1

ARTICULATING BABEL

A Conceptual Geography for Cultural Evolution

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After the initial construction of the mathematical theory of population genetics in the first third of the twentieth century, its amplification and application took place largely through an elaboration of a mostly simplified theory based on panmixia, or random mating. This assumption was equivalent to ignoring any significant form of population structure. Much richer theories that explore dimensions of population structure and evolution in metapopulations have only taken off within the last generation—despite the foresight and theoretical directions provided by Sewall Wright. A corresponding uptake within theories of cultural evolution has not yet occurred despite the multiplicity of developmentally and culturally mediated sources of population structure. In an effort to facilitate an increasing incorporation of these factors, allowing a richer set of theories, I describe the many ways that developmental and population structure can enter into processes of cultural evolution, with special attention to the kinds of results they can produce. Corresponding to the architecture of the genome as an important source of structure in genetics (e.g., for linkage mapping), cultural evolution has as a source of structure the developmental dependencies (or what I have termed *generative entrenchment*) among cultural elements acquired over time in the learning of complex abilities. This structure is not as simply specifiable as the genetic structure of linkage relations (being more akin to the causal network structure of gene action), but it is well defined and, for culture, relatively accessible for reasons I discuss below. Corresponding to the external population structure of biology, cultural evolution has structured environments of learning and production that are scaffolded by social organizations, institutions, technological infrastructure, and specialized material artifacts and practices. The technological infrastructure and its articulation with our practices are particularly important since they are formative elements in our cognitive constructed niche (e.g., Wolf 2008) and not merely a kind of transmitted cultural content.

I begin with a survey of the multifarious disciplinary approaches to cultural evolution. Next, I characterize the structures that guide and amplify cultural change processes, as well as examine how they articulate with diverse disciplinary approaches, and then discuss their implications for what counts as relevant cultural units required for an adequate theory. Just as evolutionary theory can be seen as an organized series of heterogeneous models in relation to several general principles, so also theories of the evolution of culture should exhibit a similar structural heterogeneity, given the large diversity of hereditary and production systems that interact in rich and varied ways.

THE SCOPE OF THE PROBLEM

The field of evolutionary developmental biology (evo-devo) has emerged as a rich and multifaceted paradigm over the past three decades (Love 2003, 2013, 2015). It includes cross talk between developmental genetics, genomics, evolutionary genetics, cell biology, morphology, embryology, paleontology, systematics, and even, increasingly, behavioral biology and ecology. Each of these areas has provided important perspectives on the evolutionary role of development and, through substantial interactions, changed both the problem space and what count as acceptable solutions across these disciplines. Evo-devo is a natural paradigm for the interdisciplinary linkages one should expect to appear in the study of cultural evolution. Although it is tempting to think of "culture" simply as a complex adaptation of one species, this ignores the internal structural and dynamic detail of human cultures. Cultures are complex beasts, in many ways more analogous to evolving ecosystems, in part because of the richness and diversity of modes of horizontal transmission. This tends to break down what might otherwise be seen as species boundaries. But there are other complexities. The multiple evolving and interdependent lineages acting on different time and size scales within cultures and the recursive embedding of cultural elements and processes operate similarly to richly interacting species in an ecology that contains everything from primary producers to keystone predators, bacteria-mediating digestion, and, ultimately, the recycling of its constituents into the biosphere.[1]

Evolutionary theory is interdisciplinary; it spans the whole of biology and draws insights, concepts, and tools from many diverse disciplines. For the study of cultural evolution, almost all of these insights, concepts, and tools are relevant. However, the emerging interdisciplinarity surrounding the study of cultural evolution is in its early stages—the range of relevant theories substantially exceeds (and, in many cases, complements) those of the biological theory. Pertinent dimensions include an elaboration of the ecology of human evolution and the characterization of new hereditary channels, many of which are transmission pathways for information not present in most biological cases, such as spoken language,[2] written language, the telegraph, the telephone, and the Internet. Each of these provided new channels for information transmission that were independent of and yet complementary to the others. Although written language was probably the greatest facilitator of cumulative culture, the relative contributions of different transmission pathways in different contexts demand further study.

Inquiry into the evolution of different cultural forms requires combinations of approaches within recognized disciplines (e.g., combinations from cultural anthropology, paleoanthropology, and archaeology within anthropology, broadly construed), as well as combinations from across disciplines (e.g., from genetics, epidemiology, history of technology, and linguistics). For example, to understand a particular exemplar of culture, say, a primitive wheel, researchers might require an array of diverse techniques that includes a search for related artifacts; radioisotope dating for archaeological artifacts; phylogenetic methods, modified to handle reticulation resulting from horizontal transfer, to analyze data from comparative linguistics; and agent-based modeling to ascertain likely patterns of spatial movements for and between groups.

Our growing technologies have midwifed elaboration of our constructed niches, scaffolding differentiated roles and communities of language and practice. These in turn yield new complex ecosystems of production. As a consequence, an interdisciplinary approach to cultural evolution is necessary. This applies in discussions where the focus is the intersection of cultural evolution and biological evolution because *gene–culture coevolution* perspectives must articulate with various dimensions of biological theory as expanded to include evo-devo. It also applies when dimensions of culture have become sufficiently autonomous, and their rates of change have escalated to the point that standard genetic variation is largely irrelevant, though even there, in some cases, epigenetic variation may still be important. Even in these circumstances, when we consider culture as an evolutionary system in its own right, we need new techniques and new conceptual frameworks—not simply new massive data sets—to develop an adequate theoretical viewpoint from which to investigate and explain cultural evolution.

Currently, there is no consensus paradigm for how to approach cultural evolution, not even along the lines of the synthetic theory of evolution or the neo-Darwinian paradigm, which itself is being openly scrutinized (Laland et al. 2015). However, there are signs that different theoretical accounts from relevant disciplines could be on trajectories that lead to increased coordination in the near future. Take, for instance, the *dual-inheritance* approach spawned by Cavalli-Sforza and Feldman (1981) and subsequently elaborated by many others (Boyd and Richerson 1985; Richerson and Boyd 2005; Durham 1992). Rich developments of these ideas have appeared in economics (e.g., Nelson and Winter 1982; Mokyr 2002; Murmann 2003), linguistics (e.g., Mufwene 2008; Pagel 2009), and archaeology (e.g., O'Brien and Shennan 2010; Andersson 2011, 2013; Tostevin 2013). These and other expanding research programs are often governed by a specific paradigm that is manifested in graduate students, programs, conferences, and jobs. Of these, the work of Boyd and Richerson has had the broadest influence. Other areas, such as the history of technology (e.g., Basalla 1988; Arthur 2009) or history of scientific change (Griesemer and Wimsatt 1989; Wimsatt and Griesemer 2007; Wimsatt 2012; see chapter 4 of this book) have practitioners with an evolutionary perspective, and there is a large literature on innovation studies (e.g., in management and business) relevant to but mostly not integrated with work on cultural evolution (e.g., Lane and Maxfield 2005; Lane et al. 2009).

Given this diversity, it is not surprising that no common unifying focus has emerged for studies of cultural evolution.[3] Indeed, besides difficulties arising from trying to cover such a complex problem space, some researchers resist these kinds of studies altogether. For example, symbolic anthropologists tend to deny the relevance of any evolutionary or biological perspective on culture and sometimes ignore or dismiss the cultural changes that do occur.[4] This type of view is more widely distributed among social scientists and some biologists (e.g., Fracchia and Lewontin 1999; Gerson 2013b). In cognitive psychology from the mid-1960s up into the 1990s, psychologists cultivated a perspective that was both anti-evolutionary and asocial.[5]

Language competency was a paradigm case that spearheaded Chomsky's attack on Skinner's behaviorism. But the internalism of psychology that emerged in response to behaviorism (complete with methodological justifications; e.g., Fodor 1980) was a swing too far and especially paradoxical as applied to language because Chomsky's claims about the unity of a "language module" and his assumed account of innateness were both biologically problematic (Wimsatt 1986; Dove 2012; see chapter 9 of this book) and because language is such a richly social and cultural phenomenon.

