.0	0.16	0.07
Player B aced	0.0	0.0	0.36	0.0	0.0	0.3	0.0	0.0	0.34
some player scored	0.0	0.14	0.11	0.14	0.17	0.14	0.11	0.14	0.05
some player aced	0.0	0.0	0.22	0.0	0.0	0.19	0.22	0.19	0.18
every player scored	0.0	0.0	0.0	0.0	0.31	0.27	0.0	0.27	0.14
every player aced	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0
no player scored	0.31	0.14	0.12	0.14	0.06	0.05	0.12	0.05	0.01
no player aced	0.18	0.19	0.08	0.19	0.14	0.06	0.08	0.06	0.0
0	0.01	0.01	0.32	0.01	0.01	0.15	0.32	0.15	0.0

Embedded implicatures with unconstrained refinement

	NN	NS	NA	SN	SS	SA	AN	AS	AA
Player A scored				0.24					
Player A aced							0.36		
Player B scored		0.24							
Player B aced			0.36						
some player scored					0.17				
some player aced			0.22				0.22		
every player scored					0.31				
every player aced									1.0
no player scored	0.31								
no player aced		0.19		0.19					
0			0.32				0.32		

Embedded implicatures with unconstrained refinement

	NN	NS	NA	SN	SS	SA	AN	AS	AA
Player A scored				0.24					
Player A aced							0.36		
Player B scored		0.24							
Player B aced			0.36						
some player scored					0.17				
some player aced			0.22				0.22		
every player scored					0.31				
every player aced									1.0
no player scored	0.31								
no player aced		0.19		0.19					
0			0.32				0.32		

Embedded implicatures with unconstrained refinement

	NN	NS	NA	SN	SS	SA	AN	AS	AA
Player A scored				0.24					
Player A aced							0.36		
Player B scored		0.24							
Player B aced			0.36						
some player scored					0.17				
some player aced			0.22				0.22		
every player scored					0.31				
every player aced									1.0
no player scored	0.31								
no player aced		0.19		0.19					
0			0.32				0.32		

Embedded implicatures with unconstrained refinement

	NN	NS	NA	SN	SS	SA	AN	AS	AA
Player A scored				0.24					
Player A aced							0.36		
Player B scored		0.24							
Player B aced			0.36						
some player scored					0.17				
some player aced			0.22				0.22		
every player scored					0.31				
every player aced									1.0
no player scored	0.31								
no player aced		0.19		0.19					
0			0.32				0.32		

Embedded implicatures with unconstrained refinement

	NN	NS	NA	SN	SS	SA	AN	AS	AA
Player A scored				0.24					
Player A aced							0.36		
Player B scored		0.24							
Player B aced			0.36						
some player scored					0.17				
some player aced			0.22				0.22		
every player scored					0.31				
every player aced									1.0
no player scored	0.31								
no player aced		0.19		0.19					
0			0.32				0.32		

Embedded implicatures with neo-Gricean refinement

1. $\mathcal{R}_c(\textit{Player A}) = \{[\![\textit{Player A}]\!], [\![\textit{only Player A}]\!]\}$
2. $\mathcal{R}_c(\textit{Player B}) = \{[\![\textit{Player B}]\!], [\![\textit{only Player B}]\!]\}$
3. $\mathcal{R}_c(\textit{some}) = \{[\![\textit{some}]\!], [\![\textit{some and not all}]\!]\}$
4. $\mathcal{R}_c(\textit{no}) = \{[\![\textit{no}]\!]\}$
5. $\mathcal{R}_c(\textit{scored}) = \{[\![\textit{scored}]\!], [\![\textit{scored and didn't ace}]\!]\}$
6. $\mathcal{R}_c(\textit{aced}) = \{[\![\textit{aced}]\!]\}$

