Introduction

Cause and effect. Action and reaction. The principle is built into the Western tradition, both in science and in the popular imagination. It is an expectation for the way things work, for the way things must work. If you push the first domino then it will fall, and the force will be transmitted to all of the other dominoes in as long a sequence as you might care to set up. We commonly extend the idea to domains beyond the physical, as for instance the "domino theory" according to which allowing one state to change its politics will in turn cause other states to do so as well. How could we ever have an effect without a cause? When we see that something has happened and the cause is not immediately apparent, we expect that we can find the cause, or we believe that somebody else sufficiently motivated and sufficiently skilled could eventually find the cause if they tried hard enough. In the domain of language, we have been used to thinking in generative terms that a universal grammar is the cause of human language, presumably a grammar with biological connections of some sort because language is a property of the species that no other living species shares in quite the same way or to the same extent. We have expected that somehow, someday, somebody would find that cause, would reveal universal grammar for what it really is.

This book takes a different position, not just about universal grammar and language but about cause and effect itself. Surely the principle of cause and effect does operate in a great many domains. However, in recent decades it has become clear that some effects arise without particular causes, as the result of random interactions of large numbers of elements in complex systems. Such effects just *emerge* from the random interactions, without any deterministic cause; given the same elements, different effects can and do emerge. Adding grains of sand to a pile makes a larger and larger pile until landslides begin to occur, and mostly small and some large landslides then continue to occur unpredictably as grains continue to be added to the pile (Kauffman 1995: 28–29). There is no simple cause and effect relationship between the sand, the pile, and the size of the landslides. Landslides thus emerge from the system: we can predict that landslides will occur, but we cannot predict the exact timing or size or location of any individual landslide. Stuart Kaufmann has called this kind of emergence "order for free" (1995: 83), by which he means that we achieve regularity in behavior, the certainty that there will be larger and smaller landslides as more sand is added to the pile, without any simple cause or assemblage of simple causes. We cannot reduce the landslide problem to cause and effect, and so we get "order for free" in the sense that the regularities do not occur at the cost of particular causes. Speech, language in use, is like landslides: order in language just emerges from the linguistic interactions of speakers, agents using speech. I demonstrated this fact from first principles in an earlier book, *The Linguistics of Speech* (2009), which also deals with the issue that speakers as agents are much, much more complex and hard to describe than grains of sand falling on a pile. In this book, I will show how an understanding of language in use as a complex system helps us to think differently about a number of problems in linguistics, and helps us to address the great complexity of linguistic interactions.

In the chapters that follow, I will first introduce the central ideas of complexity theory as they are relevant to human culture, and especially to speech, and then in each subsequent chapter treat an important issue in linguistics to which an understanding of complex systems can bring new perspective. These chapters do not offer a replacement for well-established and successful methods of structural and generative linguistics, derived as these are from a different, causal scientific approach. These traditional methods arose in an attempt to bring new science to problems in the study of language, along with new social sciences that sought to do the same thing in other realms of human experience. The social sciences have not failed (*pace* Wilson and Gould, as described in Chapter 2) but rather have made great progress over the last century in our understanding of human social issues, from cultural systems in anthropology to cognition in psychology. A new humanities approach to the study of language with complex systems adds the same kind of alternative perspective that complex systems add to reductionism in other sciences, from physics to evolutionary biology to economics, at the same time that it respects the social history of the different disciplines. Every humanist knows that one's point of view means a great deal to the understanding of whatever facts and problems we wish to confront.

That said, even though the methods of studying complex systems do not replace those of generative and structural linguistics, no linguist can afford to ignore the fact that human language is a complex system. All approaches to human language must begin with speech, and all speech is embedded in the complex system. We all must take account, first, of speech as people use it. This means that we cannot remain satisfied with traditional assumptions about grammaticality, in which we rely on speakers' intuitions about what pronunciations, words, and constructions belong to their languages and which ones do not. The complex systems view tells us that 80 percent of what people can and do say occurs only rarely, so that most speakers would not use those forms.

