study by Anderson *et al.* [5] and those obtained in PET studies and experiments investigating the effects of stress hormones administered after learning may well reflect different degrees of emotional arousal. The degree of emotional arousal induced by training very significantly influences amygdala activity, as assessed by the release of noradrenaline within the amygdala and firing of amygdala neurons [17,18]. Thus, emotional stimuli that induce greater emotional arousal than those used by Anderson *et al.* [5] should modulate the memory of insignificant stimuli appearing at intervals longer than those used in their study. Such enhancement would be expected both because of the rapid increase amygdala activity induced by the emotional experience as well as the subsequent influence of stress hormones on amygdala activity mediated by β-adrenergic activation. Although it is possible that a sustained increase in emotional arousal during the encoding session may have enhanced memory of the neutral stimuli (as well as the emotional stimuli) presented throughout the session, the design of the study did not enable examination of this possibility. Subsequent research stimulated by the Anderson *et al.* [5] findings will no doubt shed more light on this emotionally arousing issue.

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Experiments on the emergence of human communication

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Children learn language from their parents and then use the acquired system throughout the rest of their life with little change. At least that is commonly assumed. But a recent paper by Galantucci adds to the growing evidence that adults (and children) are able to create and negotiate complex communication systems from scratch and relatively quickly, without a prior model. This raises questions of what cognitive mechanisms are implied in this joint construction of communication systems, and what the implications are for the origins of human language.

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Galantucci's recent paper on how human communication systems emerge [1] is remarkable in many ways. His ingenious experimental design allows the systematic collection of data on how humans invent and implicitly negotiate a shared communication system. The data confirm some earlier findings from studies of natural dialogue, such as the importance of alignment and innovation. They also show that differences in social intelligence can have a big impact on success in communication.

Lessons from the study of natural dialogue

Until recently, empirical data on whether and how humans can create a shared communication system was extremely rare. We essentially had to make do with unique 'natural' experiments, like the emergence of a new Nicaraguan sign language [2]. But such an event can obviously not be recorded exhaustively nor repeated in controlled laboratory settings. Clark [3], Garrod [4], and others started to pioneer the detailed study of natural dialogue in the late 1980s. They introduced challenging task settings (for example, joint traversal of a maze) and recorded very carefully the verbal interactions that took place. Three important findings came out of this research:

(1) Even though these researchers looked at an existing communication system (natural language), they observed that partners in dialogue occasionally introduce significant innovations at all levels of language: new ways of conceptualising the situation, new meanings for existing words, extensions of existing grammatical constructions, and so on.
(2) Dialogue partners align their verbal behavior at all levels: their speech sounds and gestures become similar; they start to see the world in similar ways as they coordinate their situation models; they quickly adopt word meanings used by others; they tend to echo the same grammatical constructions.
(3) There is often remarkable variation in how different pairs of individuals tackle the same task. But when pairs are selected consecutively from the same group, alignment leads to 'sublanguages', with much more sharing and therefore higher communicative success among the group members than across groups.

More recently, Healey and co-workers extended this paradigm to a graphical medium, with essentially the same results [5]. They asked subjects to describe a piece of music graphically so that other subjects could decide whether they were listening to the same piece or a different piece. A graphical medium brings us closer to the emergence of a new communication system because it is less constrained by prior convention and so the degree of innovation is higher. Besides innovation, Healey again observed alignment, variation and the formation of shared subsystems in groups.

A new experiment on emergent communication

Galantucci's experiment [1] is a brilliant continuation of this line of research. He has designed an ingenious videogame in which players can only succeed when they communicate with each other. The game world consists of a set of rooms located on a grid and marked with geometrical figures (Figure 1). Players have to move to the same room, but they only have a local view and so they cannot see where the other player is located. As they need to know this in order to decide on their next move, players are encouraged to develop ways for describing their own positions, where they intend to move next, or what they suggest the other player should do.

Galantucci's key contribution is to introduce an unusual graphical medium by which players can communicate: a scratchpad that moves vertically as one draws on it. Thus drawing a horizontal line results in a diagonal line with a slant that reflects the velocity profile of the drawing motion. Because of this novel medium, players are forced to totally invent a new communication system. There is no prior inventory, not even an established set of signs to build from. Remarkably, most pairs of players manage the task and the same findings as seen in natural dialogue are observed even more sharply: innovation, alignment and variation. It is also clear that the emergent communication system is tightly embedded in the coordination of the behavioral processes between dialogue partners.

