Signal to act: game theory in pragmatics
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Chapter 4
Perspective, Optimality & Acquisition

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This chapter compares the IBR model with bidirectional optimality theory (BIOT), an alternative formal framework for Gricean pragmatics, as introduced by Blutner (1998, 2000) (see Blutner and Zeevat 2008, for a recent overview). The chapter is structured as follows. Section 4.1 will first briefly introduce optimality theory (OT) in general, and then zoom in on the use of BIOT in the context of Gricean pragmatics. Subsequently we will explore ways of comparing optimality theoretic with game theoretic pragmatics. Section 4.2 reviews critically a previous characterization of OT in terms of strategic games. Section 4.3 draws a different picture of the connection between OT-pragmatics and game theory: I argue that OT-pragmatics should be linked to signaling games, and attempt an epistemic characterization of optimality notions in terms of particular restrictions on the belief formation strategies of IBR reasoners.

4.1 Optimality Theory in Pragmatics

Optimality theory has its origin in phonology (Prince and Smolensky 1997), but has been readily applied to other linguistic subdisciplines such as syntax, semantics (Hendriks and de Hoop 2001), and pragmatics (c.f. the contributions in Blutner and Zeevat 2004).

4.1.1 OT-Systems

Abstractly speaking, OT is a model of how input and output representations are associated with each other based on a set of ranked, violable constraints that express relative preferences for input-output matching. More concretely, an OT-system for a set $M$ of (input) forms and a set $T$ of (output) meanings\(^1\) is just a pair $(\text{Gen}, \succeq)$ consisting of a generator $\text{Gen} \subseteq M \times T$ that gives us the initially possible form-meaning pairs and an ordering $\succeq$ on elements of $\text{Gen}$. For $\text{Gen}$ and other sets $O$ of form-meaning pairs, write:

$$O(t) = \{ m \in M \mid \langle m, t \rangle \in O \}$$
$$O(m) = \{ t \in T \mid \langle m, t \rangle \in O \}$$

1. For the pragmatic applications that we are interested in here, the inputs of an OT-system are (representations of) linguistic forms and the outputs are (representations of) meanings. In anticipation of a comparison between game theoretic and optimality theoretic pragmatics, I will write $M$ for the set of forms and $T$ for the set of meanings. For the time being, these are just variables. We will come back later to the issue of identifying forms and meanings in OT with messages and states in a game theoretic setting.
and let $\succeq_m$ and $\succeq_t$ be the orderings induced by $\succeq$ on the sets $\text{Gen}(m)$ and $\text{Gen}(t)$ respectively:

$$
t \succeq_m t' \iff \langle m, t \rangle \succeq \langle m, t' \rangle
$$

$$
m \succeq_t m' \iff \langle m, t \rangle \succeq \langle m', t \rangle.
$$

I will assume for simplicity that every $\ot$-system is such that $\succeq_m$ and $\succeq_t$ are well-founded, linear orders on $\text{Gen}(m)$ and $\text{Gen}(t)$ for all $m$ and $t$.

The ordering of an $\ot$-system measures how well the elements of the generator satisfy certain standards of grammaticality, normality, efficiency, or whatever might be at stake for a particular application. For instance, $m \succeq_t m'$ would mean that $m$ is (somehow) a better form for meaning $t$ than $m'$ is. What exactly the ordering measures may be left unspecified if we just want to assess the general architecture of $\ot$-systems. It might also be defined directly in terms of properties of the elements of the generator. But for most applications of $\ot$, the ordering is actually derived from a (finite) set $\text{Con}$ of violable constraints that are ranked with respect to importance by an ordering $\gg$. Constraints in $\text{Con}$ compare elements in $\text{Gen}$ with respect to other elements in $\text{Gen}$ according to some criterion of preferred input-output matching. Abstractly, for a given set $\text{Gen}$ each constraint in $\text{Con}$ is just a mapping from $\text{Gen}$ to a natural number, possibly zero, specifying the number of times and/or the magnitude that a given form-meaning pair violates the constraint in question. There are two kinds of constraints:

(i) **Markedness Constraints** compare either only the input dimension or only the output dimension;

(ii) **Faithfulness Constraints** compare input-output pairs to each other based on how well each pair’s input associates with its output.

An easy example of a markedness constraint is the processing cost of a form: if a form $m'$ is more costly to process than a form $m$, then this can be expressed in a markedness constraint $C$ for which $C(\langle m', \cdot \rangle) > C(\langle m, \cdot \rangle)$ irrespective of the meaning component in the to-be-compared pairs. An easy example for a faithfulness constraint is Gricean Quality: a pair $\langle m, t \rangle$ would violate this constraint just in case the meaning $t$ is incompatible with the semantic meaning of the form $m$; so for this comparison we crucially need to refer to both dimensions of the form-meaning pair.

---

\[2.\] Let $\succeq_m$ be well-founded on $\text{Gen}(m)$ if for all subsets $X \subseteq \text{Gen}(m)$ there is at least one $\succeq$-maximal element in $X$. Analogously for $\succeq_t$ and $\text{Gen}(t)$. 
The ordering \( \gg \) on the set Con represents the importance of the constraints relative to each other. In the simplest case \( \gg \) is a linear order and the set of constraints \( C_1 \gg C_2 \gg \ldots \gg C_n \) can be enumerated starting with the most important and ending with the least important constraint. For a linearly ordered set of constraints, we could think of Con as a mapping of each element of Gen to an \( n \)-tuple \( \text{Con}(\langle m, t \rangle) = \langle c_1, c_2, \ldots, c_n \rangle \) of natural numbers, where each \( c_i \) is just the number \( C_i(\langle m, t \rangle) \), i.e., the number of times and/or the magnitude that the input-output pair \( \langle m, t \rangle \) violates the constraint \( C_i \).

Finally, the ordering \( \succeq \) of the ot-system is derived from the number or severity of the violations of the ranked constraints. For a linearly ordered set of constraints we obtain an ordering with the desired properties from the following definition. Let \( g, g' \in \text{Gen} \):

\[
g \succeq g' \iff \exists i \forall j < i : C_j(g) = C_j(g') \text{ and } C_i(g) < C_i(g') \quad \text{or} \quad \forall i : C_i(g) = C_i(g').
\]

To give life to an abstract ot-system for applications we need to define the inputs and outputs and, most importantly, the ordering on the generator in some reasonable way. In the present context we are particularly interested in \textsc{pragmatic ot-systems} in which form-meaning pairs are evaluated by an ordering that formally captures how well —relative to others— a primitive form-meaning pair satisfies certain basic pragmatic principles.

4.1.2 Uni- and Bidirectional Optimality

Based on an ordering \( \succeq \) that is either derived from Con or otherwise defined as an ordering on Gen, an ot-system can specify the preferred input-output associations in several ways. Since \( \succeq \) is an ordering on a set of input-output pairs, we can either take a production perspective and ask which output is best when we fix the input dimension, or we can take a comprehension perspective and ask which input is best when we fix the output dimension. The former production perspective is taken by ot-syntax, the latter comprehension perspective is taken by ot-semantics. Abstractly, we can define the set of \textsc{unidirectionally optimal pairs} as follows:

\[
\begin{align*}
\text{ot}_{\text{syn}} &= \{ \langle m, t \rangle \in \text{Gen} \mid \neg \exists t' : \langle m, t' \rangle \in \text{Gen} \land t' \gg m \ \& t \}\ \\
\text{ot}_{\text{sem}} &= \{ \langle m, t \rangle \in \text{Gen} \mid \neg \exists m' : \langle m', t \rangle \in \text{Gen} \land m' \gg m \ \& m \}
\end{align*}
\]

Optimization along both dimensions at the same time is also possible, of course. This is \textsc{bidirectional optimality} and it comes in two varieties, a
strong notion and a weak notion (Blutner 1998, 2000). We say that an input-output pair is strongly optimal iff it is unidirectionally optimal for both production and comprehension: let
\[
\text{biOT}_{\text{str}} = \text{OT}_{\text{syn}} \cap \text{OT}_{\text{sem}}
\]
be the set of all strongly optimal pairs. The definition of weak optimality is a bit more intricate. Adopting Jäger’s reformulation of Blutner’s original definition (Jäger 2002), we say that a pair \( \langle m, t \rangle \) is weakly optimal iff

(i) there is no weakly optimal \( \langle m, t' \rangle \) such that \( t' \succ_m t \); and

(ii) there is no weakly optimal \( \langle m', t \rangle \) such that \( m' \succ_t m \);

and we denote the set of all weakly optimal pairs with \( \text{biOT}_{\text{weak}} \). It is obvious that all strongly optimal pairs are also weakly optimal, but it may be the case that there are weakly optimal pairs which are not strongly optimal.

Unfortunately, the recursive definition of weak optimality is somewhat difficult to apply. In practice, therefore, most often weakly optimal pairs are computed via a manageable algorithm which iteratively computes optimal pairs. The \( \text{biOT} \)-algorithm given in figure 4.1 iteratively computes three disjoint sets of form-meaning pairs:

(i) the set \( \text{Pool}_n \) of form-meaning pairs still in competition for optimality after \( n \) rounds of iteration;

(ii) the set \( \text{Opt}_n \) of form-meaning pairs that have been identified as optimal after round \( n \);

(iii) the set \( \text{Blo}_n \) of form-meaning pairs that are blocked by an optimal pair and therefore removed from the pool.

Initially, \( \text{Pool}_0 \) is the set Gen and there are no optimal or blocked forms. The algorithm then iteratively computes optimal pairs based on a comparison of forms left in the pool and removes optimal and blocked pairs from the pool until every form-meaning pair is removed from the pool as either optimal or blocked. We could think of the pool at round \( n \) as a reduced OT-system. The \( \text{biOT} \)-algorithm thus repeatedly checks for strong optimality in ever more reduced OT-systems.

Let me briefly mention two obvious but relevant properties of the \( \text{biOT} \)-algorithm: firstly, \( \text{Opt}_1 = \text{biOT}_{\text{str}} \), and secondly, \( \text{Opt}_n \subseteq \text{Opt}_{n+1} \) and \( \text{Blo}_n \subseteq 3. This algorithm is widely used in practice and goes back to Jäger (2002).
Pool\(_0\) ← Gen
Opt\(_0\) ← ∅
Blo\(_0\) ← ∅
n ← 0

while Pool\(_n\) ≠ ∅ do
    Opt\(_{n+1}\) ← Opt\(_n\) ∪ \{⟨m, t⟩ ∈ Pool\(_n\) | ¬∃⟨m′, t⟩ ∈ Pool\(_n\) ⟨m′, t⟩ > ⟨m, t⟩ \∧ ¬∃⟨m, t′⟩ ∈ Pool\(_n\) ⟨m, t′⟩ > ⟨m, t⟩\}
    Blo\(_{n+1}\) ← Blo\(_n\) ∪ \{⟨m, t⟩ ∈ Pool\(_n\) | ∃⟨m′, t⟩ ∈ Opt\(_{n+1}\) ⟨m′, t⟩ > ⟨m, t⟩ \∨ ∃⟨m, t′⟩ ∈ Opt\(_{n+1}\) ⟨m, t′⟩ > ⟨m, t⟩\}
    Pool\(_{n+1}\) ← Pool\(_n\) \(\setminus\) (Opt\(_{n+1}\) ∪ Blo\(_{n+1}\))
    n ← n + 1
end while

Figure 4.1: The biot-algorithm

Blo\(_{n+1}\), for all \(n \geq 0\). It is moreover relatively easy to check that the biot-algorithm in figure 4.1 computes all and only weakly optimal pairs.

Proposition 4.1.1. If the biot-algorithm terminates in round \(n\) with Pool\(_n\) = ∅, then ⟨m, t⟩ ∈ Opt\(_n\) iff ⟨m, t⟩ is weakly optimal.

