Conversation, cognition and cultural evolution: a model of the cultural evolution of word order through pressures imposed from turn taking in conversation

Seán G. Roberts[1,2] and Stephen C. Levinson[2,3]

1. Department of Archaeology and Anthropology, University of Bristol, 43 Woodland Road, BS8 1UU Bristol, United Kingdom

2. Language and Cognition Department, Max Planck Institute for Psycholinguistics, Wundtlaan 1, 6525 XD Nijmegen, The Netherlands

3. Donders Institute for Brain, Cognition and Behaviour, Radboud University, Kapittelweg 29, 6525 EN Nijmegen, The Netherlands

sean.roberts@mpi.nl, stephen.levinson@mpi.nl

Abstract

This paper outlines a first attempt to model the special constraints that arise in language processing in conversation, and to explore the implications such functional considerations may have on language typology and language change. In particular, we focus on processing pressures imposed by conversational turn-taking and their consequences for the cultural evolution of the structural properties of language. We present an agent-based model of cultural evolution where agents take turns at talk in conversation. When the start of planning for the next turn is constrained by the position of the verb, the stable distribution of dominant word orders across languages evolves to match the actual distribution reasonably well. We suggest that the interface of cognition and interaction should be a more central part of the story of language evolution.

Bio
Seán G. Roberts studies cultural evolution at the University of Bristol as part of the group *Exploring the evolution of cultural diversity*. He is interested in whether differences between languages are the product of adaptation.
Stephen C. Levinson is the director of the Language and Cognition group at the Max Planck Institute for Psycholinguistics. His work focusses on language diversity and its implications for theories of human cognition. He uses methods ranging from fieldwork and conversation analysis to neuroimaging studies to explore the role that language plays in our everyday cognition.

1 Introduction

The evolution of linguistic structure is constrained by various cognitive pressures. For example, studies have argued that basic word order (the dominant order of Subject, Verb and Object in a transitive clause) is adapted to pressures including: efficient storage or processing (e.g. Krupa, 1982; Hawkins, 1994; Ferrer-i-Cancho, 2008; Ferrer-i-Cancho, 2015); the effectiveness of conveying semantic information (e.g. Goldin-Meadow et al., 2008; Schouwstra and de Swart, 2014; Gibson et al., 2013); semantic and syntactic restrictions (e.g. Tomlin, 1986; Christensen, Fusaroli & Tylén, 2016); acquisition (Lupyan & Christiansen, 2002); and information structure (e.g. Mithun, 1992).

While these effects are no doubt part of the story, we suggest that the greatest functional pressures on language structure are likely to come from the very special circumstances in which it is primarily used. That special niche is conversation, or more generally, face to face interaction. This is where language is learnt, and most heavily deployed: we each produce something like 15,000+ words a day in some 1200 turns at talk (Levinson 2006, 2016). Therefore, understanding the constraints and affordances of conversation is crucial for understanding the selective pressures on language use (see also Givòn, 1983a; Ochs, Schegloff, & Thompson, 1996). As Schegloff, one of the founders of the field of Conversation Analysis, put it:

"What is the primordial natural environment of language use, within which the shape of linguistic structures such as grammar, have been shaped? Transparently, the natural environment of language is talk-in-interaction, and originally ordinary conversation. The natural home environment of clauses and sentences is turns-at-talk. Must we not understand the structures of grammar to be in some important respects adaptations to the turn-at-talk in a conversational turn-taking system with its interactional contingencies?" (Schegloff, 1989, p. 143-144)

As we will explain below, the interactional uses of language are cognitively intensive, due to the high speed of the expected response being right at the limits of human performance (see below and Levinson, 2016). The demands of interactive conversation should therefore impose selective pressures on linguistic structures. If there is variation

65 in how effective different structures are in conversation, and if more effective structures

66 are more likely to 'replicate' and be used again, then this suggests that such structures

67 should be under selection over time by the forces of cultural evolution (Croft, 2000).

68 In other words, languages should change over time to better serve turn taking.

69 An example of this process links constraints from pragmatics to predictions about

70 typology. Thompson (1998) points out that interrogative structures make turn transition

71 relevant: a question demands an answer. Thompson argues that, in order to be effective,

72 interrogatives should generally apply to prosodic units, and therefore appear at turn

73 boundaries, rather than in the middle of turns. If interrogatives are morphologically

74 bound to the verb, this constraint leads to a specific prediction: languages that place the

75 verb at the end of a sentence should have interrogative suffixes (so that the interrogative

76 appears after the verb at the boundary), while languages with verbs at the beginning

77 should have prefixes (see supporting materials for an updated statistical test of this

78 claim). This is a well-known pattern in typology, but we suggest that part of the

79 pressure that leads to the emergence of this pattern could be motivated by the pragmatic

80 – and more specifically interactional - pressures on structures of this kind.

81 In this article, we consider a specific aspect of conversation - turn taking - and how the

82 tight processing constraints it entails may lead to the selection of specific grammatical

83 structures within a cultural evolution framework. While the work is preliminary, we

84 hope to demonstrate the possibility and promise of linking domains that are not usually

85 considered together: language structure, conversation, cognition and cultural evolution.

86 The paper is organized as follows. First, we review the literature on turn taking and

87 how it links to processing in conversation. Section 2 includes a brief review of the

88 literature on the typological distribution of word orders. Section 3 outlines a

89 computational model of the cultural evolution of word order under pressures from turn

90 taking. Section 4 shows the results of the model and section 5 discusses them. We

91 leave the relationship between our approach and others until the end when our position

92 is clearer.

93 **1.1 A cognitive pressure derived from turn taking**

94   In a conversation, speakers take turns at talking and try to minimise the amount of gap
95   or overlap between the turns (Sacks et al., 1974). When talking in groups, there is
96   competition for who speaks next (Levinson, 1983), and a delay in response is
97   pragmatically marked, for instance, it can be interpreted as unwillingness (Kendrick and
98   Torreira, 2015; Bögels, Kendrick & Levinson, 2015; Roberts, Margutti & Takano,
99   2011). This puts speakers under pressure to respond quickly in conversation.

100   Indeed, the average gap between questions and answers is around 200ms (Stivers et al.,
101   2009). What makes this surprising is that the time to plan and begin executing a *single*
102   *word* is at least 600ms (Indefrey, 2011). Even though speech planning is incremental
103   (speech may start before the whole sentence is planned, Levelt, Roelofs & Meyer,
104   1999), this implies that at some point we must be predicting the course of the incoming
105   turn, extracting its action or speech act, and preparing our response in advance of the
106   other speaker coming to a conclusion (Levinson, 2016). This imposes a kind of 'crunch
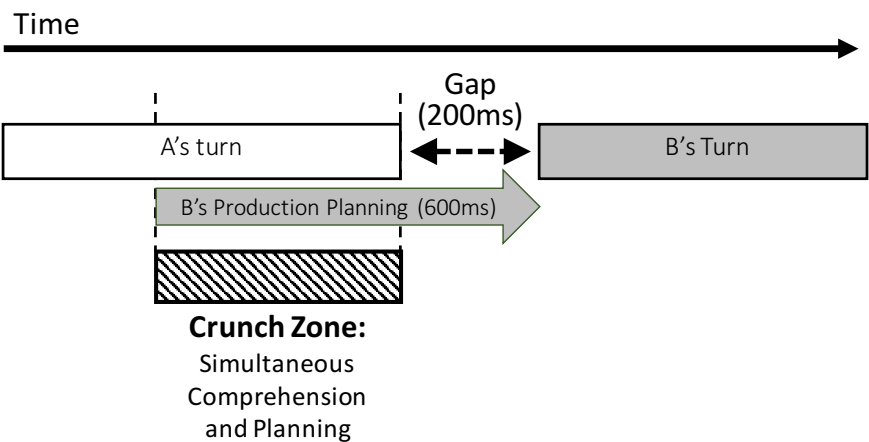107   zone' in which production and comprehension must overlap in time (see figure 1).

108

109   **Figure 1: A schematic representation of turn taking.**

110   This is a highly demanding ecology for rapid language use. The timing is remarkable –
111   even in a non-linguistic context, 200ms is the normal minimum reaction time for a pre-
112   prepared single response choice, and response times increase logarithmically in relation
113   to the number of choice that have to be made ('Hick's Law', Hick, 1952, discovered
114   first by Donders, 1868). Language speakers have vocabularies of 30,000 or more from
115   which to begin a response.

This ecology puts a premium on speed for the most complex human skill, language. For example, if a recipient finds the incoming turn at talk unintelligible or hard to comprehend, he or she should respond with a request for repair (e.g. *"Huh?", "Who?", "Did I buy what?"*) before someone else continues because repair is hard to achieve beyond the immediate locale in which it occurs – it is only slightly delayed to allow the speaker to do self-repair (Schegloff, Jefferson & Sacks, 1977; Kendrick, 2015). The repair system has adapted to this niche by an ordered preference for repair: self-repair is preferred over other-initiated repair, and specific repair initiators (*Who?; Which bottle?*) over general ones (*Huh?*, see also Dingemanse et al., 2015*)*, thus expediting repair.

We suspect that there are a large variety of adaptations to this niche in the interactive system itself (as just illustrated), but also in language structure, and indeed the cognitive skills that make it all possible. But here we focus on basic word order as an illustration of how language structures might adapt to the constraints of turn taking.