Although we must reject some of the attitudes of the critics of an evolutionary approach to culture, that does not mean we can afford to ignore their chosen phenomena and subject matter. The realm of intention, meaning, and symbolic thought is crucial to understanding the nature of culture. Connections between thought, culture, and language are very deep. However, intentionality and the symbolic character of thought are not isolated logically from evolutionary processes. A perception of this isolation may derive from how critics of evolutionary approaches represent these aspects of human culture. Language is profoundly developmental and social; the formation of dialects (Mufwene 2008) and the differential stability of words for commonly used concepts across languages (Pagel 2009) exhibit some of the clearest evidence and crispest data for cultural evolution. The origins of language (see chapter 9) and the coevolution of linguistic capacities with human sociality, cognition (Sperber 1996, 2001), and tool use pose one of the most challenging and rewarding areas of study for archaeology (Sterelny 2012; see chapters 7 and 8 of this book). More recently, the explosive acceleration and expansion of cultures with the invention, adaptive radiation, and divergence of *written* language is a prime area of study for the evolution of technology (see chapter 9 of this book; Woods 2010) Moreover, there is a correlative coevolution of cognitive skills and reading that reflect the impact of our technology on our own evolution (Wolf 2008).

Subsequent chapters in this volume explore some of the new interdisciplinary linkages that might move us toward a more productive articulation of existing disciplines bearing on cultural evolution, including new kinds of cases to act as *model organisms* (see chapter 6) and new concepts to aid in their analysis (e.g., the temporally structured characterization of differentiated cultural breeding populations). One strategy allied with these approaches is the use of more general themes, principles, structures, and causal processes to midwife new linkages among relevant disciplines. For example, are there core problems or techniques that can provide foci for organization, as well as residua not captured by existing theoretical frameworks or methods that expose revealing exceptions and point to other relevant perspectives? Biologists have taught us that we must be opportunistic in seeking cases that are tractable and generate meaningful data. We must "seek the right organism for the job," and this volume brings together promising approaches to finding and leveraging suitable models to comprehend the evolutionary dynamics of different aspects of culture.

Commonly, the first theories to be formulated in a domain focus on dominant causal factors in a maximally simplified context to illuminate the operation of major mechanisms. Later theoretical developments amplify the explanatory power of earlier theories by adding layers of context that characterize real systems. In this the likely most productive strategy will be to place special emphasis on localizing the failures of these simpler models and on the estimated effects of including what is left out (Wimsatt 1987, 2002a). The chapters herein emphasize the roles of diverse types of structure in guiding and scaffolding cultural change in acting agents engaged in diverse relationships of interaction, which manifest more broadly as organizations and institutions that themselves facilitate and channel cultural change. The results point to much more powerful, versatile, and realistic theoretical resources.

ELEMENTS OF A PROTOTHEORY FOR CULTURAL EVOLUTION

The different disciplinary approaches to culture demonstrate that it has an impact on an observer at multiple levels and from multiple perspectives. An account of culture must show how these act and how they articulate. Thus, we can track different ideas, practices, habits, conventions, skills, individuals, artifacts, technologies, art forms, disciplines, religions, social structures, institutions, organizations, theories, and more. The list goes on almost indefinitely. These are not different species, however, for the multiplicity of their interactions—symbiotic, parasitic, and competitive—make them too interdependent, so the relevant unit for most cultural evolution is more like a richly interacting ecosystem or subsystem.

It may be too soon to construct a full-blown dynamic account of cultural evolution, but I wish to lay out here the conceptual geography of the necessary factors and elements of such an account, and why they are necessary. A fuller theory can then result by constructing different submodels of the interaction of these elements and studying their behavior. Two additions are necessary elaborations of the present population-based dual-inheritance theory as it stands, one emphasizing a perspective on developmental dependencies and another elaborating a notion of breeding populations relevant to cultural evolution. In conjunction with these additions, I delineate five crucial elements that comprise the components whose interactions produce cultural maintenance and change and a crucial relationship articulating them.

One cannot have an adequate account of cultural evolution without recognizing a central role for cognitive and social development. Different dimensions of culture are cumulatively acquired by individuals through a life cycle in which there is a rich structure of sequential and parallel dependencies mediating the sequential acquisition of skills (Wolf 2008; Hiscock 2014) and the parallel development of different facets of the individual. A rich and variegated array of social and cultural organizations and institutions support and structure these developmental processes (Wimsatt and Griesemer 2007; Sterelny 2012; Andersson 2011, 2013; Caporael, Griesemer, and Wimsatt 2013; Anderson, Tornberg, and Tornberg 2014). In light of this, what form should an evolutionary theory of culture take? Part of this task lies in characterizing the kinds of units that must be *used* in theories of cultural evolution, as well as what units must be *accounted for* since they are themselves cultural products. Then we have to look at the kinds of things that are evolving through interactions among these kinds of units and determine what heuristics are available for coming to understand their dynamics.

The Roles of Development and Population Structure for Culture

Two things seem central to account for the reticulate complexity of culture from an evolutionary point of view. The first is an insight from evo-devo applied to culture: development is even more important to the dynamics and structure of cultural transmission and change than it is to biological evolution. The second is a transformed notion of “breeding population” derived originally from population genetics but modified to reflect the nature and modes of cultural inheritance in individuals.

Aspects of Culture Are Acquired Sequentially by Individuals throughout a Life Cycle

I would argue that the primary target of analyses of cultural evolution should be skills. Some must be acquired before others can be. This sequential acquisition means that dependency relations within and among complex, sequentially acquired skills should play a central role in characterizing aspects of culture and their evolution. All skills are honed through practice, and complex skills are taught and assembled through a succession of stages where performance at later stages requires mastering and assimilating earlier ones (Greenfield, Maynard, and Childs 2000; Stout 2005; Thornton and Raihani 2008). Wolf (2008) documents this extensively for the coevolution and development of written language, reading, and cognition, both in history and in the developing child, and Hart and Risley (1999, 2003) show how different exposures to spoken language in deprived versus enriched language environments have multiple downstream impacts on cognition and socialization in young children. Many cultural elements cannot be understood or used unless appropriately prepared by prior experience and training. This provides a rationale for ordered teaching curricula that are organized and structured to facilitate the seamless assimilation of both intellectual content and practical skills (Warwick 2003). And one generally requires a deeper mastery of an element to teach it or to demonstrate its use than merely to use it.

A particularly striking case is the interweaving of mathematics and quantitative sciences through mutually supporting skills that are first acquired during primary and secondary school and further developed in college and graduate school. However, sequential dependencies are found as formative structures throughout most complex skills, including reading and reading-dependent cognition as well as argumentative skills (Wolf 2008). Thus, we must understand cognitive development, both in general and in particular kinds of cases. It is inadequate to scrutinize only the acquisition of general skills, like language use in speaking, along with the socialization processes studied by cognitive psychologists (many of which are acquired "spontaneously" in normal interaction). One must also investigate more particular forms of cognitive development, especially those that demand explicit training or the design of curricula, such as reading, writing, mathematics, and more specialized and professional skills such as car repair, animal husbandry, medical diagnosis, engineering drawing, chemistry, the solution of ordinary differential equations, programming in Java, and genetics. Humans have many such skills, which are deployed in different combinations. The notion of scaffolding is crucial in understanding and facilitating their acquisition (see below, section 4). These skills and their codeployment, such as the role they play in constructing group identities (see chapter 12) and configuring the status of such groups in a society, are the source of most differentiated complexity observed in culture. The work on the generation and nature of subcultures in the professions, or even within individual corporations, document what makes an “IBM man” or a photovoltaic engineer (Bucciarelli 1996). A major problem for memetic and most dual-inheritance theories is their inability to recognize the organizing structure provided by these dependency relations.

Although the curricula of the natural sciences and other academic disciplines reflect this kind of sequential dependency for complex skills, it is no less characteristic of complex manual skills in prehistory or in contemporary life (Hiscock 2014). Tostevin (2013, chapter 8 of this book) argues that the products of lithic technology can be produced in multiple ways and therefore do not reveal (by themselves) the culture transmitted to produce them. As a consequence, he formulates an observational and experimental methodology to uncover the sequences developed to make stone tools and lithic-dependent technologies in order to track their evolution. Mathematical development requires developing the subject sequentially (Warwick 2003), as does the experimental methodology of classical genetics. More advanced techniques require the mastery and practice of more basic ones.

> We have attempted to treat the subject . . . as a logical development in which each step depends upon the preceding ones. This book should be read from the beginning, like a textbook of mathematics or physics, rather than in an arbitrarily chosen order. (Sturtevant and Beadle 1939, 11)

Yet to learn a skill is not enough for the elements to be presented in the right order. The earlier elements and techniques must be mastered through practice so that their execution becomes habitual, quasi-automatic, and standardized. This is what makes assimilating these skills possible.