We have traditionally considered the remaining common forms to be "grammatical," and yet the rare forms are no less a part of one's language. We all use some of the rare forms along with the common ones, just different uncommon forms for different speakers. Human language has a great capacity to allow for and retain a wide range of alternate possibilities for how to say the same thing. Moreover, the scaling property of complex systems tells us that other people are bound to vary in how often they use any of the possibilities, in groups at every level of size. While each group of speakers, from neighborhoods and small communities of practice all the way up to regional, national, and super-national groups, will use a great many of the same rare and common variants, we can always distinguish the usage of different groups by the different frequencies with which the speakers use the different variants. Our own experience as an individual speaker, which includes our membership in the large number of different groups to which we each belong, thus provides poor evidence for what may be "grammatical" for others. We all use a language ourselves at our own nexus of spatial and social and textual possibilities in the wider society around us. Our own intuitions about our own language give us little sense of the range of alternative possibilities available in the wider range of speakers of our language, and we have only a little more sense about the frequencies with which speakers from different groups use the available variants. The most basic assumption of generative and structural linguistics, that we speakers all share the system of a language, share the rules for a language, is simply wrong. We all participate in speech, but the language is a little different, both in its available features and in the frequency with which we use those features, for each one of us individually and for each of us as a participant in every group to which we belong. When we think about rules and systems, these are actually generalizations that we make after the fact from our perceptions of our own language and the language we observe around us; they are not generative or structural in any sense essential to language, but instead just serve to help us organize our perceptions.

The only way to cope with these distributional facts is to take account of them from the beginning. If we do so, we can still make grammars as generalizations about the usage of different groups of speakers, now with better knowledge of how the complex system of language in use forms the empirical basis for those generalizations. Moreover, special areas of linguistics like usage-based linguistics, historical linguistics, cognitive linguistics, and sociolinguistics have all brought traditional assumptions of grammaticality to their own pursuits. The complex systems view can isolate problems in these areas, and a knowledge of complex systems makes it possible to see opportunities for improvements. Therefore, in this volume I will review some of the key points and the literature in these areas, identify problems, and suggest possibilities for a new way forward.

The realization that speech is a complex system is a new and fundamental fact about language. It is not the frosting on the cake, but provides us with an understanding of the flour out of which the cake is made. The realization that speech is a complex system changes everything for linguists. Yes, we can still make grammars, we can still study usage, history, cognition, and social aspects of language, but now we must do so with a new idea about the empirical basis for the generalizations we want to make. This kind of change has happened in other fields. The idea that earth, air, fire, and water were the basic elements of the natural world had to be replaced with the notion of atoms. The idea that the earth was at the center of the universe had to be replaced with the notion of the sun at the center of our solar system. The assumption of Darwinian gradual evolution has more recently had to be replaced with the notion of punctuated equilibrium. It is no overstatement to say that linguists now have to make a similar transition. Our paradigm for how to think about language has changed. Our most basic evidence about language has turned out to be different from what we had earlier expected and assumed. This book suggests why we should and how we can face that fact.

1 Language and complex systems

In Mitchell's (2009: 13) definition, a complex system is "a system in which large networks of components with no central control and simple rules of operation give rise to complex collective behavior, sophisticated information processing, and adaptation via learning or evolution." Complexity, in this sense, does not just mean 'complicated.' The etymology of the word refers to Latin *complexus*, and thus to a number of things encompassed together; something that is *complex* has acquired in English the more specialized meaning 'interwoven,' which conforms to the etymological origins of *complicated*. We can talk about a *complex problem* or a *complex relationship* without meaning anything much more than that the problem or the relationship has many parts that are intertwined together. But Mitchell means something much more specialized that that.