1.2 Linking processing and pragmatics

We could go further in linking pragmatics and typology by integrating constraints from online processing of interactive language use into a model of the cultural evolution of language. We argue that languages do not adapt just to our individual cognition (cf. Christiansen & Chater, 2008), but to the way we actually deploy the cognition in interaction. It is not only the evanescent speech signal, but also the temporal pace of conversation that makes the cognitive pressures on normal language use so intensive. Therefore, one would expect the structure of language to adapt to this ecology, and we should be able to see signs of these adaptations in today's languages. For example, one possible locus of adaptation would be the order that information is presented in a turn. Information presented to a listener later is more likely to occur inside the crunch zone, and therefore present a greater challenge to producing the next turn on time.

Let us consider the implications for basic word order - that is, the order of the subject, object and verb in a canonical transitive clause. Through its lexically-specified argument structure, the verb provides the syntactic frame for a sentence and provides crucial semantic information about the action reported. Hence its position in the sentence might adapt to several processing pressures (see the final section for a

146 discussion of this assumption). Predictions here are complicated by the fact that the
147 functional adaptation of a sentence structure to its interactive use must be viewed from
148 two perspectives: the point of view of the speaker, and the point of view of the recipient
149 or comprehender. As has been noted in previous pragmatic work, what is good for the
150 speaker may be bad for the recipient, and vice versa (e.g. Hawkins, 2004; Langus &
151 Nespor, 2010; Jaeger, 2010; Piantadosi & Gibson, 2011; Fedzechkina, Jaeger &
152 Newport, 2012; Ferrer-i-Cancho, 2014;). Consider, for example, the structure of the
153 lexicon: making many semantic distinctions may be helpful for the recipient trying to
154 recover the speaker's intended referent, but force the speaker to make careful choices
155 between many alternatives (Zipf, 1949; Horn, 1984). In a similar way, verbs in final
156 position may give speakers more time to plan the most complex component of the turn.
157 On the other hand, verbs in initial position allow listeners to anticipate the unfolding of
158 the incoming turn, using the predictive possibilities offered by the verb's argument
159 structure, and thus start planning their own response much earlier. Here there is again a
160 zero-sum type of situation: what is good for the speaker (verbs at the end) is bad for the
161 recipient, and what is good for the recipient (verbs at the beginning) is bad for the
162 speaker (who must plan the whole sentence up front).

163 Notice that a mixed strategy will not help: if I put my verb at the end, it falls in your
164 'crunch zone', and it will be therefore especially difficult for you to put your verb at the
165 beginning – you will not have had time to formulate the response. However, if you put
166 your verb at the end too, then you will have most of the duration of the turn to plan the
167 verb, the complex frame for the sentence (Figure 2). Alternatively, suppose I am
168 considerate to you the recipient, then I could begin my turn with a verb, well clear of
169 your crunch zone, and now aided by my co-operative gesture and the following more
170 predictable components of the turn you will have time to compose your verb also in
171 initial position, so returning the favour (see Figure 2). Both strategies will get the
172 maximal distance between predicates, which is what will aid processing. Thus we
173 conclude that *coordination* of verb-placement, either at the end or at the beginning, is
174 strongly favoured by processing under rapid turn-taking. Even in languages with
175 flexible word order, we suspect that there are biases towards a particular word order in
176 everyday conversation (e.g. Samoan, Duranti, 1981, p. 171; Ochs, 1982, p. 661, see
177 discussion).

178 Note however that the co-operative verb-initial solution is vulnerable, like all co-
179 operation, to a selfish move: you could always suit yourself and return a verb-final turn.
180 These considerations suggest that while both solutions are viable, the verb-final solution
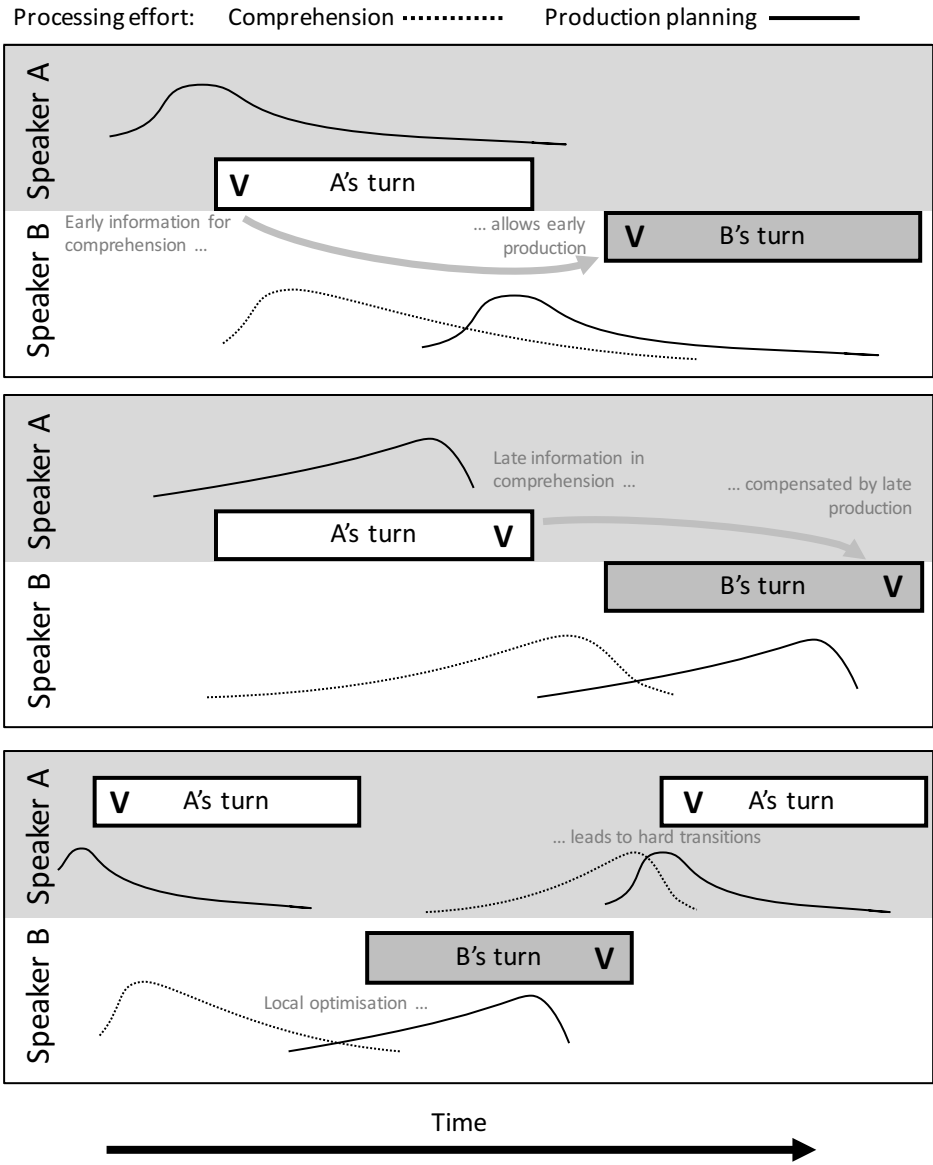181 might predominate in cultural evolution.

182

183

184 Figure 2: A schematic representation of the timeline of turn taking and the processing
185 effort for comprehension and production. Speaker A and B take turns at speaking,
186 placing the crucial information – the verb – at different points in the turn. Curves show
187 the processing effort for comprehending their interlocutor's turn and planning their own

turn. Top: Verb-initial order provides information for the listener early in the sentence, allowing them to begin planning earlier. Middle: Verb final order provides information late, meaning that planning must start later, but this can be compensated by leaving the planning of the production of the verb until later. Bottom: Speakers could maximize the distance between verbs locally, optimizing the spread of processing that B has to do. However, this leads to a difficult subsequent transition for A, who has simultaneous high comprehension costs and high production planning costs.

196   Another solution might be to put the crucial verbal or predicate information in the
197   middle of the utterance. This balances the distance from the crunch point for both
198   comprehension and planning. This has the added bonus of preserving crucial
199   information from overlap – the tendency for a small percentage of turns to be just
200   slightly mistimed, with a second speaker coming in a bit early. This looks like a good
201   compromise solution, again keeping maximal distance between successive predicates.
202   In all cases, we see that the structure of A's turn has a knock-on effect on B's turn
203   structure. Any strategy can facilitate turn taking, as long as everyone is using the same
204   strategy.

205   We should note here that these considerations obviously oversimplify conversational
206   exchanges which are often elliptical, but the point is that where full clauses are
207   involved, they should be subject to constraints of this kind. These could – indeed should
208   – have implications for how languages change over historical time, that is the cultural
209   evolution of linguistic structure. We would predict that a language would be more likely
210   to change to facilitate better turn taking than in the opposite direction. This suggests that
211   the proportion of languages that facilitate turn taking (e.g. by having fixed word orders
212   ensuring coordination) should increase over time, while the proportion of languages that
213   make turn taking less efficient should decrease[1].