> Genetics also resembles other mathematically developed subjects, in that facility in the use and understanding of its principles comes only from using them. The problems at the end of each chapter are designed to give this practice. It is important that they actually be solved. (Sturtevant and Beadle 1939, 11)

The mastery of earlier skills, including the modulation of different steps, allows their *chunking (or articulation)* and deployment as components in still more complex skills in a semiautomatic manner. These, in turn, are mastered similarly, thereby creating a hierarchy of increasingly complex skills. The skills and competencies acquired in one discipline affect the possible reach of individuals into other disciplines without substantial supplementary training or close collaboration. They also attune individuals to the relevance of other disciplines for their research problems. This dependency structure of skills and knowledge thus modulates likely directions for forming interdisciplinary linkages.[6] Dependencies recapitulate the order of instruction and the design of curricula. Biochemistry presupposes organic chemistry, which presupposes general chemistry. And the dependencies continue: biochemistry is presupposed by cell biology, as cell biology is for developmental biology. And correlative skills are required as well: none of it can be taught without mathematics—often, increasingly sophisticated mathematics to master the details of some kinds of interactions. In instruction within a discipline, the same topic is often revisited multiple times as more sophisticated and powerful methods enable a more detailed and deeper analysis of the subject matter. Janssen (see chapter 4) demonstrates how earlier theory guides and scaffolds the creation of later theories in the transition from classical mechanics and electromagnetic theory to relativity theory and quantum mechanics, which suggests how this dependency structure plays a role not only in learning but also in complex theory development. So this structure of dependencies is reflected both in the evolution of experimental methodologies and in the construction of successor theories.

Such dependencies exist everywhere in culture, and there are broader consequences of this generative entrenchment for culture and technology. They affect what we can learn, what we must learn first, and where we can go from what we have learned so far. But these dependencies affect more than learning. They condition what changes can be made in our technologies and institutions, and in what order. A deeply entrenched trait in biology or culture is one that is difficult or impossible to change because so many other things depend upon it, and virtually any other change wreaks havoc elsewhere in the system (Wimsatt and Griesemer 2007). Thus, the dimensions of English and metric threaded fasteners are deeply entrenched, fixed within their respective mechanical technologies, and mutually incompatible (Wimsatt 2013).

Such changes are relatively rare, but analyzing them has methodological consequences. A successful change in a functional element of an adaptively integrated system requires that the main functions of the existing element and compatibilities with other parts be maintained. The more downstream dependencies that exist, the more demanding are the standards for a successful replacement.[7]

This process of replacement can span years or generations and is nicely illustrated with the development of the IBM 704, 709, and 7090 computers. In 1958, IBM released its vacuum-tube 709 scientific computer, the first to emulate an older computer, the IBM 704 of 1954. The move from the 704 to the 709 took four years. The emulation was so the 709 could continue to run older software, particularly FORTRAN, which ran for the first time on the 704 and rapidly become crucial for scientific computing. (This backward compatibility became a virtual requirement for newer computers and software packages from then on and illustrates my point.) IBM then put the 709 team to work producing the 709T, (or 7090), a logically identical computer substituting transistors for tubes. This is conservation of function in spades! Released only a year later, the 7090 was smaller, more reliable, and half the cost, with much lower (five volt) power requirements (no high-voltage filament transformers for vacuum tubes) and a much reduced need for air conditioning. It also ran six times faster. With higher reliability, it had much less downtime, and its higher speed allowed real-time control of processes that the 709 could not manage. But for all of these massive (and advantageous) changes in support structures, the 7090 was logically identical as far as running programs was concerned. This conserved function made it quick to develop, since it immediately had functioning software, and its other characteristics gave it much wider distribution and use. It fomented a revolution and guaranteed the role of the transistor and, in later descendants, the integrated circuit, as the basic construction element in future computers. The broader use of integrated circuits spawned an information technology revolution that has penetrated all aspects of our other technologies and has deeply modified our behavior, connectivity, and culture.

A successful change in a deeply entrenched element can play a major generative role in the elaboration of downstream elements, effectively producing in science or technology an adaptive radiation or a scientific or technological revolution, as exemplified above in the development of computers and also by the development of the internal combustion engine as a power source. It is now used in applications ranging all the way from chain saws and lawn mowers, through automotive engines, to truck and marine diesels. In each case it provided a lighter, more tractable, and more powerful substitute for steam power or, at the smaller end, a power source where steam would have been impracticable. (This proliferation was noted extremely early: Page

[1918] lists a three-page classification of types of internal combustion engines only thirty years after their invention.) And it reaches far beyond the target element. Thus, the Chicago yellow pages for 2001 had ninety-five pages, at five columns per page, listing thousands of businesses falling under dozens of different categories relating to "automotive," and the integrated chip spawned an information technology revolution that has penetrated all aspects of our other technologies and deeply modified our behavior.

The probability of a successful change declines with the acquisition of further dependencies. Elements with different degrees of entrenchment can be expected to evolve at different rates. Working from different evolutionary rates to degrees of entrenchment, together with looking at which things change or are conserved together, is a fundamental tool of inference in untangling developmental programs and in constructing phylogenies in biological evolution (Wimsatt 2015, see below). Similar design principles are integral to biological organisms, which can be seen as complex variations on the theme of cellular organization and conserve the entrenched features necessary to cellular function and reproduction. Our technologies are even more obviously organized; dependencies that recapitulate their histories exist in the design of our computer software and hardware, as well as in other technological systems, where sequential acquisition and hierarchical modularity is endemic (Arthur 2009; Wimsatt 2013), and early contingent commitments can leave a long shadow as they become increasingly entrenched. Such things are difficult and expensive to change, as was illustrated in the massive readjustments involving reprogramming software and the purchase of new computer hardware to address the Y2K threat posed by the two-digit representation of years widely embedded in software. The two-digit representation would in 2000 AD have become ambiguous between that date and 1900 AD and wreak havoc on financial and other time-sensitive data (Webster 1999). The necessary changes to a four-digit representation were extremely far reaching and costly, including massive reprogramming (contracting out work to programmers in India, thus creating an industry to compete with our own) and a substantial peak in the purchase of new computers with the appropriate hardware.

Individuals Participate in Multiple Sequential and Parallel Cultural Breeding Populations

Biological evolution (in sexual species) has a single breeding population in which diploid mating mediates heredity in a systematic fashion. The genetic bases for all traits are inherited together at the same time. Cultural evolution, by contrast, takes each individual through learning trajectories that traverse multiple successive and simultaneous parallel cultural breeding populations. The acquisition and transmission of diverse skills acquired over time include multiple "parents" in proportions that can vary from person to person and generation to generation (Wimsatt 1999, 2010; chapter 5 of this book). We inhabit and pass through a number of culturally defined peer groups (or *reference groups*) in our life cycle that delineate our identities and inform our skills, sometimes sequentially and sometimes contemporaneously (see chapter 12). The structure of such groups, membership criteria, migration patterns between groups, and the factors mediating these movements are proper objects of study for sociology. The identities we acquire in the process of participating in and across different breeding populations (Smaldino) inform us and provide values that shape future choices and trajectories.

Depending on the mobility and degree of role differentiation within a society, these trajectories may differ substantially from individual to individual. However, they can still exhibit strong similarities from "common education" or within "trades" and "professions" with standardized content and modes of training, often with certification exams or procedures to increase the heritability of skills and standardize knowledge and competence, generating subcultures within the society. Medical doctors display diplomas on the walls of their office but so do many auto mechanics! It is crucial to understand the production, maintenance, and articulation of these groups through individuals that participate first as students in successively more advanced training and subsequently as teachers to those earlier in the learning sequence for groups they comprise (Wimsatt 2001). Some of this knowledge and competence is transmitted to other groups that will use it but only require training up to a less advanced level; secondary math teachers, physicists, and engineers are typically less advanced users of mathematics than mathematicians. This is the analog of *age-structure* models in biology, though they must be elaborated further to capture cultural phenomena.[8] Such professions are in many respects organism-like and self-reproducing within the context of a broader supportive society. How groups articulate with one another is also crucial; societies in which reading and writing are promulgated only through a priestly class or in monasteries are very different from those in which these skills are acquired in a universal public education system. The groups themselves have an identity and characteristic content.