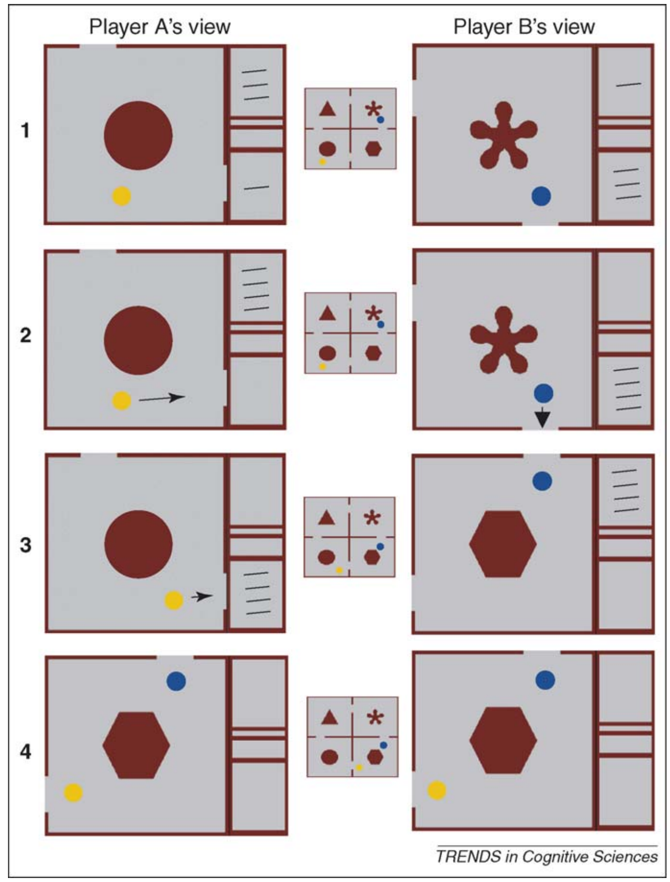

Figure 1. Four steps in a videogame designed to study the emergence of communication systems between two human players, '*A*' and '*B*' [1]. The left side of each panel shows *A*'s view with a window for the current room on the left and two panes on the right displaying communications (Top: *A*'s signals; Bottom: *B*'s signal). The right side gives *B*'s view, showing the current room to the left, *B*'s signals in the bottom right pane and those of *A* in the top right pane. Player *A* can move the small yellow circle, whereas *B* can move the small blue circle. The middle figure of each panel shows the overview of the game rooms, which the players do not see. 1. Players exchange signals and determine their respective location on the map. 2. *A* indicates in which room to meet to *B*, who moves accordingly. 3. *B* has moved to the indicated room and waits for *A*. 4. *A* and *B* are now in the same room and can see each other. Figure adapted from Box 2 in Ref. [1].

Because Galantucci then makes the task more complex by increasing the number of rooms and by introducing other additional challenges, he is able to study the further evolution of a communication system once it has emerged, and shows beyond doubt that communication systems continue to be adapted by players while retaining earlier solutions as much as possible.

Interestingly, not all pairs of subjects in the Galantucci experiment manage to bootstrap a communication system. The challenge seems to require a cooperative attitude – a particular type of social intelligence. Some players behave like Humpty Dumpty. They just assume that others see the world in their way and use symbols the way they decide. They fail to realize that their communication is ambiguous and do not have the social inclination to negotiate repairs.

Frustration can run very high. A task that some pairs manage in ten minutes, takes others three hours before they give up. The impact of social and cognitive capacities on communication has also been observed by other researchers in human dialogue [6]. This makes me think that Galantucci's experimental set-up can be used to develop a measure of sociality with respect to communication. When the basic skills to bootstrap or adapt a communication system are lacking, this must give all sorts of problems in real life as well. This game could be used to detect such problems. Perhaps it can even take on a therapeutic value, helping those who lack the social intelligence for communication to develop it.

Iterated transmission vs. dynamic coordination

Galantucci's findings also have a bearing on the question of the origins of human language. So far, most researchers have adopted an iterated transmission view, which is a model of cultural evolution originally developed by biologists, most notably Boyd and Richerson [7]. Children are assumed to learn the language system from their parents and then transmit it again to their children as adults. Innovation, variation and alignment towards a shared inventory in the group happen at this moment of transmission but the language of a learner does not influence that of a teacher, just like the genetic endowment of a child and her subsequent behavior does not influence the genome of the parent. When communication and culture is seen from this viewpoint it becomes similar to genetics, and so a century of mathematical modeling of genetic evolution can be carried over to cultural evolution almost without change. A recent set of mathematical [8] and computational models (for example the iterated learning framework of Hurford and co-workers [9]) have been doing just that.

But there is an alternative, namely that language originated when a group of (mostly adult) speakers with 'language-ready' brains started to create, expand and negotiate a rich communication system, similar to the way that this happened in the Galantucci experiment, giving rise to a collective semiotic dynamics as the participating population became larger [10]. According to this dynamic coordination view, language is forever changing. It is a complex adaptive system shaped and reshaped by the members of a population in order to satisfy their needs. Transmission across generations happens automatically, as incoming members build and align their own inventories, but it is not the primary motor through which language emerges or evolves. The experimental findings of Galantucci and others provide convincing evidence that this coordination view is empirically plausible. It complements the efforts by myself and others [11,12] to operationalize the invention and negotiation processes required for emergent communication. We have already some remarkable experiments where a population of situated, embodied artificial agents build and negotiate a shared communication system and its underlying ontology [10]. So an obvious challenge now is to compare these artificial experiments with observed human behavior.

Conclusion

To get a complete picture of human communication, both iterated transmission and dynamic coordination need to be studied. Today we know a lot about the former but almost nothing about the latter. Many researchers have studied how words or grammatical constructions are learned. Only few have considered the question of how they get invented or coordinated among dialogue partners. Studies in natural dialogue, experiments on emergent communication among human partners, and computational experiments with artificial agents, are beginning to yield clues for unraveling the mysteries behind the remarkable creativity of human beings in collectively building shared efficient communication systems. Obviously, there is more to be done in all these areas to explain the incredible complexity and richness of human communication. But if we can do so, we will also have a theory of how our species managed to start the adventure of human natural language.

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