Introduction

A perspective on cultural evolution that utilizes human cognitive development throughout the life cycle is critical to understanding how we learn, comprehend, use, and modify complex cultural structures. Evolutionary developmental biology, or “evo-devo” as it is now known to practitioners, has emerged within the last two decades to cast new light on evolutionary problems in half a dozen disciplines. We argue that to understand cultural evolution, we must take cultural development seriously. This requires a sociological view of culture in which cultural inheritance is understood to depend on varying patterns and modes of cultural development. “Thin” views of culture such as memetics and dual-inheritance models black-box human ontogeny and the developmental acquisition of cultural traits and describe cultural inheritance as only a mapping relation between “parents” and cultural “offspring.” “Thick” views of culture take the phenomena of interest to be limited to human language users and assume such a rich social milieu in which human cognition and communication occur that it seems impossible for any other species to have culture. This of course also makes it totally mysterious how we could have evolved culture. Most of these writers reject any attempt to give an evolutionary account of the origins of culture or the nature of cultural change.

In this chapter, we argue that an account of units of cultural reproduction can open the black box of development left closed by replicator-based accounts of inheritance (whether cultural memes or biological genes). We utilize generalizable features of developmental processes, in particular, different modes of generative entrenchment, to support a “medium viscosity” theory of culture and cultural evolution. Applying an evolutionary perspective to a developmentally sensitive view of culture requires, in addition, a variational or populational perspective on units of cultural reproduction.
In other words, there must be countable units that develop and vary and that form populations of potential interacting reproducers in order for a (Darwinian) evolutionary theory to apply.

Existing theories make little significant use of developmental resources or explain how we acquire and use them (but see Caporael 1997; Ingold 2000; Bateson 2001). But this alone would not suffice: a focus on individual organisms or people, however they develop, still suggests an exclusively “bottom-up” approach to culture and cultural change. The approach must work both from “bottom-up” psychological and from “top-down” sociological and anthropological perspectives because culture is nothing if not shared. Complex cultural structures are not just givens of social organization, however. Nor are they usefully understood as the aggregation over time of a large collection of memes: we need to know why memelike things are attractive to individuals with particular histories, in particular niches or local contexts, given the rich structures already present. The evolution of such structures, how they become structurelike, their social and cultural differentiation, their transgenerational maintenance through recruitment and dissemination processes, and their elaboration through the directive activity of group organization on various scales all require attention to processes of individual human development and of entrenchment in enculturation.

An “evo-devo” theory of culture must not result in a new variety of methodological individualism: human learning and development are irreducibly social (Brewer 1997, 2004). The socializing trajectories of individual learning and development are unintelligible without the structured shaping, guidance, and reinforcement that social institutions and organizations provide. These are not just environments for learning, but interactive products of culture—both produced by and feeding back to form enculturated individuals. Adequate theory requires an integral account of both levels and their reciprocal interaction. Perspectives derived from our respective research programs on reproduction and generative entrenchment yield insights into these processes.

Our new grip on the nature of cultural inheritance emerges through reexamination of an apparent deep difference between biological and cultural inheritance: that the former invariably uses and indeed requires material overlap, while the latter is commonly taken not to (Griesemer 2000a). A process involves material overlap if later stages of the process include material parts that had belonged to earlier stages, for example, when biological offspring include material parts of their biological parents. The contrast is suggested by comparing the semiconservative replication of DNA, a process
of direct material transfer of one of two nucleotide strands, with the disembodied transmission of information—for example, when someone reads a copy of this chapter in the library or online. The contrast is actually not quite so simple, and we would argue that more revealing instances of cultural transmission occur when offspring include persistent niche components engineered by their biological or cultural “parents,” or when organizations at later stages include individual members, equipment, or physical plant persisting from earlier ones. Developing arguments to see why gives handles on other important properties of cultural inheritance and evolution, including the facts that it can take place at a much faster rate and can lead to the adoption of major “deep” cultural changes whose biological analogues would almost always be profoundly lethal mutations. So how does culture get away with such major changes, and do so, at least sometimes, at such a precipitous rate? These are crucial differences we seek to explain. They relate to the multiplicity of transmission channels, to easing and directing the production of variation, and to how various organizational structures can modulate escape from entrenchment.

Structurally, a scaffold is a supporting framework, often temporary relative to the time scale of what it supports. Scaffolds support materials, tools, agents, and processes, as when builders use scaffolding to support workers and their materials while erecting or repairing a building. Developmental psychologists extend the notion to functional processes critical in child development such as “attachment.” When a child “attaches” to mother (placing trust in mother to be a safe guide), mother can then facilitate skill acquisition on the part of the child by creating a safe or otherwise supporting, for example, simplifying, context in which the child can learn and practice a potentially threatening but advantageous activity, like walking, thus blocking or lessening negative fitness consequences of risky behavior. Skill acquisition is a key form of learning relevant to culture because it is generative, though it is not the only cultural process that is both crucial and generative. Acquisition of authority is another key generative form of cultural development not explored in this essay. Social and cultural structures and activities that play a role in generating learning trajectories are both known as scaffolding—scaffolding, respectively as state and process (Bickhard 1992). According to Bickhard (1992, 35), “Functionally, scaffolding is precisely the creation of…bracketed trajectories of potential development through artificially created nearby points of stability.” In addition to allowing “the child to accomplish something that he or she could not otherwise accomplish alone—it also allows the child to develop further competencies through being provided with such bracketings of ‘normal’
selection pressures. It is this further variation and selection development, made possible by the context-dependent successes, that makes scaffolding a critical aspect of the development of less context-dependent abilities."

Thus, two key features of functional developmental scaffolding are: (1) the lowering of “fitness barriers” to developmental performances or achievements (Bickhard’s “artificially created nearby points of stability”), which (2) make accessible new competencies (capacities, skills or authority) that become the “self-scaffolding” of later developmental performances. Looking ahead, a third is generative entrenchment and its consequences. The dependencies created by increasing use of the new competencies make them essential, stabilize many of their features, and engender further elaboration of scaffolding on top of them.

In the United States, differential access to quality early education among blacks and whites and attempts to control broader aspects of the supporting (or not-so-supporting) environments has motivated attempted interventions from Head Start programs on. Scaffolding is not always so direct, nor is it confined to early development. In the remainder of this section, we describe several cases of scaffolding phenomena further analyzed in succeeding sections. In the first, we look at the advanced training of MDs in two empirical studies documenting the different degrees and kinds of scaffolding support received by men and women and its consequences for their career choices and commitments. In the second, we review the impact of the advent of the tutorial system at Cambridge University on the development of mathematical physics over a 180-year span. Both of these studies track individuals’ trajectories through institutions, with the first focusing on individual development and the second also looking at the cumulative impact on those institutions. In the third, we consider the particular role of dwellings in culture, and then consider the spread of “kit” houses in America over thirty years in the early twentieth century. Here, we look at the institutional framework supporting this change and features that made this innovation attractive to individuals.

First Pass: Scaffolding the Development of People and Institutions

Scaffolding Cognitive and Professional Development in Advanced Medical Training

B. Wimsatt (1997) documents rich processes of cognitive and professional development along ten dimensions of encouragement and support among eighty residents and fellows of both sexes in advanced medical training. Her data illustrate the importance of scaffolding by mentors and significant
others in helping to acquire skills crucial to advanced cognitive development and the professional development continuous with it. Male and female medical residents and fellows recalled experiences during their training that led to career decisions they made. Men more than women, and increasingly at successive stages of training, chose “encouragement” by mentors as important reasons for their choices. Women tended to downplay their need for faculty encouragement, citing their independence, while for men, it was considered vitally important. However, several women (and no men) volunteered that they depended heavily on support from fathers or spouses.

On closer inspection, Wimsatt found that modes or dimensions of encouragement are (statistically) differentiated by sex. Men described a process in which their interests and cognitive development were shaped in a coordinated (Caporael 2003) interaction with mentors. Further, encouragement can run the gamut of support and investment from emotional to cognitive input, to active and extended sponsorship and promotion. Women more often reported receiving the first type—praise, help with specific tasks, or advice on career decisions—while men far more often reported receiving the more valuable recruitment into research projects and professional sponsorship and promotion. Some women relied primarily on physician-spouses or fathers for support. Interviews revealed that while both men and women felt encouraged in comparable numbers, they actually meant different things by it, had different standards for feeling encouraged, and to a large extent, relied on different sources of encouragement.

Along with this she found coordinated differential choices by men and women. The women rarely selected traditionally male-dominated disciplines, higher-level subspecialty training, or academic research, all of which are higher status and more highly rewarded options. Given that subspecialties and research involve further training, these choices marked asymmetries that increased at later professional stages.3

For families with children, it might seem plausible to attribute these differences to sex-role differences. But this cause is not determinative. A follow-up study ten years later interviewed ten couples who had children at the time of the first interview (B. Wimsatt 2001). In all cases where there were asymmetries in career development versus child care and home responsibilities, the parent who had more career capital at the time of the earlier interview was the one with fuller career commitments and lighter loads at home ten years later. In two out of ten cases, this was the woman, and so it was the male, also educated at the professional level, who was the stay-at-home parent.4
Women commonly marry older men, who tend to have more advanced careers. Thus even if both began on identical trajectories at comparable ages, age differences would tend to generate later asymmetries in age-specific career development, with the younger (usually female) partner more commonly scaffolding the development and maintenance of professional competency and performance of the “more committed” partner (usually male) by taking on otherwise necessary tasks and allowing them more time to dedicate to their careers. So pair-bonding plus gender-differential age structure can produce or enhance other scaffolding effects.

Scaffolding the Discipline of Mathematical Physics

Perhaps the most striking extended discussion of scaffolding in science never mentions the term. It is Andrew Warwick’s (2003) study of the rise and development of mathematical physics at Cambridge between 1750 and about 1930. This is a period long enough that one can see not only rich interactions of scaffolding and individual development or career trajectories, but evolution and cumulative entrenchment elaborating a whole discipline, precipitated by significant and competitively evolving means of scaffolding. Mathematics and mathematically rich sciences provide particularly good opportunities to observe entrenchment because of the strong sequential dependence of later methods and results on earlier methods and results. And the content of mathematics and the mathematically rich sciences often utilize a series of successively richer models, each elaborating, but depending on and arising from the former, which they are often expected to regenerate as special limiting cases.

The case of mathematical physics in this period at Cambridge is a particularly rich surprise for those used to focusing just with an “internalist” lens: a change in the examination system from oral disputations to written exams precipitated a series of changes resulting in many of the modes of study and practice known to physics students around the world today, as well as an enormous amplification in the content they had to study. Originally motivated by a desire for increasing objectivity in the examinations, the move to written exams changed the kinds of questions that could be asked from more philosophical and conceptual discussions of texts like Newton’s *Principia* to requests to produce proofs and derivations of increasing complexity. Oral effectiveness disappeared as a measure of performance and excellence to be replaced by the ability to reproduce and then increasingly to *produce* multiple new problem solutions on paper in very limited time. Technical competence for the first time became the primary measure of achievement. Those excelled who could construct arduous derivations...
quickly and had the stamina to withstand the stress of written examinations lasting *many days*. Overall rankings of students became possible, facilitated by the relative ease of generating quantitative measures for performance in mathematics, which also thereby came to assume greater importance in the curriculum. Increasing pressure to perform well amplified and enormously elaborated the practice of studying with outside tutors. Since these tutors were paid and evaluated by how well their students did on the written exams, they experimented with various practices to improve their effectiveness that have become common today.

Strategies invented within the next 100 years included constant practice with solving mathematical problems of diverse kinds. These were also arranged by difficulty, like the “A, B, and C problems” in the back of the math book, so familiar to modern physics students. The A problems served to exercise basic competency in the topic, the B questions to give more challenging, creative, but still standard extensions of it, and the C questions a challenge for the very brightest students, often drawn from the instructor’s latest research or even unsolved problems. All of the following techniques emerged in this period: face-to-face teaching with interactive questioning rather than passive attendance at lectures, guided problem solving, regular examinations, textbooks, coaching manuscripts, graded exercises giving feedback on performance, grouping students by ability so that group members can all go at the same pace and learn from each other, and extended private study (Warwick 2003, 41). Because (rag) paper was then expensive (cheap wood-pulp paper came in the mid-nineteenth century), its use for taking notes and doing problem exercises might at first have seemed a wanton waste. The practice of taking notes in classes was employed originally by one tutor to increase the ability of his students to write quickly and for extended periods of time in preparation for the exams, but this exercise in physical fitness quickly took on its own cognitive functions, and spread—cost be damned.

Fitness for the exams and for the amplifying study regimes led to exercise breaks that themselves amplified competitively, and athletic performance became a correlative, and then an independent value. Performance here, but even more on the exams, became increasingly meritorious and the center of ceremony. Although this self-generated competition began in the mathematical sciences, it came to be imitated by the other disciplines. Tutors were outrunning the Cambridge lecturers in competence. They came to have increasing roles in setting questions for the exams and some moved on to become lecturers themselves. Cambridge, embarrassed that the expertise was coming from outside, moved to internalize the tutorial
system in written examinations and extensive interactions with tutors, which subsequently spread laterally to other disciplines until it became characteristic of higher education at Cambridge and Oxford. This transformation accompanied changing (and secularized) criteria for lecturers: from “exemplary people taking holy orders and giving example” (c. 1750) to “technical masters capable of teaching cutting edge methods and doing new research” (100 years later). As Cambridge products of the system themselves became tutors and lecturers, many more graduates went out as teachers in the better secondary schools, taking their ideas of the proper teaching and content of the mathematical curriculum with them, thus escalating the number and level of preparation of mathematically inclined students entering universities.

Training for the exams involved studying questions from past exams, entrenching older topics in some places and generating a constant pressure to add newer ones across the board. As these accumulated, they came to be published—initially informally along with notes for their solution by tutors, and later by Cambridge itself. This became an accepted venue of professional publication—for both the questions and their answers! As the top graduates of the system became examiners in turn, the cumulative body of exams tended increasingly to include the research questions of the tutors and lecturers who taught them and their extent became so broad that one could not expect to cover them all in courses and training leading up to the exams, so diverse monographs and courses specializing in different topics in mathematical physics emerged and spread. Globally, this marked a transition from studying the paradigmatic text as exemplar (in England, Newton’s *Principia*) to studying textbooks and an expanding literature on problems and using methods never envisioned in the *Principia*.

The growth in specialization in all of the sciences—which has often and long been remarked on—took off increasingly, beginning in the nineteenth century. But that it should have been so strongly mediated in mathematics by a change in the structure of an exam, followed by the creative escalation of teaching methods by tutors outside of the official Cambridge educational system, is a striking demonstration of the power and multifarious dimensions of scaffolding in the elaborative evolution of the content and methods of a discipline. A similar story could be told for the earlier rise to hegemony of the medical profession in the United States through the first third of the twentieth century, where the Flexner plan for “scientific medicine” became a tool not only for the generation of increasingly scientifically informed and technologically dependent medical practice, but also for controlling access to medical education, and for disenfranchising other
groups such as midwives and homeopaths, who also had prima facie calls in the “healing professions” (Abbott 1988).

These examples indicate the rich diversity of modes of scaffolding: attachment, guidance with complex tasks, ordered design and structuring of curricula and practice, multiple possible dimensions of acquisition of values, encouragement, help and promotion in professional development, and labor and emotional support of networked individuals, in part channeled and differentially conferred by sex, age, kind of relationship, and specialized competence. They also indicate a rich diversity of uses of scaffolding, which are not limited to communicating knowledge, practices, and values. The medical case particularly, but also the course of Cambridge mathematics, is full of examples of the emergence of organizations and of sources of power, as well as the shifting roles of education, institutions, incentives, standardization, and regulation. These penetrate deeply into the Gordian knot of culture, and leave many traces that we cannot pursue here. Many of these diverse modes and uses are not cognitive in kind, but all can affect cognitive development, and all can be inherited.