214   This can be tested in the following way. First, we identify a constraint that turn taking
215   makes on a particular linguistic structure. That should lead to some predictions about
216   the distribution of that structure we should see in the world's languages. We can then

---

[1] One might wonder, assuming that the pressures from turn-taking were present at very early stages of language emergence (Levinson, 2006), why structures that go against this pressure would emerge at all. There are three responses to this. First, we assume that the pressure is weak bias rather than an absolute condition. Communicating in a variety of ways can be successful enough for everyday needs. Secondly, the pressure from turn taking comes from the interaction between two individuals, and may go against the selfish biases of individuals. At early stages, Individuals may be unlikely to innovate a solution that fits turn taking. Over time, however, the turn taking pressure may override the individual biases. This means that we assume random innovation and guided selection. There is some evidence for this in studies of iconicity in the lexicon, which may emerge over time and through interaction, rather than being present at the beginning (e.g. Verhoef et al., 2015; Blasi et al., 2016). Finally, change is probabilistic rather than strictly directional. Adapting to turn taking has many solutions and interacts with pressures from other domains. Because a language changes piece by piece rather than by wholescale renovation, it is not guaranteed to reach an optimal turn-taking solution quickly, nor to remain there if it does reach it. However, modelling the interaction between turn taking and other processes such as grammaticalisation or contact is beyond the scope of the current model. Here, we ask simply how turn taking might influence the way that a conventional word order arises in a population.

217   test whether the prediction can be observed in real data.

218   However, this involves two challenges. First, the precise interactions between
219   conversation, cognition and cultural evolution are not easy to predict, since they form a
220   complex system. In order to generate predictions, we implement a simple agent-based
221   model of turn taking. Computational agents are simple computer programs whose
222   behaviour we can specify. By placing many agents together in a model, we can see how
223   they interact. In other words, the model helps us to generate predictions from our
224   assumptions. In the sections below, we define and explore such an agent based model
225   of cultural evolution through conversation.

226   The second challenge is testing whether the predictions from the model fit data in the
227   real world. This is also not straightforward because the actual distribution of linguistic
228   structures in the world are complicated by historical factors (for example, the colonizing
229   success of particular social groups). In the next section, we explain this further and
230   estimate the target phenomena which should emerge in the model.

231   **2 Identifying the target phenomenon**

232   We would like to account for two basic phenomena in word order patterns. First, for the
233   vast majority of language communities, speakers use the same basic word order for
234   expressing the same kinds of meanings. There is certainly optionality within languages,
235   and individual variation. For the most part, however, speakers do not use completely
236   random word orders. Dryer (2013a) notes that under 14% of languages can be said to
237   have no dominant word order, but we speculate that in conversation these too will
238   mostly have a statistically dominant pattern. That is, basic word order is nearly always
239   coordinated within a language community.

240   The second phenomenon is that some basic word orders are more frequent than others.
241   For example, if we count the raw number of basic word orders, then the pattern we see
242   is that SOV and SVO are more frequent that VSO order. However, this does not take
243   into account the historical relations between languages. For example, many Celtic
244   languages are VSO, just as nearly all Dravidian languages are SOV, but the Celtic
245   languages are all related historically, so it would bias the sample to count each as an

246   independent data point (see Roberts and Winters, 2013; Dunn et al., 2011).

247   In this study we will use Harald Hammarstrom's estimation of word order types in
248   language isolates, that is, languages that are not known to be historically related to any
249   others, and thus approximate to fully independent data points.[2] This also happens to be
250   close to other estimates based on using non-isolates and controlling for historical
251   relations. This turns out to be 11% VSO, 16% SVO, 66% SOV and other orders account
252   for 7%. That is, the further from the start of the sentence the verb is, the more frequent
253   that word order type turns out to be (note some other approaches use number of
254   speakers, e.g. Bentz & Christiansen, 2010, but we are more concerned with the number
255   of communities). The majority of the world's languages place the subject before the
256   object in canonical transitive sentences, so we focus on those, but the model below does
257   not actually distinguish between subjects and objects - only the position of the verb is
258   important in the models below.

259   In later sections, we also look at the interaction between basic word order and other
260   typological variables. In this case, we use data from the World Atlas of Language
261   Structures (Haspelmath et al., 2008) in a mixed effects model. We use this to estimate
262   the relationship between basic word order and other typological features while taking
263   into account historical relations. See the supporting information for details and results.

264

---

[2] This is an approximation because with further study some isolates may prove to be actually distantly
related to known languages families, and indeed ultimately, all languages may be historically related.
What is likely though is that isolates have gone their separate ways in cultural evolution over millennia.

3 A computational agent based model of turn taking

266   We model a conversation as an interaction between two computational agents A and B.
267   Agent A produces a turn at talk which consists of three abstract elements - a verb, a
268   subject and an object. There are three turn types of word order in the model - VSO,
269   SVO and SOV. The agents do not understand these elements, and there is no meaning
270   associated with the elements – the model simply captures the idea that in each turn there
271   is some linear order, with some elements (e.g. the verb) being more crucial than others.

272   Each agent has an exemplar memory which stores all the turns it has heard. When
273   agents produce a turn at talk, they select one turn from their memory at random to be
274   the template for their utterance.

275   Once A has produced a turn, agent B now has to decide how to respond by choosing a
276   template turn from its own memory. However, we constrain the probability of choosing
277   different turn types according to the distance between the verbs in the sequence. For
278   example, if A produces a VSO turn, then B has more time to process this information
279   and so is more likely to be able to produce a verb at the start of their turn. If A produces
280   an SVO turn, then this verb is closer to the crunch zone and B is less able to produce a
281   verb-initial turn. If A produces an SOV turn, then the verb is in the crunch zone and so
282   B is very unlikely to be able to produce a verb-initial sentence in time, and quite
283   unlikely to be able to produce a verb-medial sentence in time.

284   To model this, each item in the agent's memory is given a weight which affects its
285   probability of being chosen. If A produces a turn T1 which has the verb at position
286   $V_{initiate}$ (start = 0, middle = 1, end = 2) and a length L_1 (at this stage, all turns have a
287   length of 3), then a responding turn by B, T2, which has the verb at position $V_{respond}$ is
288   given the following weight,

289   $$W_{T2} = ((L_1 - V_{initiate}) + V_{respond})^{\alpha}$$

290   where α is a parameter which controls the strength of the effect. When $\alpha = 1$, then the
291   weight increases linearly as the distance between the two verbs increases. The
292   probability of choosing item i from a memory which contains M items is then directly
293   proportional to its weight.

$$P_i = \frac{W_i}{\sum_{x=1}^{M} W_x}$$

294

295 Put another way, agents are less likely to choose turn structures which involve more
296 verb processing in the crunch zone. The α parameter, then, controls how quickly the
297 processing cost increases with time. This mechanism captures the basic idea that the
298 location of crucial information in A's utterance has a knock-on effect for the structure
299 of B's turn. The constraint on B's choices are greatest when A produces a turn with the
300 verb at the end.

301 Conversations proceed in the following way. A produces a first turn by selecting
302 randomly from her memory. B then produces a turn, drawing from his memory
303 according to the weight function above. Then A produces a third turn, weighting her
304 selection by the turn type that B produced. Then B responds, and so on.

305 Conversations are independent from each other, and always start with an un-weighted
306 selection. Therefore, we can manipulate the strength of the effect from turn taking. For
307 example, agents can have one conversation of three turns, which imposes a constraint
308 after each turn, or three conversations of a single turn, in which case the turn taking
309 constraints have no effect. The greater the number of turns in a conversation, the greater
310 the knock-on effect of the crunch zone. In each generation (see below), agents will have
311 $N_{conversations}$ conversations with N_{turn} turns each.

312 We also model a small amount of noise in communication. With a small probability β,
313 an agent produces a random turn type from all possible turn types.

3.1 Cultural evolution

315 Now we need a model of cultural evolution. We start with a small population of N_{agents}
316 'adult' agents. Each agent is initialised with a random selection of turn types in their
317 memory. This means that populations are initialised with no bias in their word order
318 preferences (see the SI for different starting conditions). Each agent is randomly paired
319 with another agent and they have a conversation with N_{turn} turns. This repeats until they
320 have had $N_{conversation}$ conversations. This results in a series of turns and conversations,

321 and we can measure the frequency of each turn structure.

322 At the same time, there is a second population of 'child' agents listening to the
323 conversations of the adult population and 'learning' from them by adding their turn
324 structures to their exemplar memory. That is, generation 2 are like children acquiring
325 language. When the adult generation are done with their conversations, they are
326 removed from the population and the child generation 'grows up' and become adults.
327 This new generation starts having conversations in the same way as the first generation,
328 while a new child generation (generation 3) listen and learn (so called "iterated
329 learning", see Kirby, Griffiths & Smith, 2014).

330 This repeats for $N_{generations}$ generations. For each generation, we can track how the
331 proportions of each type of sentence change.

3.2 Sentence particles

333 We can expand the model again to explore more complicated interactions between
334 grammar and turn taking, for example the role of utterance final particles. Tanaka
335 (2000; 2005) notes that the grammar of Japanese limits the projectability of turns. The
336 predicate comes at the end of the sentence, and the sentence can be widely transformed
337 by elements that come after the predicate. This appears to work against rapid turn
338 taking. However, final particles can potentially act as a 'buffer' which push crucial
339 information away from the crunch zone and allow more time for the next speaker to
340 plan their turn (this insight from Kobin Kendrick, 2012, see figure 3). While sentence
341 final particles are usually quite short, we assume that any extra time is beneficial and
342 may lead to selection in the long term.

