Communicative and Cognitive Pressures in Semantic Alignment

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Abstract

Descriptions used by participants in conversation tend to be progressively systematized. A paradigmatic example of this phenomenon is the global shift from concrete to abstract descriptions observed in Maze Task dialogues. We propose to explain this trend by the appeal to communicative and cognitive pressures exerted on participants during conversation. We conclude that models of meaning coordination in dialogue should incorporate communicative and cognitive biases towards expressiveness and ease of processing.

1 Introduction

One of the most robust findings in experimental psychology of dialogue is that participants tend to spontaneously systematize their means of referring in task-oriented conversation. Since the seminal maze task experiment by Garrod and Anderson (1987), the evidence for this has been ubiquitous (Garrod and Doherty, 1994; Healey, 1997; Healey and Mills, 2006; Mills and Healey, 2006; Healey, 2008). Despite several empirically motivated approaches to modelling meaning coordination in dialogue (Garrod and Anderson, 1987; Garrod and Doherty, 1994; Pickering and Garrod, 2004b; Healey, 1996; Healey, 2008), the acclaimed global trend of conceptual and semantic change has remained largely unexplained.

The maze task involves two participants, connected by a two-way audio link and seated in separate rooms in front of a computer displaying a two-dimensional maze. Each player is supposed to reach a target node by moving his position marker through the maze. None of the players can see the position nor the target of the other participant. Crucial paths are blocked by gates which can be opened by stepping onto switch nodes but this can only happen by guiding one's partner and making him step onto the switch he cannot see. Thus, participants are faced with the recurrent coordination problem of developing and sustaining a system of descriptions to refer to maze locations.

Figural: refers to salient features of the maze

"the l-shape sticking out at the top"

"the uppermost box"

Path: refers to a route from one node to another

"Go 2 up, 1 down, 2 along, 5 up"

"up, right, down, up"

Line: refers to nodes treated as intersects of horizontal and vertical vectors

"3rd row, 5th box", "4th column, 2nd square"

"The third row, fifth to the left"

Matrix: coordinate-system

"4,2", "A,1"

Figure 1: Description types used in Maze Task experiments.

Garrod and Anderson (1987) classify descriptions used by participants in maze task experiments into four types (see Figure 1). It has been repeatedly observed that description types used most frequently initially tend to be abandoned later on in favour of new, previously less frequent forms (Garrod and Anderson, 1987; Garrod and Doherty, 1994). Crucially, descriptions used in Maze Task experiments tend to migrate across trials from more "concrete" (Figural and Path) to more "abstract" (Line and Matrix). As reported by Mills and Healey (2008), a typical shift is exemplified by the excerpt of dialogue presented in Table 1. Still though, participants occasion-

0 mins:	The piece of the maze sticking out
2 mins:	The left hand corner of the maze
5 mins:	The northenmost box
10 mins:	Leftmost square of the row on top
15 mins:	3rd column middle square
20 mins:	3rd column 1st square
25 mins:	6th row longest column
30 mins:	6th row 1st column
40 mins:	6 r, 1 c
45 mins:	6,1

Table 1: Semantic shift from Figural/Path to Line/Matrix descriptions in Maze Task dialogues.

ally change descriptions to more "concrete", especially when they encounter problematic dialogue (Healey, 1996; Healey and Mills, 2006; Mills and Healey, 2006).

The question is why the migration pattern looks as in Figure 1? Crucially, the pattern cannot be seen as a simple contraction of form as different description schemes seem to rely on incompatible situation models (Garrod and Anderson, 1987). The drift of description types is thus better seen as a directional conceptual and semantic change.

The migration pattern is also difficult to reconcile with existing models of semantic alignment in dialogue. For example, the input-output coordination model by Garrod and Anderson (1987) and the interactive alignment model by Pickering and Garrod (2004b) are based on a tacit priming mechanism and as such are claimed too conservative to account for innovative changes in description schemes (Garrod, 1999; Healey, 2004; Pickering and Garrod, 2004a; Mills and Healey, 2006). The repair-driven account by Healey (1997; 2006; 2008) sketches how alignment might proceed through local resolution of problematic understanding but does not explain why meanings tend to migrate the way they actually do.

What we propose is to account for the directional drift of description types by the appeal to communicative and cognitive pressures acting on interlocutors during alignment in dialogue.