Proof. Let \(g, g′ \in Gen\) be arbitrary elements of the generator and \(n\) be the smallest number for which Pool\(_n\) = ∅. First, we will show that \(g \in Opt\(_n\)\) implies that \(g\) is weakly optimal. Clearly, Opt\(_k\) ⊆ Opt\(_{k+1}\) for any 1 ≤ \(k\) ≤ \(n\). So it suffices to show by induction that \(g \in Opt\(_k\)\) implies \(g′\)'s weak optimality for 1 ≤ \(k\) ≤ \(n\). For \(k = 1\), this is trivially so: if there are no better \(g′ \in Gen\) that differ from \(g\) only either along the form or the meaning dimension, then there are also no better weakly optimal \(g′\) with this property. Suppose therefore that all \(g \in Opt\(_k\)\) are weakly optimal and suppose further, towards contradiction, that some newly added \(g \in Opt\(_{k+1}\)\) that is not in Opt\(_k\) is not weakly optimal.

If \(g\) is not weakly optimal, then there is some \(g′ ∈ Gen\) which shares with \(g\) either the form or the meaning component, which is weakly optimal, and is preferred to \(g\). If \(g′\) is still in Pool\(_k\), \(g\) is not in Opt\(_{k+1}\). So either \(g′\) is blocked or optimal after round \(k\). If \(g′\) is in Opt\(_k\), \(g\) should no longer be in the pool, because it is blocked by \(g′\). And if \(g′\) is in Blo\(_k\), then there is some better form \(g'' ∈ Opt\(_k\)\) (varying along either form or meaning dimension only), which by induction hypothesis is weakly optimal. But that means that \(g′\) cannot
be weakly optimal. Since this exhausts the space of possibilities, we have established that \( g \) is weakly optimal, which concludes the induction step.

It remains to be shown that \( \text{Opt}_n \) contains all weakly optimal pairs. Towards contradiction, assume that there is a weakly optimal \( g \) that is not in \( \text{Opt}_n \). If \( g \notin \text{Opt}_n \), then \( g \in \text{Bl}_n \). But that means that there is some \( g' \in \text{Opt}_n \) which varies from \( g \) only along either the meaning or form dimension such that \( g' \succ g \). From the above we know that \( g' \) is weakly optimal. But if it is, \( g \) cannot be. \( \square \)

4.1.3 Example: M-Implicatures in BiOT

Here is a simple example to illustrate how the \text{biot}-algorithm works. The example is \text{biot}'s treatment of M-implicatures, as initially suggested by Blutner (Blutner 1998, 2000). We would like to explain why an unmarked form (9a) is paired with an unmarked meaning (9b), while a marked form (10a) is paired with a marked meaning (10b) (see also sections 1.1.2 and 2.2.2).

\[(9a) \quad \text{Black Bart killed the sheriff.} \]
\[(9b) \quad \leadsto \quad \text{Black Bart killed the sheriff in a stereotypical way.} \]
\[(10a) \quad \text{Black Bart caused the sheriff to die.} \]
\[(10b) \quad \leadsto \quad \text{Black Bart killed the sheriff in a non-stereotypical way.} \]

Let us assume that there are two forms \( m \) and \( m' \) corresponding with (9a) and (10a) respectively and two meanings \( t \) and \( t' \) representing (9b) and (10b). Initially, all four possible form-meaning pairs are in Gen. (This is because we assume that both forms are in principle compatible with either meaning.) We also assume that \( m \) is more costly than \( m' \) and that \( t \) is more stereotypical than \( t' \). This gives rise to the following ordering \( \succ \) over form-meaning pairs, basically two markedness constraints:

\[\langle m, \cdot \rangle \succ \langle m', \cdot \rangle\]
\[\langle \cdot , t \rangle \succ \langle \cdot , t' \rangle\]

In words, \( m \) is preferred over \( m' \) independently of the associated meaning (because it is less costly to process), and \( t \) is preferred over \( t' \) independently of the associated form (because it is more stereotypical).

The initial situation, with which the algorithm starts, can be plotted as follows:
A bullet point $\bullet$ indicates that a form-meaning pair is in the pool, arrows between bullet points represent the ordering. Based on this initial configuration, the algorithm will compute the optimal pairs. In this case, $\langle m, t \rangle$ is the only optimal pair. This optimal pair will block —and therefore remove from the pool— the pairs $\langle m', t \rangle$ and $\langle m, t' \rangle$. The resulting situation after one round of iteration is:

$$\text{Opt}_1 = \{ \langle m, t \rangle \}$$
$$\text{Blo}_1 = \{ \langle m', t \rangle, \langle m, t' \rangle \}$$
$$\text{Pool}_1 = \{ \langle m', t' \rangle \}$$

This can be represented as in the following diagram where a circled dot $\bigcirc$ marks an optimal pair, and pairs no longer in the pool are crossed out $\times$:

$$m \quad m'$$

With only one pair left in the pool there is not much competition for optimality, so in the second round of iteration the $\text{biot}$-algorithm adds $\langle m', t' \rangle$ to the set of optimal pairs, removes it from the pool and terminates. The output of the algorithm is $\text{Opt}_2 = \{ \langle m, t \rangle, \langle m', t' \rangle \}$ and the situation after two rounds of iteration looks like this:

$$m \quad m'$$

Under the above markedness constraints weak optimality thus predicts a unique mapping where $m$ is paired with $t$ and $m'$ is paired with $t'$.

4. With only the above markedness constraints, strong optimality does not predict that a marked form is associated with a marked meaning, since $\text{Opt}_1 = \text{biot}_{str} = \{ \langle m, t \rangle \}$. Nevertheless, strong optimality can account for M-implicatures in full if we additionally assume a preference for associating marked forms with marked meanings, for instance in the form of additional so-called harmony constraints. However, this seems much less explanatory (see Blutner and Zeevat 2008, for discussion).
4.1.4 BiOT as a Model of Pragmatic Interpretation

The iterative BiOT-algorithm is certainly superficially reminiscent of the IBR model. BiOT’s explanation of M-implicatures is also very much parallel to the treatment in the IBR model: a first iteration step deals with unmarked forms and meanings, and once this association is settled the actual M-implicature is accounted for, associating the marked form with the marked meaning. The main question to be explored in this chapter is therefore: how much of a parallel is there between BiOT on the one hand and IBR on the other? In order to address this question it is necessary to be clear about the conceptual interpretation of various optimality notions. What exactly does it mean when an ot-system selects a given form-meaning pair as weakly optimal but not strongly optimal, or as unidirectionally optimal but not strongly optimal?

Proponents of ot-pragmatics are not unanimous about this issue. Some propose to think of unidirectional and strong optimality as measures of on-line pragmatic competence, but reject the notion that weak optimality has anything to do with actual pragmatic reasoning (Blutner and Zeevat 2004, 2008). Weak optimality is rather viewed from a diachronic, evolutionary perspective as giving the direction into which the semantic meaning of expressions will most likely shift over time, by pragmatic pressures.

Opposed to this view, others treat also weak optimality as a model of pragmatic reasoning competence. Under this interpretation different notions of optimality express different levels of perspective taking: whereas unidirectional optimization does not require to take the interlocutor’s perspective into account, bidirectional optimization does:

“[B]idirectional optimization requires the coordination of two opposite perspectives: the speaker’s and the hearer’s perspective. At the root of the mechanism of bidirectional optimization lies the assumption that the hearer takes into account which options the speaker has for expressing a given meaning, and that the hearer has some understanding of what makes the speaker choose a certain form. The latter assumption requires that the hearer takes into account that any choice the speaker makes is co-determined by the speaker’s belief that the hearer will indeed be aware of these options. This means, first of all, that bidirectional optimization may require a child hearer to have a second-order theory of mind, and to be able to compute the implications of a recursive theory of mind.”

(Hendriks et al. 2007, section 5.6.2)

5. Hendriks et al. (2007) do not subscribe fully to this interpretation, but maintain it alongside other possible interpretations of optimality.
More strongly even, optimality theory in pragmatics is often related to theory of mind (tōm) reasoning (Premack and Woodruff 1978) (see also section 2.1.2). Unidirectional optimization is taken to involve no tōm reasoning (or zero-order tōm), strong optimization would correspond to first-order, and weak optimization would involve second-order tōm reasoning (see, for instance, Flobbe et al. 2008, p. 424).

Given the controversy about its conceptual interpretation, what would be required is, in a manner of speaking, an epistemic interpretation of optimality theory that clarifies (some of) its intended use in pragmatic applications. Thus conceived, a comparison to a related game theoretic model can help achieve this, especially when a game theoretic model has a proper epistemic interpretation, such as the Ibr model does. This is what this chapter tries to achieve. I will eventually try to compare biot under the interpretation that different optimality notions express different competencies in perspective taking, to tōm reasoning in the vein of Ibr.

Summary. In summary, a pragmatic ot-system abstractly defines preferences among possible form-meaning associations. There are then various notions of optimality which yield the predictions of the ot-system. This is reminiscent of the distinction between a game model on the one hand and various solution concepts on the other that was introduced in section 1.2. The questions that this comparison raises are (i) which game exactly a pragmatic ot-system corresponds to and (ii) which solution concept (together with a possible epistemic characterization) the different notions of optimality instantiate. The next section summarizes the ‘received wisdom’ on the matter.

4.2 BiOT and Game Theory

Bidirectional optimization is simultaneous optimization of both the production and the comprehension perspective. At first glance, this looks very similar to an equilibrium state in which the speaker’s and the hearer’s preferences are balanced. And, indeed, there is a prima facie very plausible link between biot and game theory. Dekker and van Rooij (2000) (henceforth D&vR) show that the notion of strong optimality corresponds one-to-one to the notion of Nash equilibrium in an optimality game.6 An optimality game is a straight-

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6. D&vR use the term “interpretation games” for what I call “optimality games.” The former term would be equivocal in the context of this thesis, so I use the latter.
4.2. BiOT and Game Theory

forward translation of an ot-system into a strategic game. D&vR continue to show that weak optimality corresponds to the outcome of a process that we could call iterated Nash-selection. Let’s first look at the analysis of D&vR in more detail and then reflect critically.

4.2.1 BiOT and Strategic Games

Optimality Games. Recall from section 1.2.1 that a strategic game is a triple \( \langle N, (A_i)_{i \in N}, (\succeq_i)_{i \in N} \rangle \) where \( N \) is a set of players, \( A_i \) are the actions available to player \( i \) and \( \succeq_i \) is player \( i \)'s preference relation over action profiles \( \times_{j \in N} A_j \), i.e., possible outcomes of the game. A Nash equilibrium of a strategic game is an action profile \( a^* \) such that for all \( i \in N \) there is no \( a_i \in A_i \) for which:

\[
(a^*_{-i}, a_i) \succ_i a^*.
\]

Take an ot-system with forms \( M \), meanings \( T \)—assuming for simplicity that \( \text{Gen} = M \times T \)—and some ordering \( \succeq \) over form-meaning pairs. An optimality game, as defined by D&vR, is a strategic game between a speaker \( S \) and a hearer \( H \) such that the speaker selects a form, \( A_S = M \), the hearer selects a meaning, \( A_H = T \), and the players’ preferences are just equated with the ordering of the ot-system, \( \succeq_S = \succeq_H = \succeq \).

Strong Optimality as Nash Equilibrium. An action profile \( \langle m, t \rangle \) is a Nash equilibrium of an optimality game iff

1. there is no \( m' \in M \) such that \( \langle m', t \rangle \succ_S \langle m, t \rangle \); and
2. there is no \( t' \in T \) such that \( \langle m, t' \rangle \succ_H \langle m, t \rangle \).

But since \( \succeq_S = \succeq_H = \succeq \) this is the case just when \( \langle m, t \rangle \in \text{biot}_{\text{str}} \). Consequently, every Nash equilibrium of an optimality game is a strongly optimal pair in the corresponding ot-system, and every strongly optimal pair of an ot-system is a Nash equilibrium of the corresponding optimality game. D&vR’s result in slogan form: strong optimality is Nash equilibrium (in an optimality game).