Does this also affect the common coinage of folk culture? How could it fail to do so? As we turn below to the Sears catalog and Sears kit houses, we can imagine a rural child watching parents search through a Sears catalog and feeling their values expressed in their choices and discussions of them. At the same time they learn to recognize the images, learn to read the text with the pictures, and learn how to work with and use the things ordered from the catalog. As Sears builds a market for their products, the children and adults build and elaborate a structured world of desires, hopes, plans, and subsequent actions, supported by the contents of the catalog, and embodied in their work and dwellings. We return to consider this case after discussing dwellings in general.

Second Pass: Developing Culture and Culturing Development

Culture and the Anthropology of Dwelling—A Theoretical Excursion

Dwellings have long occupied an important place in anthropology and archaeology. They are relevant for us, too, as prime exemplars and iconic metaphors for scaffolding that assume a central importance in our developmental account of cultural cumulation and change. They are complex expressions of material culture, having diverse forms, functions, styles, and traditions with long and rich histories that are specific to society and place, and at the same time reflect broad physical, biological, and human conditions and constraints. They also raise theoretical problems. For
example, should we view dwellings as products of builders’ activities—things people make according to preconceived plans—or as ongoing processes of dwelling, continuous and contiguous with our history as a species? Ingold (2000) argues for the latter view on grounds compatible with our argument that a developmental view of culture is prerequisite to understanding cultural evolution.

Understanding dwellings as cultural artifacts and dwelling as a sociocultural process is problematic because the building-builder metaphor shares the limitations of biological dualisms such as phenotype-genotype and acquired-innate. These are frequently invoked to explain products of development, but have been vigorously attacked by developmentalists interested in the richly interactive, “systems” quality of units undergoing processes of repeated assembly with recurrent states—that is, life cycles (Oyama 2001; Caporael 2003). Although there is certainly value in treating human dwellers as agents and their dwellings as patients or products, there is also value in interpreting dwellings and dwellers as parts of a developmental system. Dwellings, or their interactions, are generative as are the dwellers. Dwellings afford opportunities to dwellers for their own personal development that they otherwise might lack: places for the stable, safe, and even leisurely acquisition and practice of skills, beliefs, customs, practices, and desires, in addition to the various modes of social exchange and bonding, and to satisfy the needs for protection from extreme weather, predators, places for food storage and preparation, mating, and rest. Dwellings, that is, scaffold the socialization, enculturation, development, sustenance, and reproduction of dwellers, and so play an important dynamic role as generators of those who in turn “make” dwellings and pass them on to others.

The dwelling perspective poses a challenge to “thin” descriptions of culture and cultural transmission offered by some who wish to reconcile biology and culture. Thin descriptions take culture to be any trait or phenotype transmissible by means other than genetics—for example, the dual-inheritance theories of Cavalli-Sforza and Feldman, Boyd and Richerson, and Odling-Smee and colleagues. As such, all sorts of social organisms, that is, organisms that interact with one another—which is to say, all organisms—are potentially capable of having culture, limited only by contingencies of habitat, biological capacity, and evolutionary history. Thin description thus leads to a wide scope for culture. The line between cultural and noncultural species becomes empirical and calls for theoretical explanation (e.g., Boyd and Richerson 1996). “Thick” descriptions take culture to be a symbolic realm open (so far) only to humans in which having and communicating meanings unrelated to the intrinsic or “natural” properties
of things require extremely refined capacities for rational thought and articulate speech, that is, language. Such descriptions typically take the difference between humans and other animals to be categorical, even if the biological roots of culture evolved in a particular primate lineage (or lineages). Thick descriptions lead to a narrow scope for culture and makes the difference between cultural and noncultural species a matter of conceptual distinction or definition. We believe that this hides and refuses to address some of the very most interesting problems.6

We agree that there is a major difference in kind between human and animal cultures, but perhaps not one intrinsically greater than the differences before and not long after the advent and cultural developments issuing from the origins of written language.7 The first attempts to push an analysis of culture further should be to see what aspects of a difference in kind are resolvable as differences in degree with the recognition of thresholds leading to major changes in behavior and emergent structure.

Nevertheless, “thin” models are unsatisfying for the vast majority of aspects of cultural phenomena. Like population genetics, which is based on a distinction between genotype and phenotype, thin models of culture presume that cultural transmission just means direct phenotypic transmission, in contrast to the direct transmission of genes or genotypes and indirect transmission of phenotypes assumed by Weismannism (Griesemer and Wimsatt 1989). Thin models of cultural transmission are thus sometimes described as “Lamarckian.” These thin models for culture coexist with population genetics models because each is thought to describe a distinct transmission process, separated by a process of development through which genotypes make phenotypes.8 In both, it is supposed that we need not take seriously the rich contextual details of either development or culture to gain a deep understanding of these evolutionary processes. They have no purchase on the rich details or even on their very existence. In abstracting away from these details, they must fall crucially short of an adequate account of the nature and transmission of culture. We believe that there is a productive middle ground that can do so.

How are we to understand cultural transmission when there is such deep disagreement about the nature of culture? Even among those seeking to reconcile biology and culture, there is disagreement. Some developmental systems theorists deny a distinction between biological and cultural evolution on grounds that there cannot be separate channels of inheritance (Griffiths and Gray 1994, 2001). Ingold (2003) writes sympathetically that “the changing forms and capacities of creatures—whether human or otherwise—are neither given in advance as a phylogenetic endowment
nor added on through a parallel process of cultural transmission but emerge through histories of development within environments that are continually being shaped by their activities.” Such sentiments seem to suggest “medium viscosity” views lying somewhere between thick and thin descriptions and their corresponding conceptions of culture, but give little help in analyzing their nature. They say more about how distinctions such as “nature-nurture” are inadequate than about workable alternatives. This often leaves the field to the obsolete machinery that they criticize. 9

The difficulty in distinguishing the contributions of resources to a developmental system subject to an evolutionary process are substantial, but there are structural, functional, and dynamic roles that must be distinguished if we are ever to understand cultural processes of transmission and change. We think that the changing forms and capacities of human dwellers emerge through an interplay of reproduction, scaffolding, and generative entrenchment in groups acting and interacting in space and time. This can be illustrated with an example from the recent history of home building: the advent and spread of “kit” houses by Sears, Roebuck and Company in the early twentieth century.

Case Study: Sears Kit Houses

Sears, Roebuck and Company is widely known as a general merchandiser that grew by selling through mail-order catalogs. In the United States, this mail-order business began in Chicago, the birthplace of Sears, with the innovation of Sears’ competitor, Aaron Montgomery Ward (“Montgomery Ward & Co. (Am. co.),” 2004). Ward worked as a clerk and a traveling salesman for the Chicago department store, Marshall Field (founded in 1865). “Department stores” had emerged in the mid-nineteenth century in Europe and spread to the United States. 10 Mail-order catalogs could be sent through the mails at very low cost because special subsidized postal rates (fourth class, for printed matter) were set by the U.S. Constitution to encourage the widespread distribution of newspapers, which the framers felt was essential for a well-informed citizenry (Chandler 2000, 8–9). Low postal rates encouraged increasing distribution of catalogs and the growth of mail-order businesses after the Civil War. Sears began selling watches by mail order in 1866 (“Sears, Roebuck and Company (Am. co.),” 2004). The advent of rural free delivery in 1896 and parcel post in 1913 by the U.S. Postal Service, together with the expansion of the railroads and the highway system (“Sears,” 2004), as well as cheap paper and steam-press typesetting, furthered this commercial explosion, bringing the contents of the new department stores to rural America.
On the edge of the antebellum American frontier, Chicago marked a boundary between the well-connected network of efficient Eastern transportation and the frontier economy and transport network of the plains and Western states. Ward recognized that mail order would provide better service (indeed usually the only service) to rural customers without ready means to travel to urban centers to shop in department and other retail stores. Ward's and Sears both began as mail-order-only businesses. In the 1890s, Sears expanded to include a wide range of items when Julius Rosenwald, a clothing manufacturer, purchased Roebuck's interest in the company (“Sears,” 2004). The first retail store—building on their monetary success and now familiar name—opened in 1925, after Robert Wood joined the company and took advantage of the increased accessibility of urban shopping with the spread of the automobile. By 1931, retail sales exceeded mail-order sales (“Sears,” 2004). Thus, mail order emerged as a means of extending the reach of department stores beyond the “neighborhood” defined by the travel distances of consumers, but it also leveraged a national expansion of successful retail stores. Both extensions took place through the catalog, scaffolded by the various institutional, technological, and organizational innovations of society and government mentioned above. The Sears catalog became an icon of American popular culture: in many rural homes in early twentieth-century America, it was one of the few reading materials besides the Bible. According to Thornton (2002, 6), many rural children learned to read using Sears catalogs.

In 1895, Sears introduced a catalog specializing in building materials such as lumber, hardware, and millwork in addition to the 10,000 items of general merchandise in the regular catalog (Thornton 2002, 2). In 1908, Sears introduced a “Modern Homes” catalog of plans and kits for building whole houses (see figure 7.1). Within a few years, the kits included the framing lumber needed to build each plan, and in 1914, the lumber was offered precut, with each piece labeled to facilitate inventory and assembly (Thornton 2002, 12). With the end of World War I, during which the building of new housing was virtually suspended, increased immigration and returning veterans generated significant demand for housing and created a large pool of available construction labor without the capital to realize their “American dream.” In 1911 Sears introduced mortgage financing of their kit houses, but by 1918 the terms had become successively more liberal, with much lower down payments than commonly available from banks at that time. Sears’ kit-home business peaked in 1929, with ninety different house designs and sales of $12 million (Thornton 2002, 33). In 1930, sales declined to $10.6 million. In 1934, with the Great
Figure 7.1
Page 34 of the 1926 Sears catalog: The “Priscilla,” six rooms and sleeping porch, No. P3229, “Already Cut” and Fitted, Honor Built, $3,198. The house plans collectively were supplemented by forty-one pages detailing house fittings and accessories, construction details for the different grades, the advantages of Sears designs, factory-cut assembly kits, mortgage application, and a good deal of hortatory prose. Note the appeal to “lovers of colonial architecture.”
Depression in full swing, Sears foreclosed on $11 million worth of mortgages, bringing their housing bubble to an agonizing end for company and customers alike (Thornton 2002, 29; citing Emmet and Jeuck 1950). Together with Sears’ reputation as a purveyor of quality goods and materials, the expanding rail and postal network, the entrenchment of its catalogs, the demand for housing, and the abundance of labor all contributed to the spread of Sears Homes. By the time the company closed the doors on the Modern Homes division in 1940, they had sold around 75,000 house kits and listed between 350 and 450 different designs (Thornton 2002, 1, 5).

These patterns emerged, moreover, in a context of “rationalization” of many segments of American social, economic, and technical life (Gerson 1998).11 Interest was piqued in a clean, organized, and economical way of life that contrasted with the dusty and cluttered image of Victorian living (Thornton 2002, 7). The rise to prominence of the germ theory of disease in the nineteenth century led to increased interest in cleaning devices, electricity, and changes in domestic patterns, practices, and habits (Thornton 2002, 8; citing Gowans 1986). The emergence of a working middle class without servants also helped generate a market for time- and labor-saving devices and strategies. Sears tapped this market by using their home kits as a marketing tool for the thousands of items in their regular catalog. Though not usually architecturally innovative (Sears tended to try to produce the styles already most popular in an area), they made central heating, indoor plumbing and toilets, electricity, and gas available in houses for middle-class people, and thus often drove styles and standards in their neighborhoods. Sears was also technologically modern and an “early adopter” of the new safer and more economical “platform” construction, when they switched (wholesale, in 1928) from the earlier “balloon construction” design.12

Sears also “rationalized” its business practices in this period: standardizing house designs and styles (in contrast to houses individually contracted and crafted by architects), mass-producing parts for houses in its own lumber mills, and precutting lumber on a mass scale to eliminate wood waste and shipping costs. They organized and standardized fittings, furnishings, and financing terms along with systematizing and coordinating their general merchandise with the various home plans, which all contributed to the creation of a market.13 And despite the common perception that standardization and mass production threaten “craft quality,” Sears’ rationalizations actually increased their reputation for quality products: by judicious precutting, they were not only able to reduce shipping costs, but
also to remove knotholes from lumber, thus elevating their wood product from second- to first-grade (Thornton 2002, 15).

The advantages of “rationalization” to the customer were substantial. Before modern portable electrical tools, precut lumber generated especially significant savings in time and hand labor for the customer, as Sears never tired of saying in advertisements. The coordination problems solved by having a unitary kit should not be underestimated. The “average” housing kit had 30,000 parts and filled two railcars. Even making sure that all of the parts arrived at the building site on time obviated the need to seek them out individually, or to delay while a suddenly recognized necessary part could be found or ordered and shipped. And the downstream advantages for maintenance and repair of having windows, doors, screens, and fittings to standard specifications was enormous (as restorers of older Victorian houses often find out to their dismay).

Sears encouraged customers who sought alternatives to Sears’ designs to work with their architects to get a set of plans and kit from Sears—after which Sears could add a new choice to its catalog. Within a design, they advertised that any house could be “mirror inverted,” and designs morphed in simpler ways that called for many systematic changes, but did not require major design reconfigurations. (This could include, for example, making the house three feet wider, adding the space to the living room, dining room behind it, and the two bedrooms above it, without disturbing the rest of the design.) One Sears customer cut out a catalog picture of the roof line of one design, taped it to the bottom of another, and mailed it to Sears with a note requesting the hybrid design, which the company agreed to produce (Thornton 2002, 67). Local housing offices in big cities had “showrooms” (sometimes with associated model homes), and places where customers could consult for modifications, or see the combinatorial possibilities for the multiple options at every stage.

To coordinate some systematic changes, Sears offered two grades of construction, “Honor built” and “Standard,” with a third for garages and summer cottages, specifying different qualities, thicknesses and kinds of wood, flooring, shingles, windows, furnace and plumbing provisions, trim, and the like (Thornton 2002, 14–15; Sears Roebuck and Co., 1991, 12–13). A customer could order a quality level, and then modulate that design as they chose, avoiding the hundreds of coordinated decisions that such a quality change entailed.

Coming to Sears for a home kit in the virtual sense of shopping their catalog encouraged coming there for other goods, thus coupling the spread of
Sears home styles and the styles of other artifacts. Indeed, this motivated Sears’ initial move into the housing market. Sears sold nails, screws, bolts, more complicated fittings, plumbing fixtures for kitchen and bathroom, furnaces, tools, lamps (electricity, gas, kerosene—early electricity and gas distribution was urban only) in different styles and costs, different decorative door, stained glass window, mantelpiece, and bookshelf combinations, even books for your library, and a machine to make concrete blocks (in various decorative styles) for your home’s foundation.

Sears also built clusters of homes, and even a large chunk of a town. In 1918, Sears contracted with Standard Oil to build 192 houses in Carlinville, Illinois, and in nearby “Standard City,” complete with streets, sewers, and sidewalks (Sears Roebuck and Co., 1991, 2–3; Thornton 2002, 35–67). This was a “company town,” but also in some ways a worthy predecessor to post–World War II’s paradigmatic suburb, Levittown.

All in all, Sears’ activities with kit houses introduced changes and provided new paradigms in lifestyle and made homes affordable for many middle-class Americans. Along many of the older roads of the Midwest, which often paralleled the railroad rights of way, one sees houses (and foundation bricks!) that look like they came right out of the Sears catalogs. Sears brought “Fordism” and the benefits of mass production, scale, standardization, labor savings, and technical innovation to a new sector of the economy at the same time they populated American homes with artifacts from the rest of their catalogs. In this way Sears scaffolded home ownership for consumers, lowering the cost and risk of building a middle-class house outside an urban area, and at the same time extended their catalog sales and projected the same American values that they helped to create in ever-deeper mercantile layers to a widening public.

