

Game Theoretic Pragmatics

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Game Theoretic Pragmatics ...

- aims for mathematically precise models of language use and interpretation ...
- by formally representing interlocutors':
 - (i) action alternatives
 - (ii) preferences
 - (iii) beliefs about (i)–(iii).

Today's Agenda

- introduce game theory
- charter how to apply GT to linguistic pragmatics
 - ↪ IBR-model
- compare BiOT with IBR-model and reinforcement learning
 - ↪ find an interpretation of strong/weak optimality

Running Example: Division of Pragmatic Labor

- Horn (1984)
- a.k.a. M-Implicature (Levinson, 2000)
- unmarked form pairs with unmarked meaning
- marked form pairs with marked meaning

 $m \leftrightarrow t$
 $m^* \leftrightarrow t^*$

Example 1

(Black Bart)

- (1) a. Black Bart killed the sheriff. m
- b. \rightsquigarrow Black Bart killed the sheriff in a stereotypical way. t
- (2) a. Black Bart caused the sheriff to die. m^*
- b. \rightsquigarrow BB killed the sheriff in a non-stereotypical way. t^*

Running Example: Division of Pragmatic Labor

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Example 1

(Black Bart)

- (3) a. Black Bart killed the sheriff. m
- b. \rightsquigarrow Black Bart killed the sheriff in a stereotypical way. t
- (4) a. Black Bart caused the sheriff to die. m^*
- b. \rightsquigarrow BB killed the sheriff in a non-stereotypical way. t^*

Example 2

(Sue's Smile)

- (5) a. Sue smiled. *m*
 b. \rightsquigarrow Sue smiled genuinely. *t*
- (6) a. The corners of Sue's lips turned slightly upwards. *m**
 b. \rightsquigarrow Sue faked a smile. *t**

Example 3

(Mrs T's Song)

- (7) a. Mrs T sang 'Home Sweet Home.'
 b. \rightsquigarrow Mrs T sang a lovely song. *t*
- (8) a. Mrs T produced a series of sounds roughly
 corresponding to the score of 'Home Sweet Home.'
 b. \rightsquigarrow Mrs T sang very badly. *t**

Example 2

(Sue's Smile)

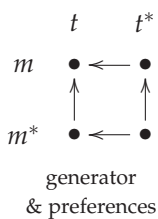
- (9) a. Sue smiled. *m*
 b. \rightsquigarrow Sue smiled genuinely. *t*
- (10) a. The corners of Sue's lips turned slightly upwards. *m**
 b. \rightsquigarrow Sue faked a smile. *t**

Example 3

(Mrs T's Song)

- (11) a. Mrs T sang 'Home Sweet Home.'
 b. \rightsquigarrow Mrs T sang a lovely song. *t*
- (12) a. Mrs T produced a series of sounds roughly
 corresponding to the score of 'Home Sweet Home.'
 b. \rightsquigarrow Mrs T sang very badly. *m**
*t**

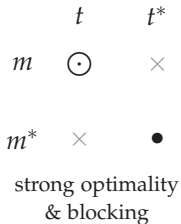
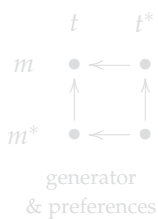
BiOT's Explanation



explanation:

- : possible
- ⊙ : optimal
- × : blocked

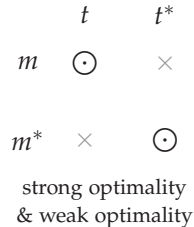
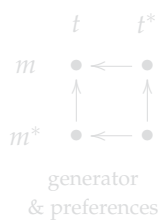
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BiOT's Explanation



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- : possible
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Controversial Issue

how to interpret strong/weak optimality?

- 1 online reasoning? (e.g. Hendriks et al., 2010)
- 2 diachronic optimization? (e.g. Blutner and Zeevat, 2008)



Branches of Game Theory

- classical game theory (since 1940)
 - (mostly) assumes perfectly rational agents
 - central notion: Nash equilibrium
- evolutionary game theory (since 1970)
 - long-term optimization of boundedly-rational agents
 - central notions: evolutionary stability & replicator dynamics
- behavioral game theory (since 1990)
 - studies interactive decision making in the lab
 - seeks regularities in choices beyond perfect rationality

Let's Play: p -Beauty Contest

(with $p = 2/3$)

Everybody choose and write down a number from 0 to 100 (including each). We will sum and average all choices. The person(s) closest to $2/3$ of the average will win.