The sustained interruption of a profession that teaches and practices a complex of sequentially acquired skills can lead to the cultural equivalent of species extinction, or even the disappearance of a whole ecosystem. The destruction of the giant Chinese wooden junks—far more advanced than European vessels of the same period—by the Ming dynasty in the fifteenth century and the halting of their production for three generations led to the irreversible loss of the associated skill complex (Diamond 1997). U.S. leadership in public education in the nineteenth and twentieth centuries generated a workforce capable of mastering new machine technologies. This education, in combination with the GI Bill that fostered college education after World War II, midwifed our technological and economic ascendancy. Our current shortfall in elementary and secondary school education with respect to mathematics and the sciences is crippling our technological society. Our universities increasingly instruct able and enthusiastic foreign students who will return home after their education, thereby changing the geography of international economic competition.

A variety of training curricula have established trajectories through our complex culture where individuals experience differential exposure to parts of it and isolation from other parts.[9] The distribution and interrelation of social roles in society help to link these population groups, their distribution, the support that society provides them, and the migration of individuals through them. A prominent example is the concentration of innovation, education, jobs, marriage patterns, other institutions and organizations, and financial well-being in city hubs at the national level (Moretti 2012). Moretti uses well-structured economic and sociological information to reveal insights into what fosters creativity and innovation and builds the institutions that scaffold them. His account articulates naturally with economics, psychology, and education, as well as with how developing technologies radiate invention and expansion across fields. It is a paradigm of the kind of cross-disciplinary study required to comprehend the various strands of evolving cultural lineages.

These two elements—sequential acquisition through a life cycle and multiple cultural breeding populations—serve to indicate the central role that development and population structure play in the maintenance, transmission, and elaboration of culture. Population structure is a central feature of modern evolutionary theory, but its importance is far greater for culture than for biology due to the role of development in the acquisition of knowledge or skills and the elaboration of social structure.[10] The critical role of sequential acquisition indicates that we need to actively combine evolution and development. To account for cultural change over time, we must adopt an evo-devo perspective. Cultural population structure, mediated by social institutions, organizations, and technological scaffolding must be integrated with this and incorporate new dimensions of theorizing about cultural transmission and evolution. Few of the extant perspectives on cultural evolution have considered either (but see Wimsatt and Griesemer 2007; Wimsatt 2010; Sterelny 2012; Caporael, Griesemer, and Wimsatt 2013). An expanded ontology is needed for an integrated account of cultural evolution that accommodates these complexities (see below, section 4).

A Curious Theoretical Inversion in Biological versus Cultural Evolution

An intriguing and important difference between biological and cultural evolution is that the study of biological heredity has become more tractable with technological progress in classical transmission genetics, population genetics, and (subsequently) molecular genetics.[11] By comparison, the study of development or developmental genetics in biology, though getting easier, is a much more difficult topic. As a consequence, it is tempting to see genetics at the center of the theoretical structure of biological evolutionary theory, with development and even ecology being derivatively informed by the same source. For culture, by contrast, heredity is a mess. The possibility of multiparental inheritance of varying degrees, latencies of transmission (e.g., cultural influences can skip generations; Temkin and Eldredge 2007), and diverse modes of transfer that can vary irregularly makes the study of cultural transmission enormously complex (Wimsatt 1999; chapter 5 of this book). *However, the developmental acquisition of a cultural element has to be possible for learners in the relevant audience so that it can be transmitted and employed. If the appropriate subjects can learn it, then it should be easier for us to study and untangle.*[12]

Specialization reduces the technological overhead that must be mastered by any one individual, vastly expanding the complexity that can be managed by a culture. But there is another crucial element. Learning the technology becomes manageable in part through the fact that past technologies can be chunked or “black boxed” and used without understanding or transmitting all of the knowledge necessary to generate them (Wimsatt 2013); any generation need only study the outermost layer of an accreting onion. Thus, in the teaching of science, it is not necessary to engage in a complete recapitulation of theory development; a designed representation of theoretical accounts resembling earlier simpler stages suffices, as it captures simpler phenomena or acts as a scaffolding for more complex cases (see chapter 4). Technology represents an even more extreme case. Since massive amounts of detail often can be collapsed into a portable result, highly complex nested sets of technological dependencies can be transmitted.[13] Although it would take an enormous team of specialists to dissect, understand, and be capable of reproducing any piece of modern technology from scratch, we only need to master its outer "user interface" or in design, the chunked components that are assembled and articulated at that level.

Therefore, heredity and development in some respects interchange roles in the study of biology and culture. For cultural evolution, a study of developmental, learning, and teaching processes could provide essential levers in understanding cultural heredity and supply the core for understanding cultural evolutionary processes, just as for biology the study of heredity has provided a crucial tool in understanding development. Indeed, I believe this will prove to be the case and yield theoretical perspectives for cultural evolution that will look quite different in spite of many recognizable similarities with what is found in biological evolutionary theory. Will development emerge as providing the core architectural elements for cultural evolution in a way similar to the role played by genetics in biological evolution? It will be interesting to see how this develops.

Additional factors common to both are the layered complexity and generative entrenchment of elements, both in biological evolution and technological development, leading to the evolutionary conservation and cumulative architecture that makes the study of their histories an essential source of insight in both areas. Thus, I have found that my study of original sources in the history of genetics rendered intelligible otherwise mysterious aspects of modern theory, or its choice of certain problems, as crucial, and often with new handles on modern disputes.[14] So developmental generative entrenchment has had a systematic effect on evolving systems from biology and culture.

RELEVANT UNITS OF THE CULTURAL SYSTEM FOR A THEORY OF CULTURAL EVOLUTION

The roles of development and population structure for culture suggest five kinds of units that must be included in any adequate theory of cultural evolution to properly capture the dynamics of cultural change. In discussing them, I will attempt to suggest how they articulate with relevant capabilities and disciplines, sketching the causal linkages pertinent to cultural evolution that are scaffolded by culture itself and characterize the scaffolding relation. Second, I argue that cultural evolution can be seen as interrelations of evolutionary change in several different kinds of processes, which are driven or modulated by a number of correlative changes in other evolving lineages.[15] Finally, I comment on the relevance of time scale in the analysis of these processes and their interactions.

The five kinds of elements necessary for an adequate theory of cultural evolution that account for the role of scaffolding in articulating these elements can be divided into two main categories.

Category 1

1. *Transmissible or replicable elements* (TREs). Examples of TREs include artifacts, practices, and ideas that are taught, learned, constructed, or imitated. These include ideational, behavioral, and material items, which are capable of being modularly decomposed or chunked and black boxed hierarchically.[16] Thus, they can engender multiple levels of organization that may not all be accessible to inspection at a given time. Their modular structure can be circumscribed either within an individual's cognition, capabilities, and interactions with an environment or by an organization or profession that assembles a team of individuals that collectively have the necessary capabilities. There will be populations of TREs at different levels of organization that show variation and therefore can be targets of differential selection.

Conceptualizing TREs as memes has been criticized heavily. The loose characterization of memes allows almost anything to count as one. As a result, it is not possible to explicate how the resulting heterogeneity of items can be reproduced or transmitted in any unitary way. This is especially problematic for an account that focuses so strongly on heredity. This heterogeneity becomes more manageable when one sees that particular kinds of TREs are part of a complex array of elements that interact to produce cultural change and that many of these causal structures facilitate or constrain their reproduction (Griesemer 2013b). Unlike memes (Dawkins 1976), TREs are not autonomous, self-replicating elements. Their spread is conditioned by developing individuals through a life cycle, an aspect not utilized in standard dual-inheritance accounts, and their reproduction is mediated by scaffolding elements from category 2 (Wimsatt 2010, see below). We must not make the mistake of memeticists and fail to see the contextual forest for the TREs.

