Authors' response

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In our article, we argue for an approach to linguistic explanation that takes seriously the fact that language arises from the interaction of complex dynamical systems. One of the unusual features of this type of explanation is that there is often an opaque relationship between components of a theory and the predictions that theory makes. To reiterate our central point: the consequence of this is that a model of the language learner and the resultant structure of language cannot be directly equated. In other words, it is a mistake to use language universals as evidence for any kind of theory of UG (or equivalently any kind of theory of language use) without exploring the mechanisms that link the two.

We place a good deal of emphasis on the use of modelling to find a solution to this opaqueness problem. Computational techniques based on multi-agent modelling are particularly effective for relating local behaviour and global dynamics. This is why we believe them to be an important and appropriate tool for theoretical linguistics. Developing computational models is not without its problems, however. One necessarily needs to balance the simplicity of a model against its realism, and the specific choices made in constructing the model against the generality of the results.

We cite many computational models throughout the article all of which represent different approaches to getting this balance right. Ultimately, it is the convergence of results in so many different models that convinces us that our general conclusions are valid. Understandably however, Croft raises some issues with the *particular* model that we chose to describe in depth.

For example, his commentary suggests that compositionality is there from the start in the simulation — specifically, in the type of meaning space we used. We should be clear that, for us, compositionality is a property of the *relationship* between meanings and utterances, and therefore cannot be said to hold for the meanings alone. This is merely a terminological problem. So, in Croft's terms we might say that we have shown the emergence of *iconicity* in a model that starts with a non-iconic language.

Nevertheless, it seems that the substance of this criticism is that by using such a highly structured representation of meanings, and by implementing a learning model that seeks appropriate generalisations, the result is somehow unsurprising.

Studies in Language 28:3 (2004), **612–614.**
ISSN 0378–4177 / E-ISSN 1569–9978

If this is the case, then our key point about the complex nature of the relationship between learning and emergent universals is undermined. In other words, the dynamical system of transmission has little explanatory role to play.

It is important to note, however, that it is far from inevitable that a learner will acquire a compositional (iconic) language in this model. For many generations, the languages do not look like that. It is not even the case that perfect compositionality is the inevitable end-point of the transmission dynamic. Brighton (2002) and Smith, Brighton & Kirby (forthcoming) show that the relative stability of compositional languages varies depending on assumptions about meaning-space structure and the size of the learning bottleneck. In addition, we note that languages are *not* perfectly compositional. Kirby (2001) shows how varying the frequency of meanings in the model results in islands of non-compositionality in high-frequency parts of the space. From this we can see that the irregularity-by-frequency interaction in the morphology of many languages could also be a result of linguistic evolution driven by transmission pressures.

Croft suggests that starting with a meaning-space of a particular structure is the wrong approach. After all, where did this structure come from? We agree that this is a very important question, and one that could impact on the validity of our conclusions. If meaning structure develops hand-in-hand with utterance structure, then can we be sure that the transmission dynamic will behave the way we think it will? This is an area where we expect to see many exciting development in the years to come. Researchers like Hurford (2003) are beginning to relate semantic constructs like predicate and argument to non-linguistic structure like that found in the brain's perceptual system. As we point out in the article, Vogt (2003) and others are developing versions of the iterated learning model where meaning structure emerges out of agent interactions grounded in a real perceptual world. From initial results, it would appear that our general conclusions apply here as well.

Despite the central role of simulation models in our argument, they are really only a means to an end. Our aim, of course, is to begin to sketch out a truly explanatory theory of language — a theory that is based on an understanding of the dynamic relationship between the individual and the population. We suggest that such a theory will treat language itself as an adaptive system. It is perhaps inevitable that this brings to mind parallels with evolutionary biology and that arch mechanism for the explanation of adaptive structure: natural selection.

Croft's work has demonstrated that there are very useful analogies to be made between language and biology. We should keep in mind, however, that a theory of language is not right or wrong on the basis of how well it maps onto such an analogy. It seems to us a self-evident truth that the mechanisms of linguistic and biological information transmission are very different, so we should not expect there to *necessarily* be a universal theory of selection that can be applied in both cases. In our discussion, we note that language exists in two different states: as mental representations and actual utterances. For language to persist, there must be mechanisms that transform one state into the other and vice versa. Croft appears to

deny this, but really the difference between our positions may be one of emphasis. For us, language adapts to solve particular problems it faces: to be used and learnt. Whereas Croft's work concentrates on instances of socially-driven language change, we seek explanations for the origins of fundamental and universal properties of linguistic structure.

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