Kinds of Games

uncertainty	choice points	
	simultaneous	in sequence
no	strategic/static	dynamic/sequential with complete info
yes	Bayesian	dynamic/sequential with incomplete info

Games vs. Solutions

- **Game Models:**
representations of a choice situation
- **Solutions Concepts:**
capture *particular* behavior:
good, optimal, rational, stable (...)

Static Games

- players choose simultaneously
- players have complete information

Examples

	a_c	a_d
a_c	2,2	0,3
a_d	3,0	1,1

Prisoner's Dilemma

	a_{stay}	a_{go}
a_{stay}	2,2	0,0
a_{go}	0,0	1,1

Coordination Problem

Static Games

- players choose simultaneously
- players have complete information

Examples

	a_c	a_d
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Prisoner's Dilemma

	a_{stay}	a_{go}
a_{stay}	2,2	0,0
a_{go}	0,0	1,1

Coordination Problem

Nash Equilibrium (Intuition)

Arrangement of strategies, one for each player, such that no player would benefit from unilateral deviation (i.e., no player would be better off doing something else if everybody else keeps doing the same thing).

Example (Prisoner's Dilemma)

	a_c	a_d
a_c	2,2	0,3
a_d	3,0	1,1

- single pure NE: $\langle a_d, a_d \rangle$

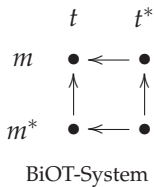
Example (Coordination)

	a_{stay}	a_{go}
a_{stay}	2,2	0,0
a_{go}	0,0	1,1

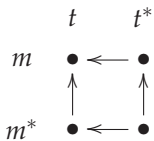
- two pure NEs: $\langle a_{\text{stay}}, a_{\text{stay}} \rangle$, and $\langle a_{\text{go}}, a_{\text{go}} \rangle$

Interpretation Game for DoPL

(Dekker and van Rooij, 2000)



Interpretation Game for DoPL



BiOT-System

(Dekker and van Rooij, 2000)

	t	t^*
m	2,2	1,1
m^*	1,1	0,0

Static Game

Interpretation Game for DoPL

	t	t'
m	⊙	×
m'	×	●

Strong Optimality

(Dekker and van Rooij, 2000)

	t	t^*
m	2,2	1,1
m^*	1,1	0,0

Static Game

Interpretation Game for DoPL

	t	t'
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m'	×	●

Strong Optimality

(Dekker and van Rooij, 2000)

	t	t^*
m	2,2	1,1
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Nash Equilibrium

Interpretation Game for DoPL

	t	t'
m	⊙	×
m'	×	⊙

Weak Optimality

(Dekker and van Rooij, 2000)

	t	t^*
m	2,2	1,1
m^*	1,1	0,0

Nash Equilibrium

Interpretation Game for DoPL

	t	t'
m	\odot	\times
m'	\times	\odot

Weak Optimality

(Dekker and van Rooij, 2000)

	t	t^*
m	2,2	1,1
m^*	1,1	0,0
	???	

Static Games & BiOT

(Dekker and van Rooij, 2000)

- BiOT-Systems \leftrightarrow Static Games
- strong optimality \leftrightarrow Nash equilibrium
- weak optimality \leftrightarrow iterated Nash equilibrium (???)

Criticism

- static interpretation game means that:
 - 1 speaker and hearer choose simultaneously
 - 2 speaker chooses utterance independently of meaning that she wants to express
 - 3 hearer chooses interpretation independently of any utterance that needs to be interpreted

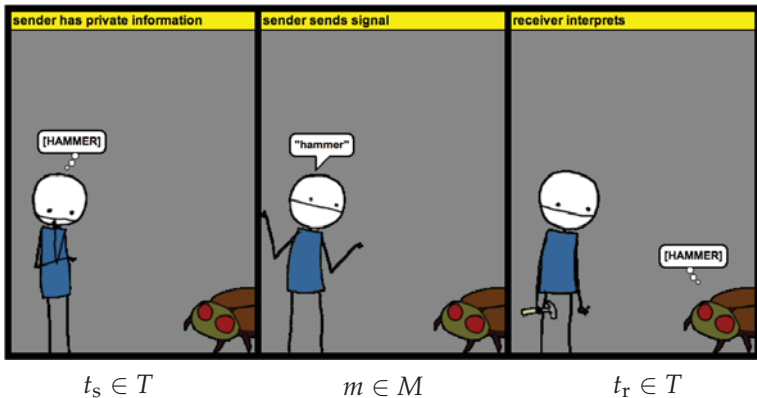
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yes	<i>Bayesian</i>	<i>dynamic/sequential</i> with <i>incomplete</i> info
		∪ signaling games
		∪ interpretation games