	NN	NS	NA	SN	SS	SA	AN	AS	AA
Player A scored	0.0	0.0	0.0	0.45	0.11	0.22	0.15	0.05	0.02
Player A aced	0.0	0.0	0.0	0.0	0.0	0.0	0.42	0.36	0.22
Player B scored	0.0	0.45	0.15	0.0	0.11	0.05	0.0	0.22	0.02
Player B aced	0.0	0.0	0.42	0.0	0.0	0.36	0.0	0.0	0.22
some player scored	0.0	0.25	0.09	0.25	0.06	0.12	0.09	0.12	0.01
some player aced	0.0	0.0	0.24	0.0	0.0	0.21	0.24	0.21	0.11
every player scored	0.0	0.0	0.0	0.0	0.61	0.16	0.0	0.16	0.07
every player aced	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0
no player scored	0.61	0.0	0.16	0.0	0.0	0.0	0.16	0.0	0.06
no player aced	0.19	0.17	0.1	0.17	0.13	0.07	0.1	0.07	0.0
0	0.15	0.13	0.13	0.13	0.1	0.09	0.13	0.09	0.05

Embedded implicatures with neo-Gricean refinement

1. $\mathcal{R}_c(\textit{Player A}) = \{[\![\textit{Player A}]\!], [\![\textit{only Player A}]\!]\}$
2. $\mathcal{R}_c(\textit{Player B}) = \{[\![\textit{Player B}]\!], [\![\textit{only Player B}]\!]\}$
3. $\mathcal{R}_c(\textit{some}) = \{[\![\textit{some}]\!], [\![\textit{some and not all}]\!]\}$
4. $\mathcal{R}_c(\textit{no}) = \{[\![\textit{no}]\!]\}$
5. $\mathcal{R}_c(\textit{scored}) = \{[\![\textit{scored}]\!], [\![\textit{scored and didn't ace}]\!]\}$
6. $\mathcal{R}_c(\textit{aced}) = \{[\![\textit{aced}]\!]\}$

	NN	NS	NA	SN	SS	SA	AN	AS	AA
Player A scored				0.45					
Player A aced							0.42		
Player B scored		0.45							
Player B aced			0.42						
some player scored		0.25		0.25					
some player aced			0.24				0.24		
every player scored					0.61				
every player aced									1.0
no player scored	0.61								
no player aced	0.19								
0	0.15								

Embedded implicatures with neo-Gricean refinement

1. $\mathcal{R}_c(\textit{Player A}) = \{[\![\textit{Player A}]\!], [\![\textit{only Player A}]\!]\}$
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5. $\mathcal{R}_c(\textit{scored}) = \{[\![\textit{scored}]\!], [\![\textit{scored and didn't ace}]\!]\}$
6. $\mathcal{R}_c(\textit{aced}) = \{[\![\textit{aced}]\!]\}$

	NN	NS	NA	SN	SS	SA	AN	AS	AA
Player A scored				0.45					
Player A aced							0.42		
Player B scored		0.45							
Player B aced			0.42						
some player scored		0.25		0.25					
some player aced			0.24				0.24		
every player scored					0.61				
every player aced									1.0
no player scored	0.61								
no player aced	0.19								
0	0.15								

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1. $\mathcal{R}_c(\textit{Player A}) = \{[\![\textit{Player A}]\!], [\![\textit{only Player A}]\!]\}$
2. $\mathcal{R}_c(\textit{Player B}) = \{[\![\textit{Player B}]\!], [\![\textit{only Player B}]\!]\}$
3. $\mathcal{R}_c(\textit{some}) = \{[\![\textit{some}]\!], [\![\textit{some and not all}]\!]\}$
4. $\mathcal{R}_c(\textit{no}) = \{[\![\textit{no}]\!]\}$
5. $\mathcal{R}_c(\textit{scored}) = \{[\![\textit{scored}]\!], [\![\textit{scored and didn't ace}]\!]\}$
6. $\mathcal{R}_c(\textit{aced}) = \{[\![\textit{aced}]\!]\}$