Weak Optimality as Iterated Nash-Selection. D&vR’s characterization of weak optimality is inspired by the biot-algorithm given in section 4.1.2. Recall that the biot-algorithm iteratively computes strongly optimal pairs, based on a shrinking pool of candidate pairs. Since strong optimality can be likened to Nash equilibrium in optimality games, the workings of the biot-algorithm can be recast in game theoretic terms as a process of iteratively
removing action profiles from competition for Nash equilibrium that are, in a way of speaking, dominated by a Nash equilibrium.

In order to make this idea more precise, D&vR allow strategic games to have partial preferences. For games with partial preferences, not every definition of Nash equilibrium will do, but the one given above applies. The process of **iterated Nash-selection** on a strategic game $I_0 = \langle N, (A)_i \subseteq N, (\succeq)_i \in N \rangle$ is defined inductively as follows: let $NE_n$ be the set of Nash equilibria of game $I_n$; $I_{n+1}$ is derived from $I_n$ by restricting the preferences $\succeq_{n,i}$ to:

\[
\succeq_{n+1,i} = \{ (x, y) \in \succeq_{n,i} \mid \neg \exists z \in NE_n : z \succ_{n,i} x \}.
\]

If for some index $n$ we have $I_n = I_{n+1}$, we consider the process to be terminated, and call $NE_n$ the outcome of the process of iterated Nash-selection. D&vR show that this process corresponds to the Biol-algorithm if applied to optimality games: if $I$ is the optimality game corresponding to an $\ot$-system, then the outcome of iterated Nash-selection on $I$ contains all and only the weakly optimal pairs of the $\ot$-system.

### 4.2.2 Critique

The characterization of strongly optimal pairs as Nash equilibria in an optimality game has some *prima facie* plausibility and seems unanimously endorsed as the link between $\ot$ and game theory by the pragmatic $\ot$ community. But on closer look the suggested parallel turns out not to be very sensible. Moreover, although weak optimality has a very tight correspondence via the Biol-algorithm with the process of iterated Nash-selection, this latter is not a standard solution procedure in game theory — and that is so for a good reason. This is what the following lines will argue for, with the conclusion that the true connection between optimality theoretic and game theoretic pragmatics is still an open issue.

**On Optimality Games.** I would like to argue first that the translation of a pragmatic $\ot$-system into a strategic optimality game is dubious. This point is best made based on a simple example. Here is a very simple $\ot$-system that captures the wine-choice scenario from section 1.2.2 where Alice would like to inform Bob whether it’s beef or fish for dinner. There are two forms $m_{\text{beef}}$ and $m_{\text{fish}}$ and two meanings $t_{\text{beef}}$ and $t_{\text{fish}}$. As for the ordering, let’s only require that form-meaning pairs are subject to Gricean Quality as a faithfulness constraint: any pair $\langle m, t \rangle$ where $m$ is semantically compatible with $t$
is strictly preferred over any pair where this is not so. We thus obtain the following \( \text{ot-system} \) for the obvious meanings of \( m_{\text{beef}} \) and \( m_{\text{fish}} \):

\[
\begin{array}{c}
\text{t_{beef}} \\
\downarrow
\end{array} \quad \begin{array}{c}
\text{t_{fish}} \\
\downarrow
\end{array}
\]

\[
\begin{array}{c}
\text{m_{beef}} \\
\downarrow
\end{array} \quad \begin{array}{c}
\text{m_{fish}} \\
\downarrow
\end{array}
\]

![Diagram](image.png)

The strongly optimal pairs are \( \langle m_{\text{beef}}, t_{\text{beef}} \rangle \) and \( \langle m_{\text{fish}}, t_{\text{fish}} \rangle \), and this clearly is the only reasonable prediction with hardly a reason to worry. But let’s now have a critical look at what it means to imagine that Alice and Bob are playing a strategic optimality game here. It would mean that Alice has to make a decision what to say irrespective of the actual state, while Bob chooses a meaning independently of Alice’s choice. It is quite clear that this is not the correct analysis of an informative utterance and its possible interpretation (compare the argument in section 1.2.2): speakers do not choose a form irrespective of the idea that they want to express, and hearers do not choose an interpretation irrespective of a form that they want to interpret. But this is exactly what it means to play an optimality game. The characterization of an \( \text{ot-system} \) as a strategic game is not faithful to our intuitions about the temporal and informational dynamics of an utterance and its uptake. Therefore, if an \( \text{ot-system} \) is to serve as a model of pragmatic interpretation, an analysis in terms of a strategic game seems dubious.

**On Nash Equilibrium.** This has repercussions for the analysis of strongly optimal pairs as Nash equilibria. Under the standard interpretation of Nash equilibrium as a *steady state* in the behavior of agents when playing a game recurrently (see section 1.2.1), we predict Alice and Bob to have settled by force of precedent on, for instance, saying \( m_{\text{beef}} \), no matter what is actually prepared for dinner, and always taking it that beef is going to be prepared, irrespective of any observed message. Clearly, not only the interpretation of the communicative situation as a strategic game, but also the interpretation of a strongly optimal pair as a Nash equilibrium is inadequate.

**On Iterated Nash-Selection.** What should we then say of the characterization of weak optimality in terms of iterated Nash-selection? Obviously, the

---

7. It does not matter for the argument at hand that there are no attested pragmatic inferences in this scenario. We could also assume that only pairs \( \langle m, t \rangle \) are allowed in the generator such that \( m \) is true in \( t \). The gist of the argument remains. In fact, my point could equally well be made based on *any* arbitrary \( \text{ot-system} \) that has more than one strongly optimal pair.
latter is the direct translation of the $\textit{biot}$-algorithm into game theory, if we assume that a pragmatic $\textit{ot}$-system should be analyzed as a strategic game. Despite the above arguments why this is not a good analysis, we can still review arguments for or against iterated Nash-selection independently. This procedure is not standard in game theory, and so the question arises why.

The simple answer is: iterated Nash-selection is not an attractive solution procedure because it crucially hinges on but strictly goes against the idea of a Nash equilibrium as the solution concept of a strategic game. In classical game theory, Nash equilibrium is used as a predictor of how instrumentally rational agents would or ought to behave in a repeated situation of strategic interaction. Behavioral explanations in terms of Nash equilibrium then face the difficulty that the presence of multiple equilibria undermines a unique prediction. This dilemma also arose for $\textit{gtp}$, as we have seen in sections 1.2.3 and 1.2.4: we wanted to restrict the set of possible equilibrium solutions, not to make it even larger. So conceived, iterated Nash-selection only makes matters worse: it produces even more equilibria, even in a case, like the M-implicature example in section 4.1.3, where there is initially exactly one, beautifully unique prediction of Nash equilibrium. That is why classical game theory would not endorse iterated Nash-selection.

### 4.2.3 $\textit{BiOT}$ and Signaling Games

The above considerations suggest that the natural way of interpreting a set of form-meaning pairs —be they optimal or not— is not as a set of Nash equilibria, but rather as a (possibly partial) specification of a sender or a receiver strategy in a signaling game. Consider again the set of optimal pairs in the wine-choice example of the last section. In this simple example, all four notions of optimality coincide and yield the same two form-meaning pairs as the prediction of the $\textit{ot}$-system:

$$\{\langle m_{\text{beef}}, t_{\text{beef}} \rangle, \langle m_{\text{fish}}, t_{\text{fish}} \rangle\}.$$  

How should we interpret this prediction? Obviously, this set specifies the speaker’s optimal production behavior and the receiver’s optimal comprehension behavior: it specifies that the speaker would optimally choose $m_{\text{beef}}$ whenever she wants to express the meaning $t_{\text{beef}}$ and $m_{\text{fish}}$ when she wants to express the meaning $t_{\text{fish}}$, and that the hearer would optimally interpret $m_{\text{beef}}$ as meaning $t_{\text{beef}}$ and $m_{\text{fish}}$ as meaning $t_{\text{fish}}$. But this means that form-meaning pairs should not be looked at individually but rather interpreted as
a set that specifies a function: a set of optimal form-meaning pairs should be linked to a strategy, i.e., a specification of conditional behavior, in a suitable dynamic game.

In particular, a set of form-meaning pairs partially defines a sender or receiver strategy in a signaling game with interpretation actions where

(i) the set of states in the signaling game are the meanings $T$ of the ot-system; these are the meanings that the speaker might want to express;

(ii) the set of messages in the signaling game are the forms $M$ of the ot-system; these are the messages the speaker can choose to express a meaning when she wants to; and

(iii) the set of receiver actions in the signaling game are interpretations, i.e., the meanings $T$ of the ot-system.

In general, we can read off a (partial) description of a sender and receiver strategy for such a game from any set $O \subseteq M \times T$. The set of pure sender strategies in a signaling game with interpretation actions compatible with $O$ is:

$$S(O) = \{ s \in S \mid O(t) \neq \emptyset \rightarrow s(t) \in O(t) \};$$

and the set of pure receiver strategies compatible with $O$ is:

$$R(O) = \{ r \in R \mid O(m) \neq \emptyset \rightarrow r(m) \in O(m) \}.$$

Obviously, an arbitrary set $O$ need not specify a full strategy. There may be states $t$ for which $O(t)$ is empty, so that when taken as a description of a sender strategy $O$ is only a partial description. I suggest that this is really how we should set the link between ot and game theory in pragmatics: sets of form-meaning pairs —no matter whether any notion of optimality has selected these— are specifications of strategies in a corresponding signaling game with interpretation actions.

---

8. Recall that we use the following notation:

\[
O(t) = \{ m \in M \mid \langle m, t \rangle \in O \}
\]

\[
O(m) = \{ t \in T \mid \langle m, t \rangle \in O \}.
\]
4.3 An Epistemic Interpretation of Optimality

Natural as it may be, linking form-meaning pairs to strategies does not yet fix a complete translation between \( \text{ot} \)-systems and signaling games. Some correspondences are hardly worth mentioning. Speakers correspond to senders and hearers correspond to receivers, of course. The generator places restrictions on the set of possible form-meaning associations and this naturally finds its expression in the semantic denotation function

\[
\langle m, t \rangle \in \text{Gen} \text{ iff } t \in \llbracket m \rrbracket
\]

if we assume that the corresponding signaling game makes truthful signaling obligatory. This leaves us with the ordering \( \succeq \) of the \( \text{ot} \)-system, and three elements of the signaling game left to be matched and/or somehow specified: the prior probabilities \( \Pr(\cdot) \), and the utilities \( U_{S,R} \) for both sender and receiver.

Formally, there are many possibilities of translation between \( \text{ot} \)-systems and signaling games. Which formal possibility is most sensible depends on the intended application of \( \text{biot} \). Recall from section 4.1.4 that the prevalent interpretation of \( \text{biot} \), if considered a description of online pragmatic competence, is that unidirectional optimization involves no perspective taking, but that bidirectional optimization does. In this section I would like to address this interpretation of optimality critically, with a comparison of \( \text{ot} \) and \( \text{ibr} \). To motivate my formal comparison, I will first discuss a case study in section 4.3.1 showing how \( \text{biot} \) is applied to data from language acquisition, in particular comprehension/production mismatches in early acquisition. This is to set the scene, motivate and exemplify the way a notion of “perspective taking” is employed in \( \text{biot} \) for explanatory purposes. I will then argue that optimality notions should be linked to strategic types of, in particular, the \( R_0 \)-sequence of the \( \text{ibr} \) model. This yields an interesting epistemic characterization of optimality notions as follows: unidirectional optimality is Bayesian rationality in its most basic form; strong optimality corresponds to one round of perspective taking of a naïvely updating receiver; and weak optimality is the limit behavior of a receiver who adheres to the \( \text{biot} \)-algorithm’s conservative notion of blocking and optimality.