Perhaps the advantages to consumers of social investment in Sears’ “external” scaffolding rather than their own personal investment in direct transmission of goods is best seen in the contrast between pioneers who had to pack up a household in a wagon that could be self-sustaining for months or years as they made their way across the frontier versus the spread of Sears houses after the railroads and other infrastructure were set up as a persistent network of scaffolding that supported rural settlement. As long as the rails are repaired, rights-of-way and law and order maintained, customs, conventions, and institutions sustained for ordering from Sears, then you would not need to move an operating household from the East to the West: just take the train West, stay in a hotel when you got to the provincial town, order your Sears house from the catalog, have it
delivered to the railhead, and build it nearby (or contract with a local builder) when it arrived. And the children raised in that and in other houses would see and share the values they would buy in the catalog.

The multilevel richness of this case demands further analysis. We return to it in the section on “cultural reproducers” after we have developed the theoretical apparatus to do so.

A Central Role for Scaffolding
Biologists as well as anthropologists, sociologists, social psychologists, and historians of science have taken a theoretical interest in scaffolding, though not by name. The construction of scaffolding is a special kind of niche construction, but that theory as elaborated by the biologists Odling-Smee, Laland, and Feldman (2003) “black-boxes” ontogeny. Without opening this box to make significant use of development, they take only the first steps (though important ones) toward an adequate theory of human cultural evolution. This beginning does not reach far enough to capture some of the most important parts. Development seems so complex and particular, like the adaptive designs of different phenotypes, that those seeking general theory tend to avoid it. But there are abstractable and general features of development, and each of our approaches has sought for and used them.

Consider how extraorganismal cultural resources form repeated assemblies that serve as critical scaffolding for the development and inheritance of culture. "Repeated assemblies’ are recurrent entity-environment relations composed of hierarchically organized, heterogeneous components having differing frequencies and scales of replication” (Caporael 1995, see also her 1997, 2003). Scaffolding leads to self-scaffolding as individuals gain skills they can use to acquire new skills (Bickhard 1992). As skilled individuals contribute resources to the development of behavioral traditions within social groups (Avital and Jablonka 2000), they facilitate the repetition, and thus the accumulation, of the particular configurations of resources that we identify as items of culture, whether artifacts, behaviors, practices, or traditions. It is as if, through a designed structuring of the environment, we are able to sequester the right kind of prebiotic soup (or pizza—see below) to synthesize the kind of artifact we seek to produce, then learn how to package it, and then we are off, producing—if we are wildly successful—a new sector of the economy. Moreover, the order in which resource configurations become repeatedly assembled creates downstream dependencies in the productive role of scaffolding, which entrenches the dependencies in development.
As entity-environment relations (e.g., actor-artifact relations) are repeatedly assembled, so that culture becomes generatively entrenched, it also *thereby* becomes reproductive, forming a level of potential inheritance in its own right. That is, when individuals in a particular social group context exercise their relatively context-dependent abilities, scaffolded “from outside,” so as to develop “mature” abilities that are more robust and less context sensitive, they achieve that measure of autonomy and authority needed to serve as agents of scaffolding to others (e.g., biological or cultural kin). The “internalization” of scaffolding—gaining relatively context-independent abilities to perform services for others similar to those experienced in one’s own development—is a form of generative entrenchment that then becomes portable and tied to the agent. If it is central enough, the context dependence may become black-boxed and invisible to the sufficiently socialized community that can take it for granted, with its ethnocentrism apparent only to an outsider. The internalized scaffold, like a skeleton, becomes visible to an insider only if something sufficiently untoward and disruptive happens that the fabric unravels and we see again the bones making up the movements we have been following in each of our examples.

Social-group development depends on this internalization of individual ability to perform scaffold services as a means to the maturation of group members and thus to group development. Internalization facilitates social-group reproduction and identification at its own level: those particular features of a social group that distinguish its artifacts, traditions, and practices as its *culture* are propagated to new generations of individuals and groups. Thus we seek also to understand culture in terms of the emergence of new levels of inheritance and the ways the entrenchment of generators at lower levels become the basis for scaffolding development at higher levels.

An important aspect of the emergence of new levels of inheritance is the evolution of developmental mechanisms that depend on the direct transmission of organized packages or propagules at the new level (Griesemer 2000a). Biological transitions to new levels generally achieve this by new organizations of material propagules—for example, genes organized in material chromosomes, chromosomes organized in gametes and cells, cells in bodies, and bodies in social reproductive units (Maynard Smith and Szathmáry 1995). It is an open question to what extent cultural transmission depends on reproduction via organized *cultural* propagules. Many of the products of culture are material artifacts that serve as models for imitation and social learning, and are also transmitted or inherited as property. Parts
of the social “infrastructure” that sustain culture are material as well. The theory of the firm in evolutionary economics must treat the firm as a hybrid legal-material object, an institutional/organizational complex that attracts and feeds on investment, uses and transforms material resources, and derives energy (or capital) and evolves through competition, growth, and reproduction. Firms attract trainees and produce “company men” (the sexist language still seems to fit here!). Firms are born, swallowed, sued, and wooed. They “respire,” recruiting and relinquishing (or, too often, excreting) workers in the aperiodic seasonality of market ebb and flow. They are agents in our economic and political environment, but they too are scaffolded and enculturated, in ways that sometimes require great care, as multinationals must discover when they buy or bud a firm into a different country.

All of these dimensions, from different national industrial cultures, patent laws, industry-university relations, and the use and production of technology and scientific research are explored in Murmann’s (2003) lovely economic and technological history of the growth of the synthetic dye industries in England, Germany, and the United States from 1858 to 1914. Murmann’s work illustrates particularly well the importance of a multilevel approach to cultural evolution. The rich interpenetration of organizations, institutions, professions, and networks of people in nationally particular evolving configurations can engender such a context sensitivity of the players at various levels that one longs for entities as well individuated as those in biology. In culture, the evolving system is often more like a messy ecosystem that a species. Such rich embedding makes material and ideational cultures inseparable—not as Siamese twins that can, however laboriously, be separated, but as gently poured and incompletely mixed cream into coffee.16 Our explorations of the theoretical role scaffolding can play in a developmental model of culture lead us to consider below the role of material organization in cultural evolution.

Models of Culture
A variety of simple models for culture can be used to explore the ways repeated cultural assemblies develop, reproduce, and become generatively entrenched through adaptive evolution. Though they are specified very abstractly here, each tries to capture key features of more complex relationships. For any given case one may need to consider them as alternatives, but in the whole of cultural descent, all of them are represented, and in more complex cases, we may see a tangled web of several of them for different aspects of or actors in the system simultaneously.
First, if we think of material culture as the set of artifacts produced by actors belonging to a culture, then culture grows and accretes by means of the activity of actors. Particular artifacts may be passed from actor to actor (cultural property inheritance) and even embellished or simplified by descendants (cultural evolution of an attenuated sort). But artifacts (clay pipes, automobiles, Gibson guitars, heirloom watches) do not typically give rise to new artifacts via a material transfer of their parts. The “evolution” of artifacts is the result of descendant actors producing new artifacts that are variations on the themes of the artifacts of their ancestors. Artifact “evolution” is Weismannian, with artifacts as “dead-end” soma (see figure 7.2).

Second, we may instead think of culture not as the artifacts, but as the shared conventional understandings needed to produce artifacts, or the set of behaviors or practices of producing them, in which case artifacts are mere indicators of culture, while culture is activity that can be passed from cultural ancestors to descendants by facilitation of trial-and-error learning or by teaching and social learning. In this way of thinking about culture, artifacts may provide a feedback mechanism for a growing and changing culture insofar as the interaction of actors and artifacts alters the understandings or practices that are transmitted in teaching and learning, but it is the altered actors producing artifacts and a population of actors that evolve culturally (see figure 7.3).

Third, under either conception of culture, actors may evolve as a consequence of engineering their environments via the production of artifacts. People who live in dwellings that protect them from the elements may happen or plan to provide a dry place for storing food protected from scavenging animals. They may thereby evolve dietary interests and needs different from those of people whose food is exposed to destruction, loss, and theft. We can track changing artifact types such as dwellings or changing...
understandings and practices of actors who produce dwellings, but in either case, the consequences or effects are filtered through the Weismannian channel from actor to actor. This “builder perspective” is Weismannian, focusing on the way actors change as a function of the fitness of their constructed artifacts or cultural “phenotypes” (Ingold 2000, 2001).

Fourth, more radical conceptions of culture (in the sense of departing from conventional biological wisdom that inheritance is always Weismannian) include those in which cultural elements themselves constitute a “channel” of inheritance distinguishable from that of the biological actors who form the generative basis for culture and, still more radical, those in which the generative basis of culture does not lie solely with biological actors. Consider the following two broad classes of such multichannel conceptions (see figure 7.4). In dual-inheritance models, patterns of variation in cultural items have a direct path of influence on the patterns of such items in subsequent generations so that tracking the reproduction of the biological actors alone cannot explain those patterns of variation (Boyd and Richerson 1985; Richerson and Boyd 2004). So-called memetic theory

Figure 7.3
Cultural Weismannism with feedback. Biological actors (BA) make artifacts (A) in a given generation and biological actors in the next generation, as in cultural Weismannism (see figure 7.2). But the process of making an artifact in the parent generation affects biological actors in the next generation—for example, by teaching and learning.

Figure 7.4
Cultural reproduction and coreproduction. In cultural reproduction (left), biological actors (BA) make artifacts (A) and also biological actors of the next generation, but artifacts also contribute to making artifacts of the next generation. In cultural coreproduction (right), in addition to the relations shown for cultural reproduction, the artifacts coproduce with parental biological actors the biological actors of the next generation—for example, when artifacts scaffold the development of the offspring actors.
(e.g., Aunger 2000, 2002) would fit here too, though we have deeper problems with it that we will not consider here (Wimsatt 1999, 2002).

Fifth, in the other, more radical departures from Weismannism, there would be reproductive elements of the culture besides the biological actors: artifacts or practices that, as it were, give rise to more (and varying) artifacts or practices rather than merely being repeated in subsequent generations due to new acts of making by descendant biological actors. Differently put, in the previous case, if artifacts and practices are tracked separately from biological inheritance, a more adequate prediction of changing patterns of variation can be made than if only biological inheritance is tracked and artifacts and practices are treated as parts of the biological phenotype caused by genes. Models pursuing such an approach aim to overcome the implausible view that genotypes are the sole determinants of cultural phenotypes. In the cultural-reproduction approach, on the other hand, the relation (and mechanism of development) between items of culture across generations would differ from that of the dual-inheritance models (see figure 7.4). Cultural items would directly reproduce, just as biological actors do, contributing parts to offspring items, and our reasons for tracking them would be the same as for biological actors. In this case, the population dynamics of culture would be coevolutionary for a variety of “species” of reproducers interacting in a cultural ecosystem.

Sixth, a variant on these reproduction and coreproduction representations that focuses on the process of producing actor-artifact relations treats the practices linking biological actors and artifacts as the objects reproduced and reproducing rather than their elements (see figure 7.5).

We do not argue in favor of this pure form of cultural reproduction, although we think that to explain cultural evolution a more nuanced account of the cultural development of items typical of human culture (both actors and artifacts) than spartan dual inheritance mapping relations is necessary. It is likely too that all of the alternatives we have described are relatively accurate for different cultural life forms, just as biology has a diversity of reproductive modes (some Weismannian and some not). We do not
claim to have given an exhaustive list of the possibilities. Cultural artifacts and practices are more than mere objects of imitation and learning, but probably less than reproducers, so a medium-viscosity theory is required to account for their development and seems the best strategy. Moreover, in addition to feedback effects of the use of artifacts and engagement in social practices, we must consider ways biological actors function as cultural artifacts and practices for other biological actors. That is, the development of a biological actor in a society with culture involves other actors functioning as scaffolding to facilitate the acquisition of skills (and authority; Gerson, forthcoming) on the part of a developing actor. And it is certain that anyone interacting negatively ("impersonally") with a large bureaucracy has experienced the other side of this coin of "person as artifact," in which human actors become so entrained by the policies and stereotypes their roles engender that they seem like, and effectively are, parts of the machinery.

Actor-artifact complexes persisting over extended developmental time have an integrated and constitutive unity that needs to be taken very seriously. Our view is that although this scaffolding function of biological actors and scaffolding uses of artifacts in culture do not render particular artifacts (mathematics exam papers, Sears kit houses) cultural reproducers, they do render cultural systems developmental and biological actors in them cultural reproducers. Because such systems can also become emergent cultural reproducers, the material transfer of "nonbiological" components can take on a reproductive role. This is just how the material transfer of nonreproducing biological components of a cell (such as membrane lipids, cytoplasmic proteins, and DNA strands) render cells reproducers when they transfer developmental capacities via these molecular mechanisms. In other words, cultural developmental systems become reproductive when components perform generative scaffolding functions internal and vital to the production of cultural items within cultural reproducers, whether these are artifacts, practices, or biological actors (see figure 7.6).

In our examples, this is probably most obvious in the evolution of mathematical physics. The practices that developed around written exams were passed on and refined, and the cumulative publication of exam questions and answers forced generation of new ones (through desires to avoid repetition). The cumulative use of earlier mathematical techniques and results in new problems gave them a generative role in the production and reproduction of new knowledge.

Finally, the different time scales of production and reproduction for the various interwoven and embedding biological actors, artifacts, and hybrid
Figure 7.6
Coreproduction of cultural systems. A cultural system consists of a number of biological agents (BA), artifacts (A), and practices, simplified here as a single population rather than a complex network of partially overlapping, structured reference groups and social worlds. The system reproduces (in a very “broadband channel”) when material components are transferred in space and time to offspring systems. The developmental mechanisms transferred yield a cultural system-level reproducer when they are generative and provide scaffolding relations within and among elements and substructures (not shown).
cultural systems in our cultural “tangled bank” explain a lot of the ambiguity many feel about whether we should be talking about cultural development, or cultural evolution, or given that ambiguity, about neither. After all, if we cannot pick out the units, and cannot even agree on their life courses enough to say whether they are developing or evolving, why bother? This requires a closer look.

**Cultural Inheritance and Cultural Life Cycles**

Any Darwinian theory of evolution, whether biological or cultural, must be populational, following Mayr (1964), Boyd and Richerson (1985), and Hull (1988). For cultural evolution, this means modeling the fates of different variants of what are regarded as the “same” cultural entities among individuals or larger social groups (see figure 7.6).

Boyd and Richerson (1985) study the conjoint operation of biological heredity and cultural heredity. Thus their theory is a “dual-inheritance” theory. They argue that earlier attempts to cash out cultural processes and change solely in terms of biological genes and biological fitness will not do. We agree. Recognizing the dual nature that they note for biocultural inheritance gives a good first approximation for the dynamics driving biocultural evolution in cases like those discussed by them and by Durham (1992). But here we diverge.

The nature of embodied reproduction requires us to reconceptualize processes of evolution and inheritance in a developmental mode that reveals significant problems with the replicator concepts of Dawkins (1982) and Hull (1988), and many more problems with their use to conceptualize evolutionary processes (Griesemer 2000a, 2000b, 2000c, 2002). Moreover, generative entrenchment is a phenotypic property with implications for differential evolutionary stability of traits and trait complexes that provides a framework operating directly on the causal structure of development to predict differential rates of evolutionary change without invoking genetic information (Wimsatt 1999, 2001, 2003). Analysis of phenotypic structures in terms of generative entrenchment can thus be used to complement genetic analysis, but can also proceed independently of it (Schank and Wimsatt 1988; Wimsatt and Schank 1989, 2004).