	NN	NS	NA	SN	SS	SA	AN	AS	AA
Player A scored				0.45					
Player A aced							0.42		
Player B scored		0.45							
Player B aced			0.42						
some player scored		0.25		0.25					
some player aced			0.24				0.24		
every player scored					0.61				
every player aced									1.0
no player scored	0.61								
no player aced	0.19								
0	0.15								

Embedded implicatures with neo-Gricean refinement

1. $\mathcal{R}_c(\textit{Player A}) = \{[\![\textit{Player A}]\!], [\![\textit{only Player A}]\!]\}$
2. $\mathcal{R}_c(\textit{Player B}) = \{[\![\textit{Player B}]\!], [\![\textit{only Player B}]\!]\}$
3. $\mathcal{R}_c(\textit{some}) = \{[\![\textit{some}]\!], [\![\textit{some and not all}]\!]\}$
4. $\mathcal{R}_c(\textit{no}) = \{[\![\textit{no}]\!]\}$
5. $\mathcal{R}_c(\textit{scored}) = \{[\![\textit{scored}]\!], [\![\textit{scored and didn't ace}]\!]\}$
6. $\mathcal{R}_c(\textit{aced}) = \{[\![\textit{aced}]\!]\}$

	NN	NS	NA	SN	SS	SA	AN	AS	AA
Player A scored				0.45					
Player A aced							0.42		
Player B scored		0.45							
Player B aced			0.42						
some player scored		0.25		0.25					
some player aced			0.24				0.24		
every player scored					0.61				
every player aced									1.0
no player scored	0.61								
no player aced	0.19								
0	0.15								

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1. $\mathcal{R}_c(\textit{Player A}) = \{[\![\textit{Player A}]\!], [\![\textit{only Player A}]\!]\}$
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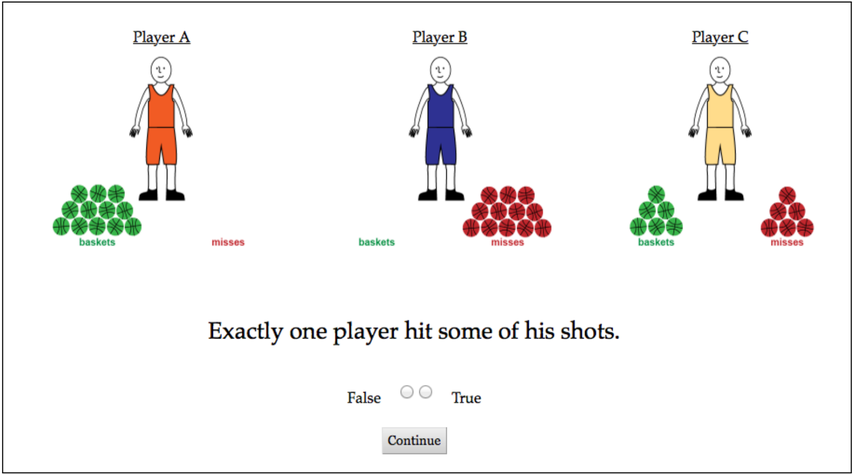
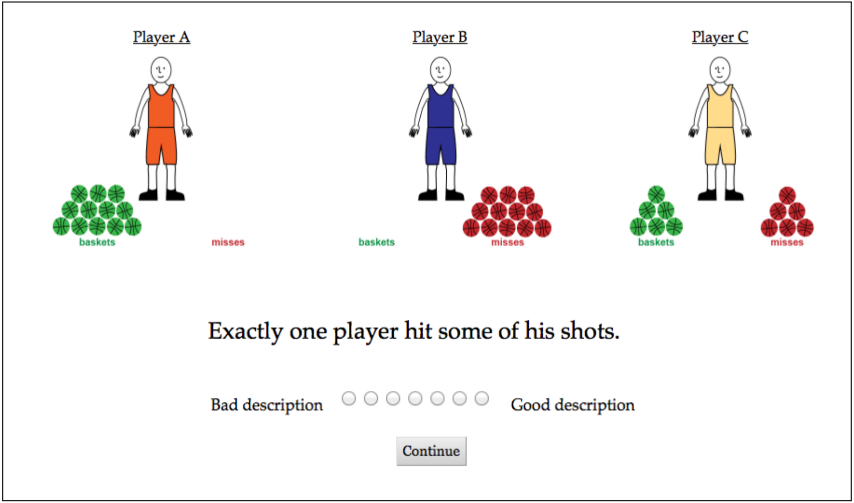
	NN	NS	NA	SN	SS	SA	AN	AS	AA
Player A scored				0.45					
Player A aced							0.42		
Player B scored		0.45							
Player B aced			0.42						
some player scored		0.25		0.25					
some player aced			0.24				0.24		
every player scored					0.61				
every player aced									1.0
no player scored	0.61								
no player aced	0.19								
0	0.15								