4.3.1 Comprehension Lags in Language Acquisition

When a young child learns its first language, common sense might expect that competence in comprehension temporally precedes competence in production (cf. Smolensky 1996): after all, how should a language-learning child
be able to use correct expressions in the right circumstances, when it isn’t
even able to understand these forms properly when it hears them? In general,
yany mismatch in comprehension or production competences during acquisi-
tion challenges a theory of grammar, because it needs to be explained how
it is possible to use grammatical competence correctly in one way, but not in
another way. When production lags behind comprehension, an explanation
in terms of insufficient computational resources, such as working memory
or planning capacity, might seem (relatively) ready at hand. But COMPRE-
HENSION LAGS, i.e., examples where children first acquire competence in pro-
duction and only later in comprehension, are not quite as easy to explain in
terms of computational demands: it is much more plausible to assume that
‘active’ production is a more resource-intensive process than mere ‘passive’
comprehension, or so it would seem.

Nonetheless, there are numerous examples of comprehension lags, such as
in the interpretation of reflexive and non-reflexive pronouns (Hendriks and
Spenader 2005), the interpretation of indefinites (de Hoop and Krämer 2005),
or the interpretation of contrastive stress (Hendriks et al. 2007).

It pays to zoom in on only one of these examples in some detail, so as to understand
the general pattern of explanation and to pick up the main idea for subsequent
discussion and comparison to a game theoretic approach.

**The Pronoun Interpretation Problem.** Hendriks and Spenader (2005) dis-
cuss the following astonishing comprehension lag concerning the meaning of
reflexive pronouns. Clearly, for (most) adult speakers of English the sentence
(59) has only a coreferential reading for the reflexive pronoun, i.e., (59) means
that Bert washed Bert (and not Ernie or any nearby male yellow rubber duck).
In contrast, sentence (60) has no coreferential reading for the non-reflexive
pronoun, i.e., (60) means that Bert washed someone other than himself.

(59) Bert washed himself.
(60) Bert washed him.

Young children, on the other hand, have difficulties with these sentences and
show a peculiar pattern of production and comprehension asymmetry in early

---

9. For general discussion see also Hendriks et al. (2007) and Hendriks (2008).
10. I would like to encourage the reader not to get carried away too far in imagining possible
referents of the pronoun in (60). In laboratory experiments, there would just be two salient
referents: Ernie and Bert.
acquisition (see Hendriks and Spenader 2005, for details and further references). In comprehension, up to 95% of 3-year-olds assign a correct coreferential reading to (59), but about half the children of this age group wrongly assign to (60) a coreferential reading as well. By the age of 6-7, however, comprehension of these sentences matches adult competence. In contrast, production equals adult competence already at the earlier stage of language acquisition. This data poses the interesting question how it is possible that young children’s grammatical knowledge and their general computational abilities enable (i) adult-like production of both forms (59) and (60), (ii) adult-like comprehension of (59), but (iii) improper comprehension of (60)?

A biot Account of Pronoun Interpretation Data. Hendriks and Spenader propose that this asymmetry originates in the inability of young interpreters to reason about alternative forms the speaker could have used. This idea is spelled out in a model of grammatical competence in the form of an ort-system with two forms \(m_{\text{himself}}\) for (59) and \(m_{\text{him}}\) for (60), and two meanings \(t_{\text{BB}}\) for a situation in which Bert washed Bert and \(t_{\text{BE}}\) for a situation in which Bert washed Ernie. All possible form-meaning combinations are generated in this system and the ordering is derived from two constraints:

**Principle A:** a faithfulness constraint that gives preference to coreferential readings of reflexives: only the pair \(\langle m_{\text{himself}}, t_{\text{BE}} \rangle\) violates this constraint; and

**Referential Economy:** a markedness constraint on forms that prefers reflexive pronouns over non-reflexive pronouns: both pairs \(\langle m_{\text{him}}, \cdot \rangle\) violate this constraint once.

It is assumed that Principle A outranks Referential Economy, which results in an ort-system that can be visualized as follows:

```
    t_{BB}  t_{BE}

m_{himself}   ● ←●

m_{him}       ● ←●
```
The ordering gives rise to the following sets of optimal pairs (the notation is suggestive of my preferred functional interpretation of these sets):

\[
\text{Opt}_{\text{syn}} = \begin{cases} 
  t_{BB} &\mapsto m_{\text{himself}} \\
  t_{BE} &\mapsto m_{\text{him}}
\end{cases}
\]

\[
\text{Opt}_{\text{sem}} = \begin{cases} 
  m_{\text{himself}} &\mapsto t_{BB} \\
  m_{\text{him}} &\mapsto t_{BB}, t_{BE}
\end{cases}
\]

\[
\text{BiOT}_{\text{str,weak}} = \begin{cases} 
  t_{BB} &\leftrightarrow m_{\text{himself}} \\
  t_{BE} &\leftrightarrow m_{\text{him}}
\end{cases}
\]

This fits the acquisition data beautifully: young children’s comprehension and production behavior may be mapped onto unidirectional optimization, while adult-like performance corresponds to bidirectional optimization. Hendriks and Spenader propose that this models the young child’s inability to take the speaker’s perspective, in particular her expression alternatives, into account.

4.3.2 Unidirectional Optimality

Suppose we accept Hendriks and Spenader’s explanation of the comprehension lag in pronoun interpretation. Suppose also that we accept my characterization of sets of form-meaning pairs as partial strategies in signaling games with interpretation actions. The relevant question then is: how do we translate unidirectional and bidirectional optimality into a game theoretic model in a way that respects the spirit of Hendriks and Spenader’s explanation, i.e., in a way that respects the idea that young children fail bidirectional interpretation because they do not take the speaker’s options into consideration? The obvious idea is to assume that young language learners have not yet acquired either the skills or the resources to perform higher-level reasoning in the ibr model. Unidirectionally optimal behavior maps onto lower-level strategic types. Bidirectionally optimal behavior maps onto higher-level strategic types. The question then becomes: which types exactly?

Unidirectional Optimality as Behavioral Bias. A possibility that I would like to raise, only to dismiss it eventually, is to match unidirectional optimality with the behavior of level-zero players in the obvious sense that \(\text{Opt}_{\text{syn}} = S_0\) and \(\text{Opt}_{\text{sem}} = R_0\). The problem I have with this idea is that it requires amendment of the ibr model. To see this, consider the above ot-system for the pronoun interpretation puzzle. As it stands, since \(S_0\) is defined to send arbitrary true messages in each state, the only way of matching \(S_0\)’s behavior
with $\text{Opt}_{\text{syn}}$ is to assume that $[m_{\text{himself}}] = \{t_{\text{BB}}\}$ and that $[m_{\text{him}}] = \{t_{\text{BE}}\}$. This is clearly not a plausible assumption for a signaling game model of this scenario, but even if we made this contestable assumption, it would not be possible to match $R_0$’s behavior to $\text{Opt}_{\text{sem}}$, because if $[m_{\text{him}}] = \{t_{\text{BE}}\}$ then it is not possible that $t_{\text{BB}} \in R_0(m_{\text{him}})$ under the given definition of the $\text{IBR}$ types.

To maintain an interpretation of unidirectional optimality with level-zero players, we would therefore have to redefine the beginning of the $\text{IBR}$ sequences. For instance, we could assume that $S_0$ is unstrategically sending only true messages but is moreover susceptible to message costs. This way it is possible to match $\text{Opt}_{\text{syn}}$ for the pronoun interpretation puzzle by assuming, as is usual in signaling games, that costs of messages depend on states. Slightly differently, but to a similar effect, we might also assume that the constraints specified by a given $\text{ot}$-system are additional grammatical biases of otherwise unstrategic level-zero players: thus conceived, we would implement not only truth-conditional meaning but more complex syntactico-semantic features such as non-binding focal elements into a pragmatic reasoning system.

I find especially this latter idea plausible enough and even appealing and promising: after all, considering further grammatical biases as focal reasoning points might open up the game theoretic model to new realms of application. Still, I will not pursue this approach any further here, because, firstly, for the time being I would prefer a more conservative comparison of $\text{biot}$ with the $\text{IBR}$ model as it stands, and, secondly, there is another plausible alternative approach to comparison for which we do not have to change the basic definitions of the $\text{IBR}$ model.

Unidirectional Optimality as Least Sophisticated Optimization. Although unidirectional optimization does not take the other interlocutor’s perspective into account, it is nonetheless a process of optimization. This suggests that we should match unidirectional optimality with the least sophisticated strategic types in the $\text{IBR}$ model that do perform some kind of optimization. These are, interestingly enough, $R_0$ and $S_1$.\footnote{This is an interesting point to notice in passing: level-zero senders need not behave rationally at all; level-zero receivers, on the other hand, behave rationally given a possibly irrational belief in literal interpretation. Whence the asymmetry in players’ optimization behavior.} Matching $\text{Opt}_{\text{sem}} = R_0$ and $\text{Opt}_{\text{syn}} = S_1$ implies that the ordering of a given $\text{ot}$-system gives the expected utilities of $R_0$ and $S_1$ respectively. Thus conceived, the question is whether
this always necessarily yields a full translation of an ot-system into a signaling game.

A straightforward translation is possible for the pronoun interpretation puzzle. This behavior of agents falls out under a standard definition of the ibr model for a signaling game like in figure 4.2. However, it may be objected here that to assume $[m_{himself}] = \{t_{BB}\}$ is unwarranted and not what the corresponding ot-system would do. If this is perceived as a problem, an alternative way of setting up the signaling game is conceivable. If we assume that $[m_{himself}] = \{t_{BB}, t_{BE}\}$, then we need to make sure that $R_0$ still matches Optsyn. This is possible if we take recourse to the idea that prior probabilities in an interpretation game are only a compact way of specifying posterior probabilities (section 3.1). Whenever this compact representation proves too restricted, as in the present case, we may wish to resort to a different, more flexible specification. It is thus compatible with the interpretation of the context model and the standard ibr model to assume that $Pr(t_{BB}|m_{himself})$ is bigger than $Pr(t_{BE}|m_{himself})$ while $Pr(t_{BB}|m_{him})$ is equal to $Pr(t_{BE}|m_{him})$. In fact, if we allow for this latter more flexible specification of posterior beliefs of the receiver it is immediate that there is always a signaling game model that corresponds to any given ot-system in the sense that the sets of unidirectionally optimal form-meaning pairs match $R_0$ and $S_1$. Such corresponding signaling games may have to assume sender response utilities and message costs quite uncharacteristic of interpretation games, and the translation from ot-system to signaling game model is not unique but one-to-many. Nonetheless, existence of a suitable signaling game is guaranteed.

**Primacy of Production.** The obvious criticism is that my suggested parallelism renders the sender strangely more sophisticated than the receiver. This, however, need not be implausible for a model of language use and interpretation. Some people see production as a more active, deliberate process than passive, reactive interpretation: for instance, Zeevat (2000) argues that there seems to be a natural primacy of production over comprehension in the sense

<table>
<thead>
<tr>
<th></th>
<th>$Pr(t)$</th>
<th>$a_{BB}$</th>
<th>$a_{BE}$</th>
<th>$m_{himself}$</th>
<th>$m_{him}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$t_{BB}$</td>
<td>$1/2$</td>
<td>1,1</td>
<td>0,0</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>$t_{BE}$</td>
<td>$1/2$</td>
<td>0,0</td>
<td>1,1</td>
<td>–</td>
<td>✓</td>
</tr>
</tbody>
</table>
that even the most naïve form of intentional speaking is more of an active decision making than the most naïve form of listening. Zeevat therefore argues for an asymmetric approach to optimality notions and suggests a system that takes OT-syntax as its central axis around which cooperative pragmatic reasoning optimizes for both speaker and hearer. Thus conceived, by mapping the OT-ordering ≤ to R₀ and S₁, Zeevat’s asymmetric picture is compatible even with standard BIOT. Moreover the parallel between BIOT and IBR that I suggest here may perhaps even be taken as a formal plausibility argument for the priority of production over comprehension in a model of language competence: in the IBR model the least sophisticated speakers that optimize at all are more sophisticated than the least sophisticated optimizing hearers.