Signaling Games

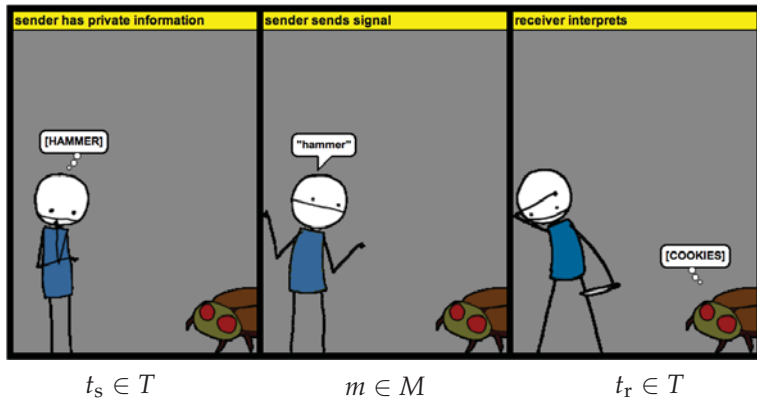
- models simplest case of information flow between two agents
- sender has info, sends message, receiver reacts
- originally to account for evolution of linguistic conventions (Lewis, 1969)
- but also many others:
 - economics: Spence (1973)
 - biology: Grafen (1990)
 - pragmatics: Parikh (1991)
- overview on signaling games:
 - Sobel (2008)
 - Skyrms (2010)

Signaling Games



$t_s = t_r$
⇕
success

Signaling Games



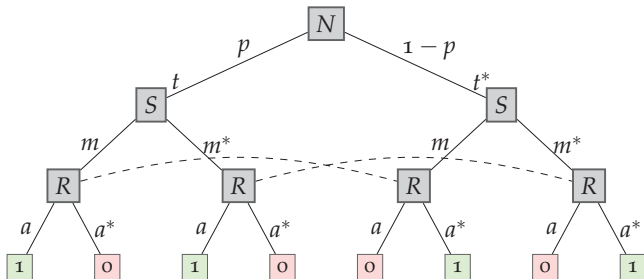
$$t_s \neq t_r$$



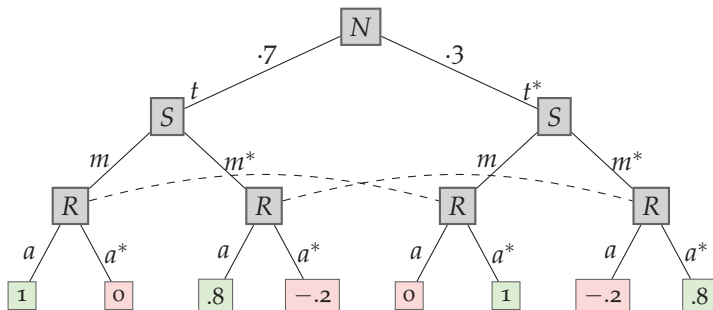
failure

Signaling Games — Informal Characterization

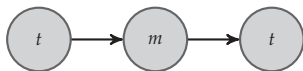
- fix set of states T
- each $t \in T$ occurs with some *prior probability* $\Pr(t)$
- sender S knows *actual state* $t \in T$
- receiver R doesn't but knows *prior distribution* $\Pr \in \Delta(T)$
- S chooses a message $m \in M$
- R observes m and chooses an action $a \in A$
- both S and R receive payoffs depending on t, m and a