Experiment: scalars under quantifiers

Experiment display



Experiment display



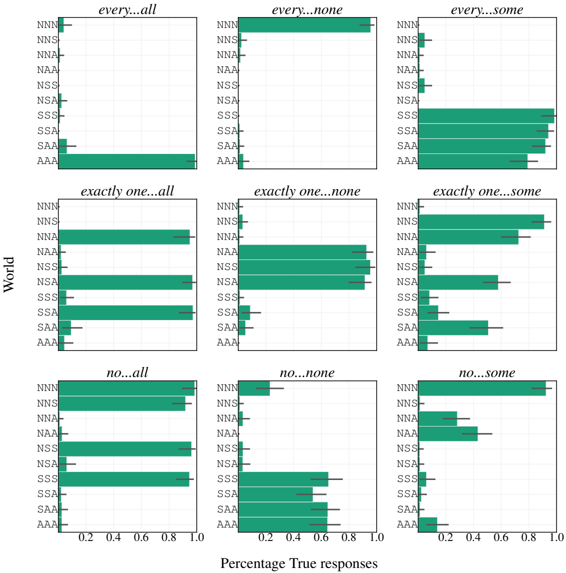
Other experiment details

- 800 participants recruited via Mechanical Turk (no participants or responses excluded)
- Between-subjects design
- 3 training items; 23 fillers; 9 target sentences:

$$\left\{\begin{array}{l}\text{Every}\\\text{Exactly one}\\\text{No}\end{array}\right\}\text{ player hit }\left\{\begin{array}{l}\text{all}\\\text{none}\\\text{some}\end{array}\right\}\text{ of his shots.}$$

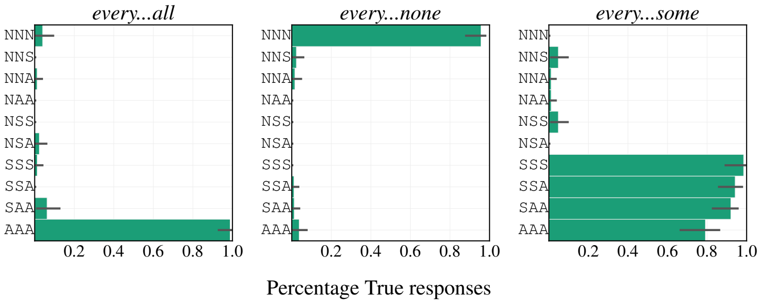
- Worlds: $\{\mathtt{NNN}, \mathtt{NNS}, \mathtt{NNA}, \mathtt{NSS}, \mathtt{NSA}, \mathtt{NAA}, \mathtt{SSS}, \mathtt{SSA}, \mathtt{SAA}, \mathtt{AAA}\}$
- Average 80 responses per target–world pair
- Visual display of worlds and jersey colors randomized

Results


every...all
every...none
every...some
exactly one...all
exactly one...none
exactly one...some
no...all
no...none
no...some
NNN
NNS
NNA
NAA
NSS
NSA
SSS
SSA
SAA
AAA
World
0.2 0.4 0.6 0.8 1.0
Percentage True responses