**Quantity as Semantic Strength.** Further support for my translation proposal can be found in other applications of BIOT to pragmatics. In early work, Blutner (1998) applied OT — though it was not yet identified as such at the time— to the computation of conversational implicatures. Towards this end, Blutner assumed that each form $m \in M$ was associated with a cost $c(m) > 0$, and a meaning $[m] \subseteq T$. Blutner then defined the ordering $\succeq$ directly in terms of a function $C : Gen \rightarrow \mathbb{R}$ as:

$$g \succeq g' \text{ iff } C(g) \geq C(g')$$

where

$$C(m, t) = c(m) \times -\log_2 \Pr(t | [m]).$$

Blutner left the prior probabilities of states unanalyzed, but the main idea behind his approach is apparent: a form-meaning pair is relatively preferred the cheaper the form is, and the more likely the meaning is given that the form is true. For a fixed form, the hearer ordering $\succeq_m$ will select the most likely meaning given the semantic meaning of the message. For a fixed meaning, the speaker ordering $\succeq_t$ will select the form which at the same time minimizes the costs and maximizes the likelihood of the to-be-expressed meaning.

It is easy to see that Blutner’s hearer ordering implements the expected utility of a level-zero receiver in an interpretation game:

$$t \succeq_m t' \text{ iff } \Pr(t | [m]) \geq \Pr(t' | [m]) \text{ iff } EU_R(t, m, \mu_0) \geq EU_R(t', m, \mu_0).$$

Similarly, Blutner’s speaker ordering implements the expected utility of a level-1 sender in an interpretation game with flat priors if we assume that
4.3. An Epistemic Interpretation of Optimality

Costs \(c(m)\) are infinitesimally small, so as to assimilate nominal costs. In general, Blutner’s ordering contains the idea that the speaker prefers a true form \(m\) over another true and equally costly form \(m'\) if (but not necessarily only if) \([m] \subset [m']\). But that means that Blutner’s ordering implicitly implements a speaker conjecture that the receiver is interpreting literally: only under an expectation of literal uptake devoid of pragmatic inference is it always rational to prefer semantically stronger statements all else being equal.

A similar point can be made in connection with the constraint-based pragmatic OT-system initiated by Aloni (2007), which is further developed by Pauw (2008). Both Aloni and Pauw translate Gricean Maxims rather directly into constraints of a pragmatic OT-system. Quantity is implemented as a constraint that strictly prefers a form \(m\) over a form \(m'\), all else being equal, just in case \([m] \subset [m']\). Just as before, we again discern here the hidden assumption—in essence a speaker conjecture—that the hearer is naïve and interprets forms based on their semantic meaning only.

The insight that emerges here is actually noteworthy in general. It’s interesting to ask why we would like to implement Gricean Quantity in terms of semantic strength. Why is it that a more informative message is one that is semantically more specific? After all, one could imagine that the requirement to be informative aims at the outcome of communication rather than the input. To wit: if you manage to understand me perfectly, even if I use a tautology—semantically totally uninformative—and even better than when I had used any semantically stronger sentence, why should I still prefer semantically stronger messages? My argument therefore is that whenever a pragmatic approach implements Gricean Quantity, as relevant OT approaches have done, in terms of semantic strength (as opposed to in terms of any further systematic pragmatic enrichment), these approaches are implicitly assuming that speakers are (something like) level-1 players that rely on literal, non-enriched uptake in their optimization. Whence that it is legitimate to link \(\text{Opt}_{\text{syn}}\) with \(S_1\) and \(\text{Opt}_{\text{sem}}\) with \(R_1\).

4.3.3 Bidirectional Optimality

If unidirectional optimality corresponds to the behavior of \(R_0\) and \(S_1\), what then does bidirectional optimality correspond to? It is certainly not far-fetched to suspect that strong optimality might coincide with \(R_2\)'s interpretation behavior, and that the iterating OT-algorithm, which computes weak optimality, just corresponds to the interpretation behavior of higher-level re-
receiver types in the $R_0$-sequence. This suggestive idea is made even more plausible if we compare the way generalized M-implicatures are computed in both systems. If after $i$ rounds of computation of the $\textit{biot}$-algorithm a form $m_j$, $j \leq i$, is in the set of optimal form-meaning pairs, then we find $R_{2i}(m_j) = \{t_j\} = \text{Opt}_i(m_j)$, at least if we assume divine $k$-dominance. With only weak $k$-dominance or no $k$ assumption at all we still get that if after $i$ rounds of computation of the $\textit{biot}$-algorithm a form $m_j$, $j < i$, is optimal, then $R_{2i}(m_j) = \{t_j\} = \text{Opt}_i(m_j)$ and $R_{2i}(m_i) \supseteq \{t_i\} = \text{Opt}_i(m_j)$.

The following results show that this plausible conjecture is only almost correct: if we assume that the $\textit{ot}$-system can be translated so that its ordering corresponds to the expected utility of $R_0$ and $S_1$ in an interpretation game then we can show that strong optimality is characterized by higher-order receiver types that perform certain, restricted kinds of belief update. In particular, strong optimality is equivalent to the interpretation of an unsophisticated level-2 receiver as introduced in section 2.2.3. Weak optimality, on the other hand, is not equivalent to the limit behavior of unsophisticated receivers. To match the behavior of the $\textit{biot}$-algorithm in $\text{iBR}$ we need to assume an even more restricted form of receiver belief formation. Weak optimality is equivalent to the interpretation behavior of a myopic receiver who strongly adheres to a strictly conservative notion of optimality: once a form is associated with a given meaning, a myopic receiver will always adhere to this association in forming his posterior beliefs. Together, these results then give an epistemic characterization of bidirectional optimality within the $\text{iBR}$ model in terms of different kinds of belief formation of the receiver.

**Strong Optimality as Unsophisticated Update**

Section 2.2.3 elaborated on the difference between sophisticated and naïve posterior belief formation of the receiver. Recall that a receiver of level $k$ updates naively if he adopts posteriors of the form

$$\mu_k(t|m) = \Pr(t|S_{k-1}(m)),$$

where

$$S_{k-1}(m) = \{t \in T \mid \exists s \in S_{k-1} : s(t) = m\}.$$

An unsophisticated receiver $R_k$ assumes —possibly inconsistently— that all types $t \in S_{k-1}(m)$ that may send a given message $m$ according to the behavioral belief $S_{k-1}$ always send this message.
If we equate the ordering of an or-t-system with the expected utility of $R_0$ and $S_1$ in an interpretation game, then strong optimality can be characterized as the interpretation behavior of an unsophisticated level-1 receiver.

Proposition 4.3.1. If for some message $\text{biot}_{\text{str}}(m) \neq \emptyset$, then $\text{biot}_{\text{str}}(m) = R_2(m)$ if $R_2$ performs an unsophisticated update.

Proof. Let $t \in \text{biot}_{\text{str}}(m)$. Then $m$ is a rational choice for $S_1$ in state $t$. That implies that $m$ is not a surprise for $R_2$, so that $\mu_2(\cdot|m)$ is derived from naïve consistency as $\mu_2(\cdot|m) = \Pr(t|S_1(m))$. Next, since $t \in \text{biot}_{\text{str}}(m)$, we also know that $t \in R_0(m)$, which means that $t$ maximizes $\Pr(\cdot|\llbracket m \rrbracket)$. But then $t$ also maximizes $\Pr(\cdot|S_1(m))$, given that $S_1$ will not send untrue messages by assumption. But that just means that $t \in R_2(m)$.

As for the other direction of inclusion, assume that $\text{biot}_{\text{str}}(m) \neq \emptyset$ and $t \in R_2(m)$. The former implies that $S_1(m) \neq \emptyset$ and the latter just means that $t$ maximizes $\Pr(\cdot|S_1(m))$. Together this yields that $t \in S_1(m)$, or alternatively that it’s rational for $S_1$ to send $m$ in $t$. It then remains to show that it’s also rational for $R_0$ to interpret $m$ as $t$, i.e., we need to show that $t$ maximizes $\Pr(\cdot|\llbracket m \rrbracket)$. Towards this end, observe that there is some $\bar{t} \in \text{biot}_{\text{str}}(m)$ by assumption, which is therefore maximal in $\Pr(\cdot|\llbracket m \rrbracket)$. From the above we know that $\bar{t} \in R_2(m)$. But that means that $\Pr(t|S_1(m)) = \Pr(\bar{t}|S_1(m))$. This implies that $\Pr(t) = \Pr(\bar{t})$ which in turn implies that $t$ also maximizes $\Pr(\cdot|\llbracket m \rrbracket)$ if we assume that $S_1$ sends only true messages. Together we obtain that $t \in \text{biot}_{\text{str}}$. \hfill $\Box$

Why Naïveté is Necessary. For a characterization of strong optimality as level-2 interpretation behavior, the restriction to unsophisticated update behavior of the receiver is necessary. To see where sophisticated update differs from strong optimality, consider the some-all game with skewed priors that was discussed already in section 2.2.4. The example was a some-all signaling game with $\frac{2}{3} > \Pr(t_\forall) > \frac{1}{2}$. With these prior probabilities the $R_0$-sequence starts as follows:

$$R_0 = \begin{cases} m_{\text{some}} & \mapsto t_\forall \\ m_{\text{all}} & \mapsto t_\forall \end{cases} \quad S_1 = \begin{cases} t_{\exists,\forall} & \mapsto m_{\text{some}} \\ t_\forall & \mapsto M \end{cases}$$

A sophisticated $R_2$ would respond to $m_{\text{some}}$ under the belief in $S_1$ by properly taking into account that $S_1$ also sends $m_{\text{all}}$ in state $t_\forall$. With $\frac{2}{3} > \Pr(t_\forall) > \frac{1}{2}$

12. Remember that this is how we implemented the restrictions of the generator.
this yields:

\[ R_2 = \{ m_{\text{some}} \mapsto t_{\exists \forall}, m_{\text{all}} \mapsto t_\forall \}. \]

Opposed to that, an unsophisticated \( R_2 \) plays:

\[ R'_2 = \{ m_{\text{some}} \mapsto t_\forall, m_{\text{all}} \mapsto t_\forall \}. \]

This is because a naïve \( R_2 \) updates his priors with the set of states in which \( S_1 \) would ever send a given message, which in the case of \( m_{\text{some}} \) is the set of all states.

Strong optimality does not model the sophisticated update behavior, but follows the unsophisticated receiver. The set of strongly optimal pairs in this example are:

\[ \text{BIOT}_\text{str} = \{ (m_{\text{some}}, t_\forall), (m_{\text{all}}, t_\forall) \}. \]

Roughly speaking, since strong optimality merely computes the intersection of strategies of \( R_0 \) and \( S_1 \), it is not sensitive to the kind of distributional information —which message is sent in how many states— that a sophisticated updater takes into account.

**Weak Optimality as Myopic Update**

Let’s briefly recapitulate some of the previous results. Strong optimality specifies the behavior of unsophisticated level-2 receivers. Furthermore, strong optimality is also the set \( \text{Opt}_1 \) of optimal form-meaning pairs after one round of iteration of the \( \text{BIOT} \)-algorithm. Since moreover the \( \text{BIOT} \)-algorithm is a repeated application of strong optimality after removal of optimal and blocked form-meaning pairs, it is tempting to suspect that the set of optimal interpretations \( \text{Opt}_i \) after \( i \) rounds of iterations partially characterizes the behavior of level-2\( i \) receivers, if we assume that the receiver performs an unsophisticated update throughout.