Neither Griesemer’s reproducer dynamics and hierarchy of reproducer concepts nor Wimsatt’s generative entrenchment require genes or things modeled too closely on them to generate results. This is fortunate. Culture has no genes—at least none determining particular cultural variants or adaptations at any level. And, meme advocates to the contrary, it has no
memetics—at least nothing at all similar to genetics, or with its analytic power (Wimsatt 1999; Sperber 2000).

Although we accept Boyd and Richerson’s framework involving both genetic and cultural change as having significant heuristic power and a formative influence on problem structure in several respects, we focus here on shorter time scales involving cultural change only. The problems we discuss have not involved significant gene-culture coevolution, though we agree that it occurs and is important on the longer time scales necessary to consider the origins of language, our basic forms of sociality, and the Neolithic origins of agriculture and culture (Boyd and Richerson 1985; Richerson and Boyd 2004). On the time scales that interest us, from minutes to months and from decades to hundreds of years, depending on mode of transmission and scale of analysis, gene-culture coevolution is less important than gene-culture codevelopment: the ways culture and genes interact to scaffold individual and group development in the context of social groups and social worlds.

We also agree that biological and cultural inheritance processes must be treated as distinct for purposes of modeling cultural evolution, but this is just a start on what is required for a robust understanding of cultural inheritance. We must consider more than two channels, even on short time scales. To understand the properties of the relevant inheritance processes or the character of cultural innovation, neither biological inheritance nor especially cultural inheritance can be treated as single-channel processes.

We return to this issue shortly, but because issues of time scale, stasis, and change come up repeatedly below, we take a short detour to consider them here more generally.

Elements of any complex organization exhibit a spectrum of rates of change. Choosing an object or phenomenon to study determines a time scale on which its behavior is interesting, with trajectories that evolve, develop, decay, oscillate, or simply change. On that time scale, some (commonly larger) things change so much more slowly as to appear constant or nearly so, and are treated as structural, objectified, or background constraints. (Usually smaller) things changing much more rapidly become transients, fluctuations, interruptions, or background noise. We bracket or filter them out to focus on the target entities and relationships between them (Lotka 1925; Wimsatt 1994). When these change at different rates, this difference can dominate the outcome, restricting what can happen (Simon 1962). Thus we cannot eradicate insect or disease pests because their short generation times allow them to simply evolve their escapes,
while their large populations quickly give them the mutations to do so. Differences in rapidity of response condition any evolutionary process, and particularly the interactions between biological and cultural change.

Two striking deviations from the general pattern of larger-is-slower and smaller-is-faster are relevant here. The first is cultural evolution itself which, though we tend to think of it as (very) high level, is capable of changing at much faster rates than biological processes commonly do. This claim will be the topic of the next to last section. The second exception is that specific mechanisms can make something much more stable than one might expect for things of that size. Two alternative explanations for this in biology are developmental canalization and generative entrenchment. These (and their cultural analogues) can be important for culture, but entrenchment particularly so, since it plays a role in understanding how scaffolding can support much higher rates of successful cultural invention and change and enormous growth in social complexity.

A particularly curious “time-scale” lacuna in “thin” accounts of cultural evolution marks off our approaches from most others. We both make central uses of development. Very few of the quite diverse theories of cultural evolution do so, though all effectively presuppose it. Cultural evolution today is as devoid of a developmental perspective as population genetics was in 1970. This is a serious mistake. Development figures centrally in understanding the most important differences between biological and cultural inheritance, and consequently the differences between biological and cultural evolution. Let us see why.

Culture involves multiple channels of inheritance. But unlike the genome, which is acquired effectively simultaneously at the formation of the zygote, the sequential acquisition of culture by maturing individuals gives these multiple channels incomparably rich possibilities for interaction and intermodulation. Contrast the processes for cultural acquisition, modification, and transmission in the cultural life cycle of an individual with the much less complex life-cycle diagram for biological inheritance and evolution. We start with the far simpler (while still complex) biological life cycle (see figure 7.7).

Explicit representations of these life cycles in biology texts are usually much simpler than this one, aiming to convey only the features of the simple abstracted model being discussed there. This life cycle is intended to represent all of the major forces acting and information required for a full evolutionary account—forces discussed elsewhere (often in a family of other complementary models) in a more complete treatment. The aim is to bring the description of the biological life cycle as close as possible in its
The Structure of Biological Life Cycles
as Used in Population Genetic Models of Evolution

Key: Objects in bold, theories or sources of theoretical description (plain), selection processes in italics.

stage 1: [DETERMINE A BREEDING POPULATION]

Population(t₀)
⇒ [demography, mating rules
(sexual selection)]
⇒ mating pairs

stage 2: [COMPOSE OFFSPRING GENOTYPES]

⇒ [Mendelian (transmission)/cytological/molecular genetics,
(molecular, genic, gametic selection)]
⇒ offspring genotypes/zygotes

stage 3: [DEVELOPMENT AND SELECTION → NEXT GENERATION]

⇒ [(development, physiology, ethology, ecology,
biogeography, geophysics)
⇒ [(phenotype, environment) →
(Darwinian) selection/fitness]]
⇒ Population(t₁) [RETURN to stage 1 for NEXT LOOP]

Figure 7.7
This life-cycle diagram (after Wimsatt 1999, figure 1) is more detailed than commonly found in biology texts (to better parallel the complexities of figure 7.8), and includes for each of the usually separated stages, the biological objects present at that stage (in bold), the processes of selection acting (in italics), and the theories brought to bear to describe and account for the transformations at that stage. It is often simplified into three or even lumped into two boxes, connected by arrows with the author’s focal mechanisms in one box, and the rest in another.
The Developmental and Network Structure of Organism-Centered Cultural Life Cycles

Stages 1.1 through 1.n (reflecting age or experience structure):
[DETERMINE A BREEDING POPULATION]

Given a population of potential transmitters, determine which ones do so, and to whom* [iterate n times for reception and transmission periods in age-structured life cycle];

COMMENT: This requires knowledge of transformations in 2.1 through 2.n from preceding iteration

Stages 2.1 through 2.n: [COMPOSE OFFSPRING GENOTYPES]
(inseparable from stages 1.1 through 1.n); [iterate n times for reception periods in life cycle]:

a. For each individual i, and each stage j, determine who receives how much from whom, as functions of their prior state s and place p in the transmission network. [This state includes the structured and coadapted prior assemblage of cultural viruses, acting as filters for new memes, and affecting how they are received (and possibly transformed)].

b. For each individual i, determine how the reception of the input vector changes the cognitive/normative/practical Umwelt (prior state s) and social locus (place p in the transmission network).

c. For each individual i, and each stage j, determine whether these changes make i a potential transmitter at stage j, and of what and to whom. (Consider capability + opportunity + determination?)

Stages 3.1 through 3.n: [DEVELOPMENT AND SELECTION]
(Is this separable from stages 1 and 2? No: the composition rules (analogous to Mendelian genetics) but also selection and development are implicitly represented in the transformation rules in 2.1 through 2.n a–c above, and presupposed in stages 1.1 through 1.n above, so these processes are almost impossibly confounded!)

COMMENT: So this is already done in 2.1 through 2.n above. Perhaps clause 2.c belongs here, though some of it with equal justification could be placed at stage 1.

Figure 7.8
An attempt to construct a “life cycle” for enculturating individuals paralleling the biological life cycle of figure 7.7 for a “population genetic”–style model of cultural
relevant complexity to that of the next figure, for cultural evolution. For an example of the simplifications of this diagram in simple population genetic models, the population at $t_0$ is simply assumed to be the mating pairs, and to be in Hardy-Weinberg equilibrium, thus eliminating or trivializing the first stage. Molecular selection (e.g., transposons) and gametic selection are assumed not to occur, simplifying the second stage. The role of the organism in creating its environment is also ignored. The six scientific domains in the flowchart at stage 3 describe processes playing roles in constructing both phenotypes and the selection forces acting on them. But the whole of stage 3 and all of the levels of organic form and behavior is collapsed to assign fitnesses as scalar multipliers for genotype frequencies, ignoring all of these complexities in returning to stage 1. Nonetheless the complexity of this life cycle seems minimal when we frame the dynamics of cultural evolution in the same way (see figure 7.8).

This complex figure of the causal structure of processes of cultural evolution is depicted from the perspective of a population of individual developing and enculturating organisms to maximize the similarity between this representation and the preceding. However, its complexity is daunting, in effect a reductio ad absurdum showing the futility of trying to treat cultural evolution on the model of population genetics or “memetics.” Conceptually, it is useful to provide a matrix on which one can hang all of the different kinds of causal interactions and processes, but unlike the schematic biological life cycle of figure 7.7, it could not readily be turned into a computer program for which one would input data describing the population and expect to get a simulated run of its future cultural trajectory, even for relatively short periods.

One often uses models for biological evolution and inheritance without age structure, but the sequential character and order dependence of cultural acquisition in learning and socialization make this impossible for cultural evolution. This explains the iterated subscripts 1.1 through 1.n,

Figure 7.8 (continued)
evolution (after Wimsatt 1999, figure 2). Here the age structure of the population must be made explicit, and cultural transformations are gerrymandered to fit into boxes corresponding to the three for the population genetic account of the biological life cycle in figure 7.7. But then each of the stages can be seen to presuppose information from the other two in order to determine what happens at that stage. As a result, except for very special and not very useful simplifying assumptions, processes of heredity, development, and selection are almost impossibly confounded.
2.1 through 2.n, and 3.1 through 3.n in the steps of the three causal stages of transmission, reception, and generated capacity for transmission, and we must perform an iteration through the n developmental stages and for all transmission from actors (i) and reception by actors (j) mediated by the communication network, and all of the selections and transformations performed by each actor from what they receive or take from their environments.

The dependencies that make this so are implicit in the structure of the clauses (a), (b), and (c) of stage 2, which corresponds to the action of Mendelian genetics in assembling new genotypes from the gametes contributed by the two parents. But the two parents with equal contributions of biological inheritance dissolve in a welter of confusion. The cultural information is acquired through the course of development, so we break the acquisition up into stages. (This is intended here as a conceptual or mathematical device to order input, not endorsement of a stage theory like Piaget’s.) A given piece of culture, however individuated, may be assembled from a varying number of parents, who may have contributed different amounts. Nor are the amounts additive, but they interact richly as the cultural element takes form, more like the highly nonlinear structures of organic synthesis. But whether it is acquired is a product of both the location of the learner in the social network, and also whether their extant cultural resources lead them to accept or reject it. (This may also depend on who they got it from, as parents quickly learn.) In either case, these will affect how an actor will understand and transform, and apply it, as they take it in or reject it.

In principle, the analysis of the cultural “genome” (if it makes sense to speak of one) seems almost impossibly complex. There is no time at the beginning of the life cycle when we have a completely assembled cultural genome analogous to the zygote for biology, so it is clear that we cannot separate hereditary and developmental “components” for culture. And because the assembly process for the cultural genome involves a major component of cultural selection—the sum of what we think of as individual choice, socialization, and the acquisition of explicit, tacit, and procedural knowledge (Reber 1993) as mediated through cognitive development and education—we cannot separate heredity from selection (Wimsatt 1999). Acquisition of some cultural elements may potentiate, rule out, necessitate, bias, or variously transform subsequently acquired cultural elements. So heredity, development, and selection are almost impossibly confounded for cultural evolution, and population genetic–style models will be intractable if we cannot find other sources of constraint to simplify the specification of relevant interactions.23
It is obviously possible to abstract from this complexity in special and simplified cases, as biologists do, but to understand the evolutionary dynamics, processes, and character of culture, one needs representation of this causal structure in its full interactive form, or in forms yielding complementary simplifications to study different aspects of the dynamics. One important consequence of this sequential developmental complexity is that it should be particularly revealing to track individuals in narrative biographical detail. (This should include both biological individuals and higher-level individuals like organizations, firms, and nations.) Complementing these narrative accounts, we would need more synchronic phenomenological descriptions of characteristic modes of behavior and interaction at cultural strata where they appear, acting as structuring elements in the trajectories of individuals. If these two modes of explanation look familiar, they should. In many respects, we would expect to find the disciplinary structure of the human sciences much as we find them today, so no sociobiology-style “urban renewal” of disciplines is anticipated. We also expect that it would not be particularly revealing to try for a direct theoretical implementation of the structure of this figure in all of its complexity to generate a dynamic simulation: one would have to invent or make up values for too many of the parameters for it to be realistic, and there are too many parameters in it even to figure out what would be interesting starting values, or for us to get significant illumination from the results (Levins 1966). Whether there are interesting hybrids of these two approaches (of significantly reduced complexity) is worth considering further, and there are some encouraging signs.

We live in a world that is almost indefinitely complex in its fine details, and in some of its coarser ones too—a world that has also become a lot more complex by our own hands. But it is also a world rich in pattern, with many sources of predictability, and if its patterns were too complex for us to deal with we would not be here; a kind of biopsychosocial existence proof: we have to get through multiple biological and cultural hoops to survive and reproduce. Furthermore, most of what we acquire in cultural development has to be accessible to us or we could not teach it or acquire it. The developmental machinery for enculturation has to be mostly accessible to us or else it could not work on us.24 Some of this machinery is clearly internal, and cognitive, affective, conative, and normative. But the explosive growth of scaffolding processes—those things that have given us our rich and complex cultures—makes large chunks of it at least partially external.

The environments in which we are raised are not so unpredictable, and we are socialized in regulative and directive ways toward behavior that is
convergent in many respects, canceling out much of the variability we face. Individuals make choices, or choices are made for them. None of us has to do everything for ourselves or choose among the whole range of possibilities. Even though in some sense, most of us could learn to do any of an arbitrarily wide range of things sufficiently early, to do almost all of these other things we would have to be differently placed in the sociocultural-economic network, and for many of them differently placed in space and time. Richard Levins (1968) suggested that organisms evolve in such a way as to minimize the uncertainties in their environments. With some important qualifications (Wimsatt 1994) that also seems an important factor or theme in our biological and cultural evolution (Richerson and Boyd 2004). One of the ways we can enormously reduce the range of possibilities and uncertainty is to have us key quickly into a variety of specific factors characteristic of our culture and our place in it, so that our acquisition and elaboration of skills and roles can proceed in an environment of manageable complexity. The complex interactions in acquiring culture that concern us are mediated through processes of scaffolding and niche construction. They focus the cumulative wealth of culture (or that part of it accessible to us at our location in the linguistic and technosocial network\(^2\)) into nourishing our cognitive, conative, affective, and normative trajectories into tracks that are usually (locally) socially productive and either attractive, or more attractive than the accessible alternatives. This focus bootstraps us to do more than we could otherwise achieve, but also coordinates a tolerable level of social predictability within our particular culture and subcultures. The character of these interactions would be impossible without a temporally extended period of development, a fact that developmental systems proponents of niche construction recognize (Griffiths and Gray 2001, 205), making it absolutely crucial to include development in theories of cultural transmission.

Scaffolding involves a mix of (relatively) static resources and constraints and dynamically interacting processes that together facilitate the acquisition of complex skills, knowledge, and behavioral routines when these interactions are appropriately organized. This kind of interactive structure is the key to new kinds of possibilities for innovation and change in culture. It also generates greater possibilities for “deep” or “revolutionary” modifications and much greater rates of change than are characteristic of biological evolution. So understanding the particular potentialities of cognitive development and individual and social learning requires recognizing a multiplicity of systematically interacting cultural channels.\(^2\)
An earlier version of our view, “hierarchical multilevel Weismannism,” observed that cultural inheritance was multichannel, and richer for it (Griesemer and Wimsatt 1989; Callebaut 1993, 425–429). However, none of these earlier accounts goes far enough in recognizing the complexities introduced by the serial acquisition of knowledge and competencies and the social structure of its acquisition, transmission, and distribution through the network of actors sketched in figure 7.8. We propose now to correct these limitations of earlier hierarchical models.