343 In the example of Japanese conversation in figure 4, we see that the sentence final
344 particle is appearing constantly in overlap. This suggests that they can be treated as non-
345 crucial elements of the turn (the overlap in the example can be partly attributed to the
346 general projectability of the sentence in which the two speakers are agreeing with each
347 other, but in general particles are not overlapped). A theory based on ease of production
348 or perception which does not consider relationships between turns would have a hard
349 time explaining why speakers bother to include these.

14

350 In this case, turn final particles seem to aid turn-transition in this verb-final language.
351 However, the general prediction about which word order would benefit from final or
352 initial particles is difficult to make. If a language is verb-initial, should sentence
353 particles come at the start of the turn, or the end of the previous turn? At the beginning
354 they would help to buffer the production by the speaker, while at the end they would
355 serve to buffer the next speaker's production problems. Both would be logically helpful,
356 but which are more likely to emerge? Are there some word orders which are less likely
357 to need particles at all? It is difficult to work out the logical implications in a cultural
358 evolutionary system, but this is precisely what the model is for. We can use it as a kind
359 of transparent thought experiment.

360 Sentence particles were included in the model as follows. As well as the three basic
361 word order types without particles, agents could also produce versions with a sentence
362 final or sentence initial particle (thus 9 combinations of types to choose from). Turn
363 types with particles were less likely to be picked for production, since they are slightly
364 longer (agents prefer to produce shorter turns). The relative length of particles to other
365 words (verb, subject and object) could be manipulated via a parameter p. From the
366 examples in Japanese, we would expect particles to be shorter than most words. The
367 inclusion of a particle which added distance between verbs in a turn boosted the
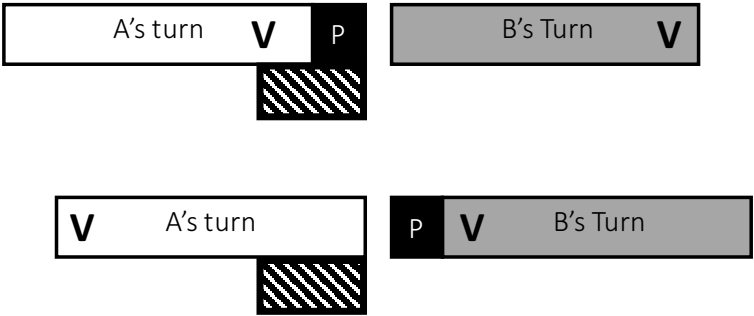368 possibility that the verb can come earlier in a following sentence.

370 **Figure 3: Sentence particles 'P' can act as a 'buffer' between turns, taking the**
371 **crucial information away from the crunch zone.**

372

```
W: 'N:  soo [ne
   yeah so  [FP
  "Yeah isn't it?"

G:          [Sore wa  aru   deshoo[: ne
            [that TOP exist COP   [  FP
            ["That's quite plausible, isn't it"

W:                               [Soo na n de[shoo ne
                                 [so COP N  C[OP   FP
                                 ["That's probably right, isn't it?"

G:                                         ['N ...
                                           [yeah ...
```

373

374 **Figure 4: A conversation in Japanese. Square brackets indicate where the next**
375 **speaker overlaps with the previous one. The utterance final particles are in bold.**
376 **Adapted from Tanaka (2000), Tokyo 7, p.26.**

377 **3.3 Summary of assumptions**

378 Here we summarise the basic assumptions and simplifications of the model:

379 • All turns contain verbs

380 • We do not model semantics or detailed syntax/morphology. There are no processing
381   costs related to syntactic dependencies in the model

382 • Speakers must minimise gaps and overlaps

383 • Planning crucial elements is increasingly difficult as they approach the 'crunch zone'

384 • Verbs are crucial elements (they are hard to plan)

385 • The production cost of sentence is related to sentence length (though in the main
386   model all sentences have the same length)

387 • In cultural evolution, agents learn by observing others and storing examples of
388   behaviour

389 • Generations are discrete (not necessary, but a simplifying assumption)

390 Clearly, these assumptions are idealisations, and the actual factors are much more
391 complex than this. As noted earlier, the assumption that all turns contain verbs is clearly
392 counterfactual, given the elliptical nature of many responses. However, as a starting

393   point, we think that this model captures some of the crucial constraints on interactive

394   language use under temporal pressure. We are attempting to construct the simplest

395   model which will help us think about the intricate inter- relationships between

396   conversation, cognition and cultural evolution. One way to construe the model is that it

397   captures only some conversations, not every interaction between agents, and that the

398   selective pressure only applies in turns which match the conditions above.

399

400   4 Results

401   Figure 5 shows, as an example of the kinds of results obtained, three independent runs

402   of the model with a population of 10 agents taking 2 conversations of 10 turns each.

403   Along the horizontal axis we see generations and each line represents how the

404   frequency of each type of basic word-order (or major sentence type) changes over time.

405   We see that in the first generation, agents are equally likely to use any of the three

406   types, but that the use of VSO rapidly declines. In the first two runs, both SVO and

407   SOV are used for some time, but after about 15 generations, all agents are using SOV

408   all the time (with some small deviations due to noise). So, we can classify the language

409   of these agents as SOV. In the third run, enough agents selected SVO by chance that the

410   conventional pressure pushed the frequency up. Eventually, the third population

411   converges on SVO order. That is, a dominant word order emerges, and we are not

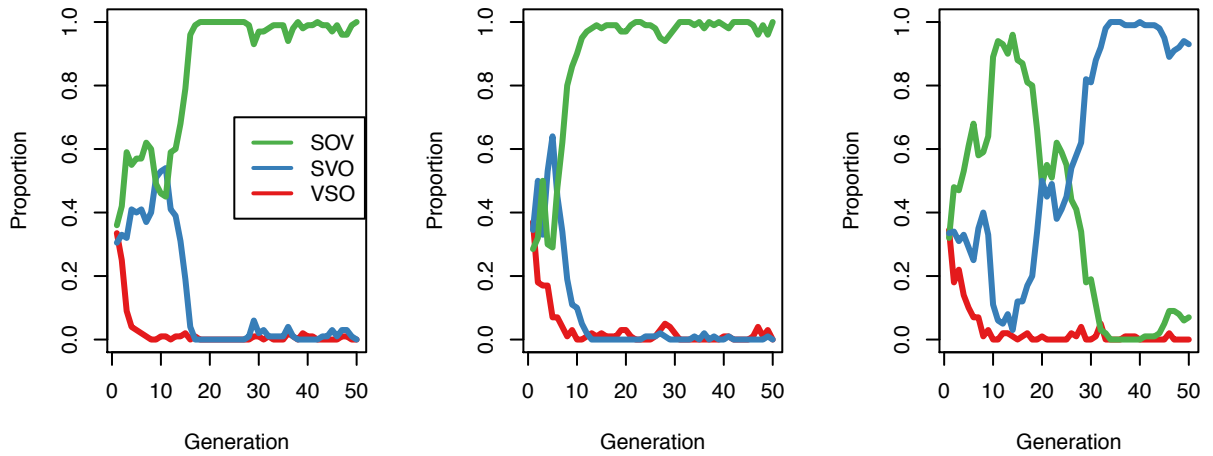412   concerned with the distribution of word orders within a language.

413

Figure 5: Proportions of each turn type used at each generation for three independent runs of the main model (N_{Agents}=10, N_{Turns}=10, $N_{Conversations}$=2, β =0.01, α =0.1).

We ran the model 1000 times and measured the proportion of runs that converge to each word-order type on each run. In every simulation, the population converged on a single word order type within 100 generations. This is not surprising, since any set of communicating agents will tend to converge on a common set of variants, as has been shown in a variety of models (e.g. Steels & Belpaeme, 2005; Nowak & Baggio, 2016) and experiments (e.g. Garrod & Pickering, 2009).

Figure 6 shows the resulting proportions of word orders in two different conditions (α = 0.1). When agents only have conversations with 1 turn (no constraints from turn taking), then each word order type is equally likely to win. When turns follow each other within a conversation, the proportions look very close to the actual 'natural' distribution of word orders we see in real languages, as measured by the proportions of word-orders in the language isolates of the world, where SOV is most frequent followed by SVO and VSO.

Essentially, the turn taking constraints impose a bias against having a verb in initial position. VSO is an unstable word order due to what we call the *first turn push*. The first turn in a conversation is unconstrained by turn-taking pressures - the first speaker is

433   free to choose any order in their memory. If they choose a verb-initial order, the choice
434   of order in the 2nd turn is not affected much. However, choosing an order with the verb
435   in a later position will bias the 2nd turn to also place their verb later, which will bias the
436   3rd turn to also place their verb later, and so on. SOV is a more stable order for the
437   same reason.