2. *Developing biological individuals* (DBIs). DBIs develop, are socialized, and are trained over time in multiple cultural breeding populations. The earlier training of DBIs affects their capabilities, exposure, and receptivity to subsequent TREs or to participation in or interaction with elements from category 2 (below). A developmental process of sequential acquisition and assimilation is crucial because the developmental state of an individual determines whether they are "infectible" by a TRE, as well as how they will interpret and use it. The culturally induced population structure of individuals that mediates the exchange and development of TREs is the main driver of cultural evolution and is also a major element of social structure, especially for generating identities, and this has an impact on power structure. This population structure is generated as a consequence of various lower-level units that compose the population (Wimsatt 2010, 2013). Thus, the cognitive and social characteristics of DBIs matter, and the study of cognitive heuristics is pertinent to elucidating the architecture of culturally induced population structure (Sperber 1996; Gigerenzer et al. 1999; Heintz 2013). Individuals may differ in their success or competence at specific skills and therefore be preferred targets for imitation or association (see chapter 12); they may use other heuristics, such as conformity bias, in deciding who to imitate (Richerson and Boyd 2005).[17]

DBIs are socialized through their developmental life histories and make culture through social and enculturated interactions, especially in the acquisition, application, and extension of complex skills. These include both common skills (e.g., language use or socialization, largely in family dyads and family or small peer groups) and specialized skills, such as those acquired and practiced in differentiated roles attached to institutionalized task groups. A distinctive array of specialized skills can be grouped together as a *repertoire* (Leonelli and Ankeny 2015), which gives unity to scientific specialties and helps to organize their research efforts institutionally (Gerson 2013a, 2017). The structure and texture of repertoires characterize much of the complexity we find in culture. DBIs also have psychological tendencies that affect who they interact with and how and what they draw from others.

Gene–culture coevolution (e.g., Richerson and Boyd 2005) and memetic-inspired theories incorporate only some of the structure of TREs and DBIs.

Development and the order-dependent sequential acquisition of complex skills is ignored in extant theories. Population structure is not a significant element in most gene–culture coevolution accounts except for the recognition of biological kin and group selection, along with the fitness possibilities of trait-group effects. The most significant omission is culturally induced population structure and its scaffolding effect on training for complex skills, including coordinated tasks with role differentiation and group identity formation (see chapter 12).

Structures of this kind emerge naturally from interactions of DBIs with elements of category 2, providing further reason for their inclusion in any adequate theory of cultural change.[18] These culturally created structures are constructed parts of the human cognitive, normative, and affective environment that scaffold the acquisition and the performance of knowledge and skills and coordinate their acquisition. Thus, the choice of a profession (an organization with richly structured curricula and institutional norms) scaffolds subsequent learning and commits one to a trajectory of exposure to relevant knowledge and procedures, institutions, and population structures that condition their life course (B. Wimsatt 2013; Warwick 2003). These trajectories structure the sequence of the peer groups we move through and the dependency relations among skills utilized during this migration. This substantially reduces the complexity of social and cultural structure that an individual must face, making the cognitive tasks more manageable. Whether it is promotion to middle management (which may change friends and neighborhood as well as job tasks) or a group identity change associated with age-structured roles (like becoming parents or grandparents), this culturally induced population structure brings order—both in navigating and in theorizing—to an otherwise forbidding complexity of overlapping peer groups.

Category 2

1. *Institutions.* Institutions are ideational structures at a social or group level that constitute or contain explicit or implicit (and commonly internalized) normative rules or frameworks that guide the behavior of individuals: “A collective enterprise carried on in a somewhat established and expected way” (Gerson 2013b). These rules or frameworks apply to individuals either universally or as classified by society for a certain role, class, or profession (e.g., social norms of behavior, legal codes, and transition rituals like bar/bat mitzvahs and graduations). They are diverse and can be quite complex.

The complicated expectations for individuals participating simultaneously in diverse institutions indicate an important role for habit in the formation and explanation of behavior (Duhigg 2012). More broadly, larger swaths of culture can be seen as systems of institutions that are made up of conventions where each institution mediates a collective capacity to carry out a task (Gerson 2013a). Institutions also evolve under changing conditions and demands from social groups. The promulgation and elaboration of engineering standards for different kinds of interchangeable parts in manufacturing was a critical element in the explosion of technology beginning in the nineteenth century and serves an important coordinating function for the design and manufacturing of parts that must meet many constraints to function properly in diverse complex mechanisms (Wimsatt 2013).

2. *Organizations.* Self-maintaining groups of individuals that have self-organized for some purpose or set of shared purposes are organizations. These are like DBIs, but at a social/group level, and include interest groups, such as unions and political parties, firms, nations, and professions.[19] Departments at universities are an excellent example. They recruit students and faculty, produce academic products (papers, books, technology, students), teach classes, and inculcate professional values. They may undergo development as a function of their size, demography, and histories. Sometimes, they reproduce, either with characteristic members that propagate to constitute similar groups or by spinning off new organizations that reflect some of their values, aims, and structure. Although I focus here on their role in transmitting elements of culture, such groups are also commonly foci of political action and the expression of power through their common purposes.

Complex group interactions in organizations allow the production of entities, artifacts, and practices that individuals could not generate on their own (Theiner, Allen, and Goldstone 2010). Organizations develop the capability for cooperative and coordinative interaction and socialization and may also interact competitively. Group structure manifests on different size and time scales, sometimes as a hierarchical organization and sometimes in a stable manner that cuts across hierarchical relations. Organizations mediate much of the specialized role differentiation and training that make our society and others so reticulate.

Organizations can be seen as socially or culturally determined *core configurations* that are widely found in different human populations; they are naturally configured groups of individuals of different characteristic sizes adapted to different functions (Caporael 1997; 2013; Sterelny 2012). These act as cultural breeding populations to define, maintain, elaborate, and teach knowledge, procedures, and values and are central elements in identity formation. Organizations and their interactions play a formative role in generating institutions that provide further structure to their identity and interactions (Murmann 2013). Individuals follow trajectories through organizations, pursuing their ends while at the same time having them shaped by the groups they inhabit or pass through, with the institutions appropriate to those organizations coming to bear in relevant contexts along the way.

3. *Artifact structures.* Artifacts or physical structures mediate short-term activities or processes (like those found or used in a work environment, including physical tools, and reading and writing or utilizing or producing specialized language, serving multiple functions) or provide physical infrastructure that is maintained on transgenerational time scales to yield "public goods." These may be produced, interacted with, and maintained by organizations like manufacturing firms or by institutions in society at large. Both units can facilitate a range of activities or, in other circumstances, provide specific infrastructure for a delimited subgroup, such as practitioners of a specialty or users of a specialized technology. Markets mediate the development and distribution of new or transformed artifacts or procedures involved in using them. Complex technologies require and generate complex distribution networks and a host of standardized practices (Wimsatt 2013; Arthur 2009).

Many regard artifacts only as products of culture rather than as elements or producers of culture, especially if artifacts are treated as external tools for accomplishing tasks instead of integral parts of thought processes (e.g., Richerson and Boyd 2005).[20] However, embodied theories of cognition and of distributed cognition reveal that artifacts and the structured interactions and motor activities they induce play an essential part of the cognition of individuals and groups; they must be recognized as components of thought processes (Wilson and Clark 2009; Theiner, Allen, and Goldstone 2010). Artifacts not only extend and change our cognitive skills (Wolf 2008) but also facilitate the formation of new kinds of groups as cognitive units and help segment us into new skill groups and cultural population structures (see chapter 3). Although this can be seen as a friendly extension of niche construction theory (Odling-Smee, Laland, and Feldman 2003), the conceptual tools required for the "cultural niche" must encompass much more than niche theory has currently embraced (see Wimsatt and Griesemer 2007). These components of distributed cognition make possible particular cultural interactions (e.g., Internet communication for the collective solution of complex problems in data analysis) and products (e.g., open source software; Nielsen 2012). Scientific research, practice, and institutions are important examples of this collective activity that is a technological and cognitive expansion of our niche (see chapters 2 and 3).

Institutions, organizations, and artifact structures are components of a society and of many things we find in culture. Government bodies are hybrids of all three of these entities, as are most other complex cultural constructions. Organizations at one level are the primary source of formal institutions at another level; networking interest groups are the source of informal institutions.[21] An important contrast between biological and cultural evolution enters here: the single breeding population for biology is replaced by multiple overlapping reference groups of culture, each being a possible source of interaction and learning or the transmission of knowledge and practices (e.g., professional associations, places of employment, political and governmental affiliations, and religious congregations, inter alia). Each has characteristic norms of behavior and modes of interaction—a subculture—and their structure is modulated by core configurations of people of various sizes that we find natural (Caporael 1997).