The scientific field known as complexity science can trace its history back to 1984, when the Santa Fe Institute (SFI) was founded (for more details and the quotations here, formerly in the Profile/History statement on the SFI website, see www.intelros.ru/subject/karta_bud/10841-santa-fe-institute.html). Complex systems, also called complex adaptive systems, are "firmly grounded in the quantitative methods of physics, chemistry, and biology" as they are studied at the Institute, and work there extends to a wide range of topics including "global climate, financial markets, ecosystems, the immune system, and human culture." SFI was originally the idea of scientists at the Los Alamos National Laboratory like the chemist George Cowan, and attracted support from well-known physicists Murray Gell-Mann and David Pines and mathematician Gian-Carlo Rota. Also significant was support from the CEO of Citibank, John Reed, who saw complex systems as an alternative to traditional economics. SFI remains focused on a new approach to science:

> doing complexity science required a commitment to observation, experience, and experiment that is in balance with the transdisciplinary, out-of-the-box curiosity that gave rise to the original question. It's not that outcomes in complex adaptive systems are repeatable as they are in many scientific disciplines; complex systems are by definition unpredictable, and often downright squirrelly. But finding the patterns embedded in complex systems requires a distinct brand of scientific rigor and methodological approaches that in many cases haven't yet been invented.

Complexity science, then, grew up at SFI and elsewhere in opposition to what the founders thought was the "stove-piped, bureaucratic, funding-centric approach to science that had taken hold both at the federal laboratories and academia." At bottom, modern complexity science is committed "to looking at any problem through an empirical lens and seeking quantitative patterns" in its founding scientific fields but also in economics, the other social sciences, and the humanities. Complex systems, as Mitchell defines them, stand in opposition not just to the funding patterns of modern science but also as to cause-and-effect reductionism, the model most often applied in modern science. Complexity science does not abandon the empirical observation, rigorous methods, and quantitative analysis that characterize modern science, but also does not expect that simple causes can be found for the effects we observe in "large networks of components with no central control," the domain where complex systems can be found. Complexity science does not replace reductionism completely, which works very well in many domains, but rather serves as a better alternative for a scientific model in its own domains. As I argued in Kretzschmar (2009), speech is one of those domains.

While complexity science was taking off at SFI, it did receive some early allusive discussion in linguistics: Lindblom, MacNeilage, and Studdert-Kennedy published a 1984 paper on self-organizing processes in phonology; Paul Hopper presented his seminal paper called "Emergent Grammar" in Berkeley in 1987 (see Chapters 3 and 4); Ronald Langacker published a chapter titled "A Usage-Based Model" for cognitive linguistics in 1988. Gradually more papers attempting to use complex systems in linguistics appeared in the 1990s, such as Van Geert (1991). In 1996 Edgar Schneider presented a paper whose title was a question, "Chaos Theory as a Model for Dialect Variability and Change?" (published 1997). At that time, it had already been over twenty years since the original paper on climate by Edward Lorenz that asked the question, "Does the Flap of a Butterfly's Wings in Brazil Set off a Tornado in Texas?" (1972), and over ten years since the founding of the SFI, where chaos theory was studied as part of the emerging field of complexity science. But it was very early for a student of language to consider the subject as a serious model for speech. In the same year, J. K. Chambers commented in a book review that "We will need a coterie of sociolinguists expert in chaos theory before we can make a start [at applications to our field]" (1996: 163). Chambers noted that the biggest problem for language applications then was that chaos theory seemed to require a long series of observations over time, a rare commodity for those who systematically record language in use. At about the same time, Diane Larsen-Freeman (1997) suggested the use of complexity science for the study of language acquisition. Five years later, Joan Bybee proposed that frequency effects observable in language use could be connected with complex systems, in that linguistic structure itself might thereby be generated (2001, discussed more fully in Chapter 3). In the meantime, there was no thoroughgoing attempt to align evidence from speech with the basic principles of complexity science until Kretzschmar (2009).[1] As will become clear, not only does language in use conform to the requirements of a complex system, analysis of speech evidence in terms of a complex system can help to resolve a number of long-standing problems faced by linguists.