438   However, the pressure from turn taking is not so strong as to make convergence on
439   verb-initial order impossible. To be clear, although there is a small proportion of
440   populations with VSO order in the model, within those few populations all agents are
441   using VSO order. That is, the model is producing the two target phenomena:
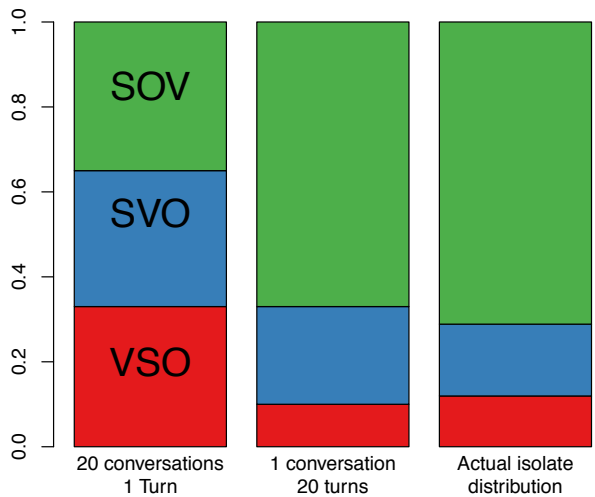442   convergence within populations and a bias for verb-later orders across populations.

443

444   **Figure 6: Proportions of each turn type that 1000 generations converge to in: Left:**
445   **a model without pressures for turn taking (N$_{Agents}$=10, β =0, α =0.1); Middle: a**
446   **model with turn taking constraints; and Right: actual language data from the**
447   **world's isolates (right).**

448   The results in figure 6 fit the data qualitatively, but also quantitatively (the proportions
449   as well as the ranks are quite close to the real ones). This quantitative fit depends on the
450   parameters of the model. Figure 7 shows how the distribution of word order types varies
451   with the α parameter, which controls how the distance between verbs relates to the

452 processing cost by weighting the effect. When α is close to 0, there is little difference

453 between each of the sentence types in any context, and roughly the same proportion of

454 each sentence type emerges. When α is positive, reflecting greater processing cost as the

455 verbs enter the crunch zone, then the SOV advantage appears. If processing cost scales

456 linearly (α = 1), then the model predicts that almost all populations should converge on

457 SOV order. With negative values of α, where cost decreases as the verb enters the

458 crunch zone, we see a preference for VSO languages. This suggests that the best fitting

459 assumption would be for a positive, convex function: the cost is large for verbs inside

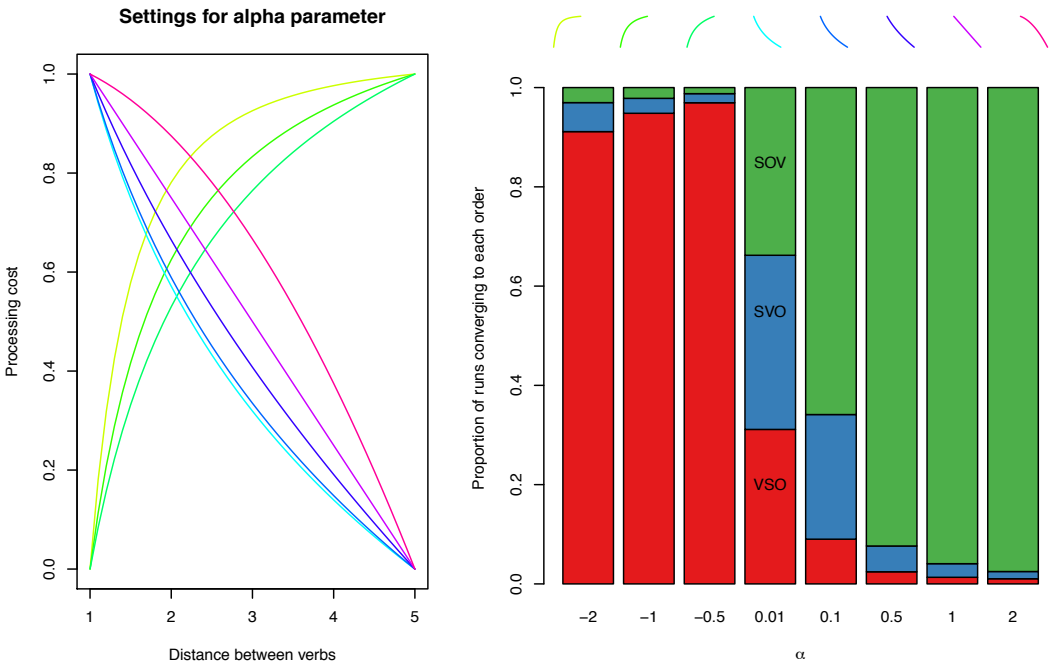460 the crunch zone, but rapidly declines as the verb moves further away.

461

462 **Figure 7: Left: how the α parameter affects the function which relates the distance**

463 **between verbs in adjacent turns and the cost of processing for the speaker of the**

464 **2nd turn. Right: how the proportions of different word-order types varies with the**

465 **α parameter. For example, the extreme negative curve (yellow) represents α = -2**

466 **and around 90% of runs converge on VSO, while the extreme exponential positive**

467 **curve (pink) represents α = 2 and over 90% of runs converge on SOV. The best fit**

468 **to the real world distribution happens when α is between 0 and 1, which creates a**

469 **convex curve.**

470   The supporting information shows that the model results are robust to settings of
471   various parameters, including N_{agents}, $N_{conversations}$, N_{turns}, β and initial conditions
472   (discussed below).

473

4.2 Sentence final particles

Figure 8 shows some results for sentence final particles ($\alpha = 0.1$, $\beta = 0$, $p = 0.5$, $N_{agents} = 10$, comparing 20 conversations of 1 turn with 2 conversations of 10 turns). The model without turn taking constraints predicts that languages are similarly likely to have initial or final sentences regardless of verb position. However, with the constraint we see two things. Initial particles are more likely than final particles for verb initial languages, and final particles are proportionately more likely for verb final languages. That is, if a language happens to settle on verb final structures, it is also more likely to develop sentence final particles. This prediction also matches the real data quite well (data from position of polar question particles, Dryer, 2013b, see figure 8 and SI). Interestingly, it also predicts that verb final languages should be less likely to have particles at all. The explanation may be the following. If the first turn in the conversation places the verb later (the first turn push), the second turn now has two options to mediate the pressure: either move the verb further back or add an initial particle to the 2nd turn. Therefore, languages are more likely to gain initial particles than final particles. However, since SOV order is more robust to the turn taking pressures and a more stable state in general and, it is less likely to transition to using a particle at all.

However, this result was not robust to changes in parameters. The fit to the data was better when noise level was low, and in addition the inclusion of a question particle in a buffer zone had a big effect. This is a reasonable result, given that the first model predicted that the processing cost declines rapidly as the verb moves away from the crunch zone. Outside of a narrow window around the parameters above, the predictions range from no effect to the opposite of the effect we see in the data (final particles more likely for verb-final languages). This suggests that the use of particles to buffer interactive language use emerges only under specific conditions.
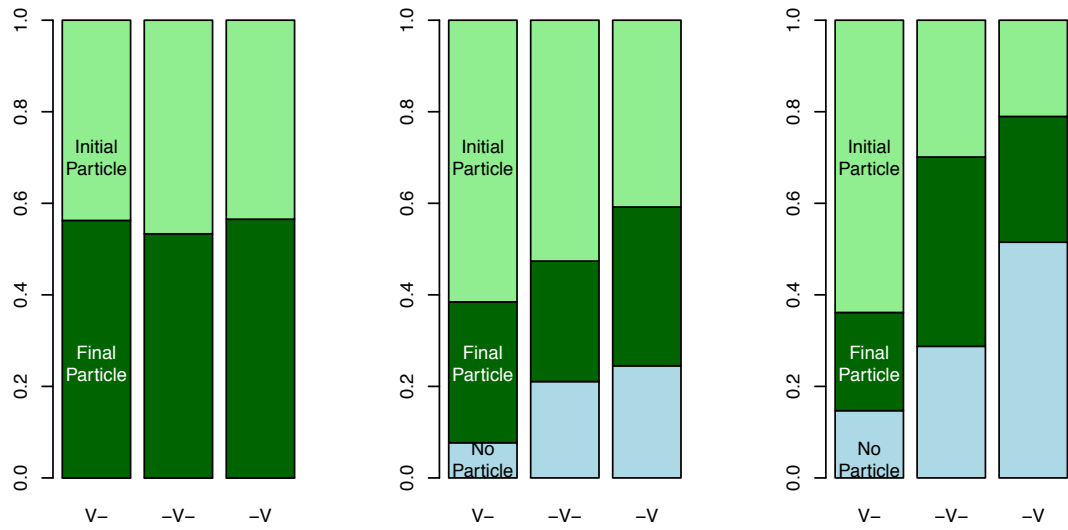
Figure 8: Distribution of word order types and the presence of absence or sentence particles in a model with: (Left) no turn taking constraints ($N_{conversations}$=20, N_{turns}=1, N_{agents} = 10, α = 0.1, β = 0, p = 0.5); (Middle) with turn taking constraints ($N_{conversations}$=2, N_{turns}=10); and (Right) the distribution in real languages (Dryer, 2013b).