This idea is not correct. It turns out that the \( \text{BIOT} \)-algorithm actually is peculiarly conservative: the monotonicity of the sets \( \text{Bl}_n \) and \( \text{Opt}_n \) means that (i) if a form-meaning pair is blocked, it will be completely removed from further consideration, and that (ii) if \((m, t)\) is selected as optimal at some round, the association between \( m \) and \( t \) is fixed for good and always. The \( \text{IBR} \) model, on the other hand, whether defined with sophisticated or unsophisticated receivers, does *not* generally block or fix form-meaning associations once and
for all. Here are two examples that show, respectively, how (i) the IBR model can select interpretations in later rounds that the BIOT-algorithm has discarded as blocked, and how (ii) the IBR model can rule out an interpretation that the BIOT-algorithm has selected as optimal in earlier iterations.

**The Symmetry Problem Again.** Consider anew the simple extension of the some-all game that we have looked at before, in section 2.3, where we assume that an additional third form \(m_{sbna}\), short for “some but not all,” is given which has the obvious semantics but which also incurs a slight cost. Translating this constellation into an OT-system would yield the following initial constellation under the Blutner ordering:\(^{13}\)

\[
\begin{array}{c}
\exists \neg \forall \\
m_{sbna} \\
\exists \forall \\
m_{some} \\
\forall \\
m_{all}
\end{array}
\]

This is also exactly what a direct translation from \(R_0\)’s and \(S_1\)’s expected utilities would yield.

The optimal pairs after the first round of iteration are the strongly optimal pairs \(\langle m_{sbna}, \exists \neg \forall \rangle\) and \(\langle m_{all}, \forall \rangle\) and this leads to the blocking of all pairs with the form \(m_{some}\):

\[
\begin{array}{c}
\exists \neg \forall \\
m_{sbna} \\
\exists \forall \\
m_{some} \\
\forall \\
m_{all}
\end{array}
\]

The BIOT-algorithm terminates here and leaves the form \(m_{some}\) dangling.

The IBR model, on the other hand, of course replicates the predictions of bidirectional optimality for messages \(m_{sbna}\) and \(m_{all}\). But in contrast to the

\(^{13}\) In this diagram and the following diagrams, only strict preferences are drawn. Form-meaning pairs that are not in the generator are left blank in order to indicate a difference between blocked and non-generated form-meaning pairs. Recall that the generator translates into semantic meaning in the corresponding signaling game in which the sender cannot send false signals.
\textsc{biot}-algorithm, \textsc{ibr} does not block the interpretation $t_{\exists-\forall}$ for later association with the form $m_{\text{some}}$. With \texttt{fi} assumption, the \textsc{ibr} model does not terminate here, but evolves into a prediction different from weak optimality, as we have seen in section 2.3. Abusing the \texttt{ot}-diagrams to represent the prediction of the \textsc{ibr} model succinctly for visual comparison, here is the fixed point of the \textsc{ibr} model with \texttt{fi} assumption:

\begin{align*}
    & t_{\exists-\forall} & t_{\forall} \\
    m_{\text{sbna}} & \circ & \\
    m_{\text{some}} & \circ & \times \\
    m_{\text{all}} & \circ
\end{align*}

Although this prediction does depend on weak $k$-dominance, it does not depend on whether the receiver is sophisticated or not. The important point about this example is that the \textsc{ibr} model does not necessarily replicate the strong blocking behavior inherent in weak optimality: in \textsc{biot}, if a form or a meaning is blocked, it will never be revived, but not so in \textsc{ibr}. The example furthermore shows that this strong blocking behavior leads to unintuitive predictions for scalar reasoning, if we include non-ambiguous, yet nominally more costly forms; in other words, \textsc{biot} does not seem to include enough forward induction reasoning to overcome the symmetry problem.

The suspicion may be raised that \textsc{ibr} differs from \textsc{biot} here only because of forward induction, and that the basic \textsc{ibr} model without \texttt{fi} assumption coincides with the predictions of the \textsc{biot}-algorithm and hence, in the limit, with weak optimality. This is not so, as another example demonstrates. Even with naïve updaters, and absolutely unspectacular flat prior, cheap-talk interpretation games, \textsc{ibr} does not follow the conservativeness of the \textsc{biot}-algorithm.

\textbf{IBR Overrules Optimality.} The next example shows that the \textsc{ibr} model may give up associations between a form and a meaning that were labeled optimal by the \textsc{biot}-algorithm in a previous round. Suppose there are three forms and three meanings with semantic meaning as indicated by bullets in the following diagram.
The arrow represents the only strict preference between form-meaning pairs according to the Blutner ordering, if we assume that all forms are equally costly and all meanings are initially equiprobable. The \textit{biot}-algorithm will return the following output after one round of iteration after which it also terminates:

\[
\begin{array}{ccc}
  t_1 & t_2 & t_3 \\
  m_1 & \bullet & \bullet \\
  m_2 & \bullet & \circ \\
  m_3 & \circ & \circ \\
\end{array}
\]

The \textit{ibr} model, in contrast, yields the same prediction for an unsophisticated \( R_2 \) in the corresponding interpretation game, but has not yet reached a fixed point. With \( R_2 \)'s interpretation behavior as in the above diagram, \( S_3 \) will send only \( m_2 \) in state \( t_2 \), because this gives her an expected utility of 1 instead of an expected utility of \( \frac{1}{2} \) for sending \( m_3 \). This is what \( R_4 \) realizes and the fixed point is reached with \textit{ibr}'s prediction as in the following diagram:

\[
\begin{array}{ccc}
  t_1 & t_2 & t_3 \\
  m_1 & \circ & \bullet \\
  m_2 & \times & \circ \\
  m_3 & \circ & \circ \\
\end{array}
\]

14. Although it is not strictly necessary to back up the example with reasonable content for the structural point that I would like to make, we can think of this as a scalar implicature case between the three forms \( m_1 \) for “it is certain that \( p \)”, \( m_2 \) for “it is likely that \( p \)”, and \( m_3 \) for “there is a remote chance that \( p \).” For the sake of the example, let’s take the following test as indicative for the semantics chosen above:

(i) a. It’s likely that \( p \), and it’s maybe even certain that \( p \).

b. There is a remote chance that \( p \), and it’s maybe even likely that \( p \).

c. ? There is a remote chance that \( p \), and it’s maybe even certain that \( p \).
That means that, effectively, IBR is not stuck with the strongly optimal pair \( \langle m_3, t_2 \rangle \), but weak optimality is. The example shows how IBR is not committed to monotonicity of optimality in establishing form-meaning associations.

**Weak Optimality from Myopic Update.** These last two examples suggest that the conservativeness of the biot-algorithm in terms of blocking and optimality can be modelled in IBR terms only if we assume that the receiver forms posterior beliefs in such a way that all form-meaning associations of the biot-algorithm are respected. Towards this purpose, say that a receiver of strategic level \( 2i, i \geq 1 \), is **myopic** if he computes his posterior as

\[
\mu_{2i}(t|m) = \Pr(t|\opt(m))
\]

whenever \( \opt(m) \) is non-empty. A myopic \( R_{2i} \) cares for nothing else than the optimal form-meaning associations at round \( i \) when he hears a message that is part of an optimal form-meaning pair. With this strong assumption about receiver belief formation we can show that, somewhat unsurprisingly for sure, weak optimality in an or-system whose ordering defines the expected utilities of \( R_0 \) and \( S_1 \) corresponds to the limit behavior of a myopic receiver in an interpretation game.

**Proposition 4.3.2.** If for some message \( \opt(m) \neq \emptyset \), then \( \opt(m) = R_{2i}(m) \) for myopic receivers.

**Proof.** Let \( \opt(m) \neq \emptyset \). This means that, in an interpretation game, a myopic receiver of level \( 2i \) plays:

\[
R_{2i}(m) = \max_{t \in T} \Pr(t|\opt(m)).
\]

We therefore need to show that all states in \( \opt(m) \) are equally likely *a priori*. Suppose this is not so, i.e., let there be \( t \) and \( t' \) in \( \opt(m) \) for which \( \Pr(t) > \Pr(t') \). In that case, it is impossible for \( \langle m, t' \rangle \) to be in \( \opt \), because this pair is blocked by the (optimal) \( \langle m, t \rangle \). It follows that \( \opt(m) = R_{2i}(m) \). \( \square \)
4.3. An Epistemic Interpretation of Optimality

Reflection. A couple of remarks on this last result are necessary. First of all, this epistemic interpretation of weak optimality seems very much like a brute-force result. Myopic update is certainly a very strong, seemingly artificial assumption about belief formation as it basically requires the formation of posterior beliefs after each optimal form to neglect everything except that form’s optimal meanings. Still, it seems that this really is the way we should characterize weak optimality in terms of restrictions on belief formation in interpretation games. The strictly monotonic removal of blocked and optimal pairs in the \textsc{biot}-algorithm does not square with interpretation in \textsc{ibr} at all: in a manner of speaking, \textsc{ibr} reconsiders all possible form-meaning pairs in higher rounds of iteration. So, in order to restrict \textsc{ibr} not to consider certain possibilities, some drastic undermining of \textsc{ibr}’s reasoning mechanism is necessary. Consequently, it is not the positive result that \textsc{ibr} can model interpretation behavior based on weak optimality that is of importance here, but rather at what expense we can characterize weak optimality, i.e., how much of \textsc{ibr} we apparently have to give up in order to assimilate weak optimality.

But, of course, the above is only a sufficient characterization in the sense that it gives sufficient epistemic conditions for interpretation based on weak optimality. It thus suffers the same fate that, e.g., epistemic characterization results of game theoretic solution concepts face: it is hard to argue conclusively that a given sufficient characterization is also necessary in the sense that other possible sufficient characterizations are less systematic, elegant or plausible, and that other conceivable systematic, elegant and plausible characterizations are not sufficient. Consequently, I cannot claim that myopic update is a necessary or even the best characterization of weak optimality. There is clearly still room for improvement in future research here.

Finally, if we accept my characterization, it could be argued for myopic update and against \textsc{ibr} that myopic update is, in a natural sense, much more resource efficient, and therefore preferable: myopic update could be regarded as a ‘fast and frugal’ heuristic that lumps together forms and meanings, and that would just not let go of previous associations for the sake of simplicity of calculation. I would certainly be very much in favor of an epistemic interpretation of weak optimality in terms of an efficient heuristic if such a heuristic was defensible. But I do not see any pressing conceptual justification for exactly this heuristic. It is moreover not the case that the heuristic in question excels by superior empirical predictions that other approaches could not reach. I suggest that in the absence of reasons to the contrary we should stick to sophisticated updating as the normative standard.
SUMMARY. To give a résumé of this chapter so far, I have argued against the widely accepted idea of Dekker and van Rooij (2000) that bidirectional optimality should be linked to Nash equilibria in strategic games. This, my argument went, is simply not the way we conceive of sets of optimal form-meaning pairs, which intuitively specify conditional, not unconditional, production or interpretation behavior. Instead, I proposed to relate $biot$ to signaling games, in particular by translating an $ot$-system into an interpretation game such that its ordering gives the expected utilities of the lowest optimizing sender and receiver types in the $ibr$ model. This resulted in a straightforward characterization of unidirectional optimality as Bayesian rational behavior and of strong optimality as the interpretation of an unsophisticated level-2 receiver. The characterization of weak optimality in terms of myopic receivers may have seemed somewhat forced. But still, in order to pair $ibr$ reasoning, which is fairly liberal in its association of forms and meanings, with the $biot$-algorithm, which was shown to be fairly conservative, a strong assumption about locally incremental, ‘once-and-for-all’ belief formation seemed necessary.

These formal results also shed light on the issue of how $ot$’s optimality notions should be interpreted. I have in particular addressed the view that bidirectional optimization requires interlocutors to take the perspective of their conversational partners. It is this that the parallelism with $ibr$ made more precise. If what I suggested in this chapter is correct, then we should think of optimality notions in pragmatic applications as centered on a production perspective, in which basic optimizing for production already subsumes unsophisticated interpretation behavior. Strong optimality in interpretation then comes forward as the result of taking this production perspective as the basis for interpretation. \footnote{15} Weak optimality, on the other hand, presents itself as a more challenging interpretation process which takes further steps of iteration into account. Linking $biot$ and $ibr$ in the way suggested, the results of this chapter support the position of Hendriks et al. (2007) who write:

“We can view bidirectional optimization as a mechanism describing human linguistic competence while acknowledging that the recursion allowed for by this mechanism is limited by performance factors.”