In our earlier work, cultural entities such as scientific theories are treated as abstract (disembodied) generative structures, without scaffolding, and without the natural variability expected in the populations of their advocates and users. Agents who believe the theory are not represented, nor are the support structures for teaching it, learning it, spreading it, modifying it, or applying it. We cannot understand the properties of cultural inheritance without understanding how these abstract disembodied generative structures are embodied in the scientific community, developing, testing, and applying their overlappingly shared theory, while recruiting, training, and embedding new scientists in their community.

**Biological and Cultural Reproducers**

Inheritance, whether cultural or biological, is a special kind of reproduction process, so we must consider reproduction and its units in order to characterize the special case. Reproduction is the transfer of generative, developmental capacities from parents to offspring. In biological reproduction, the transfer is material: a propagule is organized as a mechanism carrying developmental capacities that begins as material parts of the parent(s) and that subsequently become an offspring. In culture, sequestration and bundling of both material and nonmaterial items can play a similar role, packaging cultural propagules into elements of cultural reproducers. In writing, for example, we bracket off the things we want to say from the rest of the text visually. Bracketing words, for instance, that introduce a new section along with visual section identifiers, sequester the material inscription from the complex, highly reactive context so that the ideas can be organized as the generators that their authors desire them to be. Bracketing words bundle ideas together—makes them an item—that can serve as a robust package or mechanism for generating the intended response in readers, in interaction with the rest of the context, but playing their own identifiable role.
Sequestration and bundling of cultural items into cultural propagules play fundamental roles in the process of cultural reproduction. The organization of these propagules, particularly the relations between material components such as biological actors and other components such as ideas (memes), practices, and behaviors, is key to articulating a view of cultural development. What, indeed, does it mean for an actor, an artifact, and a practice (such as the actor’s playing the artifact) to be “bundled” into a propagule?

**Genes and Memes**

When Dawkins wrote *Memes: The Mew Replicators* (1976, chap. 11), he considered small items of culture: bits of melodies easily hummed, statements on sheets of paper that can be photocopied, visual images repeated on billboards, dogmas and doctrines that can be turned into slogans or sound bites. He was interested in the cultural transmission of such bits on analogy with his ideas about biology: the fundamental units of genetic transmission are small items of biology—bits of DNA (or RNA) that are easily copied, divided, and reaggregated to form the beginnings of new organisms. Dawkins also told stories about how the bits of culture and the bits of biology play similar roles in the life of the individuals that have them: cultural memes and biological genes play the role of “difference makers,” things that make a difference in the development of the phenotype of the (biological or cultural) “organism” against the backdrop of other variant, competing difference makers in a process of evolution by natural selection.

For Dawkins, a gene (or meme) is an “active, germ-line replicator.” A replicator is anything in the universe of which copies are made; a germ-line replicator can be the ancestor of an indefinitely long lineage of such replicators (however this may be achieved, by whatever mechanism); an active replicator is one that influences the probability it will be copied (Dawkins 1982, 82–83). This analysis works because it depends on taking the context of activity—replicator power—for granted. The context is just there, so all that is needed for a replicator to be active is to make a difference to the probability of being copied. And the same taken-for-granted context provides the machinery of transmission.

Copying only works as the core concept of transmission in sufficiently rich and appropriately structured contexts. DNA is copied only so long as the whole properly organized and functioning transcription-translation mechanism is present to produce replication enzymes (among many others). Our chapter is photocopied only so long as the whole properly organized and functioning photocopier mechanism is present, we insert
the manuscript in the right place, and push the right buttons to adjust the parameters of copying to suitable values for the task at hand. If we wish to explain copying, however, we must explain how these mechanisms that form the context and manage the control of copying come to be. That means we must explain their development. Doing that leads to the concept of reproduction by material overlap, not replication-in-the-form-of-copies (Dawkins 1976; cf. Griesemer 2000a, 2000b). One cannot pursue the concept of copying as a means to understand development because it begs the question of where the richness of copying machinery comes from.

Dawkins's ideas about culture and biology are controversial, but attractive. As he is fond of pointing out, the best example of a meme is the idea of a meme itself, which landed him on the cover of *Wired* magazine (Schrage 1995) as well as in the pages of *Nature* (Goodenough and Dawkins 1994). Many dislike the “reductionism” of his idea of the gene—how can such bits be the whole of the fundamental story of living things—can talk of “genes for reading” or “genes for altruism” or “selfish genes” really be explanatory? Many equally dislike the “universal Darwinism” implied by his interpretation of the gene as the unit of selection. The controversy is just as heated over his cultural units. Can memetics be a genuine, let alone fundamental, science of culture? We think not (Wimsatt 1999; Sperber 2000).

We will not quarrel directly here with Dawkins’s articulation of gene and meme concepts to apply his stories about replication to the processes of biological and cultural transmission. We have each done that on multiple other occasions (Wimsatt 1980, 1999; Griesemer 2005b). We focus on the role of such items in development. The difference-maker approach Dawkins uses makes sense only so long as the rich context of difference making can be taken for granted. Dawkins’s “gene for reading” (or reading ability) takes for granted the complex developing organism that learns to read, the developed organisms that teach it, the wealth of books to teach with, and the interactions with the world (including other readers) that give what is read a richer content and a dancing gaggle of linguistically mediated referents. Dawkins’s memes—a bird’s song, the “St. Jude mind virus,” the idea of a celibate priesthood—take for granted the rich communicative, cognitive, social environment of a singing bird or a religious order. How, without such context, could such riches ever be garnered? Dawkins’s answer is: by accumulation of the small, favorable bits by natural selection and discarding of the unfavorable ones. But that is only the beginning of an answer because it treats the “richness” of organization in the simplest imaginable way: as a cumulative aggregation of many small items. Neither organisms
nor organizations nor cultures are aggregations of items—if they were, they would be far simpler to understand (W. Wimsatt 1997). They are highly organized and their organization matters to the processes of development, transmission, and selection. Dawkins’s story does not address the evolution of organization, only evolution by accretion, because he takes the richness of context for granted in order to tell the causal story of genes and memes as a story of difference making. To claim that difference-making genes and memes made the difference, historically, between the rich organizations of developed traits that have been selected is merely to beg the question of the evolution of organization. It is, in effect, to fail to recognize the difference between the unassembled Sears house kit and the assembled one, or worse, between the distributed and uncollected and transformed raw materials to make the parts, and the finished house. The parts themselves are the product of a redesigned decomposition of the process of house production and assembly, and the social, technological, and cultural infrastructure to accomplish that!

To even attempt to put Dawkins’s memes in context requires representation of at least some of the institutional and organizational structure and relations between organizations that may share individuals and interact with artifacts. Think of something like a commercial firm, which recruits new employees and socializes them to the company as well as integrating them into the organization’s task and production structure and training them for the particular tasks they will perform. Conversely, institutions and organizations form “reference groups” for the people participating in them. When individuals belong to multiple reference groups, social structures can be complex and nonhierarchical.

**Sequestration and Bundling**

Gene and meme concepts leave unanalyzed the very conditions of their replication and are consequently incapable of addressing questions of the evolution of organization. A way out of this question begging is to recognize that the problem of the evolution of organization is a problem of the evolution of development and of how the problem of transmission is entangled with it. Dawkins sought untangled accounts of transmission as replication and development as phenotypic difference making (Dawkins 1982, chap. 5). For Dawkins, as for all Weismannists (see Griesemer and Wimsatt 1989), these are simply different properties replicators may have that are aggregated in the fundamental units of selection: active germ-line replicators. In contrast, we see activity and germ-linedness as entwined by the very nature of developmental processes. Understanding how they are
entwined suggests a way to describe cultural inheritance more satisfactorily than talk of transmission of cultural “traits” admits.

The difference-maker approach factors out all of the context and content shared by things that make a difference. Following Mill’s methods for analyzing causes, the cause is the difference that makes a difference. These methods assume that difference making itself is context-free so that differences can be aggregated into total causes. But this is not how biology (or culture) or any complex mechanisms work. Difference making is context-sensitive. A gene difference in a rich environment might lead flies to have white eyes rather than red ones, but in a less rich (or just different) environment it may make no difference at all (e.g., to flies that develop without eyes). In general, the components of complex systems have many moieties and functionalities and so contribute to difference-making in multiple, interacting, context-sensitive ways.

In biology organisms can partially control the context sensitivity of difference making by various means. One of these is sequestration. Biochemical substances (and cells) in rich contexts have many reactive possibilities that are (partly) controlled by sequestering them from undesired reactions and, concomitantly, bundling them together with other substances to promote desired reactions. Cells are not mere bags of reactive molecules. They are highly organized, with internal membranes, microtubules, macromolecular binding complexes, and formative devices like the Golgi apparatus, endoplasmic reticulum, and ribosomes. Even the double-helical organization of DNA sequesters the reactive nucleotide surfaces inside the molecule. Single-stranded tRNA molecules fold up into hairpin secondary structures that hide away reactive surfaces while forming others. Ribosomes bundle RNAs and proteins into translation “machines.” Controlling reactivity through sequestration has bundling as its flip side.

Not only can bundled items act preferentially and differentially, they can also be held and transmitted together as a package. Packages can carry whole, organized mechanisms from place to place because their organization is not disrupted in transit. Individual bits transmitted separately, like the message packets of e-mail messages transmitted separately over the Internet, must be reassembled in the correct organization in order to transmit the structure of a parent organism that survived natural selection’s gauntlet. But where does the organization at the receiving end come from? If the receiver is an entity like the sender, then we hit a regress if we appeal to the organization of the sender to explain how the receiver becomes organized in development. Thus, it will not do to explain an offspring’s development by appeal to the transmission of bits from the parent unless we
have already explained the development of the parent or how organization is acquired from the environment by the receiver and yet is correlated with the organization of the sender. In the difference-maker analysis of selfish replicators, the organization carried by reproductive propagules (gametes) is neglected in the account of the transmission of “replicator power” from parent to offspring. At most, on Dawkins’s view (1995) the other elements of the propagule serve to “bootstrap” the initial process of development of the offspring, invoking the idea of development but leaving it wholly unexplained and unanalyzed.

Replicators or Reproducers?
Organized contexts in the biological world can persist by being stable on a longer time scale than other entities of interest or by being transferred from place to place and time to time in material propagules that develop a full slate of properties. The former mode is familiar from our usual treatment of the environment as a persistent context. The habitat surrounding the burrow that mother mouse dug before birthing a litter is more or less the same, seasonally adjusted habitat the offspring emerge to discover when they are weaned. Moreover, the sort of burrow and habitat the offspring experience are likely conditioned in an ongoing fashion by those participating in them, including their ancestors. As Ingold (2000, 186) put it,

For any animal, the environmental conditions of development are liable to be shaped by the activities of predecessors. The beaver, for example, inhabits an environment that has been decisively modified by the labours of its forbears, in building dams and lodges, and will in turn contribute to the fashioning of an environment for its progeny. It is in such a modified environment that the beaver’s own bodily orientations and patterns of activity undergo development. The same goes for human beings. Human children, like young of many other species, grow up in environments furnished by the work of previous generations, and as they do so they come literally to carry the forms of their dwellings in their bodies—in specific skills, sensibilities and dispositions.

Odling-Smee, Laland, and Feldman (2003) urge a similar perspective in their work on niche construction. The alternative mode, persistence by material overlap of reproductive propagules and repeated assembly in development, although familiar, needs motivating.

Dawkins and his philosophical defenders (e.g., Sterelny and Kitcher 1988) treat everything beyond a gene as its “environment.” This blackboxes development as “beyond” the relevant units of explanation and gets the difference-making analysis going. After a gene is replicated within a cell, it is transferred to a new body—the cellular body of a gamete, say,
and then the cellular body of a zygote formed by the fusion of two ga-
metes, for sexual reproduction. The parent cell and its offspring cell (or
gamete) are related by “material overlap,” physical parts (e.g., the genes,
membranes, and cytoplasm) that belonged to the parent at one time are
transferred and belong to the offspring at a later time. These “progenera-
tion” processes (see Griesemer 2000a and figure 7.9) involve the transfer
of an organization, not a mere bag of parts. If the organization transferred
is a mechanism for the development of the offspring, then call the process
a reproduction process. That is, reproduction is the transfer of organized,
material mechanisms of development. If the mechanisms of development
transferred are adaptations (evolved because they confer selective benefit
on ancestors), then the reproduction process can be called an inheritance
process, since the mechanisms of development will cause trait heritability.
If, further, the mechanisms of development are “coding” mechanisms,
then call the inheritance process a replication process. This gives an alter-
native to Dawkins’s copy-based analysis of replicators.

On the reproducer approach, a gene and its replication must involve a re-
production process. Dawkins mistakenly locates replication of the gene in
copying because the transfer of the organized mechanism of development
accompanying it and causing reproduction to exhibit a copy relation is
taken for granted.29 In biology, the difference-making power of genes
is transferred materially, along with the genes through reproduction. But
even the rest of the reproductive propagule is not enough. Some of the
power to confer difference-making power lies in the “environment” be-
yond the propagule.

The genes in the zygote do not have the power to make eyelashes, the
zygote must acquire that power through development. Nor do the genes
of the zygote have the power to make an offspring organism. The develop-
mental units of which they are parts must acquire that power through de-
velopment. The difference-making language misleads us into locating the
causal powers in the wrong place. Development, from the replicators’ point
of view, is a cascade of sequential acquisitions of replicator powers, culmi-
nating in the power to propagate difference-making power in reproduc-
tion.30 Thus, properly speaking, reproduction is the recursive propagation of the
organized capacity to develop and development is the ordered realization of the ca-
pacity to reproduce (Griesemer 2000a, 2000b).

So the sequestered genes do their work only in the protected bundles
that hold together and maintain organizations capable of development
and transferred in reproduction. But why does it happen that way in biol-
ogy? Must it? Consider the alternative. If biological reproduction did not
Figure 7.9
Modes of multiplication (after Griesemer 2000a, figure 5, p. S360). Two interpretations of the process of multiplying entities are contrasted. The left branch downward represents Dawkins’s copying idea (see text for discussion). The right branch represents the multiplication of entities by a transfer of material parts from parent to offspring (progeneration). When the transferred parts constitute developmental mechanisms, then the progeneration process counts as reproduction. Inheritance and replication are special classes of reproduction process in which the reproduction process is of evolved mechanisms of development or evolved coding mechanisms, respectively. Other, nondevelopmental progeneration processes are not shown.
propagate organized developmental mechanisms, then the power to confer difference-making power on offspring would have to be found in the “environment.” Origin-of-life scenarios often suppose that a “warm little pond,” chemical soup, or prebiotic pizza (a structured solid-surface template-catalyst to organize the reactions; Maynard Smith and Szathmáry 1995, 32) provides all the organization needed for a collection of individual bits (diffusing molecules) to become jointly autocatalytic. But in those scenarios, the first hints of life become packaged in membranes that then internalize the environment, creating a self-scaffolding organization that confers the capacity to develop on the next stage.

Presumably, this provides a competitive advantage. Proto–living things that continued to depend on exogenous scaffolding would be at the mercy of environmental instabilities, constrained by the geographic extent of their scaffolding environments. Becoming larger or more complex would raise insuperable problems, for they would simultaneously have to accomplish more complex tasks more reliably, with all of their machinery exposed to whatever else is out there. Proto–living things that internalized the scaffolding of development, for example, by making their own catalysts and relevant catalytic structures, would be more robust to environmental change, better able to propagate their organization to offspring, and able to expand into a broader range of environments with it. Biological reproduction concerns the propagation of developmental packages while Dawkins’s replication concerns the propagation of individual bits, taking the package for granted and mistaking the gene for the whole developmental package. The fitness advantage of reproduction over (bare) replication is, presumably, a real biological advantage in the earliest stages of the evolution of life on earth, or else the world would still be populated by naked RNA ribozymes. Even Dawkins recognizes this when he discusses the advantages to genes of cooperating in bundles called “chromosomes.”