5 Discussion

In this article, we have suggested that turn-taking in conversation imposes constraints on the efficiency of different basic word orders in interactive language use. Languages should adapt to these constraints, and we should see evidence of this adaptation in the structures of the world's languages. Support for this idea can be found by identifying a set of constraints that conversation imposes, generating a prediction about the distribution of linguistic structures that should emerge from these constraints, and then testing this prediction against real data. We have suggested that the need for rapid turn-taking imposes a 'crunch zone' for online language processing around the ends of turns, and hypothesised that this might affect the optimal position of crucial elements in a clause. We presented an agent-based model to help generate predictions about how these constraints should affect the cultural evolution of language, then compared the results to real data. We found a reasonable qualitative and quantitative match between the output of the model and the distribution of basic word orders in the real world.

The model suggests that, because the structure of a prior turn has knock-on effects for the production of the next turn, there is a bias for cultures to evolve towards pushing the verb further back in the turn. This leads to a distribution of basic word order which mirrors the distribution we see in the real world.

This result essentially derives from the fact that the model tends to favour SOV word order. Indeed, it would be possible to generate similar results to the current ones with a simpler model. For example, a Markov chain with a bias towards SOV, without any of the details about turn taking. However, this would be a phenomenological model fitting exercise which captures the target distribution without specifying the underlying mechanism. In this paper, we are interested in articulating a possible mechanism and investigating whether it does in fact lead to the right kind of prediction. In our case, assumptions about what constrains responding turns lead to an emergent bias towards SOV. As a consequence, when the number of turns in a conversation (N_{turns}) is low so that there are few responding turns, the proportion of populations with dominant SOV order is reduced, and in the extreme case populations are equally likely to converge on any word order (column 1 of Figure 6), which shows that the model is not biased towards SOV, except when the constraints of turn taking are applied.

538 Given this approach, the model makes two interesting predictions that other theories
539 which do not take into account the need for rapid reactions between turns would find
540 hard to explain. First, the convex relationship between distance between verbs in two
541 adjacent turns and the ease of production. This could be empirically tested using an a
542 range of new experimental techniques (see De Ruiter, Mitterer & Enfield, 2006; Bögels,
543 & Levinson, 2016). Secondly, the presence of sentence particles at the ends of
544 utterances. These do not aid prediction (since they come last) and take effort to
545 produce, but do give some advantage to turn taking.

546 **5.1 Relationship with other theories and future work**

547 The distribution of basic word orders is one of the most scrutinised phenomena in
548 typology, and this first attempt at linking typology, processing and turn taking does not
549 aim to supplant any of the other theories. Indeed, a pressure from turn taking does not
550 exclude pressures from other domains, but here we consider how they might interact.

551 One domain that clearly has an impact on the explanandum is historical change. Gell-
552 Mann and Ruhlen (2011) review historical changes to basic word order, largely caused
553 by grammaticalisation and dependencies with other aspects of grammar, and estimate
554 transitions between orders. They find that word order tends to change from SOV to
555 SVO to VSO, and suggest that languages began as SOV. In opposition to this,
556 communities in our model tend to gravitate *towards* SOV (see also the SI). Gell-Mann
557 and Ruhlen also suggest that word order distributions have not reached a stable
558 equilibrium, while in our study we assume that the target distribution is stable. Perhaps
559 it is better to see our model as a model of transition to initial consensus within a
560 population, rather than historical change between established types. However, we find
561 that, when no pressures from turn taking apply, the only way to recover the target
562 distribution is to assume that populations begin with a dominant SOV order. When
563 pressures from turn taking do apply, the target distribution is achieved from a more
564 diverse range of initial conditions (see SI). In this sense, our hypothesis is more
565 agnostic to the initial conditions of word order, which might fit better with findings that
566 the evolutionary trajectory of word order can be different in different language families
567 (Dunn et al., 2011).

568   Another issue is the model's predictions about freedom of word order. Populations in
569   the model effectively start as free word order, but then converge on a single dominant
570   order. In reality, many languages have reported flexible word order (although one
571   should note that few reported word orders are based on conversational data). However,
572   even these languages usually only use a sub-set of possible orders frequently (see
573   Austin, 2001; Hale, 1992). For example, while many orders are possible in Samoan,
574   during conversation between 70% and 86% of clauses with an overt subject, object and
575   verb are verb-initial (Ochs, 1982, p. 661; Duranti, 1981, p. 171), in line with our model.
576   However, many languages also go against our predictions. In Dryer (2013a), 79% of
577   languages coded as having two dominant word orders involve a change to the position
578   of the verb (though none alternate between verb final and verb initial). Warlpiri
579   typically has the order topic, verb phrase, comment, with verb-medial constructions
580   being most frequent of clauses with an agent, patient and verb (from written text,
581   Swartz, 1987). Indeed, word order in free word order languages is often determined by
582   pragmatic (information-structure) factors such as 'newsworthy' or prominent items
583   appearing first (Givón, 1983b; Swartz, 1987; Mithun, 1992). This goes against our
584   specific hypothesis about the position of verbs (and the predictions of the uniform
585   information density hypothesis, see below). However, it is compatible with the general
586   idea of consistently keeping elements which require more effort to comprehend in the
587   same relative position in order to facilitate turn taking. Modelling this might require
588   utterances to be sensitive to information structure or considerations of processing
589   dependencies between the different constituents (see Ferrer-i-Cancho, 2016).

590   One of the crucial assumptions of the model is that verbs require the most effort to
591   process as a listener and plan as a speaker. We assumed this since, for many
592   languages, the verb provides the syntactic frame for a sentence. In a conversational
593   discourse, topics tend to be 'given' information, while comments (predicates/verbs)
594   tend to convey the new information (e.g. Van Valin & LaPolla, 1997). Studies which
595   track the cognitive timecourse of comprehension and planning during interactive turn-
596   taking are only beginning to emerge (Gisladottir, Chwilla & Levinson, 2015; Bögels,
597   Magyari & Levinson, 2015), and do not directly address our assumption. However, we
598   note that some studies are compatible our position. For example, several studies using
599   the visual world eye-tracking paradigm show that the listener integrates constraints on

the possible or likely upcoming elements when the verb appears (Altmann, 1999; Kamide, Altmann & Haywood, 2003; Altmann, 2004; see Kamide, 2008). The semantics of verbs help listeners predict upcoming referents in verb-initial languages (Sauppe, 2016). Corpus analyses of written language also suggests that verbs carry more information to the listener (easing subsequent processing) on average than nouns (surprisal measure from Piantadosi, Tily & Gibson, 2011 as calculated in Roberts, Torriera & Levinson, 2015), which is in line with our position. However, these results are inconsistent with others. For example, integration for prediction can occur when hearing constituents other than verbs depending on the structure of the utterance (see experiment 3 of Kamide et al. 2003; Knoeferle et al., 2005), and a study of child-directed speech found that objects convey more information than subjects or verbs (Maurits, Perfors & Navarro, 2010, see below). SOV order also emerged in an evolving population of neural-network agents when there was a selection pressure for predictability (Reali & Christiansen, 2009).

More generally, real conversations are more complex than simple 3-constituent constructions. For example, speakers use a range of strategies to defer the beginning of the content of their turn (e.g. turn-preserving placeholders such as "umm…"), which mitigates the need for rapid processing to some extent. Turns in conversations often do not have overt subjects, objects or verbs. For example, Bowern (2012) shows that in Bardi (a free word order language), clauses with an overt subject, object and verb are very rare in texts (less than 2%). Furthermore, morphological marking and word order itself can help listeners predict the upcoming verb, reducing the processing load at the verb itself (Lupyan & Christiansen, 2002). Indeed, Ferrer-i-Cancho (2015) argues that verbs at the end of a turn are better for the listener because the prior context helps predict it, in opposition to our prediction.

There is therefore no simple consensus about the difficulty of processing verbs during conversation. We note that the previous literature on word order and cognition tends to focus on semantic comprehension, while an important part of turn taking in conversation is the comprehension of pragmatic acts (Gisladotir, Chwilla & Levinson, 2015). In any case, questions about how verb position, context, semantic relations and pragmatic acts relate to planning and comprehension effort is at least empirically

631 testable with recent large-scale databases and new experimental methods (e.g. Roberts,
632 Torreira & Levinson, 2015; Barthel et al., 2016; Bögels & Levinson, 2016).

633 Even if the general assumption about verbs is correct, the model could be rooted in
634 more concrete measures of processing. For example, the work on uniform information
635 density suggests that languages are optimised for conveying information at a constant
636 rate, avoiding high information rates which are unreliable or low information rates
637 which are inefficient (e.g. Jaeger & Levy, 2006; Jaeger, 2010; Piantadosi, Tily &
638 Gibson, 2011). Relating to word order in particular, Maurits, Perfors & Navarro (2010)
639 analyse spoken conversations and measure the predictability of verbs from their subjects
640 and objects. They show that VSO and SVO orders provide more uniform information
641 density, and therefore might be more efficient orders, helping to explain the drift
642 towards them in Gell-Mann & Ruhlen's study.