(Hendriks et al. 2007, chapter 5 section 5.6.1)

This much does not say anything yet about an evolutionary interpretation of $ot$, in particular of weak optimality. So when Blutner and Zeevat (2008)
write (in their footnote 11) that “the solution concept of weak bidirection can be seen as a rough first approximation to the more adequate solution concepts of evolutionary game theory that describe the results of language change” especially a diachronic interpretation of IBR seems again like the closest game theoretic counterpart. The last two examples of this chapter that demonstrated the difference between the BIOT-algorithm and IBR also suggest that indeed the latter could turn out the better, more refined evolutionary mechanism to select for optimal communication. Although I tend to believe that the IBR model as presented here is equally suited as a diachronic model, I prefer to postpone a more careful examination of this to another occasion.

4.4 Scalar Implicatures in Language Acquisition

BIOT seeks to explain asymmetries in language acquisition by appeal to the relative difficulty for young children to optimize bidirectionally. It is thus interesting to have a closer look at particularly the developmental pattern in the acquisition of scalar implicatures. Is there a production/comprehension mismatch or any other peculiar asymmetry in the acquisition of the ability to handle scalar implicatures? And if so, does BIOT or IBR help explain it?

4.4.1 Overview of Some Recent Studies

Logical Children. Ira Noveck’s was the first in a fairly recent series of thorough investigations into children’s ability to compute (scalar) implicatures and the developmental course of acquisition of pragmatic competence (Noveck 2001). Noveck’s study was designed —building on early work by Smith (1980)— as a JUDGEMENT TASK where subjects had to “agree” or “disagree” with sentences presented to them. Critical to an assessment of scalar inference in subjects were sentences like (61).

(61) Some giraffes have long necks.

Acceptance of such sentences was counted as what I will call the SEMANTIC RESPONSE (in this task): subjects accepting a sentence like (61) apparently did not compute the scalar implicature associated with the quantifier “some”, because if they had, they should have rejected the sentence based on world knowledge. Rejection of such sentences, on the other hand, was counted as what I will call the PRAGMATIC RESPONSE, for it was taken to indicate the ability to compute and integrate the scalar implicature into the overall meaning of
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Noveck tested children aged 7 to 11 in this judgement task, and compared performance with adult controls. In a nutshell, his data showed that children gave significantly fewer pragmatic responses than adults, although they performed at adult level in control sentences testing for world knowledge and linguistic competence. In slightly more detail, 89% and 85% of the children aged 7-8 and 10-11 respectively did not reject critical sentences like (61), thus showing the semantic response in this task. This is in contrast to 59% of adults who gave the pragmatic response. Noveck’s study thus suggests, among other things, that children are—as he put it—more logical than adults: pragmatic competence in comprehension seems to develop late.

Evidence for Early Pragmatic Competence. Still, a strong conclusion to the extent that children are incapable of pragmatic reasoning in general, or of computing scalar implicatures in particular, is not warranted. In a follow-up study Papafragou and Musolino (2003) elicited far more pragmatic responses than Noveck in even younger children of around 5 years of age. Their study consisted of two experiments which in conjunction support the view that (i) Noveck’s results were correct in that pragmatic competence takes time to develop, but that (ii) even very young children are capable of pragmatic responses—though not at adult level—if the task is amended adequately.

In Papafragou and Musolino’s first experiment subjects had to evaluate the answer of a puppet figure to a question about a previously acted out scene. For example, in the implicature-critical condition subjects would observe a group of toy horses all jumping over a fence; the puppet figure, who observed the scene along with the subject, was then asked what had happened and she would reply—in the critical condition involving quantifier “some”—that some of the horses jumped over the fence; subsequently the subject was asked whether the puppet “answered well” or not. The semantic response in the critical condition of this judgement task is to say that the puppet answered well, while the pragmatic response is to say that the puppet did not answer well. Papafragou and Musolino tested 30 children, aged 4;11 to 5;11, and 30 adult subjects on the contrast between

(i) quantifiers “all” and “some”;

(ii) numerals “three” and “two”;

16. There are several points of criticism to raise against this interpretation of subjects’ responses in Noveck’s task. We will come to this below.
4.4. Scalar Implicatures in Language Acquisition

<table>
<thead>
<tr>
<th></th>
<th>Adults</th>
<th>Children</th>
</tr>
</thead>
<tbody>
<tr>
<td>all/some</td>
<td>92.5%</td>
<td>12.5%</td>
</tr>
<tr>
<td>three/two</td>
<td>100%</td>
<td>65%</td>
</tr>
<tr>
<td>finish/start</td>
<td>92.5%</td>
<td>10%</td>
</tr>
</tbody>
</table>

Figure 4.3: Percentage of pragmatic responses in Papafragou and Musolino’s first experiment

(iii) verbs “finish” and “start.”

The reported pragmatic responses of both children and adults in this experiment are given in figure 4.3. For the present discussion the most interesting result is that 92.5% of adult subjects gave pragmatic responses in the some-all contrast, while only 12.5% of 5-year-olds did. This confirms Noveck’s previous conclusion that children do not draw scalar inferences at the same rate as adults do.

However, Papafragou and Musolino’s second experiment qualifies this conclusion. The set-up in their second experiment was the same as in the first, except that in the second experiment

1. there was a main character in the acted-out scene who was faced with a challenge, such as catching all of the horses;

2. the puppet figure then commented on the success of this main character in meeting the challenge;

3. subjects were told that the puppet sometimes would say something “silly” and that the subject should help the puppet “say it better”;

4. subjects were trained to correct the puppet on pragmatic anomalies in a previous naming task of the same pattern.

It seems fair to say that the second experiment made the task clearer to the subjects by raising the relevance of a pragmatically correct statement: the puppet wants to learn how to speak well, and the question whether the main character achieved his task foregrounded the distinction between, e.g., elements “some” or “all.” Indeed, under these conditions, Papafragou and Musolino found that the 5-year-old subjects’ performance on critical “some”-sentences went up to 52.5% of pragmatic responses (90% for numeral “two” and 47.5% for “start”). This is still not adult-like performance, but shows that the nature
of the task has a clear influence on eliciting pragmatic responses. In sum, a careful conclusion about children’s ability to compute scalar implicatures based on Papafragou and Musolino’s results is that young children overall do not respond as pragmatically as adults, but that pragmatic responses in children can be facilitated by different task designs, in particular if the relevance of responding pragmatically is highlighted by design and training.

Pragmatic Competence in an Action-Based Task. Pouscoulous et al. (2007) took Papafragou and Musolino’s approach even further. The group hypothesized that pragmatic inferences come at a cost and that therefore pragmatic responses could be elicited from even the youngest subjects proportional to the simplicity of the task. To test their hypothesis, Pouscoulous et al. not only replicated Noveck’s judgement task, but they also set up an action-based task which was predicted to further facilitate pragmatic responses in young children. Here is Pouscoulous et al.’s experimental set-up in some detail.

Subjects were presented with five boxes and five tokens that were arranged in one out of three possible scenarios in front of them:

1. in the subset scenario two boxes contained exactly one token and three boxes were empty;
2. in the ‘all’ scenario all five boxes contained exactly one token; and
3. in the ‘none’ scenario none of the five boxes contained a token.

In these scenarios subjects heard the sentences in (62). These were presented as a puppet figure’s wish with which the subjects were asked to comply.

\[(62)\]
\[
\begin{align*}
\text{a.} & \quad \text{I would like all the boxes to contain a token.} \\
\text{b.} & \quad \text{I would like some boxes to contain a token.} \\
\text{c.} & \quad \text{I would like no box to contain a token.} \\
\text{d.} & \quad \text{I would like some boxes to contain no token.}
\end{align*}
\]

Subjects were free to add tokens to boxes, remove tokens from boxes or leave everything as is. Consequently, there are two critical conditions in this task where we can distinguish semantic and pragmatic responses. For one, if a subject removed tokens from a box in the ‘all’ scenario when hearing the sentence (62b), this would count as a pragmatic response, whereas if no token was removed in this condition this would count as a semantic response. Similarly, if a subject added a token in the ‘none’ scenario when hearing the
sentence (62d), this would count as a pragmatic response, whereas if no token was added, this would count as a semantic response.

Pouscoulous et al. tracked the responses of three groups of children with mean age 4;5, 5;6 and 7;5 respectively and compared performance to adult controls. Children’s performance in non-critical conditions was adult-like. But in the two critical conditions children showed more semantic responses than adults, just as in previous experiments. The developmental pattern across groups for the critical conditions is given in figure 4.4 which lists the percentage of semantic responses.

Results for the first critical condition—the ‘all’ scenario in connection with the sentence (62b)—show a monotonic rise in pragmatic responses across age groups, suggesting that children grow gradually towards pragmatic maturity. The second critical condition—the ‘none’ scenario in connection with the sentence (62d)—was less clear in this respect and, Pouscoulous et al. reason, reflects the general difficulty of processing negated statements (see the paper for in-depth discussion). Noteworthy, in any case, are especially two facts about the first critical condition, namely that (i) a simpler action-based task elicited more pragmatic responses from young children than reported in previous studies, yet (ii) still 32% of 4-year-olds did not manipulate the ‘all’ scenario when confronted with the puppets wish in (62b), despite otherwise apparently comprehending perfectly well the meaning of quantifiers “all” and “some.” The hypothesis that Pouscoulous et al. (2007) started out with seems to hold: since pragmatic inference is costly, pragmatic performance is proportional to age—due to a steady increase in computational resources—and anti-proportional to task complexity.

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17. A caveat applies here, because whether, for instance, adding exactly one token to a box in the subset scenario when hearing sentence (62b) is an illogical response and should be classified differently from not manipulating the boxes in this case, may make for different conclusions (see Pouscoulous et al. 2007, for discussion).
INTERIM CONCLUSIONS & REFLECTION. So far, we have reviewed experimental evidence that the pragmatic ability to compute scalar implicatures generally seems to be acquired later than adjacent semantic competence. Still, the proportion of pragmatic responses by young children varied in the studies that we have looked at so far. Pouscoulous et al.’s study gathered more pragmatic responses from younger children, and this is plausibly so because their task was simpler than those of Noveck and Papafragou and Musolino. Minor differences notwithstanding, the main difference between studies was certainly the nature of the task: judgement vs. action-based. The results so far suggest that action-based tasks indeed elicit more pragmatic responses, but a more direct comparison of performance under both paradigms would clearly be welcome to shed more light on this issue.

However, the common-sense explanation that action-based tasks are simpler, in that they require less cognitive resources, though certainly appealing, raises the question what exactly makes a judgement task more resource-intensive and therefore difficult for young children. Also, while it may be rather uncontroversial that Pouscoulous et al.’s action-based task tests for subjects’ pragmatic comprehension skills, we should inquire more carefully into the nature of the judgement task, in particular the variety applied by Papafragou and Musolino: what exactly are we testing when we ask whether an utterance of a puppet figure is “acceptable”? Bluntly put, are we testing for comprehension or production here? On the face of it, perhaps, this judgement task seems to test on competence in production, since, after all, subjects are asked whether the puppet said it correctly. If that is so, the difference in performance between action-based and judgement tasks would suggest a comprehension/production mismatch, where production lags behind comprehension, which in turn could be explained in terms of the natural resource-intensity of production over comprehension.