Scaffolding

Scaffolding refers to structures or structure-like dynamic interactions among performing individuals that are the means through which other structures or competencies are constructed or acquired by individuals or organizations (Wimsatt and Griesemer 2007; Caporael, Griesemer, and Wimsatt 2013). Scaffolding serves a function and is thus a many-termed relation (Wimsatt 2002b); *something* scaffolds an *action* or class of actions for an *individual* or group of individuals, often *in a larger system* of interactions, in a characteristic *environment* or set of environments relative to *a goal*. Material or ideational entities that contribute to achieving this goal are *scaffolds.*

How does scaffolding emerge? Common patterns become habitual, and if widespread through conformity bias, coordination games generated by common advantage, or other means, can become standardized. This generates normal modes of behavior for all sorts of regular behavior and activities. Many cultural elements emerge in conjunction with this standardization and are specifically designed to aid in constructing or developing competencies among individuals and organizations. Thus, chaperone molecules scaffold the correct configuration for folding proteins, and the cell scaffolds gene replication and expression so profoundly that the cell is arguably the relevant reproductive unit, rather than the gene or genome.[22] A similar perspective points to the insufficiency of methodological individualism, which is the view that higher levels of social organization can be characterized exhaustively in terms of component individuals, including their internalized thoughts and actions (e.g., "*Homo economicus*" of rational decision theory and economics). For the enculturated and socialized human, whose agency is richly scaffolded in multiple dimensions, this perspective is empirically and conceptually inadequate.

It is critical to distinguish agent scaffolding, artifact scaffolding, and infrastructural scaffolding (Wimsatt and Griesemer 2007) because they cross-classify the foregoing units of and for theories of cultural evolution. Scaffolding is not necessarily introduced intentionally, but its presence is part of a means-end chain of action directed toward one or more goals. *Scaffolding for individuals* includes family structure, schools, curricula, disciplines, professional societies, church, work organizations, interest groups, governmental units, and laws. Some of this scaffolding is imposed by organizations or institutions, though individuals also pursue it actively, such as embarking on a normal training trajectory to achieve competence and certification in a profession. *Scaffolding for organizations* include (for businesses) articles of incorporation, corporate law, codes of ethics, manufacturers' organizations, dealerships, chambers of commerce, and distribution networks for manufactured parts. *Infrastructural scaffolding* is so broadly applicable that it is sometimes difficult to specify the pertinent individuals and organizations or what competencies it facilitates. Language, both spoken and written, is so obvious as to be easily overlooked. Mathematics and computer languages are natural technological extensions. Janssen (chapter 4) documents how earlier theoretical structures in physical science provided crucial scaffolding for the development of newer theories; specialized experimental technologies—from microscopes to statistical techniques—can do the same. Our technological civilization has many systems of infrastructural scaffolding: highway, sea, rail, and air networks; shopping centers; containerized shipping; distribution networks for gas, water, power, telephone, and sewage; warehouses and reservoirs; public transport; Internet; and waste removal.

The census offers an especially poignant example. Its diverse uses by governments for the distribution of resources or structuring and the distribution of political power means it is a deeply entrenched feature of our society. Markets, as institutions, are also infrastructural scaffolds that elaborate and coordinate a host of businesses, products and practices, and the choices and activities of agents.

TREs, DBIs, institutions, organizations, and artifact structures are the requisite kinds of units to formulate minimally adequate accounts of cultural evolution in its current complexity. However, what we still lack are substantive analyses that show how these units articulate in more elaborate regulative and production structures, and this should be a topic of continued and elaborative research. These structural configurations would presumably differ for different levels of organization in society, for its differently articulated microcultures, and for different cultures as a whole. This would be akin to different phyla in the biological world that are elaborations of different major body plans, each of which have diversified within different ecosystems. Thus, mathematics through calculus and statistics provide a common backbone for all the mathematical sciences, which add further differentiated skills, and programming is rapidly becoming equally essential. Structural configurations of these units generate and mediate power relations and regulate the distribution of information and resources. They also indicate what kinds of disciplinary approaches, in various combinations, are required to understand the dynamics of cultural change, which is likely most fruitfully tackled by examining how the different units are articulated in a given domain of culture. This, in addition, would tend to highlight the fact that many cultural processes require inputs from more disciplinary perspectives than they now receive and point to new interdisciplinary projects. The notion of scaffolding is crucial throughout; it creates and assists processes of varying degrees of entrenchment that extend or facilitate the exercise of our capacities (Caporael, Griesemer, and Wimsatt 2013).

ARE OTHER ELEMENTS REQUIRED?

I have introduced and articulated five kinds of units and the relations between them (especially scaffolding) that provide a more structured account of cultural evolution and begin to coordinate the joint contributions of many diverse disciplines and approaches. Are these sufficient? At least two other perspectives have claimed universality (both applicability and sufficiency) over the range of human behavior: intentionality and markets. How are they relevant, and what relations do they bear to the above discussion?

The Role of Intentionality

Means-end reasoning, planning, and the construction and use of complex tools are crucial to human intentional actions. Lane et al. (2009) see scaffolding and action as so integrally linked that they advocate a conjoint agent–artifact space to delineate the basic entities of culture. Many of the intentions implicit in cultural entities that are not features of explicit conscious plans will be scaffolding relations, such as products of intentional actions by others. These intentions are realized in a complex cognitive niche that is a product of multiple institutions, organizations, artifact structures, and standardized modes of individual behavior. They are woven deeply in the fabric of artifact design and construction, patterns of convention, standards, norms, institutions, and the acquisition of skills. That scaffolding is so central to the analysis proposed here is a reflection of the importance of intentions. Intentions manifest as emergent meanings in spoken and written language through combinatorial generative systems of communication (Wimsatt 2013). Thus, we must recognize the intentionality of complex differentiated groups that cooperate to produce technological and intellectual products (Kidder 2001; Theiner, Allen, and Goldstone 2010). Meanings and intentions both derive and emerge from heterogeneous relationships among ideational and material structures and processes.[23] Adding an explicit treatment of them is desirable and will be necessary to comprehend how they articulate with and emerge from the other five elements of culture, but this is a task for another time.

Markets

Many economists behave as if the market (or markets), together with the *Homo economicus* of rational decision theory (or its satisficing successor agent from behavioral decision theory), is an adequate framework for understanding all cultural activity. Human social and behavioral practices that facilitated institutions of exchange have been a crucial element in the evolution of culture and in coordinating behavior across distant places (Seabright 2004). In many respects, it has operated as an integrating force. Why is it absent from the primary catalog of elements required for an evolutionary theory of culture? It plays such a central role in Western economies and their colonial activities throughout the world. Perhaps it is an institution that requires special attention, though I confess to some uncertainty about how to introduce it. Although it is clearly infrastructural, does it play a special or distinctive role as an institution that is more important than others? Spoken and written language are two other infrastructural elements that act in related but disparate ways with similar breadth and import (see chapters 9 and 10). What about governance and power relations, ethnic identities, and other elements that achieve a coordination of societies as a whole? Perhaps each of these demands special treatment.

The perspective of the market does capture some features that are difficult to isolate as localizable effects of the other five elements of culture. For example, Moretti (2012) returns again and again to the "spillover effects" that arise from the concentration of individuals with technological skills in companies that make a city or region an "innovation center," improving the number of jobs, salaries, the quality of education, and the standard of living for unskilled laborers in the same area. He demonstrates how these effects emerge out of an interaction of market conditions and other relationships in a way that is not exhausted by the consideration of specific organizations and institutions. Thus, there is clearly more work to do in analyzing the unique contributions of markets to our understanding of cultural evolution.

TIME SCALES AND ENTRENCHMENT

I have already discussed (section 3.1) how widespread generative entrenchment is in the organization of complex systems in biology, culture, and technology (Wimsatt 2013). Differential entrenchment and consequent differences in evolutionary rates have been powerful inferential tools for analyzing the structure of developmental dependencies and the structure of phylogenetic relations in biology (Wimsatt 2015). They should be also for technology and for culture. The more stable elements play an important role as architectural foundations for the construction and elaboration of adaptive structures of increasing complexity and are recognizable in biology (e.g., body plans), in culture (through the roles of language and socialization processes), and in technology (through the roles of mathematics, science, and the methods of mass production). These are all important handles for the analysis of complex systems. But the existence of processes acting at different rates has other important consequences for the structure of evolving systems.