Examples of complex systems

Let us begin with a simple and familiar example of a complex system: ants.[2] Ants are not smart. They can only do a few things, like exploit food sources, build nests, and defend themselves against intrusions, but no commissar of ants tells them to do any one of them. Instead, ants just happen to be doing one of their tasks at any given time. In searching for food, for example, ants wander around randomly; if they find some food, they leave chemical traces, called pheromones, along their path back to the colony (see Wilson (1998: 74–77) for a brief treatment of his discovery of ant pheromones). Other ants can follow the traces, and leave more traces on their way back, till the path becomes a line with lots of ants on it to exploit the food resource (Figure 1.1). However, not all of the ants in the nest follow the path; some keep foraging and some stay home on nest and defense duty, again not because they are told to do so by any central authority: the queen is the biological center of an ant colony but does not direct its activities. When ants come boiling out of a nest when it is disturbed, a great number of them are changing their behavior at once from food or nest duty to defense. The defense reaction of the ants is a local example of Gould's "contingency," the fact that current conditions, whether a meteor strike on the evolutionary scale, or an incautious human footstep for the ants, must influence the outcome of a complex system (see Chapter 2). However, not all of the ants leave to gather food or rush to defense given the stimulus to do so. Some stay on nest duty during a provocation, and some ants look randomly for food when most have joined the line to a known food source. What looks

1 Kuhl (2003) does make a serious effort to align complexity science with particular data, but not for populations. Kuhl treats particular speaker interactions and, as Kuhl put it, "the idiolect as autonomous adaptive organism" (2003: 78). Dahl (2004) treats "linguistic complexity" in a different sense, from a highly formal point of view, in line with the general definition of complexity and not the more specialized sense presented here. Kretzschmar 2009 offers references to other linguists who make some allusion to complexity science, notably Mufwene's analogy of language of biological evolution (2008), or who develop a single aspect of it, notably Zipf's Law. More recently, Larsen-Freeman and Cameron (2008) and a group including Joan Bybee and Nick Ellis (Beckner et al. 2009) have discussed language structure as the outcome of a complex adaptive system, and these discussions will be treated in Chapter 3. Chapter 1 is based on Kretzschmar (2010).

2 The discussion of ant behavior is derived from Mitchell (2009: 176–184).

Figure 1.1 Ants in a line. "Ant Trail." Author: Reyham Soenasto (www.myfolio.com © Reyham Soenasto; licensed under the Creative Commons Attribution-ShareAlike 2.0 Generic License)

to us like highly organized behavior is not controlled by any leader, and it is not absolutely determined by particular stimuli, but instead patterns of activity emerge from the random instinctual behaviors of ants as they are conditioned by circumstances. These patterns of activity, the result of the complex system, make the whole more than just the sum of a few instinctive behaviors.

From the point of view of a single ant, it merely does one of three things: finds and carries food, builds the nest, or defends the colony. Lacking any sort of stimulus, the behavior of different ants is random. What the ant does at any given time is influenced, but not determined, by what happens near it; when it detects chemical traces or touches antennae, an ant becomes more likely to enact one out of the three behaviors. Individual ants are subject to feedback from other ants. In a primitive way, they exchange information by means of their antennae and pheromones. So, if we now consider whole colonies of ants, we see that the feedback within an otherwise random system is what leads to development of frequency-based patterns of activity, which is what makes such a system complex. For an ant colony to survive, the system has to be random at its core and not deterministic. If all of the ants were deterministically required to follow the line to and from the food source, the nest could decay and might be lost to attack. If all of the ants just built the nest or stayed in defense mode, they would starve. Some of the ants need to continue enacting each of the behaviors.