But it does not seem quite that straightforward to say what Papafragou and Musolino’s judgement task assesses. Take, for instance, a critical under-informative utterance that “some X are Y” when in fact all X are Y. On the one hand, a pragmatic response in this case may be taken as evidence for production competence, because subjects may be assumed to reject the utterance if and only if they themselves would not use it in the presented circumstances. But, on the other hand, rejection of the target utterance may also be taken as indicative of comprehension competence, because subjects may be assumed to reject the target if and only if they compute the associated scalar implicature which makes the utterance infelicitous. Of course, if we were to assume
that young children’s production and comprehension are just mirror images of one another, the two perspectives would collapse into one and a pragmatic response would be indicative of a combined production/comprehension competence. But, as section 4.3.1 showed, there are many cases of mismatch between production and comprehension in language acquisition. It does not seem possible to tell analytically whether pragmatic responses in the critical conditions in Papafragou and Musolino’s judgement task are evidence for pragmatic comprehension, production or maybe even something beyond that. To test this and to complete the picture unequivocally, a more direct way of probing either skill in the laboratory is needed.

Comparing Production, Comprehension and Judgements. These considerations lead to the wish for a study that combines and compares directly (i) a task which clearly tests for comprehension competence, with (ii) a judgement-based task, and (iii) a task which tests unambiguously for production competence. Such data is presented by Katsos and Bishop (2009), an early glimpse of which was presented at esslli 2008 in Hamburg (Breheny and Katsos 2008). Katsos and Bishop conducted a developmental study with children of four age groups (5, 7, 9 and 11 years of age) in which they combined a judgement-based task, as used by Papafragou and Musolino, together with a production task and a picture-matching task.

The production task of Katsos and Bishop resembled the judgement task in that the subjects observed a scene together with a puppet character. But, unlike in the judgement task, the puppet now stated that it did not know how to describe the scene, and so the subjects were asked to help out and give a description on behalf of the puppet. This task then unambiguously tests for subjects’ production competence.

The picture-matching task of Katsos and Bishop had subjects choose two pictures of situations in which, e.g., a mouse had either picked up only some, or all of the carrots that it was intended to pick up. The subjects were then asked, in the critical condition, which picture fitted a description such as “the mouse picked up some of the carrots.” This task clearly tests for subjects’ comprehension competence.

Katsos and Bishop’s results show that 5-year-olds give overwhelmingly correct responses in semantic controls, as well as pragmatic responses in the production task and the picture-matching task. Still, 5-year-olds fail on a large scale to give pragmatic responses in the judgement task. These subjects readily accept an underinformative utterance in the judgement task although
they would not be underinformative in the production task, and would grasp the corresponding pragmatic inference in the comprehension task.

The developmental part of Katsos and Bishop’s study moreover seems to show that for all age groups the ability to give pragmatic responses in the production and comprehension tasks soon matches performance in semantic controls, whereas the percentage of pragmatic responses in the judgement task only gradually rises to match performance in semantic controls as subjects mature. These data therefore suggest that children are competent hearers and speakers when it comes to scalar implicatures, but are not competent judges of other speakers’ (production) competence. In other words, it seems that the ability to reject pragmatically infelicitous statements takes more time to develop than comprehension and production competence as such.

4.4.2 Tolerance vs. Conceptualization

There are several conceivable explanations for this pattern. Certainly, the hypothesis of Pouscoulous et al. that processing cost plays a role is very much compatible with these extended findings. Both the production task as well as the picture-matching task are in an intuitive sense easier than the judgement task. Task complexity, and proper task understanding by young subjects, most definitely plays a role in the success of showing pragmatic performances. But an explanation in terms of processing costs and task complexity is also, in some sense, not entirely satisfactory, because it leaves open what exactly the added complexity of a judgement task is.

Pragmatic Tolerance. An alternative explanation of the delayed acquisition of pragmatic competence in judgement tasks is to assume that age is, so to speak, anti-proportional to pragmatic charity: the younger a child the more tolerant it is towards pragmatic infelicity, while nonetheless objecting strongly to semantically false statements. This Pragmatic Tolerance Hypothesis is proposed as a possible explanation by Katsos (2008a) and Katsos and Bishop (2009). The pragmatic tolerance hypothesis explains the discrepancy between performance in judgment tasks as compared to other tasks: by assuming that children do not hold speakers responsible for pragmatic infelicity and thus accept underinformative statements.

What possibly speaks against this pragmatic tolerance hypothesis is recent data accumulated in support of the so-called Question Answer Requirement hypothesis about children’s interpretation of scopally ambiguous sentences
(Hulsey et al. 2004). The details of the debate about models of children’s scope disambiguation are inessential, but it does add to the present concern to note that even very young children of age 3–5 were found to reject an utterance of a sentence like (63) in a judgement task in situations where there was a true interpretation available that reflected surface scope, but which did not address the relevant question under discussion (see Gualmini 2007, 2008, for details).

(63) Some of the pizzas were not delivered.

In other words, the surface scope reading would have allowed the children to accept the sentence, but still they rejected it — as comments showed: on the basis of the inverse scope reading. This is evidence against the idea that young children are more charitable than interested in relevance, at least when it comes to the resolution of syntactic ambiguity. Of course, pragmatic tolerance does not imply lenient syntactic disambiguation, but the case makes clear how modular — and to my mind therefore implausible — an assumption pragmatic lenience is.

The View from Normativity. I would then like to tentatively advance an alternative explanation of the data by suggesting that children are not tolerant in the sense that they are equipped with full-fledged pragmatic capabilities which they then do not demand to be displayed by others, due to their young, inexperienced and forgiving nature. Rather, I would like to propose that young children may have just enough pragmatic capabilities to succeed in action-based, production and picture matching tasks, but not enough to succeed in judgement tasks. To see what is at stake, let’s have another close look at the logic behind the judgment task.

Judgement tasks, I would like to argue, might require strictly more pragmatic maturity than is necessary for linguistic behavior that demonstrates pragmatic comprehension and production proficiency. Take, as before, the critical underinformative utterance “some X are Y” in a situation where all X are Y. Even if subjects would not use the underinformative sentence themselves, this does not necessarily mean that they would reject someone else’s utterance. Surely, perhaps subjects are more forgiving or tolerant in judging another’s productive performance. Or, maybe, children would not be tolerant at all, would they not lack the necessary concept of normativity here: perhaps young subjects merely lack the full introspective power to justify what they are doing right without knowing why they are and why everybody else
should do so too. This means that it is not necessarily the case that pragmatic production competence—in a, say, ‘behavioral sense’—implies rejection in a judgement task.

And a similar argument applies to comprehension. Even if subjects do not reject a critical target utterance, this does not mean that they necessarily take the target merely at semantic value. It is perfectly conceivable that subjects do interpret pragmatically—taking a “some”-statement to refer to a “some but not all”-situation—without at the same time transcending their own interpretation behavior as a basis for a normative judgement. To wit, a child may arrive at the pragmatically correct interpretation of “some” without conceptualizing that this is what it and everybody else is and should be doing. And, again, this means that it is also not necessarily the case that pragmatic comprehension—in a similar ‘behavioral sense’ of the term—implies rejection in a judgement task.

According to this explanation it is not that children are tolerant as such, but they behave tolerantly because they lack the conceptualization of the pragmatic norm necessary to assuredly reject underinformative utterances. This conceptualization hypothesis is the alternative explanation that I would like to suggest. We may think of the conceptualization hypothesis either as an alternative to pragmatic tolerance, or, as I prefer, as a refinement or reduction of it, so as to give an explanation of tolerant behavior.

**IBR and Implicature Acquisition.** The conceptualization hypothesis is supported by the IBR model of pragmatic reasoning. First of all, if pragmatic competence is reasoning competence roughly in the sense of the IBR model, then it is most plausible to assume that what develops with age and linguistic experience is the ability to reason deeper, i.e., to advance to higher levels of iterated reasoning. Children of around 4 years of age pass standard first-order false belief tasks, but only two years later will they pass a second-order false belief task (see Wimmer and Perner 1983, and follow-ups). Reasoning about other people’s minds takes time to develop, be that because the conceptual skills to do so need to be acquired, or because higher-order TOM reasoning is indeed a resource-intensive operation. In the IBR model sophisticated reasoners not only ascribe a belief (about beliefs about beliefs . . . ) to their opponents, but also compute their strategies, i.e., form conjectures about rational or optimized behavior. This may add to the complexity of the process and may cause further delays in the acquisition of pragmatic reasoning capabilities. Consequently, it is natural to hypothesize that most young children of age
4.4. Scalar Implicatures in Language Acquisition

4.5 are level-1 reasoners —without necessarily knowing, introspectively, that they are, of course— and that only later they will develop into higher level language users.

Interestingly, both level-1 senders and level-1 receivers already display what I have called scalar implicature behavior, but this behavior is not yet supported by a fully self-enforcing set of beliefs. Here is the situation in some more detail. In our standard model for scalar reasoning spelled out in section 2.2.2, a level-1 sender will use $m_{\text{some}}$ only in state $t_{\exists \neg \forall}$. Nonetheless, $S_1$ believes that her opponent $R_0$ does not interpret $m_{\text{some}}$, we could say, with a scalar implicature. A level-1 sender thus shows scalar implicature behavior without necessarily having scalar implicature beliefs. We could therefore say that $S_1$ shows scalar implicature behavior without having fully conceptualized it, since she does not expect her opponent to show scalar implicature behavior. Similarly, a level-1 receiver will choose $a_{\exists \neg \forall}$ in response to message $m_{\text{some}}$, without actually believing that $m_{\text{some}}$ is sent only in $t_{\exists \neg \forall}$. Again, $R_1$ shows scalar implicature behavior even without scalar implicature beliefs, i.e., without the belief that his opponent does so too. That suggests that even level-1 reasoners will give pragmatic responses in action-based, production and picture-matching tasks, because all of these tasks really take the form of a simple signaling game for scalar implicature in which the subjects either take the role of the sender or the receiver.

What about the judgement task then? I would like to suggest that scalar implicature behavior alone, be that comprehension or production competence, is not sufficient for a pragmatic response in the critical condition in a judgement task. What seems minimally necessary for a pragmatic response in a judgement task is that subjects can judge other people’s linguistic behavior based on —but crucially on top of— their own pragmatic competence: what is needed is that scalar implicature behavior is also supported by a belief that the opponent shows scalar implicature behavior. In the IRB model this requires at least a sophistication level 2.\textsuperscript{18}

\textsuperscript{18} On a speculative note, moreover, it seems that for a fully developed normative stance towards the proper pragmatic use of expressions, even more than sophistication level 2 seems necessary. To be able to say that some expression should be used or interpreted in such and such a way requires one’s conjectures about general use and interpretation to be in equilibrium, so to speak: it’s how we should do it because it’s common expectation that we do so. In other words, it seems that for full normative understanding of pragmatic use, reasoners must have transcended the IRB sequence. — The relation between norms, conventions and mutual or common expectations, however, is a spicy philosophical issue that I will not go into here. And, of course, this is also not needed to account for the acquisition data.
That means that an IBR model of pragmatic reasoning implements the conceptualization hypothesis, making it more precise. This way, the IBR model explains the observed data. It explains why young children show scalar implicature behavior in a simple task testing on proper production and comprehension, and it also explains what exactly is more difficult about a judgement task: a pragmatic response in a judgement task requires higher levels of sophistication in pragmatic reasoning than either the production, the action-based or the picture-matching task.

This is also exactly the reason why the IBR model seems a better formal model to back up and spell out the conceptualization hypothesis than biot. If the conceptualization hypothesis is correct, we want differently sophisticated pragmatic competencies to be concisely represented in the model. But, as section 4.3 showed, biot’s conceptually somewhat underspecified notions do not live up to this challenge. This is a problem, of course, only to the extent that the conceptualization hypothesis stands to further empirical scrutiny. It is thus up to empirical testing to decide between the pragmatic tolerance hypothesis, the conceptualization hypothesis —if these are perceived as mutually exclusive— or any other conceivable interpretation of the rather intricate acquisition data.