Interpretation Game for DoPL



Strategy Profiles for DoPL-Game



Horn Convention



Unstable Pattern

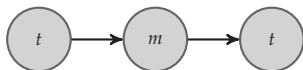


Anti-Horn Convention



Smolensky Convention

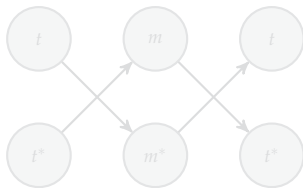
Strategy Profiles for DoPL-Game



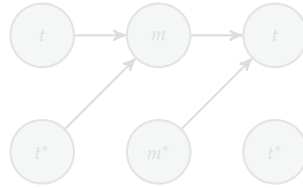
Horn Convention



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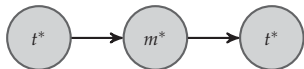


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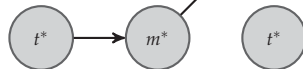
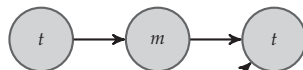


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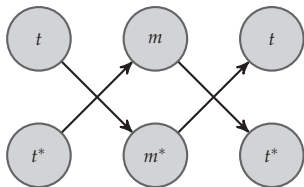
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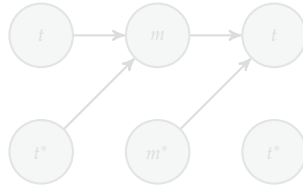
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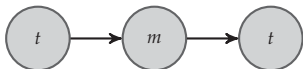


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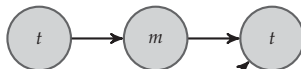


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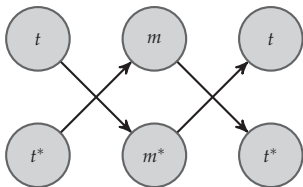
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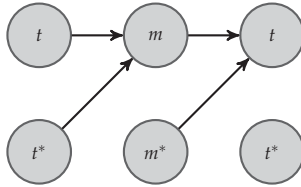
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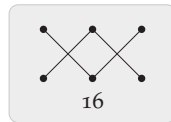
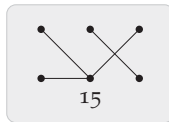
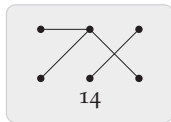
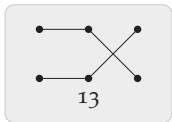
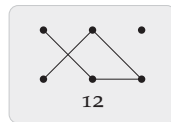
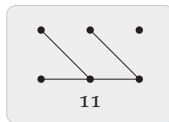
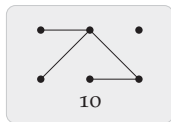
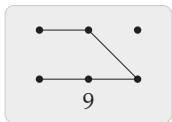
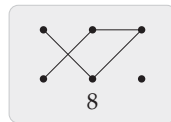
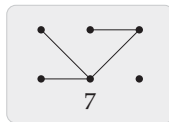
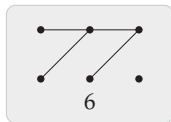
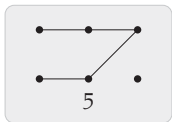
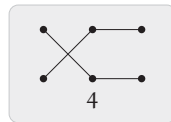
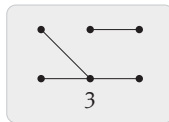
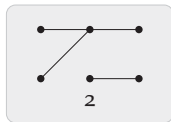
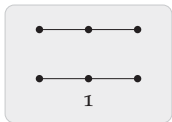


Anti-Horn Convention

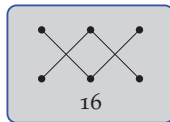
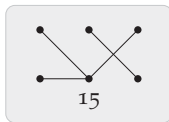
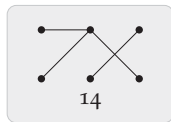
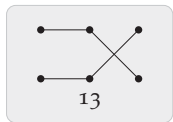
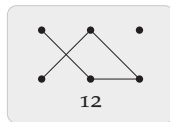
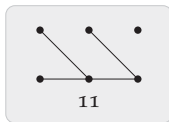
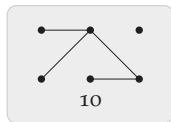
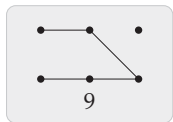
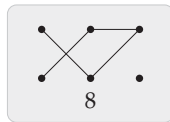
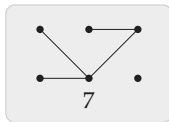
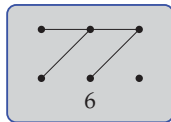
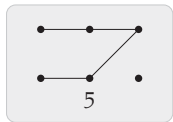
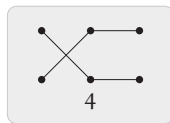
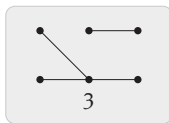
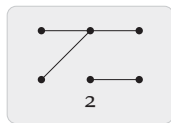
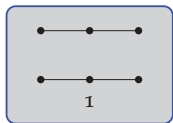