The rate at which processes happen and the rates at which they can affect change are crucial elements for understanding the dynamics of evolutionary change in biological systems. The same is true for culture. It is commonly claimed that cultural evolution operates much more quickly than biological evolution. However, it would be more accurate to say that evolutionary processes in both domains operate on a wide range of time scales, some of them overlapping to a significant degree. Bacteria can evolve significantly in weeks, with the measles virus becoming more virulent as it moves from host to host within a family while adapting to their common genetic architectures (Wills 1997), and insect pesticide resistance emerges in a few years. In contrast, in cultural evolution, some things evolve very slowly: Acheulean lithic point technology persisted and evolved gradually for over a million years.

The issue of time scale is important in part to sort the relative significance of different transmission processes. It is usually assumed that processes acting faster in time tend to dominate those acting more slowly and (intentionally or unintentionally) evolve to act as control structures for slower processes. In this context of cultural evolution, it seems clear that the maximum and average rates of change have increased substantially. We can document an interesting transformation from societies that valued stability and resisted change (perhaps culturally adapted to oral transmission) to those that valued innovation and change (often dated to the Renaissance and the concomitant rise of capitalism). In addition to time scale, the magnitude of the effects of cultural evolution has also increased, primarily through our development of methods of mass production (Wimsatt 2013) and the consequent increasing mobilization of energy and reticulate complexity of our technology. Indeed, anthropogenic global warming shows how these effects can threaten our very existence.

HOW CAN WE bring order into the study of such a multifaceted entity as cultural evolution? Our characterization of the five kinds of entities, plus scaffolding, that are required for any adequate account gives more room and resources to classify phenomena and comprehend diverse mechanisms of change that can relate productively to the approaches of existing social sciences, and this should be an aim for future development of the theory. Since our cultural activities take place in a much richer and more structured context than is typically adumbrated, our analyses must be adjusted accordingly. Despite its obvious power and adaptability, the absence of a detailed developmental component is a major lacuna in the Boyd and Richerson account; without it, all sorts of dependency relations cannot be explained or utilized in the explanation of other features of culture, and we have no structure on which to hang the different breeding populations we experience through our life trajectories. Accounts of sequential acquisition are necessary to understand who is able or likely to acquire specific cultural skills and traits or be influenced by certain ideas and forces. Additionally, the absence of diverse forms of culturally induced population structure hamstrings theoretical frameworks from capturing the reticulate and interwoven character of cultural evolution. We need to recognize that organizations and institutions develop and that relations of scaffolding and entrenchment offer tools for understanding the interlocking means-end structure of social action—organizations and individuals interact with and through artifact structures as guided by institutions. Even niche construction, which includes a developmental component, lacks the necessary theoretical perspectives on diverse forms of scaffolding (Wimsatt and Griesemer 2007), and the role of technology in facilitating our cognitive capabilities lies unelaborated.

The fact that TREs, DBIs, institutions, organizations, and artifact structures relate naturally to work in sociology, history, ethnography, the history of technology, and the history of science shows both the need for implementing *interdisciplinary* approaches to cultural evolution and finding specific resources that can enrich the connections among elements in our theoretical framework. This is a welcome change from prior approaches, such as that of the reductive sociobiology of the 1970s. Then, the suggestion was that social theory should give way to a sociobiological framework through displacement—like "urban renewing" a neighborhood with a bulldozer. In this approach, our cultural evolutionary perspective should articulate with developments in the traditional social sciences in a negotiation between equals—how can the new perspective enrich traditional insights? But this suggests a new danger: Do we need to study everything in order to understand anything? How can we avoid making the investigation of cultural change an impossibly complex task? There are reasons why the dual-inheritance theory of Boyd and Richerson has been so successful in terms of the elements they chose to model and reasons why we should be careful in arguing that the further complexities discussed here must be considered.

First, I want to note that the aim of this chapter is not to develop a complete adequate theory of cultural evolution. It is, rather, to sketch and to argue for a conceptual geography of the major elements required and how they articulate. Presumably, progress will be made by developing parts of this framework. We should not aim to capture all details of cultural phenomena but rather ask what aspects of culture might be usefully systematized. Then, efforts can be directed at including the major features and aspects of culture relevant to its evolutionary change. Progress was made in studies of heredity with Mendel's systematic work on pea plants and the Morgan school's mapping of *Drosophila* chromosomes. Crucial in both cases was the right methodology, which included significant simplifications in the experimental system (Kohler 1994) and "the right organism for the job." But *Drosophila* proved intractable for questions of development until the discovery of the *Hox* gene complex and its use as both a subject and as a tool in developmental genetics. This articulates naturally with the "problem-centered" approach argued for by Brigandt and Love (2012) since "the job" is always an identified problem with its own history and structure. Such problems are elaborated and restructured through a productive research program, but their identification and operationalization is crucial. In this we must remember that some problems are tractable with the resources at hand and others are not. And this reinforces that finding the "right organisms"—the peas of cultural heredity—is equally critical; patents and scientific diagrams are just two of many promising candidates (see chapter 6 of this book; Griesemer and Wimsatt 1989; Wimsatt 2012). But we also need to expect that different methodologies will be appropriate to different problems—for example, due to limitations of data, relevant theory, or computational complexity. No one would propose a population genetics analysis of the terrestrial origin of the vertebrates (even though it surely applies in principle), but we would look for handles within developmental genetics and within functional morphology that could give insight into particular aspects or stages of the emergence. We should expect similar disciplinary handles to give leverage on different aspects of cultural evolution.

We should expect cultural change to provide these kinds of paradigmatic examples of evolutionary change while investigation can steer away from intractable complexities that would make any such account exceedingly difficult. It will often be possible to study and confirm the operation of some of the elements producing cultural change by abstracting away from or idealizing others and through the comparative analyses of cases with selective similarities. However, an adequate evolutionary account that emerges from paradigmatic examples should offer reasonable explanations for why such complex cases are so refractory to an evolutionary analysis. For example, the characterization of the properties of "evolutionary meta-ontogenies" as a complex of interacting and embedded entrenchment processes acting on different time scales (Wimsatt 2013, 91) provides an evolutionary account that explains why some cultural elements seem to resist precise characterization as either "developing" or "evolving." Thus, habits develop through repetition, and skills develop through the accumulation and coarticulation of habits. Both of these develop through the maturing capabilities of a growing and developing individual, who develops the capabilities for a given career track. That individual may then go to work for IBM back when it was known for punch-card readers and mechanical adding machines. IBM developed to become the prime provider of computing machinery, which developed from mechanical relays through vacuum tubes to transistors and integrated circuits. In the early stages, IBM also wrote software and provided integrated business solutions, but the development of minicomputers gave other firms like DEC and Data General room to grow, particularly for scientific applications. The DEC-20 provided a new paradigm of multiuser computing and the emerging "mainframe," and the emergence of the microcomputer and Microsoft as an independent software producer spawned an efflorescence of third-party hardware and software accessories. AT&T, originally a telecommunications company, produced UNIX, and the government spawned ARPANET, which became the Internet, and the evolution and development continues. So here we have articulated developing habits, skills, individuals, firms, industries, and technologies, all on different time and size scales, with a host of emergent properties at all scales. This is clearly both development and evolution, in multiple places on different scales, depending upon the problem and the question regarding it. Given the crucial differences between evolution and development in biological theories of evolution, this has suggested to some a dangerous sloppiness that seriously compromises theories of cultural evolution (Fracchia and Lewontin 1999; Gerson 2013b), but we have the tools to address this in the dissection of cases like the preceding.

Second, following up on using abstraction and idealization, I suggest we take seriously the exploratory use of "false models" in which we construct accounts incorporating some, but not all, of the elements of which we are aware (Wimsatt 1987, 2002b), sometimes with additional false simplifying assumptions. This was characteristic of the panmixia assumption discussed in the introduction to this volume (Wimsatt 2002a). These partial accounts of the structures relevant to cultural change can be mobilized to see both what else we can relate to them and also what we *cannot* account for. The latter (especially) can suggest other structural elements or perspectives to include in a more robust theoretical framework. Agent-based models would be a particularly salient tool for this task, although here (where it is relatively easy to add a great amount of detail) it is particularly important to start with a simple orientation, to which various complexities are added, to better assess their effects (e.g., Andersson 2011, 2013). Given the diversity of cultural systems, this endeavor will surely yield a branching tree of multiple models rather than a linear sequence of increasingly "better fits" of a single model. (Schank and Koehnle [2007] consider an example of such a branching model tree.) The necessity to make central both the role of dependency in the acquisition of complex, sequentially acquired skills and the culturally induced population structures through which we proceed in acquiring and practicing them, as well as to explicitly utilize all five elements (TREs, DBIs, organizations, institutions, and artifact structures) in rich relationships of scaffolded interactions, reaches across the necessary variety of disciplines to apply in any contexts where culture or cultural change are studied. The question of whether and how structures of intentionality, economics, and power relations are integrated into this conceptual architecture remains to be answered, and other perspectives not covered here will need to be recognized. Our work is just beginning.