The history of life on earth is not only a history of adaptive accretion, but of evolutionary transition to new levels of developmental organization (Buss 1987; Maynard Smith and Szathmáry 1995; Griesemer 2000c).

Without packaging (sequestration and bundling), all of the internal organization achieved in development must be regenerated each generation from exogenous sources. If the environment is reliable in delivering resources and scaffolding to the developing entity, then (presumably) development would go faster for those entities that didn’t have to build their own internal scaffolding as part of their developmental process—they would get their developmental organization “for free.” But to the extent
that the environment is unreliable or ineffective in scaffolding development exogenously, internalizing it in organized living propagules for reproduction would be favored over mere transmission of individual replicators. There must be dynamic trade-offs in how much and what kind of organization to internalize for purposes of successful reproduction. Most multicellular organisms pass through a single-cell “bottleneck” in their life cycle (Grosberg and Strathmann 1998). Within the organism, only cell-level organization seems to be packaged for biological reproduction. The organism-level phenotype is typically, though not always, regenerated through a developmental process rather than propagated directly.

How might these concepts be extended to apply to culture? Are there “cultural reproducers” in addition to biological reproducers, or are there only cultural replicators (memes) lacking development and material transfer across generations? Or does the degree of ignoring context become so extreme for culture (and the standards for recognizing “memes” so unconstrained) that one might say the notion of a “meme” could only make sense if more richly anchored in another way (Wimsatt 1999)? We opt for this course, to anchor memes in cultural reproduction plus the relative stability of parts of the cultural reproducers required by their central role in producing other elements of development—that is, their generative entrenchment. Generative entrenchment can give deeply entrenched features the stability and generative power to make them in many ways the analogues of genes (Wimsatt 1981b, 167–171), but also to act as scaffolding.

In this we delight in following in Thomas Hunt Morgan’s footsteps. In 1909, Morgan produced a searching critique of “Mendelian factors” for many then plausible reasons, one of which was their disconnection from development, and a second was their lack of independent operational detectability from the ratios they were invoked to explain. This was a deep criticism that held until Morgan himself only two years later was forced (still only partially satisfied) to localize them on chromosomes, through which linkage mapping gave a rich set of alternative handles on Mendel’s (now robustly operationalized and materialized) factors. This paper is little known and less appreciated. It would not be reprinted or noted today but for Morgan’s famous and productive reversal, leading him to elaborate chromosomal mechanics to reproduce the study of Mendelian heredity as classical genetics. It seems quite likely to us that one may not be able to say what the “memes” are until one can figure out the hereditary channels for culture, and those can only be determined once one discovers the scope and nature of sequestration and bundling for the relevant cultural processes of development and reproduction one is tracking.
Cultural Reproducers
Let us return from these general considerations of reproduction to the specific question of cultural reproduction. Consider the Sears kit-house case described above.

The Sears kit-house case is a rich multilevel and multichannel hybrid of persistent, recurrent, and reproductive elements that we think is typical of human culture. We use this case to illustrate developmental problems of cultural evolution because it preserves detailed evidence of modular organization of component cultural artifacts (houses, house parts, furnishings, mechanisms, tools, and plans of construction) that play reproductive roles in the generative process of house consumption, production, and distribution.

The Sears kit-house case comes as close as we think typically plausible to support talk of particular cultural items as reproducers. Clearly, Sears houses are not reproducers: one house does not give rise to another by means of a transfer of material parts from parent house to offspring house. Though there may well be property inheritance of home contents and even of whole houses, it is not typical for house parts to become parts of other houses in ways that play a generative, developmental role in the production of offspring houses. But neither are new houses typically “copies” of old houses in a memetic transfer sense of cultural inheritance. Houses are typically built from common plans rather than as copies of one another, and in the Sears kit-house case, the plans are products purchased through a material, disseminated mail-order catalog. An adequate account lies somewhere in between pure memetic and pure reproductive extremes.

Sears posts a catalog to a would-be consumer, who picks out, purchases, receives, and builds a kit, possibly copying neighbors’ choices of plans, “following in the footsteps” of previous consumers, the guidance of editions of the Sears House catalog, and using the rail, road, postal, and linguistic infrastructures external to but shared with predecessors. Perhaps on occasion a child inherits a catalog from a parent or learns to read from a Sears catalog, thus acquiring a taste for Sears houses along with acquiring the material catalog as propagule from the biological/cultural parent (linking the child into a genealogy that includes its biological parents and Sears, Roebuck). Maybe she or he builds a Sears house next door, or in the next town down the road, or at the next rail stop. The catalog (and economic infrastructure) can thus be a material component transferred to a new generation of house-dweller-producers via skills, capacities, and dispositions acquired by offspring that have been scaffolded by parents, catalogs, infrastructure, and houses. New kit houses are neither copies nor material
descendants of old kit houses, but rather new productions that repeat an assembly process (Caporael 2003) and pattern according to the plans and designs contained in a kit, while the acquisition of a kit may involve a material transfer of elements that play a reproductive role in house-building practices.

Of course, transfer means something different for actor parts, house-kit parts, and infrastructure parts: material overlap of chromosomes, furniture, and roads is achieved by quite different developmental mechanisms, but they are no less material transfers or developmental mechanisms for all that. Similarly, an organism requires a material transfer of many kinds of parts via various mechanisms. These parts play more generative roles than mere supply of “food” to nourish naked DNA replicators: consuming food and reproducing are different kinds of material transfer processes, even if the food itself is reproductive. Reproduction involves the material transfer of generative developmental organization from parent to offspring—organization that becomes generatively entrenched in the process of repeated assembly by differentially successful development that comes to depend on the scaffolding effects of its presence and activity in the developing organism or cultural system.

There are “persistent” elements in the Sears kit-house story such as the Sears, Roebuck Company, houses that were built in each (cultural and biological) generation, infrastructures of rail, road, and postal delivery, suppliers who provided raw materials and component parts to Sears, language, economic, and political conventions for economic exchange, and so forth. Some of these persist on longer time scales than others and some persist by active maintenance—that is, by persistent efforts of many actors to sustain them in a particular form or condition. All function as economic “externalities” in the sense that they tend to be “there” in the environment of a given actor to be used virtually for free, but they can also function as brakes on innovation. One (or a group) can choose to build one’s own persistent elements rather than take advantage, or contribute to the maintenance of externalities, but there is typically an associated cost. Innovation, whether different in kind or only in number, trades off against cost and ease of use.

Persistent elements tend to be artifacts, items produced in the culture that play a role in the continuation and elaboration of the culture but are not reproducers. However, some biological actors such as schoolteachers persist across many student generations and may play the role of persistent artifact (playground ball remover, traffic light, metronome, pencil sharpener) for students, even while functioning as a scaffolding actor in other
contexts, as teacher, parent, and so forth. But not all artifacts play cultural roles in the same way. The line between artifact and actor is blurred, just as the line between reproductive and nonreproductive is blurred, when socio-cultural contexts are considered that shift focus to the system level.

Some artifacts contribute significant feedback effects to alter the development of the actors who use them while others merely contribute to the trajectory a target developer is already on. Thus, the rail and road systems that make it easier to transport Sears kit houses outside urban areas alter the options for people who desire to leave urban areas. A road connecting rural and urban places, extending amenities of urban life such as shopping in department stores, may increase the demand and need for such extension if the road makes it easier to move out of town. The Sears Modern Homes catalog in turn facilitates the use of roads as a means of leaving town, in turn generating further demand for catalog products, including kit houses. Other artifacts may provide externalities that facilitate some activity of a user, but could be substituted by alternatives for little additional cost and for them there is less advantage to persistence. The point is that even persistent artifacts can play a reproductive role by playing a developmental role, scaffolding the activities of actors (making them easier, cheaper, safer than they otherwise would be) or scaffolding the use of other artifacts (mail-order catalogs, kit houses, automobiles) in ways tending both to enhance the reproduction of biological actors and with them the cultural systems of which they are parts.

Artifacts that provide scaffolding services may be recurrent rather than persistent, especially if it is cheaper to produce new ones than to make longer-lasting durable ones. Toothbrushes and cleaning sponges (or hair and fingernails) as opposed to washing machines and automobiles (or muscles and bones) come to mind. Henry Ford's famous observation that automobile parts still in good shape in the junkyard are overengineered and too durable expresses the value of recurrence: it may be more economical to recurrently produce a cheaper part that lasts only as long as its role in the system has value. Recurrence suggests reproduction, but the question for a theory of cultural evolution is reproduction of what? Biological actors reproduce, and when their offspring make artifacts, these are recurrent in kind. For many aspects of culture, however, the recurrence may be the product of reproduction directly, either as the expression of a biological agent's behavior, or as a cultural emergent: when a firm spins off a subsidiary, the recurrence of a managerial or accounting practice might be counted as reproduced, especially if the subsidiary is founded with personnel leaving the parent company as a "social propagule."
Our Sears house story is not fully enough developed to determine whether there is cultural reproduction of the system. It is clear that a number of kit house companies started up, but to argue that some of these were reproduced, for example, as spin-offs from other ones, would require company data that we lack. To argue that parts of the system are cultural reproducers is plausible, but we similarly lack data detailed enough to address this question either. The seemingly obvious answer that the Sears catalogs are reproduced is only half right since it is not in virtue of the sort of copy relations a meme theorist would identify, but rather the more subtle role catalogs play in scaffolding cultural development which counts. It seems likely that furnishings would have been handed down from (biological) generation to generation and plausible to think that the deep embedding of Sears catalogs in popular culture might have combined with this artifact inheritance to affect preferences, tastes, capacities, and propensities to purchase a Sears house kit in which to put the inherited furnishings. If so, then there is only a difference of degree between the role of a Sears desk lamp and a chromosome passed from parent to offspring in triggering and shaping the eventually developed home or body of the offspring. Desk lamp and catalog together “instruct” the consumer in dwelling development just as chromosome and metabolism “instruct” the consumer’s bodily development.

Mail-order catalogs can be considered material propagules that transfer mechanisms of development for consumers who are parts of a society and culture—cultural reproducers. Consumer culture is scaffolded by the catalog, lowering the cost of consumption by packaging many artifacts, up to the whole house. Culture becomes reproductive as the catalog becomes generatively entrenched as a need to consume artifacts in packages (perhaps because the time available for item-by-item consumption is allocated elsewhere). Packaging facilitates the coordinated transfer of artifacts as well, thus, insofar as catalogs transmit, as cultural propagules, the practices that tend to lead to the reassembly of the packaged artifacts, the system becomes a cultural reproducer. Like biological gametes, mail-order catalogs transfer material parts of the sender to receivers: the catalog is produced by the company and sent to consumers, who then take material ownership of a small piece of the company.

Also like gametes, mail-order catalogs transfer organizations of heterogeneous elements—the arrangement of catalog items into functional groupings, price groupings, customer categories—in short, all the categories of marketing package items in generative configurations, for example, those that can make a house into a livable home. Ward’s first catalog was a sim-
ple list of items and prices, but they quickly developed much more sophis-
ticated structures. Moreover, mail-order customers did not have to travel
to a distant urban center to take advantage of this marketing organization
in the form of the store layout and merchandise displays, they could in-
stead browse the catalog. Unlike gametes, catalogs transfer only avatars
rather than actual items for sale (pictures, drawings, plans, or references
that are material enough—marks on paper—but highly transportable).
Again like gametes, what is transferred is not the end product, but crucial
parts of a mechanism for its generation. Gametes transfer developmental
mechanisms (genes, proteins, membranes) that must act to coordinate de-
development in situ. Catalogs transfer representations and configurations of
items that must be realized in situ by cultural developments including:
browsing the catalog, choosing items to fit into an existing cultural orga-
nization (typically, the home), ordering, waiting, receiving, and placing
the items into the home-dwelling context of use. Paralleling the roles of
the cell in “gene action” (Moss 2002) we have the operations of the post
office, roads and rails, the internal, instructed “metabolism” of the banking
industry, and Sears in the transfer of funds and transformation of the order
into a deliverable product.

Cultural reproduction by means of catalog propagules can extend be-
yond the direct company-to-customer path as well. As we pointed out
above, the catalogs may also becomes tools of instruction in reading for
children, which may vicariously convey a preference for, say, Sears’ or
Ward’s organization of goods. Although one may interpret the transmis-
sion of Sears (or Ward’s) culture as cultural replication of items or prefer-
ences for items along Dawkins’s lines, the case of the Sears kit home, with
its bundle of 30,000 pieces represented in a complex package in the home
building catalog is harder to interpret this way because the key feature—the
organization of items into developmental packages—is left out of the ac-
count. Thus, a proper account of cultural evolution, by our lights, would
include an account of the development and propagation of variant cultural
packages in populations delimited by the institutional, organizational, and
other social forms comprised of the conventions, artifacts, and actors who
jointly conspire to produce “culture.”

Developmental Scaffolding and the Process of Culture

As a first approximation to a characterization of culture, we consider H. S.
Becker’s sociological view of culture as shared conventional understand-
ings manifest in act and artifact that people use to guide the organization
of collective action (Becker 1986). One step toward a view of culture we can use for our multilevel evolutionary purposes is to track artifacts through cultural development, which Becker does only implicitly. Another step is to generalize from people to actors, where an actor is a part of a social system that can have “understanding.” This second step puts us onto terrain of interest to cultural evolutionists: we should not take it as given that culture applies only to people. Other animals might have culture, as might other social entities, such as corporations, political parties, scientific research groups, disciplines, and nations. Culture is not universal and is most plausibly a degree property depending on (evolved) capacities for representation and understanding. Becker’s view together with our additional steps toward a view of culture helps move the analysis of cultural evolution toward the medium viscosity theory we prefer and away from “thick” views of culture that, by definition, rule out human culture as an evolved product from animal ancestors and “thin” views that make culture ubiquitous as mere nongenetic trait transmission.

Three Kinds of Scaffolding

With these steps in mind, consider three modes of developmental processes for culture in terms of three kinds of scaffolding that facilitate them: artifact, infrastructure, and developmental agent scaffolding. All kinds of scaffolding are relational: scaffolds are convenient, “rationalized,” safe developmental contexts for particular things or kinds of things and acts of using them, and may serve only in some circumstances or for some actors and not for others. Scaffolds may differ in their generality—in the range of kinds of things they can act to scaffold, or agents or circumstances under which they can do so, but being very general in application or conditions of application does not make scaffolds any less essentially relational.

Artifact Scaffolding

Artifacts can scaffold acts when they make acts possible, feasible, or easier than they otherwise would have been. The painter’s scaffold makes it easier for painters to reach the upper floors to do their work than without the scaffold. The use of the artifact by the actors in their work is what makes it a scaffold.

Artifacts can become so central to the nature of acts that they are in part constitutive of them—for example, “cross the t” as a naval maneuver for warships, “take off,” “peel off,” and “strafe,” for aircraft, “back up” for computers, “emulate” for virtual machines, and “pass” as something one does in a passing zone on a highway. Human agents participate in each of these actions but the participation of the artifacts is so central to the acts
that we treat them as if they are the agents. One can then ask in what sense the artifacts are still scaffolding the acts, although at least these acts would have been impossible without multiple layers of scaffolding. Note that constitutive involvement is a strong indicator of generative entrenchment. This theme is further developed from another direction below.