2 Expressiveness and Ease of Processing

The idea that certain features of natural language stem from the pressures imposed on subjects during language learning and use has been explored in linguistics successfully on many levels. Perhaps one of the earliest such theories explains the inverse relationship between frequency and length of words by the appeal to competing motivations of speaker and hearer (Zipf, 1949). According to a more recent theory, language structure is, to a large extent, an adaptation of language itself to multiple constraints imposed during learning and use (Christiansen and Chater, 2008). For example, it has been argued that compositionality arises from the trade-off between pressures for compressibility and expressivity (Kirby et al., 2015).

If we want to explain the migration pattern in terms of pressures acting on discussants, the putative pressures should fit the timescale of a conversation. In our explanation we refer to two generic pressures which are equally applicable to dialogue situations: expressivity and ease of processing.

The pressure for expressiveness plays an important role in the maze task. Due to the novelty of the task, participants start with a little common ground and possibly few semantic precedents. To accomplish the game, they need to develop linguistic means to refer to relevant maze locations. In principle, a salient maze location could be any location in the maze whatsoever. Thus, the nature of the task imposes pressure for expressiveness on language being used and developed by participants in dialogue. We envisage a fully functional language as allowing for information exchange about arbitrary locations.

Ease of processing is another important factor which is likely to affect descriptions developed by participants. There are at least two levels at which this pressure applies. First, speaker may tend to use shorter descriptions in order to reduce his effort (Zipf, 1949). This tendency partially explains shortening of descriptions (see Table 1). Second, ease of processing is tightly coupled with deeper levels of production and comprehension. On the cognitive side, descriptions are associated with procedures which are intermediaries between formal and semantic levels of representation (Tichý, 1969; Suppes, 1980). For example "xth row, yth box" may be coupled with a particular procedure which, given a relevant situational model of the maze, and the location intended by the speaker, computes n (say, by counting rows from the bottom) and m (say, by counting boxes from the right) which are then plugged into the description form. If situational model and semantic representations are sufficiently aligned between participants (Pickering and Garrod, 2004b), the hearer's interpretation boils down to almost the same procedure: counting n rows from the bottom, m boxes from the right and thus getting the intended location right.

When thinking about semantic representations in terms of procedures, it is natural to ask about complexity of corresponding problems (functions from inputs to outputs) and linking relevant complexity measures with cognitive reality (see, e.g., Szymanik (2016)). It is also natural to expect that greater complexity of a procedure may provide a pressure for finding more efficient solutions. For example, Schlotterbeck and Bott (2013) have shown that intractable meanings tend to be avoided by human participants in verification of sentences having both tractable and intractable interpretations. It seems, however, that the pressure for ease of processing may be equally important in selecting between feasible interpretations, which are nevertheless distinguished by different complexity characteristics. We return to this in Section 5.

3 Amount of Ambiguity vs Alignment

Participants in maze task dialogues are often misaligned at the level of semantic representation and situation model. Let us define the concept of semantic misalignment in terms of procedures which participants associate with descriptions. We say that the meaning of a given description form (say, "xth row, yth column") is misaligned between participants if the procedures they associate with the description form are not extensionally equivalent. What it means is that for some instances of the description, participants' procedures fail to give the same output.

Consider a Matrix description "4,3" as an example. There are several natural algorithms matching this type of input. The input itself does not specify which coordinates correspond to horizontal and vertical vectors. Moreover, the description does not hint about counting procedure—should one start from the top or from the bottom? From left or from right? Taking into account only this sort of underspecification, we get eight extensionally non-equivalent procedures.

As for Line descriptions like "5th row, 3rd column", underspecification is less severe. Provided that "row" designates horizontal vectors, the association between coordinates and horizontal/vertical vectors is fixed and thus one degree of freedom disappears which reduces ambiguity twice (procedures not conforming to the coordinate-dimension convention are discarded). Moreover, some description forms which are classified as Line descriptions ("The third row, fifth to the left") are even less ambiguous.

Path descriptions can still manifest some amount of ambiguity. Perhaps the most precise way of tracing the route along connected nodes is by means of descriptions like "up, right, down" etc. This way we are able to trace the path to the destination node unambiguously. However, using "2 along" or even "2 up" is potentially ambiguous as it is not specified whether one should start counting from the current position (Pickering and Garrod, 2004b). Hence, certain Path descriptions seem to manifest similar amount of ambiguity as Line descriptions.

Figural descriptions pick out easily identifiable features of the maze and seem least ambiguous ("the northenmost box"). Obviously, figural descriptions sometimes fail to denote precisely one box like in "the l-shape sticking out at the top". However, they allow participants to focus on particular, easily identifiable portions of the maze without the risk of misunderstanding.