643 However, the uniform information density accounts were motivated by the rational
644 strategy for successfully transmitting a single utterance in noisy conditions (studies like
645 Maurits et al., 2010 also assume that all words are the same length and that previous
646 utterances do not carry information about the current one). Furthermore, the uniform
647 information density accounts focus on the ease of decoding rather than the ease of
648 planning. We argue that real time conversation involves simultaneous encoding and
649 decoding at certain points in each turn, and so the ideal information profile may not be
650 uniform, but one of the skewed distributions discussed above. However, in general the
651 findings may be compatible with our account. For example, according to the results in
652 Maurits et al., 2010, SVO order conveys the most uniform information rate. However,
653 considering the three orders where the subject precedes the object, the last element in
654 the utterance contains more information (and therefore requires more cognitive
655 resources) as the verb moves away from the crunch zone at the end of the turn. That is,
656 SOV order is the best profile for a turn-taking listener, since they are already able to
657 predict the verb from the subject and the object, and are therefore able to dedicate more
658 resources to planning in the crunch zone. This is compatible with the result of our
659 model that turn taking imposes a pressure to push the verb further back in the sentence.

660 In another approach, Ferrer-i-Cancho (2015) argues that the length of syntactic
661 dependencies between the verb and its subject and object (within a turn) has a

662 considerable effect on short term memory load, and that planning effort is minimised

663 when placing the syntactic head in the center of the construction. This opposes a

664 pressure for predictability by the listener, which favours verb-final constructions.

665 Furthermore, historical changes between dominant word orders tends to proceed in

666 single steps between adjacent orders (see also, Ferrer-i-Cancho, 2016). These factors

667 combine to explain many phenomena such the prevalence of SVO order, optionality

668 between SOV and SVO order, historical movement towards SVO and OVS order being

669 rare since it is many changes away from the presumed initial SOV order. Currently, our

670 model is too abstract to integrate notions of syntactic dependency within a turn, and

671 transitions between any order to any other order occur (see SI).

672 The model presented here is not intended to supplant any of these other explanations

673 and, as many others have pointed out, several factors could be at play in this complex

674 system (Hawkins, 2004; Langus & Nespor, 2010; Ferrer-i-Cancho, 2015). There is

675 clearly work to be done to relate the different accounts to each other. For now, we point

676 out that the need for processing efficiency derives to some extent from the real-time

677 nature of natural conversation, and that all of the approaches above consider processing

678 within utterances or from the perspective of an isolated speaker or hearer, while we

679 have argued that there are cognitive constraints imposed from the relationship between

680 turns by multiple individuals.

681 To conclude, there are many issues to resolve. The model is extremely simple and

682 makes many assumptions that could be relaxed. The parameters also need to be tied to

683 specific cognitive mechanisms, rather than abstract notions of processing cost. Rules of

684 the sequential organisation of conversation could also be built into the model. The

685 general hypothesis also makes more general predictions about grammatical structures

686 within conversations which could be tested. For example, do speakers alter the

687 information structure of their turns to aid processing by local co-ordination? Finally, the

688 constraints from turn taking are just one domain from many that impact the evolution of

689 grammatical structure. Despite these limitations, we believe that the model provides a

690 useful tool for thinking about the relationship between conversation and cognition in a

691 cultural evolution framework. Our take-home message is that interactive turn-taking in

692 conversation must impose constraints on cognition, and that these may have

693 implications for the way in which languages change over time.

694 **Acknowledgements**

References

Altmann, G. T. M. (1999). Thematic role assignment in context. Journal of *Memory and Language*, 41.124–45.

Altmann, G. T. M. (2004) Language-mediated eye movements in the absence of a visual world: the 'blank screen paradigm'. *Cognition* 93.79–87

Austin, P. (2001). Word order in a free word order language: the case of Jiwarli. In J. Simpson, D. Nash, M. Laughren, P. Austin, B. Alpher, (eds), *Forty years on: Ken Hale and Australian languages*, 205-323. Canberra: Pacific Linguistics.

Barthel, M., Sauppe, S., Levinson, S. C., & Meyer, A. S. (2016). The timing of utterance planning in task-oriented dialogue: Evidence from a novel list-completion paradigm. *Frontiers in Psychology*, 7: 1858.

Bentz, C., & Christiansen, M. H. (2010). Linguistic adaptation at work? the change of word order and case system from Latin to the Romance languages. In A. Smith, M. Schouwstra, B. de Boer, & K. Smith (Eds.), *Proceedings of the eighth international conference on the evolution of language* (p. 26-33). London: World Scientific.

Bowern, C. (2012). *A grammar of Bardi*. Walter de Gruyter.

Bickel, B., Banjade, G., Gaenszle, M., Lieven, E., Paudyal, N.P., Rai, I.P., Rai, M., Rai, N.K. and Stoll, S. (2007). Free prefix ordering in Chintang. *Language*, 83(1), 43-73.

Bögels, S., Kendrick, K. H., & Levinson, S. C. (2015). Never Say No… How the Brain Interprets the Pregnant Pause in Conversation. *PloS one*, *10*(12), e0145474.

Bögels, S., & Levinson, S. C. (2016). The Brain Behind the Response: Insights Into Turn-taking in Conversation From Neuroimaging. *Research on Language and Social Interaction*. Advance online publication.

Bögels, S., Magyari, L., & Levinson, S. C. (2015). Neural signatures of response planning occur midway through an incoming question in conversation. Scientific Reports, 5: 12881.

Christensen, P., Fusaroli, R., & Tylén, K. (2016). Environmental constraints shaping constituent order in emerging communication systems: Structural iconicity, interactive alignment and conventionalization. *Cognition*, 146, 67-80.

728 Christiansen, M. H., & Chater, N. (2008). Language as shaped by the brain. *Behavioral*
729 *and brain sciences*, *31*(05), 489-509.

730 Croft, W. (2000). Explaining language change: an evolutionary approach. Harlow,
731 Essex: Longman.

732 Dingemanse, M., Roberts, S. G., Baranova, J., Blythe, J., Drew, P., Floyd, S.,
733 Gisladottir, R. S., Kendrick, K. H., Levinson, S.C., Manrique, E., Rossi, G & Enfield,
734 N. J. (2015). Universal principles in the repair of communication problems. *PloS one*,
735 *10*(9), e0136100.

736 Donders, F. C. (1868). La vitesse des actes psychiques. Archives Néerlandaise, 3, 269–
737 317.

738 Dryer, M. S. (2013a) Order of Subject, Object and Verb. In: Dryer, Matthew S. &
739 Haspelmath, Martin (eds.) The World Atlas of Language Structures Online. Leipzig:
740 Max Planck Institute for Evolutionary Anthropology. (Available online at
741 http://wals.info/chapter/81, Accessed on 2017-01-11.)

742 Dryer, M. S. (2013b) Position of Polar Question Particles. In: Dryer, Matthew S. &
743 Haspelmath, Martin (eds.) The World Atlas of Language Structures Online. Leipzig:
744 Max Planck Institute for Evolutionary Anthropology. (Available online at
745 http://wals.info/chapter/92, Accessed on 2017-01-13.)

746 Dunn, M., Greenhill, S. J., Levinson, S. C., & Gray, R. D. (2011). Evolved structure of
747 language shows lineage-specific trends in word-order universals. *Nature, 473*(7345),
748 79-82.

749 Duranti, A. (1981). The Samoan fono: A sociolinguistic study (No. 80). *Pacific*
750 *Linguistics Series B*, 80. Department of Linguistics, Research School of Pacific Studies,
751 Australian National University.

752 Fedzechkina, M., Jaeger, T. F., & Newport, E. L. (2012). Language learners restructure
753 their input to facilitate efficient communication. *Proceedings of the National Academy*
754 *of Sciences*, *109*(44), 17897-17902.

755 Ferrer-i Cancho, R. (2008). Some word order biases from limited brain resources: A
756 mathematical approach. Advances in Complex Systems, 11(03):393–414.

Ferrer-i-Cancho, R. (2014). Why might SOV be initially preferred and then lost or recovered? A theoretical framework. In: THE EVOLUTION OF LANGUAGE - Proceedings of the 10th International Conference (EVOLANG10), Cartmill, E. A., Roberts, S., Lyn, H. & Cornish, H. (eds.). Evolution of Language Conference (Evolang 2014). Vienna, Austria, April 14-17. pp. 66-73.

Ferrer-i-Cancho, R. (2015). The placement of the head that minimizes online memory. A complex systems approach. *Language Dynamics and Change,* 5(1), 114-137.

Ferrer-i-Cancho, R. (2016) Kauffman's Adjacent Possible In Word Order Evolution. In S.G. Roberts, C. Cuskley, L. McCrohon, L. Barceló-Coblijn, O. Fehér & T. Verhoef (eds.) *The Evolution of Language: Proceedings of the 11th International Conference (EVOLANG11)*. Available online: http://evolang.org/neworleans/papers/83.html

Garrod, S., & Pickering, M. J. (2009). Joint action, interactive alignment, and dialog. *Topics in Cognitive Science*, *1*(2), 292-304.

Gell-Mann, M. and Ruhlen, M. (2011). The origin and evolution of word order. P*roceedings of the National Academy of Sciences*, 108(42), 17290–17295.

Gibson, E., Piantadosi, S. T., Brink, K., Bergen, L., Lim, E., & Saxe, R. (2013). A noisy-channel account of crosslinguistic word-order variation. *Psychological science*, 0956797612463705.

Gisladottir, R. S., Chwilla, D., & Levinson, S. C. (2015). Conversation electrified: ERP correlates of speech act recognition in underspecified utterances. PLoS One, 10(3): e0120068.