On the other hand, feedback, the exchange of information even between creatures with no understanding, allows for the balance of activity, the frequency with which ants enact one of their behaviors, to shift towards the task that present circumstances demand. The contingencies of the moment do not cause just a small deviation from randomness: lots more ants are in the food line when that is the current need, and lots of ants rush out in defense, dangerously so for your foot on a Southern American fire ant mound, so the frequency profile of ant behavior is subject to sudden large changes. These changes in frequency profiles "emerge" as the current output of the complex system. On the evolutionary scale, Gould described such sudden large changes as "punctuated equilibrium" in the evolution of species (see Chapters 2 and 5). On the scale of ants, it may take only a few moments for defense mode to shift back to repair of the nest. Emergence, therefore, occurs continuously for complex systems. We often recognize it as having the shape of some structure, like a new species in evolutionary time or a line of ants leading to food, but emergence is founded upon frequency shifts in the behavior of the components in the complex system: ants, antibodies, genes, quanta in physics, agents making economic transactions, or innumerable other participants in complex systems. Finally, we can see that the complex system of the colony depends upon the continual motion of the ants. Each ant has to keep moving in order to allow the exchange of information that permits the colony as a whole to react to its current circumstances. It would literally be fatal for the ants to reach some equilibrium state and stop reacting to conditions. The real story of evolution is the same: adaptability over time in response to changing conditions, over a much longer timescale than the ant colony enjoys. In an era of climate change we may soon see what parts of our ecosystem and human cultural systems are adaptable enough to change with the climate as these complex systems react to changing conditions.

Ants are not smart, but they are animate. As it happens, animate life is not required for this kind of complex behavior to manifest itself. So-called "glider guns," from a computer program called Conway's Game of Life (Gardner 1970; animated versions can be found online, at Youtube or Wikipedia for instance; popular information or common knowledge will occasionally be cited from Wikipedia here, as a supplement to the usual citation of more authoritative sources), continually generate patterns that over time move across a matrix of squares that can be either white ("alive") or black ("dead"). The complex system of change in action in which the changing patterns in one part of the matrix continually generate "gliders" results from some simple rules as they

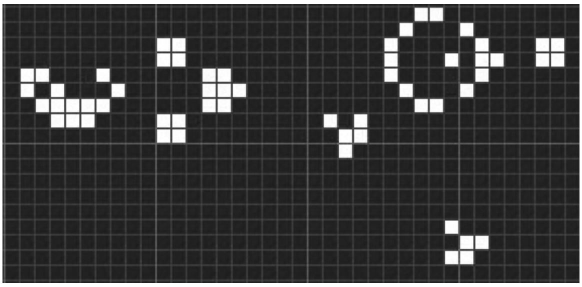

Figure 1.2 A board showing "gliders" (five cell combinations that begin in the middle and move to the lower right) from Conway's Game of Life (Gosper Glider Gun.YouTube video by nbidyanta.www.youtube.com/watch?v=pvUiA-Q-3hM)

are applied at any time step in the program: if any dead square is next to exactly three live squares, it becomes alive; if any live cell is next to two or three other live cells, it stays alive; in any other condition, the cell either stays dead or becomes dead. These simple rules generate changes in the pattern of live and dead cells across successive time steps. The initial state of the matrix clearly matters: if there were only a few scattered live squares to begin with, the matrix would immediately go dark; most arrangements of live cells do not produce the regular behavior of the gliders; but some arrangements of live cells do create the circumstances that, with these simple rules, generate a complex system. Again, for the complex system to work, it has to keep moving across time steps – we could not watch the pattern of gliders otherwise. The rules for the Game of Life represent the exchange of information in the program; as for the ants, given current circumstances, the rules allow the behavior of a cell to be influenced by neighboring cells between time steps.

The Game of Life is a particular instance of a mathematical model, most often implemented on a computer, called a cellular automaton. Life and death in cellular automata are just metaphors; the importance of discussing cellular automata here is to show that complex systems are amenable to mathematical analysis. Ants are hard to count, and of course the fact that ants can only do one of a few behaviors at a time simplifies life in the ant colony so that we can make better sense of it. Cellular automata offer us a much more controlled environment in which to study the operation of complex systems. It is possible, for instance, to study all possible outcomes of the simplest cellular automata as Stephen Wolfram has done (2002). Wolfram found that only a very small number of the possible outcomes are complex, as opposed to those that soon settle into a fixed or alternating state, or never settle down and so continue to be chaotic, essentially unpredictable except at very long timescales. It is also