Smolensky Convention

Pure Strategy Profiles of the DoPL-Game

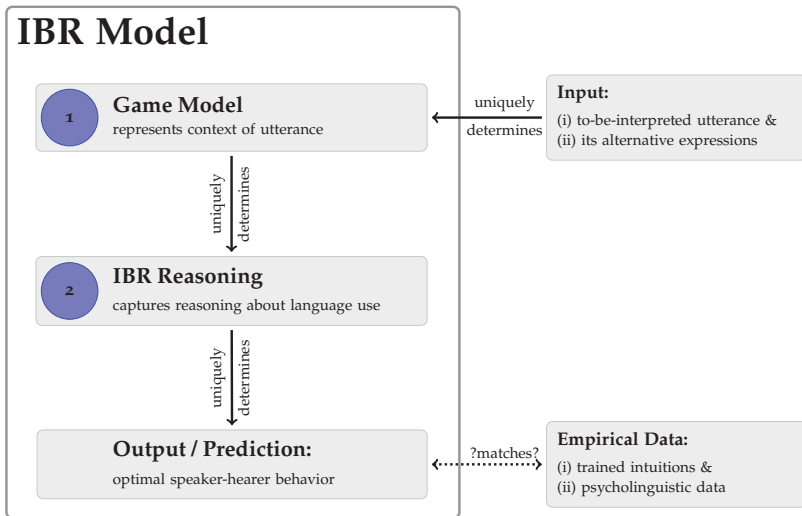


Nash Equilibria of the DoPL-Game



Challenge for Game Theoretic Pragmatics

- 1 construct/motivate interpretation games
- 2 single out desired solution with adequate solution concept



Iterated Best Response Reasoning

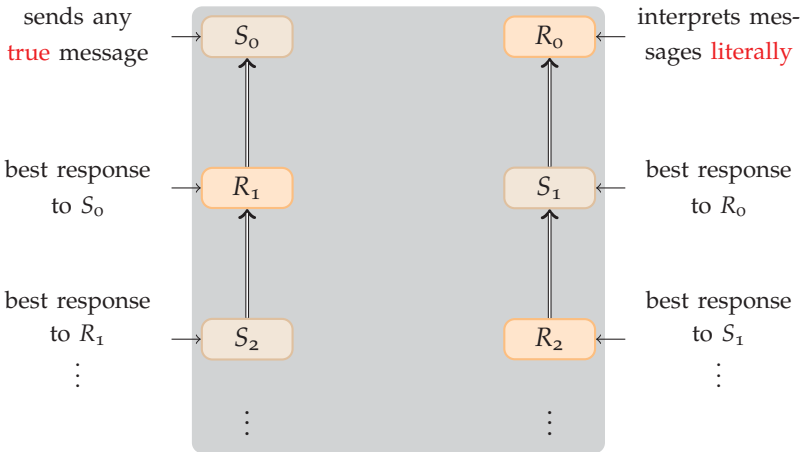
a model of stepwise, hypothetical reasoning:

- (i) player i assumes that player j does X (focal starting point)
- (ii) then player i considers *best response* Y to X
- (iii) then player i considers player j 's best response X' to Y
- (iv) ...
- (v) terminate when looping

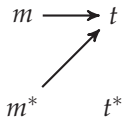
Idea: Focality of Semantic Meaning

pragmatic reasoning starts from the semantics

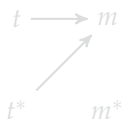
IBR Reasoning for Signaling Games



Naïve Receiver



Level-1 Sender



Level-2 Receiver

$m \longrightarrow t$

(forward
induction)

$m^* \longrightarrow t^*$

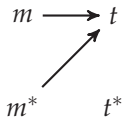
Level-3 Sender

$t \longrightarrow m$

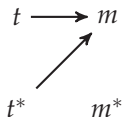
\rightsquigarrow fixed point

$t^* \longrightarrow m^*$

Naïve Receiver



Level-1 Sender



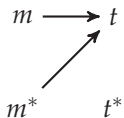
Level-2 Receiver

(forward
induction)