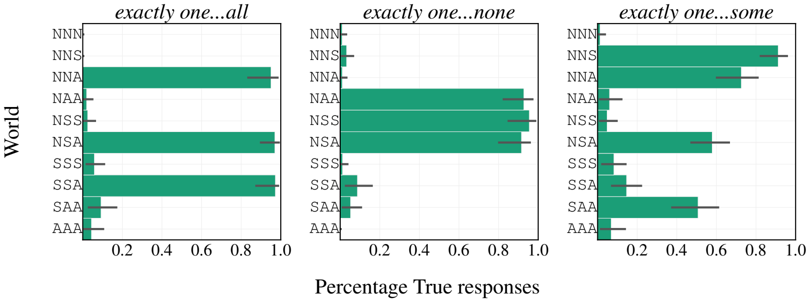
Results

$$\textbf{Every} \quad \text{player hit} \begin{Bmatrix} \text{all} \\ \text{none} \\ \text{some} \end{Bmatrix} \text{of his shots.}$$



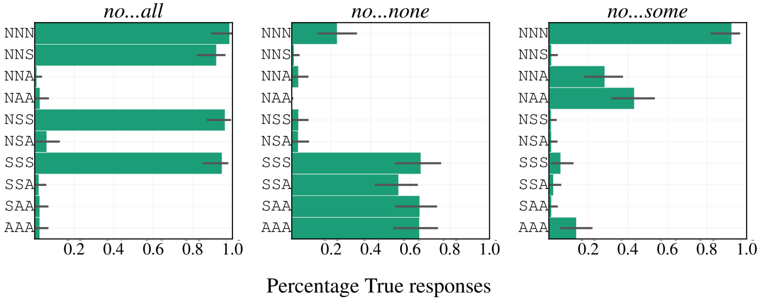
Results

Exactly one player hit { all / none / some } of his shots.



Results

No player hit $\left\{\begin{array}{l}\text{all}\\ \text{none}\\ \text{some}\end{array}\right\}$ of his shots.



Model assessment

Set-up

1. $D = \{\mathrm{a}, \mathrm{b}, \mathrm{c}\}$
2. $W = \{\mathrm{NNN}, \mathrm{NNS}, \mathrm{NNA}, \mathrm{NSS}, \mathrm{NSA}, \mathrm{NAA}, \mathrm{SSS}, \mathrm{SSA}, \mathrm{SAA}, \mathrm{AAA}\}$
3. $M =$
$$\left\{ Q(\mathit{player})(\mathit{hit}(S(\mathit{shot}))) : \begin{array}{l} Q \in \{\mathit{exactly\ one}, \mathit{every}, \mathit{no}\} \\ S \in \{\mathit{every}, \mathit{no}, \mathit{some}\} \end{array} \right\} \cup \{\mathbf{0}\}$$
4. $C(\mathbf{0}) = 5$; $C(m) = 0$ for all $m \in M - \{\mathbf{0}\}$
5. Flat state prior
6. Flat lexicon prior

Models

1. **Literal semantics**: the predicted values are the output of the literal listener l_0
2. **Fixed-lexicon pragmatics**: the predicted values are the output of L considering only one lexicon
3. **Unconstrained refinement**: the inferences of the uncertainty listener L with the largest space of refinements
4. **Neo-Gricean refinement**: as in 'Unconstrained refinement', but with just neo-Gricean refinements

Comparisons with humans

Comparisons with humans

Overall assessment

	Pearson		Spearman		MSE	
Literal semantics	.938	(.926 – .947)	.762	(.754 – .770)	.0065	(.0057 – .0075)
Fixed-lexicon pragmatics	.924	(.911 – .932)	.757	(.749 – .766)	.0079	(.0072 – .0090)
Unconstrained uncertainty	.945	(.936 – .950)	.794	(.767 – .820)	.0038	(.0035 – .0044)
Neo-Gricean uncertainty	.959	(.950 – .962)	.809	(.808 – .820)	.0034	(.0031 – .0040)

Table: Overall assessment with 95% confidence intervals obtained via non-parametric bootstrap over subjects.