In all these cases, the collective that acts involves a human actor and a non-human one. Their interaction is symmetrical: the human is scaffold to the nonhuman as well, making the actions of the artifact possible, feasible, or easier than they otherwise would have been. The painters’ scaffold is built by the painters in the course of the project, used, and then taken down, to be reassembled on another site. The artifacts we describe as scaffolds have “life cycles” just as the humans do. The scaffold can be part of the developmental system of the humans if the scaffolding interaction meets the right evolutionary conditions—namely, that such interactions in the genealogical past played a role in the survival and reproduction of the humans’ ancestors (Griffiths and Gray 1994, 2001). The symmetry of the interaction implies that the human can also be part of the developmental system of the scaffold if the scaffolding interaction meets the right evolutionary conditions—as with Warwick’s (2003) account of the development of mathematical physics at Cambridge. However, this is not likely: painters’ scaffolds are not typically genealogy-producing reproducers, hence not candidate units of evolution (Griesemer 2000a). Thus, the contributions of symmetrical scaffolding interactions to the two developing systems—human and nonhuman—may, and commonly will, have asymmetrical evolutionary consequences. The problem of cultural evolution, then, includes interpreting the ways in which scaffolding interactions among different sorts of elements of a society contribute to the development of cultural systems or processes whose reproduction may or may not be distinct from those of its participants.

The key to understanding scaffolding as a cultural process is its developmental aspect: an artifact plays a developmental role by facilitating collective action and thus contributes to cultural aspects of development in an organism, institution, or organization. A minimal evolutionary concept of development is acquisition of the capacity to reproduce (Griesemer 2000a, 2000b, 2000c). If cultural artifacts (like repainted or repaired buildings) contribute to a cultural system’s capacity to “reproduce” (by serving as models of building, paint jobs, successful maintenance projects, or whatever), there is a temptation to see the building as a reproducer, just as we tend to see a gene as a replicator. This would require an expanded view of what counts as the relevant developmental system: a viewer of the
building, say, interacts with the building, becoming part of the building’s developmental system, and then the viewer becomes a propagule of the building, going off to form a new building (or paint job) in the context of the viewer’s developmental system. Without the viewer-counting as a material propagule-in-context of the building-in-context, we ought not to consider the building as a reproducer, though perhaps systems of building that include both buildings and viewers as parts might be. Such a view of cultural reproduction might seem extreme although empirically it might turn out to be the case, and even not so infrequently.

Cultural development, then, is only acquisition of a capacity of a cultural system or process. It need not concern the reproductive propagation of each of its components, nor is this the case in biology: multicellular organisms, which develop by means of the reproduction of their cells, do not require that all of their cells reproduce. Even so, the multiple overlapping and interpenetrating hereditary lineages and channels of cultural evolution make the neatly hierarchical standard metazoan model generally impossible for cultural systems. But that is part mythology: a closer look at our life cycles as interwoven with our carried communities of internal and external parasites and endosymbionts raises more general questions about the accuracy of that model anywhere. Indeed, the failings of facile analogies between biological and cultural reproduction often trace to lack of subtlety in the treatment of the developmental aspect of reproduction processes on both the biological and the cultural sides of the analogy. So, artifacts that serve as scaffolds are symmetrically also targets of scaffolding interactions between actors and artifacts.

**Infrastructure Scaffolding** Some artifacts or artifact types have the character of infrastructure: objects that persist on a much longer time scale than typical artifact scaffolding interactions and which are commonly regarded as parts of the environment or “niche” in which an action takes place. This may be planned from the beginning, or they may acquire an infrastructural role through changes elsewhere in the environment or in the things they scaffold which coadapt to them. Then they become infrastructural basically by becoming more deeply entrenched. A painters’ scaffold is put up alongside a building and used to scaffold the repainting while the painters are on the job. It is taken down soon after. It would be “in the way” if it were left up. Road or rail systems, communications satellites, the internet, postal delivery, plumbing, meeting halls, and the like are designed to last and serve repeatedly over many scaffolding interactions.
The persistence of such a system encourages adaptation of other elements to it, which increases its entrenchment. You want your pipes to last for many water-carryings from source to kitchen sink. Home water pipes scaffold your use of water in the home by making it much easier to carry and use—controlling pouring, heating, and filtering water. Piping will get connected not only to the usual minimum array of sinks, toilets, tubs, water heater, and furnace, but in some homes, as input to or output from a sump pump, humidifier, dehumidifier, air-conditioner, fire-retardant sprinkler system, outside shower, swimming pool, and outlets for gardening and lawn sprinkling systems, each with their dependent control systems. Or the water supply may be sufficiently limiting that swimming pool and outside watering are never considered, and one installs a “gray-water system” (with quite different piping systems and tankage) to reuse water from sinks and showers for sanitation. Connection to city systems or to well and septic field, and mode of pressure generation in the system also affects design, and all of these generate needs for a host of valves, bypasses, vents, modulators and accessories to “the plumbing.”

Why does it make sense to treat scaffolding interactions as contributing to development? Some have similar difficulty seeing why the organism-environment interactions that construct niches should count toward the development of a system of interactions rather than merely as changes in the niche, that is, environmental context of development and selection for the replicators in them (e.g., Dawkins 2004). Thus Sterelny (2001) distinguishes ecological engineering from ecological inheritance and expresses skepticism of the empirical scope of the latter (Griesemer et al. 2005 critique Sterenly’s criteria). Developmental systems theory aims to address this difficulty by identifying developmental systems (or processes) as the loci of action, so that the environmental “side” of the interaction is interpreted as part of the system that develops. We pursue a different course: we are interested in those cases and conditions under which parts of the environment or niche function in an organism-like way, as reproducers with generative entrenchment relations to the rest of the developmental systems in which they act. Put differently, we are interested in the conditions under which culture develops because these will delimit emergent cultural reproducers that can propagate the conditions for culture—conditions in which cultural development fosters cultural inheritance. In turn, genuine cultural inheritance is a kind of process in which cultural variants make more cultural variants so that offspring exhibit fitness differences in a population of cultural reproducers. A key feature of our approach is the role of developmental propagules in reproduction. These are items that can be counted,
can form populations, and can share infrastructure (niche components) at the same time that their interactions with shared items of infrastructure are genuinely their own.

Scaffolding interactions with infrastructure are much the same as artifact scaffolding in other respects, although the dynamics of systems of infrastructure scaffolding are bound to differ from more temporary, smaller-scale artifact scaffolding. At first it looks simple: perhaps the up-front social costs and marginal utility of erecting an infrastructure are greater than with more ephemeral artifacts (or even longer-lasting artifacts that, due to smaller scale or fragility, have to be “brought out” for each use and thus can only intermittently function as scaffolds). And no doubt the relation of propagules to the rest of a developing system changes the dynamic properties of the system as a whole (Griesemer 2000a, 2000c). One important way is when reproductive processes entrench the factors producing them. In becoming deeply entrenched, elements become more like infrastructure as they become more polyfunctional: as infrastructural elements are co-opted for more functions because they are there, they become more deeply entrenched, and in consequence, more strongly conserved, causing a mutual positive feedback of amplifying stability relations. Thus one can build infrastructure to facilitate the amplification of structures and processes utilizing them, but one can also simply use what is there to such an extent that it becomes infrastructural. And generative entrenchment requires reproduction, so the circle is closed.

Perhaps the most important mode of infrastructural scaffolding are forms without which culture and society would not be here at all. Going backwards in time: written language, settlements and agriculture, and animal husbandry and trade practices (developing into economic systems) were major infrastructural innovations central to all that followed. Spoken language with oral traditions and tools use antedate all of these by many tens to hundreds of thousand years. All are generatively entrenched so deeply as to be virtually constitutive of all of our forms of life, limiting the kinds of presence-absence comparisons we would like to have to assess their effects. Their origins raise entirely different kinds of methodological problems that they share with archaeology and paleontology—the paucity and gappiness of the direct historical record.

By contrast, the current differentiation, cross-pollination, and mixing of language varieties, and use, often of multiple languages in different social strata and crosscutting contexts within the same society, indicate rich areas of current study in cultural evolution. Language change as studied in interaction with its “ecology” (in the broadened sense of Mufwene 2001)
already reflects the populational approach urged here. And it is full of phenomena and “model organisms” (see Griesemer and Wimsatt 1989) having all of the features appropriate for rich evolutionary study (Mufwene 2002, 2005), and a phylogeny increasingly richly correlated with archaeological remains and the genetic traces of human migrations (Cavalli-Sforza and Cavalli-Sforza 1995). Language practice, and the expansion and contraction of language varieties interact with other economic and social practices in rich ways that only begin to reflect the deep entrenchments of spoken language in our cognition and our culture in the costs of illiteracy, innumeracy, and rarer deeper linguistic deficits. The very plasticity and robustness of language acquisition indicates its central evolutionary importance for Homo sapiens.

Developmental Agent Scaffolding Artifacts and infrastructure function as scaffolding when actors use them to facilitate collective actions in a particular developmental way. The difference between use and scaffolding lies in the developmental function of the latter. We can view artifact and infrastructure as scaffolding when we can identify a developmental function, such as facilitating acquisition of a capacity that the target or an actor in the collective did not have before (or would not otherwise). Intuitively, if the builders’ scaffold is used to wash the windows of a bank, that’s maintenance (both of light transmission capacity of the windows, and of the reputation of the bank). If it is used to put a clock on the front of the bank building, then it is being used for developmental purposes: to give the bank’s façade a function or capacity it didn’t have: telling passersby the time, and conveying the image of the bank as civic institution in a new way.

Many of the interesting developmental uses of scaffolding are the development of skills (or authority) in agents, for it is only through these, developed to allow effective organization to perform the immensely complex tasks we find in a highly differentiated society, that culture can be maintained and elaborated. Skill development can be scaffolded by artifacts or infrastructure, as when a person learns to drive a car on an off-road course where mistakes are less likely to lead to injury, or when a gymnast uses an elastic training belt to learn a dangerous move on the high bar. But scaffolding skills in agents where the scaffold is (or includes) another agent are particularly interesting: the scaffold is or involves another person, social group, or organization, often in spatial and temporally organized dynamical arrangements with artifacts. These kinds of interactions can entrench modes of interaction, and build larger social and organizational
structures, from office hours through lab meetings and lecture classes to websites, professional meetings, journals, and international societies. These may themselves become elements and contexts in still larger articulations and differentiations of agents, procedures and artifacts.

Consider, for example, the scaffolding interactions between two agents discussed by developmental psychologists (Bickhard 1992). A child is scaffolded by its father when the child commits to trust the father to facilitate a risky operation like crossing the street. The child puts its hand in the father's and father teaches the child to cross the busy street safely. By towing the child across in rhythm with the passing traffic and by calling the child's attention to the relevant cues such as the color of the traffic light, position of the crosswalk, and so forth, the child develops skill in crossing the street in the safe context of the scaffolding interaction. Many such scaffolding interactions are required before the child can exercise the requisite skill on its own, without the guiding visible hand of the scaffolding agent. (Notice also the abundant infrastructure scaffolding—the father scaffolds his interaction with the child by use of the traffic light, crosswalk, and other infrastructure to render the interaction with the child in crossing the street safer than it otherwise would be.) The cases elaborated earlier all begin in processes like these child/parent interactions. Barbara Wimsatt’s elaboration of advanced medical training, which differs by sex and its (career) developmental consequences, Andrew Warwick’s discussion of the elaboration of mathematical physics at Cambridge over 150 years, and the developmental co-option of infrastructural resources and transformation of house designs and financial instruments to deliver over 100,000 kit houses to an expanding U.S. market after World War I all build on the stability inducing trust and adaptive patterns they engender.

But how are these larger structures built, and maintained—and in a way consistent with the flow of agents and resources through them, and creative new alignments tried, maintained, and elaborated on the fly?

Generative Entrenchment vs. Revolutionary Cultural Change: Can Scaffolding Resolve This Paradox?

Recognizing Dependencies: Stasis in the Midst of Change

Evolution is a process of change, but also of stasis: metazoan body plans date to the Cambrian (Raff 1996; W. Arthur 1997); while cell membranes, the genetic code, and primary metabolism are roughly as old as life itself (Morowitz 1992). For evolution to be cumulative, recognizably historical, or even possible, some things must be preserved to build on. The cumula-
tive character of evolutionary change has been debated, but once we remove a naive progressivism and admit the normal range of exceptions characteristic of patterns in biology or the human sciences, this is unproblematic. Evolution is historical by definition, but must it be \textit{recognizably} historical—must organisms and other evolving things wear their ancestry “on their faces”? Indeed they must. Evolution saves things in spades, on all space and time scales. Evolution is not just any change and stasis, but particular patterns of change and stasis, patterns that tend to preserve ancestry. Wimsatt (2001) argues that all nontrivial evolutionary processes involve entities with development, and with their different parts showing differential generative entrenchment. From these it follows that they will also show life \textit{cycles} (since they will be constrained to start each generation in very similar places by entrenchment acting more strongly earlier in development). They will also show the kind of historicity to allow reconstruction of phylogenies and to be recognizably historical as above (Wimsatt 2001; a point first made by Riedl 1978). These entities will also be reproducers, in Griesemer’s (2000a, 2000b, 2000c) sense, from which other properties discussed in the preceding sections follow. But why should such features be so pervasive and so important?

Consider an observation of commonsense engineering. Rebuilding foundations after we have already constructed an edifice on them is demanding and dangerous work. It is demanding: unless we do it just right, we will bring the house down, and not be able to restore it on the new foundations. It is dangerous: the probability of doing so is very great, and there are rarely strong guarantees that we are doing it right. We are tempted to just “make the best of it,” doing what we can to “patch” problems at less fundamental levels, leaving deeper modifications alone. This is sensible advice, given the difficulty of the task. One can’t make just any change one likes with impunity. These are the phenomena and the patterns to be explained and exploited.

This bias against doing foundational work is a very general phenomenon. Scientists rarely do foundational work before their house threatens to come down about their ears. (Philosophers relish it, but like to work on others’ disciplines!) If we cannot avoid them, actual deep revisions are preceded by all sorts of vicarious activity. We would prefer to redesign or revise a \textit{plan}, convince ourselves that it will work, rebuild only after we are satisfied with the revisions, checking during reconstruction for problems that inevitably come up, and move in only after the rebuilding is done—complete with local patches and in-course corrections. Planning and the semipublic exchanges between concerned parties accompanying it are two
major modes of social feedback. We thereby draw on the expertise of larger
groups of people in structured ways to avoid major failures. Construction
projects that forgo this, executed by theoreticians, or architects who do
not visit the site are the butt of jokes—folk wisdom about the difficulties
of foundational revisions, or in getting from new foundations to the fin-
ished product. (And why amateur builders who do not know all of the steps
and pitfalls may welcome kit houses!)

Big scientific revolutions are relatively rare for just that reason—the more
fundamental the change, the less likely it will work, and the broader its effects; so
the more work it will make for others, who therefore resist it actively. The last
two facts are organizational, institutional, social, and social psychological,
but the first two are not. They are broad, robust, deeply rooted, structural,
and causal features of our world—unavoidable features of both material
and abstract generative structures. It is this robustness that can allow dy-
namic patterns derived from generative entrenchment not only to apply
in both biological and cultural realms, but to weave patterns that tie them
irrevocably together. The first two features are central to the power of gen-
erative entrenchment in biology, but all four are relevant throughout the
human sciences and the domain of our products, including how we con-
duct our investigations in all of the sciences.

Generative Entrenchment as a Cause of Stasis in Evolutionary Processes
To know how to proceed, we must analyze the dependencies in evolved
systems. How many things fail or are changed if we change a given element
in a system? How many things jump if we pull on it? How much of the
porch collapses if you pull out a corner column, a center truss, or a floor-
board? Will it affect the rest of the house? The reach of the damage or the
spread of the change is a measure of the generative entrenchment of the
element which was changed. Its generative entrenchment is the range of
things it contributes in the normal operation or functioning of the system.
And, to a first approximation, the degree of generative entrenchment (or
GE) of an item is a predictor of the amount of change (and potential dam-
age) arising if it is changed. Since the probability that a change will be
damaging goes up rapidly with the size of the change and number of things
affected, the generative entrenchment of an item is a good predictor of its
evolutionary conservatism. We return to this below.