NOTES

I thank two anonymous reviewers for their suggestions on an earlier version of this chapter; Marshall Abrams for his commentary on a talk given at the Pacific American Philosophical Association drawing on some of these ideas; Alan Love, as always, for his multifarious and detailed insightful suggestions; and Barbara Wimsatt for her suggestions to improve intelligibility. More broadly, I thank Penny Winton and the support of the Winton Professorship since 2010, which has made possible my stay at Minnesota, my research, and the conference at Minnesota in the fall of 2014 that midwifed this book.

1. Actually, if we incorporate the complexities introduced by our microbiota, the biological and cultural ecosystems are closer (the microbiota are richly horizontally and vertically transmitted, for one), but traditional neo-Darwinism has only begun to address this and is far from incorporating its complexities.

2. It is tempting to think that these are alternative channels that merely duplicate one another, with later channels just faster, but this would be a serious mistake. Thus, the telephone not only is faster than the telegraph but

captures vocal emotive information that the telegraph does not. And written language stimulated a massive increase of a more sophisticated and detailed vocabulary in addition to leaving a persisting and potentially cumulative record (Wolf 2008).

3. Even among those who accept a "blind variation and selective retention" paradigm (Campbell 1965) or "heritable variance in fitness" (Lewontin 1970), schematic requirements for an evolutionary process leave the relevant details frustratingly underspecified, with no tools for further guidance. The diversity of possible units, complexity of hereditary processes (Jablonka and Lamb 2005), and fusion of heredity, selection, and developmental processes for various aspects of culture (Wimsatt 1999) pose challenges unique in comparison to biological evolution.

4. Part of this is due to a rejection of both earlier (largely nineteenth-century) progressivist evolutionary views in anthropology and imperialistic (and simplistic) approaches to human behavior from sociobiology in the 1970s.

5. Is evolutionary psychology, with its focus on heuristics and the search for "Machiavellian intelligence," correcting this? No, because the theoretical resources in this area are too narrow for what is required of an adequate account of cultural evolution (see below, section 3).

6. This is a double-edged sword: differences in the characteristic methodology of two different disciplines may be misleading when trying to understand how they use a common resource or tool. For example, the relative certainty characterizing mathematical inferences may lead empirical scientists to misunderstand how mathematics is used as a tentative and exploratory tool in constructing possible templates for patterns of phenomena. These templates do not give certainty to the results of the models, which often deliberately use false assumptions. Instead, these models are more instructive for the ways they fail than for how they succeed (Wimsatt 1987, 2007). Scientists who are not modelers may be improperly skeptical of the usefulness of "unrealistic" or "simplistic" mathematical modeling in their empirical area. This makes it crucial to be aware of these methodological differences.

7. Strategies for facilitating a change in a deeply entrenched element can include constructing a supportive environment to meet some of the functional requirements in other ways (common in major organ surgery), such as duplication (as in dipoidy or gene duplication) and encapsulation (so that

the bad consequences of not meeting some of the requirements are not allowed to propagate into the broader system).

8. Biological age-structure models focus on viability (what proportion of individuals survive to the next stage) and fertility (how many new organisms are produced per individual at that stage). This has cultural analogs in professional training, where administrators of programs must worry about how many students survive through a given level of training and whether enough of them begin teaching the relevant skills to maintain the profession in the numbers required. Cultural models using detail of this kind can yield useful information (e.g., Andersson, Törnberg, and Törnberg 2014), though further elaboration is necessary to answer other questions.

9. Selective isolation is no less important than selective exposure. There are limited resources for learning, and exposure to multiple diverse things may dilute and frustrate those efforts.

10. The elaboration of social structure has led some to argue that we must abandon the population structure characteristic of evolutionary biology in favor of an organizational and institutional structure to account for cultural evolution (e.g., Lane et al. 2009). I think we need both perspectives.

11. Although epigenetic processes and their interactions with developmental and ecological factors are demonstrating a greater complexity than originally thought (Jablonka and Lamb 2005).

12. Here, acquired elements (reading, writing, arithmetic, and other taught skills) are easier to investigate because we have teaching methods for them, unlike "innate" skills such as spoken language, whose scaffolding for acquisition has become internalized and must be studied experimentally and through the study of cognitive anomalies.

13. This phenomenon is visible in the evolution of automobile owners' manuals. The owner's manual for the Ford Model T (made from 1908 to 1926) dealt with topics that were quite complex. It gave detailed instructions for all but the most demanding repair operations (e.g., a paragraph lists the eleven steps necessary to remove the engine). The owner's manual for my 1962 Volvo 122S was still quite detailed, though much less so. The gory details had been moved to the "shop" manual (which I purchased)—the owner was no longer expected to play a role in the repairs, although doing so was still possible for simple to moderately complex tasks. By the time I bought my 2013 Audi A4, the diagnosis of repairs had become fully computerized, in part because integrated circuit chips had taken over multiple regulatory

and sensory roles. Diagnosis and repair have become only possible at the service department of a dealer. Repairs involve multiple specialized tools and often involve computerized notification that a module is defective, rather than needing to understand what is wrong with it. The suitably longer "shop manual" is available only on CDs, for which you need the correct computer and software in order to read it. More generally, the complexity of automobiles has grown exponentially, necessitating this increasing specialization and knowledge segregation of roles, as well as technology for scaffolding the diagnosis, maintenance, and repair.

14. For example, the importance of blending inheritance and its role in the history of population genetics (and its further application in understanding the units of selection controversy in modern times) was particularly illuminating (Wimsatt 1980, 2002a).

15. The focus here is on mature culture, not the emergence of culture in the course of evolution. An account of this, which interdigitates naturally with Wimsatt and Griesemer (2007), is Sterelny (2012). See also Tostevin (2013), Hiscock (2014), Morgan et al. (2015), and Stout et al. (2015) on the importance of the evolution of lithic technology).

16. Iterative modular decomposition, or chunking and black boxing, is a crucial feature of both the mechanical and the cognitive assembly of larger complexes of machinery and practice, going back to Miller (1956) and applied to more complex perceptual tasks by Chase and Simon (1973). For technology, see Latour 1987 (who introduced the term *black box* in this context), as well as Arthur (2009) and Wimsatt (2013) for further development. Black boxing is a crucial feature of most complex sequential skill acquisition.

17. Richerson and Boyd elaborate these heuristics of social learning but ignore the sequential dependencies in the development and practice of skills. Skills also have a structure, which is realized as individuals acquire them from experts and apprentices, with those of greater skill playing a role in the instruction of those earlier in a trajectory. This yields a hierarchy of training where top-level experts are not responsible for training early neophytes (Wimsatt 2001).

18. Boyd and Richerson (2008) analyze the properties and evolution of social institutions, but they do not address how institutions structure learning in development. These effects and the norms associated with such institutions should, for example, increase the heritability of the affected cultural traits. If changing environments are reflected in institutions, these can mobilize systematic changes in transmitted characters, such as rapidly updat-

ing the content taught in a class by requiring continuing education among teachers.

19. These similarities are not identities, and some have overextended the analogy in the U.S. legal system.

20. Richerson and Boyd (2005) characterize culture as transmissible information, which they further characterize as a mental state (conscious or not) that affects behavior (5). This rules out material artifacts, an important and problematic move. They discuss technology primarily to make the point that it evolves through piecemeal incremental improvement (51–53).

21. Informal institutions require their own treatment and should be targets for social psychology. The processes through which they are formed, as well as how and when they are formalized, are key elements in the elaboration of culture.

22. Selfish genes and selfish memes are conceptual mistakes for parallel reasons. Memetics ignores the role of organized context, internal and external, which enables or facilitates memetic transmission (Wimsatt 2010).

23. Wittgenstein's (2009) notion of a "language game" that articulates language and interactions with material artifacts is pertinent here, but the simplicity of his examples may be misleading.

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