Results on crucial items

	'*every*...*some*'			'*exactly one*...*some*'			'*no*...*some*'		
	P	S	MSE	P	S	MSE	P	S	MSE
Literal	.99	.86	.0002	.80	.70	.0180	.88	.52	.0346
Fixed-lexicon	.93	.85	.0027	.80	.70	.0179	.88	.52	.0346
Unconstrained	.88	.84	.0043	.98	.94	.0007	.76	.57	.0097
Neo-Gricean	.82	.88	.0087	.94	.87	.0036	.93	.89	.0028

Table: Assessment of crucial items. 'P' = 'Pearson'; 'S' = 'Spearman'.

Conclusion

- A synthesis of Gricean and grammar-driven approaches in a single formal, quantitative model.
- Key components: lexical uncertainty and recursive modeling of speaker and listener agents.
- Next steps: experiments with different sentences, and with different notions of refinement.
- Code and data available to facilitate such investigations: https://github.com/cgpotts/pypragmods

Conclusion

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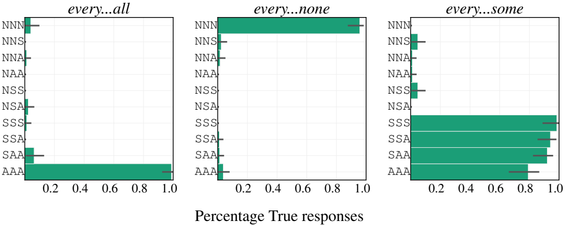
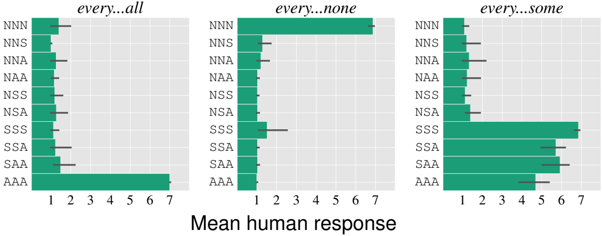
Thanks!