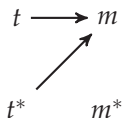
Level-3 Sender


 \rightsquigarrow fixed point

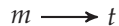

Naïve Receiver



Level-1 Sender



Level-2 Receiver



(forward
induction)



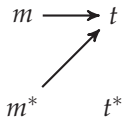
Level-3 Sender



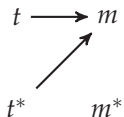
\rightsquigarrow fixed point



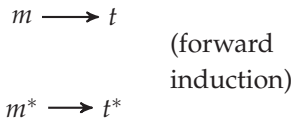
Naïve Receiver



Level-1 Sender



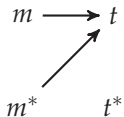
Level-2 Receiver



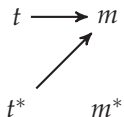
Level-3 Sender



Naïve Receiver



Level-1 Sender



Level-2 Receiver

$$m \longrightarrow t$$

(forward
induction)

$$m^* \longrightarrow t^*$$

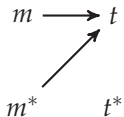
Level-3 Sender

$$t \longrightarrow m$$

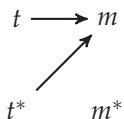
↔ fixed point

$$t^* \longrightarrow m^*$$

Naïve Receiver



Level-1 Sender



Level-2 Receiver

$$m \longrightarrow t$$

(forward
induction)

$$m^* \longrightarrow t^*$$

Level-3 Sender

$$t \longrightarrow m$$

\rightsquigarrow fixed point

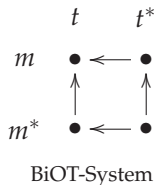
$$t^* \longrightarrow m^*$$

Relation BiOT & IBR

(Franke and Jäger, 2011)

- not equivalent, but almost
- main difference: IBR captures quantity reasoning (scalar implicatures), BiOT only does when proper constraints are given

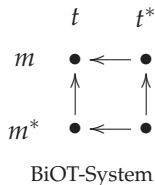
Relation BiOT & Reinforcement Learning (Franke and Jäger, 2011)



<i>S</i> 's choice	<i>m</i>	<i>m</i> [*]
<i>t</i>	.7	.3
<i>t</i> [*]	.7	.3

<i>R</i> 's choice	<i>t</i>	<i>t</i> [*]
<i>m</i>	.7	.3
<i>m</i> [*]	.7	.3

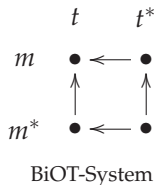
Relation BiOT & Reinforcement Learning (Franke and Jäger, 2011)



<i>S</i> 's choice	m	m^*
t	.8	.2
t^*	.6	.4

<i>R</i> 's choice	t	t^*
m	.8	.2
m^*	.6	.4

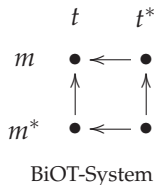
Relation BiOT & Reinforcement Learning (Franke and Jäger, 2011)



<i>S</i> 's choice	<i>m</i>	<i>m</i> [*]
<i>t</i>	.9	.1
<i>t</i> [*]	.5	.5

<i>R</i> 's choice	<i>t</i>	<i>t</i> [*]
<i>m</i>	.9	.1
<i>m</i> [*]	.5	.5

Relation BiOT & Reinforcement Learning (Franke and Jäger, 2011)



<i>S</i> 's choice	m	m^*
t	1	0
t^*	.4	.6

<i>R</i> 's choice	t	t^*
m	1	0
m^*	.4	.6

Relation BiOT & Reinforcement Learning (Franke and Jäger, 2011)

- weak optimality \approx most likely path of reinforcement learning
NB: tight connection RL-learning & replicator dynamics
(Börgers and Sarin, 1997)
- parallel is close but there are divergences:
 - quantity reasoning (as before)
 - BiOT makes no arbitrary meaning enrichment, RL might

Conclusions

- exact interpretation of BiOT still open
- IBR and RL come close
- upshot of comparison
 - BiOT is very top-level
 - more concrete reasoning/evolution schemes show limitations

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