Givón, T. (1983a) *Topic continuity in discourse: A quantitative cross-language study*. Amsterdam: John Benjamins Publishing.

Givón, T. (1983b). Topic continuity in discourse: An Introduction. In T. Givón (ed) *Topic continuity in discourse: A quantitative cross-language study*. Amsterdam: John Benjamins Publishing.

Goldin-Meadow, S., So, W. C., Özyürek, A., and Mylander, C. (2008). The natural order of events: How speakers of different languages represent events non- verbally. Proceedings of the National Academy of Sciences, 105(27):9163–9168.

786   Hale, K. (1992). Basic word order in two "free word order" languages. In D. Payne (ed),

787   *Pragmatics of word order flexibility*, 63-82. Amsterdam: John Benjamins.

788   Haspelmath, M., Dryer, M. S., Gil, D., and Comrie, B. (2008). World Atlas of

789   Language Structures. online at http://wals.info. Accessed 2013-04-18. Munich: Max

790   Planck Digital Library.

791   Hawkins, J. (1994). A performance theory of order and constituency. New

792   York: Cambridge University Press.

793   Hawkins, J. A. (2004). Efficiency and complexity in grammars. Oxford: Oxford

794   University Press.

795   Hick, W. E. (1952). On the rate of gain of information. *Quarterly Journal of*

796   *Experimental Psychology*, *4*(1), 11-26.

797   Horn, L. (1984). Toward a new taxonomy for pragmatic inference: Q-based and R-

798   based implicature. In D. Schiffrin (ed.) *Meaning, form, and use in context: Linguistic*

799   *applications*. Georgetown University Press, Washington DC. 11-42. Reprinted in

800   Kasher (ed., 1998), vol. IV: 389–418.

801   Indefrey, P. (2011). The spatial and temporal signatures of word production

802   components: a critical update. *Frontiers in psychology*, *2*(255), 1-16.

803   Jaeger, T. F. (2010). Redundancy and reduction: Speakers manage syntactic information

804   density. *Cognitive psychology*, *61*(1), 23-62.

805   Jaeger, T. F., Levy, R. P. (2006). Speakers optimize information density through

806   syntactic reduction. In P.B. Schölkopf and J.C. Platt and T. Hoffman (eds) *Advances in*

807   *neural information processing systems 19*, pp. 849-856.

808   Kamide, Y. (2008). Anticipatory processes in sentence processing. *Language and*

809   *Linguistics Compass*, *2*(4), 647-670.

810   Kamide, Y., Altmann, G. T., Haywood S. L. (2003) The time-course of prediction in

811   incremental sentence processing: Evidence from anticipatory eye-movements.

812   *Journal of Memory and Language,* 49 133 –59.

813   Kendrick, K. H. (2012) Particles at the transition space. Talk presented at the

814   Interactional Foundations of Language Meeting. Kreuth, Germany. 2012-11-01 - 2012-

815   11-02.

816   Kendrick, K. H. (2015). The intersection of turn-taking and repair: the timing of other-

817   initiations of repair in conversation. *Frontiers in psychology*, 6, 250.

818   Kendrick, K. H., & Torreira, F. (2015). The timing and construction of preference: a

819   quantitative study. *Discourse Processes*, *52*(4), 255-289.

820   Kirby, S., Griffiths, T., & Smith, K. (2014). Iterated learning and the evolution of

821   language. *Current opinion in neurobiology*, *28*, 108-114.

822   Knoeferle, P., Crocker, M. W., Scheepers, C. & Pickering, M. J. (2005) The influence

823   of the immediate visual context on in cremental thematic role assignment: evidence

824   from eye-movements in depicted events. *Cognition,* 95.95 –127

825   Krupa, V. (1982). Syntactic Typology and Linearization. *Language*, 58(3), 639–645.

826   Langus, A., & Nespor, M. (2010). Cognitive systems struggling for word order.

827   Cognitive Psychology, 60(4), 291-318.

828   Levelt, W. J., Roelofs, A., & Meyer, A. S. (1999). A theory of lexical access in speech

829   production. *Behavioral and brain sciences*, *22*(01), 1-38.

830   Levinson, S. (2006). On the human interaction engine. In Enfield, N. and Levinson, S.,

831   editors, Roots of Human Sociality: Culture, Cognition and Human Interac- tion, pages

832   39–69. Oxford: Berg.

833   Levinson, S. C. (1983). *Pragmatics*. Cambridge University Press.

834   Levinson, S. C. (2016). Turn-taking in Human Communication–Origins and

835   Implications for Language Processing. *Trends in cognitive sciences*, *20*(1), 6-14.

836   Lupyan, G., & Christiansen, M. H. (2002). Case, word order, and language learnability:

837   Insights from connectionist modeling. In *Proceedings of the 24th annual conference of

838   the cognitive science society* (p. 596-601). Mahwah, NJ: Lawrence Erlbaum.

839   Maurits, L., Perfors, A., and Navarro, D. (2010). Why are some word orders more

840   common than others? a uniform information density account. Advances in Neural

841   Information Processing Systems, 23:1585–1593.

842 Mithun, M. (1992). Is basic word order universal? In D. Payne (ed), *Pragmatics of word*
843 *order flexibility*, 63-82. Amsterdam: John Benjamins.

844 Nowak, I., & Baggio, G. (2016). The emergence of word order and morphology in
845 compositional languages via multigenerational signaling games. *Journal of Language*
846 *Evolution*, 1(2): 137-150.

847 Ochs, E. (1982). Ergativity and word order in Samoan child language. *Language*, 58(3),
848 646-671.

849 Ochs, E., Schegloff, E. A., & Thompson, S. A. (1996). *Interaction and grammar* (Vol.
850 13). Cambridge University Press.

851 Piantadosi, S. T., Tily, H., & Gibson, E. (2011). Word lengths are optimized for
852 efficient communication. *Proceedings of the National Academy of Sciences*, *108*(9),
853 3526-3529.

854 Reali, F., & Christiansen, M. H. (2009). Sequential learning and the interaction
855 between biological and linguistic adaptation in language evolution. Interaction Studies,
856 10, 5-30.

857 Roberts, F., Margutti, P., & Takano, S. (2011). Judgments concerning the valence of
858 inter-turn silence across speakers of American English, Italian, and Japanese. *Discourse*
859 *Processes*, *48*(5), 331-354.

860 Roberts, S. G., Torreira, F., & Levinson, S. C. (2015). The effects of processing and
861 sequence organisation on the timing of turn taking: A corpus study. *Frontiers in*
862 *Psychology*, 6: 509.

863 Roberts, S., & Winters, J. (2013). Linguistic diversity and traffic accidents: Lessons
864 from statistical studies of cultural traits. *PloS one*, *8*(8), e70902.

865 De Ruiter, J. P., Mitterer, H., & Enfield, N. J. (2006). Projecting the end of a speaker's
866 turn: A cognitive cornerstone of conversation. *Language*, 515-535.

867 Sacks, H., Schegloff, E. A., and Jefferson, G. (1974). A simplest systematics for the
868 organization of turn-taking for conversation. Language, 40(4):696–735.

869 Sauppe, S. (2016). Verbal semantics drives early anticipatory eye movements during the
870 comprehension of verb-initial sentences. *Frontiers in Psychology*, 7: 95.

871   Schegloff, E. A. (1989). Reflections on language, development, and the interactional
872   character of talk-in-interaction. Interaction in human development, pages 139–153.

873   Schegloff, E. A., Jefferson, G., & Sacks, H. (1977). The preference for self-correction in
874   the organization of repair in conversation. *Language*, 361-382.

875   Schouwstra, M. and de Swart, H. (2014). The semantic origins of word order.
876   Cognition, 131(3):431–436.

877   Steels, L. and Belpaeme, T. (2005). Coordinating perceptually grounded categories
878   through language: a case study for colour. Behavioral and Brain Sciences, 28(4):469–
879   489.

880   Stivers, T., Enfield, N. J., Brown, P., Englert, C., Hayashi, M., Heinemann, T.,
881   Hoymann, G., Rossano, F., De Ruiter, J. P., Yoon, K.-E., and Levinson, S. C. (2009).
882   Universals and cultural variation in turn-taking in conversation. Proceedings of the
883   National Academy of Sciences, 106(26):10587–10592.

884   Swartz, S. (1987) Pragmatic structure and word order in Warlpiri. *Papers in Australian*
885   *linguistics*, 17, 151-166.

886   Tanaka, H. (2000). Turn projection in Japanese talk-in-interaction. *Research on*
887   *Language and Social Interaction*, 33(1):1–38.

888   Tanaka, H. (2005). Grammar and the "timing" of social action: Word order and
889   preference organization in Japanese. *Language in Society*, *34*(03), 389-430.

890   Thompson, S. A. (1998). A discourse explanation for the cross-linguistic differences in
891   the grammar of interrogation and negation. *Case, typology and grammar: In honor of*
892   *Barry J. Blake*, 309-341.

893   Tomlin, R. S. (1986). *Basic word order: functional principles*. Croom Helm.

894   Van Valin, R. D., & LaPolla, R. J. (1997). *Syntax: Structure, meaning, and function*.
895   Cambridge University Press.

896   Zipf, G. K. (1949). Human behavior and the principle of least effort. Oxford, England:
897   Addison-Wesley Press.