Binary and Likert response experiments

Binary

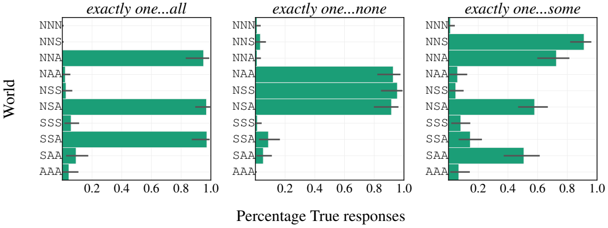


Likert

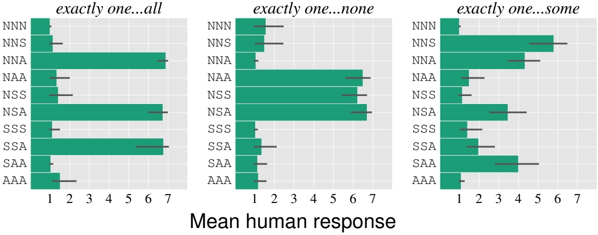


Binary and Likert response experiments

Binary

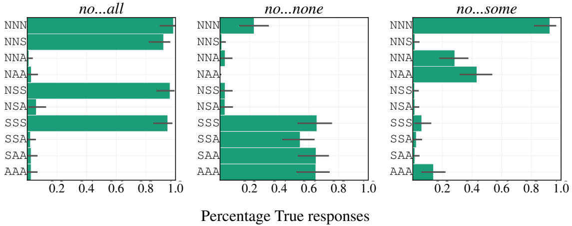


Likert

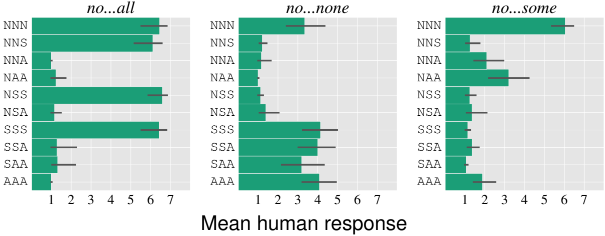


Binary and Likert response experiments

Binary



Likert



Model assessment

	Pearson		Spearman		MSE	
Literal semantics	.938	(.926 – .947)	.762	(.754 – .770)	.0065	(.0057 – .0075)
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Unconstrained uncertainty	.945	(.936 – .950)	.794	(.767 – .820)	.0038	(.0035 – .0044)
Neo-Gricean uncertainty	.959	(.950 – .962)	.809	(.808 – .820)	.0034	(.0031 – .0040)

Table: Binary

	Pearson		Spearman		MSE	
Literal semantics	.935	(.910 – .947)	.756	(.742 – .764)	.0079	(.0065 – .0099)
Fixed-lexicon pragmatics	.920	(.894 – .932)	.751	(.736 – .759)	.0094	(.0080 – .0114)
Unconstrained uncertainty	.929	(.905 – .938)	.794	(.765 – .815)	.0052	(.0045 – .0067)
Neo-Gricean uncertainty	.950	(.927 – .956)	.805	(.795 – .812)	.0046	(.0038 – .0062)

Table: Likert

Parameter exploration

			$C(\mathbf{0})$	λ	k
Literal semantics	Pearson	.94			
	Spearman	.76			
	MSE	.0065			
Fixed lexicon pragmatics	Pearson	.93	1	.1	1
	Spearman	.76	0	.2	1
	MSE	.0069	1	.1	1
Unconstrained uncertainty	Pearson	.97	1	.1	1
	Spearman	.80	1	.1	1
	MSE	.0022	1	.1	1
Neo-Gricean uncertainty	Pearson	.98	1	.1	1
	Spearman	.81	1	.2	1
	MSE	.0018	1	.1	1

Table: Best models found in hyper-parameter exploration, as assessed against the binary-response experiment. Searched λ: $[0.1, 5]$ in increments of .1; L_k for $k \in \{1, 2, 3, 4, 5, 6\}$; $C(\mathbf{0}) \in \{0, 1, 2, 3, 4, 5, 6\}$. The literal listener is not affected by any of the parameters explored.

Parameter exploration

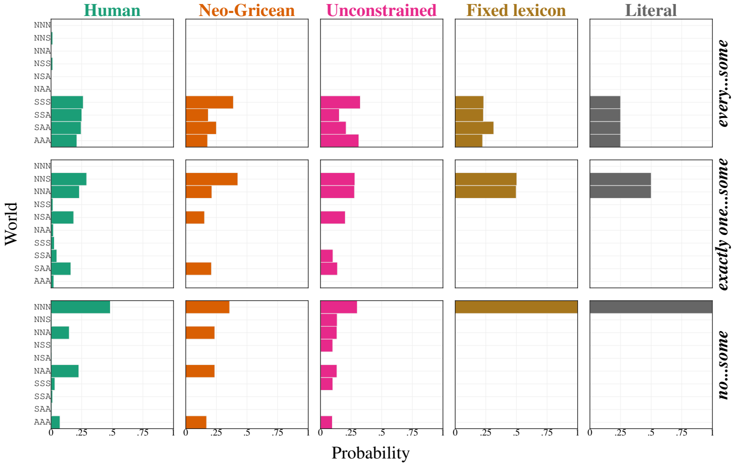

Figure: L_1, using parameters in the range that seem to be nearly optimal for all of these models: $\lambda = 0.1$; $C(\mathbf{0}) = 1$.

Parameter exploration

Figure: L_1, using the parameters we originally chose: $\lambda = 1$; $C(\mathbf{0}) = 5$.