An important link between ambiguity and semantic coordination is that greater ambiguity hinders alignment. Based on the foregoing considerations, the order of migration pattern (Figural/Path $\rightarrow$ Line/Matrix) respects the increasing order of ambiguity and, hence, of alignment complexity. This view is strengthened by the fact that meanings usually associated with each type of description are equally expressive and complex (see Sections 4, 5) which makes them roughly equally likely to be selected during alignment.

4 Expressiveness

Figural descriptions are least expressive. Certain boxes are easily describable ("the leftmost box of the row on top") while others are not identifiable by any simple figural description, especially if the maze does not contain easily distinguishable parts. On the other hand, there are maze configurations which are particularly likely to invoke Figural descriptions (Garrod and Anderson, 1987).

Path descriptions are more expressive than Figural—in principle, one can trace a route along interconnected nodes to any location reachable from a given starting point. Thus, alignment on Path description is sufficient to solve the entire maze and is strictly favoured by the pressure for expressiveness. Moreover, even if interlocutors are not aligned on Path descriptions, using them seems to be a safer strategy as it gives participants more control over the location of their partner.

Line and Matrix descriptions are most expressive. They allow to identify any node in the maze whatsoever. Hence, alignment on Line or Matrix description is also sufficient for solving the maze. However, acting according to misaligned Line or Matrix descriptions can lead to serious troubles as non-equivalent procedures of this sort fail to produce the same outputs for most inputs and—moreover—output boxes generated by such procedures may be distant from each other in the maze.

5 Complexity

By inspecting Table 1, we see that the longer the description, the earlier its place in the migration ordering. Hence, descriptions which come out as earlier in this ordering are associated with greater effort on the part of the speaker. Note, however, that Path descriptions make this picture somewhat more complicated as their lengths may vary considerably depending on the length of the denoted path. Indeed, Path descriptions of short routes can be more concise than Line and Matrix descriptions ("up, right") whereas Path descriptions of long routes can easily surpass the length of long Figural descriptions. Consequently, a Path description may be preferred or dispreferred, depending on its actual length, accordingly.

We now turn to the complexity measure associated with procedures. First, observe that Path descriptions correspond to quite a different task than Line and Matrix descriptions. In abstracto, the underlying problem is that of finding a route connecting two nodes of the graph. Obviously, participants cannot bypass this sort of problem as this is actually what they are required to do: solve the maze by going from their positions to other dedicated positions. However, this sort of task is more difficult than simply computing the position of a given node which always requires at most linear time with respect to n, where, conceptually, the maze is arranged on n horizontal/vertical lines of length n or $n \times n$ matrix. Finding a path between two nodes may require non-linear time; for example, inspecting half of the nodes of the maze, which amounts to roughly $n^2/2$ steps. Note, however, that the actual influence of this factor depends on the size of the maze and, presumably, on its structure as well.

6 Explaining the Migration Pattern

Abandoning Figural descriptions seems to be explained by the pressure for expressiveness. As already noted, crucial parts of the maze may be difficult to pinpoint using mere Figural descriptions.

Migration from Path to Line (or Matrix) seems to be driven by cognitive pressures exerted on the speaker. Line or Matrix descriptions are shorter and the associated procedures are less complex. By abandoning Path descriptions, the effort of production is greatly reduced and the cost of computing the path is delegated to the hearer. Moreover, using Path descriptions may take longer on average. Hence, steering away from them may reduce the joint effort of participants (Clark and Wilkes-Gibbs, 1986).

Finally, the advantage of Matrix over Line forms seems to be associated solely with their lengths as computational complexity of Line and Matrix procedures is the same.

As we have observed, Matrix descriptions seem to be highly ambiguous. Line descriptions are less ambiguous but can still be quite problematic. This ambiguity and its potential for causing misalignment is perhaps the main reason for not using Line or Matrix descriptions consistently right from the start. This means that language users may resolve to less ambiguous (Figural) or less ambiguous/more safe (Path) strategies. Nonetheless, due to the presence of cognitive and communicative pressures we should expect that participants will tend to align on short forms associated with computationally efficient procedures.

7 Conclusions

We have proposed to explain the migration pattern observed in dialogues from Maze Task experiments by the appeal to communicative and cognitive pressures exerted on participants during conversation. Considering the effort associated with production of descriptions and computation of referential information by means of procedures seems to be an important aspect that should be taken into account when developing models of alignment in dialogue.

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