Of course we want to know not only how much will fail, but what will
be affected, and how. This is the key to diagnosing what went wrong in a
failure after the fact, and to figure out how to design a way of repairing or
improving a system if we want to change it. This last task is difficult, and so
generally we try to fix things by changing as little as possible. This has broader consequences: it is why evolution proceeds mostly via a sequence of layered kluges which give local fixes. Nature is full of larger contingencies as well as smaller ones, but the contingencies that drive evolution usually start quite small and can grow in their effects over time. Local kluges become deeper fixes and ultimately foundational architectures only by persisting through successive generations over evolutionary time, increasingly embedded in and adapted to by a growing network of local fixes.

As their reach spreads, they become, in “evolutionary” time, necessary preconditions or framework design principles for almost everything else in that organism and major dimensions of the niche it comes to occupy, and inescapable for its expanding descendants—a “natural” mode of ex post facto rationalization. These come to define many dimensions of the organismal forms of life, the conditions that are taken to be constitutive in natural and human design and “optimization” problems. Things do not have to persist, but if they do, their resistance to being eliminated tends to increase. Natural processes make foundations as they proceed, but not by “wedging” them in at the ground. Things which are there already tend to become more foundational through use, and then are used still more as they become increasingly foundational.

House construction has an apparently “natural order” because of the dependency relations of some elements relative to others. (One proceeds roughly from bottom to top, and frame to finish, now in “ontogenetic” or “developmental” time.) Gravity is one major constraint, and not covering up what you have to work on is a second. Early elements scaffold later ones. These affect both design of the house and the order of work. Protecting workers, work and tools from major disasters, and from the elements is a third, but one that must sometimes force delicate workarounds in the first two. These do not determine outcomes in all details, but they broadly constrain the results, since proceeding in any other way is inevitably more work, more expense, and involves unmaking or redoing things that have been done already. (Contractors can sometimes change the order in which different crews come in, but sometimes must simply stop work until the necessary crew, materials, tools, or weather is available.) Organisms, theories, technologies, and complex functional structures—biological, mechanical, conceptual, or normative—also have orders imposed by relations of dependency and interdependency.

Moreover, we must often dwell in a house while it is being rebuilt. (Here we mean to include metaphorical “houses” across the disciplines!) But these “running repairs” only work because the conceptual organization
of science, of engineering practice, of much of technology, and of social organizations and institutions, is usually robust, modular, and local, each of which reduces the reach and magnitude of generative entrenchment. Shaking (local) foundations usually does not bring the house down, and we still have a place to stand (on neighboring timbers) while we do it. This is not an accident, but a deep principle of design. This is the key for how scaffolding can facilitate making deep modifications. With multiple information channels, we have new possibilities for their adaptive interaction, and one or more of them might be able to serve as scaffolding to modify the character of another channel, or its content, or how that content is to be responded to. But these modes of interaction are not interactions among abstract information flows. They are modes of interaction between embodied channels in “carpentered” environments, whose information content can affect the actions and values of agents.

This suggests an argument for why biological and cultural transmission is multichannel: if in general the information flow must be scaffolded because the information carriers have to develop in an environment in order to assimilate, use, and carry it, then the scaffolding must propagate (or persist) alongside the information “in” the channel. This might be the case if the information is sufficiently complex to be a generator of a cell, an organism, a theory, a cultural tradition—a generator of any biological or cultural item richer than a gene or a meme. (And these of course are generated easily only within their larger support structures.)

Some have argued that there cannot be multiple channels on grounds that they cannot be statistically independent and therefore do not constitute separate channels. We view matters differently. First, channel is ambiguous: it can either mean “channel conditions” as a statistically independent component of carrier plus signal or it can mean a physically separate means of transmission as with two wires. The separateness of channels is a claim about their physical (spatiotemporal) separation, not about the statistical correlation of their states. Thus, channels can be separate, but nonindependent. So symmetry arguments between channel conditions and signal are insufficient grounds to reject the multiplicity of separate channels (see Griesemer et al. 2005). Moreover, a single channel can be made to carry multiple signals, whose states are statistically independent of one another, so the single set of channel conditions can be switched symmetrically with each of them and still retain statistical independence of all of them. Thus, symmetry of signal and channel conditions is not sufficient grounds to reject the multiplicity of either separate channels or of independent signals, which is all we need to support the idea of a multiplicity of
physically separate inheritance processes. The distinction between physical separation and statistical dependency is crucial for the analysis of developmental systems.

Processes of “generative entrenchment” are important generators of complex organization across many disciplines. Generative entrenchment (or GE) causally links development and evolution, and is particularly useful in characterizing systems with both dynamic adaptive and constraining processes—cognitive, cultural, social, or biological. The core insights derive from processes that produce different rates of evolution. Differential generative entrenchment of parts or processes produce and experience differential rates of evolutionary change. This differential conservation in the evolution of the system may also lead to secondary responses, such as reducing entrenchment through sequestration or packaging (differentiating modularity), the generation of parallel redundant systems, or the generation of distributed redundancy across multiple diverse systems (“functional multiplexing”). This can in principle produce changes leading to the multiplication of hereditary channels, as well as the elaboration of adaptive order. These responses may in turn make it easier to modify the generatively entrenched element. Or we may find the production of new systems or defenses to regulate and protect the generatively entrenched elements from being modified (e.g., canalization in biological development, or deciding that a relationship should be treated as a conceptual or definitional truth or as a matter of faith, rather than as a (modifiable) empirical one in a scientific or philosophical argument). These additional relationships suggest new ways to recognize, apply, and strengthen an evolutionary perspective in some areas that have resisted it (Wimsatt 1999, 2001). We turn to this now.

**Generative Entrenchment in the Human Sciences and the Study of Cultures**

Evolutionary fixity through entrenchment affects other domains where the operative mechanisms and forces are quite different than they are in biology. Unlike most moves to biologize the human sciences, reproduction and entrenchment do not pose reductionist threats, and are quite compatible with accepting descriptions as thick as you like, as long as it is recognized that they are analyzable and explicable in terms of accounts at their own level which nonetheless relate to a broader evolutionary context of reproducers and generative entrenchment, and articulate with the micro-processes necessary to realize them. (They are thus of only “medium viscosity.”) Allowing for generative entrenchment and reproduction commonly involve reorganization of factors already recognized to see their effects
systematically in a new light, rather than denying their efficacy. (If anything, this reconceptualization should do the reverse!)

These relationships indicating entrenchment include the serious consequences of early deprivations in linguistic or other cognitive, emotional, or social development, and the fact that early training, and interwoven sources of scaffolding are crucially important for high competence in sequentially dependent and elaborated skills like playing the piano or becoming a gymnast or mathematician—that is for the rich manifestations of culture we embed in others and ourselves. It involves recognition that we build larger competencies by packaging, articulating, and comodulating parts into larger skills, and ways of interacting, an assembly process partially recognized by Simon (1962). What Simon did not appreciate sufficiently was that the stability of the subassemblies was often generated by “black boxing” and entrenching them (Latour 1987)—by contextual, rather than intrinsic (or “top-down” rather than “bottom-up”) relationships.55

But the impact of generative entrenchment goes beyond the individual. We are highly social creatures. Our culture generates, accumulates, and maintains motivations and scaffolding for us to acquire and integrate diverse skills, empowering our complex societies and cultures. Societies are structured by overlapping entrenchments, modulated by various peculiarly cognitive or social adaptations to produce surprising freedoms of change, but also frustrating anchors against it.56 Generative entrenchment is a simultaneously conservative and creative mechanism in each of these domains. It provides a systematic account of the development and evolution of richer larger-scale structures that is missing in competing accounts of cultural evolution (Wimsatt 1999, 2001).

Characteristic common transitions of particular elements occur in different domains of human culture. New qualitative features of human minds, cultures and societies emerge along these trajectories. (One must also discuss their integration in larger structures, a nearly universal feature generating the transitions listed below.) Increasing entrenchment can lead contingent associations or practices to take on the character of meaning relations and conventions. Movement along trajectories by elements through time accompanies increased fixity, resistance to change, generative, and normative roles. The second-order transformations of defensive or canalizing mechanisms arise from use of this increasing fixity in these larger structures, making categorical transformations where the underlying basis is merely a difference in degree. Metasimilarities across trajectories are
products of role changes for elements with the growth in fixity, generative role, and adaptive complexity of the resulting interpenetrating and increasingly cogenerative structures as they become larger systems:

1. Some actions become individual habits; become social commonplaces, become practices; become conventions; become institutionalized.

2. In science, some empirical patterns become regularities; become generalizations, become laws; become framework principles; become quasi-definitional truths. (Scientific techniques and technologies are not forgotten here; they would be covered under (1) and (3) respectively.)

3. Some behaviors, forms, and mechanisms become common, adapted to, built upon, generatively productive, increasingly “innate,” “natural,” and “essential” characteristics of the species.57

4. Technologies emerge as kluged experiments, become exploratory tools for early adopters, acquire “killer apps,” develop competitive markets, radiate third-party suppliers calling for standardization, rationalization, legal regulation and governmental control. In the process they have changed while transforming us and our environment: thus track the mutually elaborating automobile, petroleum industry, highways and metastasizing infrastructures, suburbs and suburban value reorientations, loss of neighborhoods and public transport, with multidimensional impacts on our foreign policy (B. Arthur 1994; Basalla 1987).

These kinds of patterns involving simultaneous increases in generative entrenchment and stability with accompanying changes in the qualitative status of increasingly entrenched elements give powerful handles in the analysis of diverse systems and in the emergence of new kinds of properties with the growth of these complex systems. But the patterns are not as simple as depicted above. And that is fortunate, because the systems are not either.

Exceptions Can Probe the Rule

Now to return to the challenge with which we began. The deeper elements of a generatively entrenched structure should be very stable because of their deep entrenchment. But exceptions to this pattern occur, and sometimes systematically. These provide ways of strengthening and enriching the theory (Wimsatt 1987) if either they can be incorporated in it in a natural fashion, or can be used to delimit its boundaries more precisely. (Most productive changes will do both simultaneously.) The aim should not be to pose reproduction plus generative entrenchment as a universal two-factor explanatory solvent, or superglue, for they are not. The aim is to show
how these important factors interact with others—just as natural selection as an account of evolution is strengthened by recognizing genetic drift, population structure, and the claims of genetic linkage.

The most important exceptions occur when apparently deeply entrenched things seem to be too easily changeable. Major but evolutionarily recent early developmental changes are known in various organisms (Raff 1996). We must understand how this is possible. Analysis of these exceptions reveal other already recognized and important features of biological organization like regulation and canalization, redundancy, and modularity whose interactions with generative entrenchment explain these anomalies and still other phenomena (Schank and Wimsatt 1988, 2004; Wimsatt and Schank 1988, 2004).

Cultural change intuitively occurs so much faster than biological evolution, and with enough deep changes, especially noticeable in science and technology, that revolutions are not uncommon. But how is this possible? This is the target question of this chapter, and forces us to reach beyond reproduction and entrenchment. We should expect these contrasts to reveal important differences between evolutionary processes in biology and culture.58 (It is reassuring to note that these deeper changes, though much more common for culture than for biology are still much rarer than changes of smaller effect in each of their respective domains—as expected with GE. This fact also suggests a search for systematic differences between biology and culture that modulate the impact of generative entrenchment without destroying it.)

**Scaffolding for Speed, Accumulation, and Depth in Cultural Change**

Now we must confront the deepest paradox of cultural evolution. While “higher-level” processes generally proceed more slowly than lower-level ones, it is a truism that cultural evolution can proceed enormously more rapidly than biological evolution, and often apparently through major almost explosive innovations and adaptive radiations.59 How?

The first-order answer is to point out that culture is commonly “horizontally” transmitted. Like a disease, it can thus spread much more rapidly from host to host than a host population could spread or expand through its own (“vertical”) biological reproduction. Successive waves of the plague spread from Asia throughout Europe in less than a decade in the fourteenth century, and roughly once a generation thereafter, as new susceptibles increased in frequency enough to sustain epidemic waves. Similarly, Islam spread around much of the Mediterranean in little more than a generation. But not everything was as fast: Christianity spread from the eastern Medi-
terranean throughout the reaches of the Roman Empire in about 400 years (Stark 1996). By contrast, the biological spread of agriculturalists due to their increased reproductive rate after the first green revolution as they replaced hunter-gatherers—an expansion at blinding speed for such a process—was only about ten miles per generation (Cavalli-Sforza and Cavalli-Sforza 1995).60

This point is useful: pointing to the speed of horizontal transmission allows us to think about maximum horizontal transmission rates, such as for the spread of news (or rumors) deemed important. And this clearly has increased by many orders of magnitude through technology, as the speeds of material migration and informational transmission have increased. For material transmission, we have walking, running (the original marathon, which served to bring news of an invasion), the mounted dispatch rider and pony express, carrier pigeon, rail, highway, and airplane, with parallel (though slower) expansions for marine transport. For information, we have drum and semaphore, the telegraph, telephone, trans-Atlantic cable, radio, television, and satellite internet transmissions developing through technologies and supporting material networks. It is this that gives the world instant access to election results, the 9/11 disaster, and declarations of war. At a more mundane and metabolic level, it has created a “world market” with activities running “24/7,” smearing “market closings” into non-events. This is the currency of the rampant meme, though (as we now see) the meme advocates have ignored the fact that their spread has increasingly required enormous interpenetrating and multilevel scaffolding. We can see this through another approach to the question.

In another important way, appeals to maximum horizontal transmission rate beg the question. Why didn’t Christianity spread as fast as the fastest runner to Rome? It worked to warn Athens and to recruit Sparta against the coming Persian hordes. Why did it take until Augustinian’s rise to power 300 years later to really cement the spread of Christianity, and what led Augustinian to declare it the state religion, which was the pivotal act which did so (Stark 1996)? Obviously a lot else was going on, and this had to do with spreading and transforming a culture and a lot of social scaffolding. The significance of the coming Persian army and the scaffolding to mobilize the Greek city-states was already there, in treaties and common perception of a common danger. Or to put it in another way which covers both cases—what makes an individual ready to accept and adopt, or even be capable of understanding a meme? Until we can understand this (and something of the special social and cultural structures through which memes are likely to spread) we have not gotten an adequate account of cultural
transmission or evolution, and even this (because of its focus on individuals) is likely to be at best necessary but not sufficient.

Now let’s ask the question again: given that culture is acquired developmentally, what kinds of things give cultural evolution the possibility of faster change, accumulation, and the acceptance of deeper modifications than is common for biological evolution? These would all contribute to the rapid hegemony culture has acquired in our relatively recent evolution.

Consider First What Speeds it Up

In his long and pivotally influential essay-review of work on “Evolutionary Epistemology,” Donald Campbell (1974) recommends that we recognize a series of ten systematic perceptual, cognitive, and social adaptations as “vicarious selectors.” These included distance perception, trial-and-error learning, thought experiments, language, and science. They had in common two things. First, although ultimately products of natural selection (and whatever other vicarious selectors were there already) they could act more rapidly and cheaply than natural selection. Second, like sexual selection, they could sometimes transcend it and drive the results in a different direction than natural selection alone would take them. So how could vicarious selection processes be “faster and cheaper,” and sometimes take processes in a different direction? The following provide a large part of the answer.

First we consider things that facilitate the structured generation of large amounts of variation at low cost. One may here consider both the cost of generating variation, and the cost of generating relevant variation. The latter (items 2 through 5 below) points to kinds of “directiveness” of variation, and thus to ways in which cultural evolution is “Lamarckian” that biological evolution is not:

0. One could begin with the intuition that it is far cheaper to generate psychological and cultural variation than genetic variation. This is probably true, but it is unclear (due to metrical and conceptual problems) how to measure it. All of the points below address this issue, but it is not clear whether they exhaust it.

1. Once something is tried and does not work, we do not need to repeat it, unlike the situation with mutations where useless and even deleterious mutations may recur repeatedly. (Actually, our efforts are not without wasteful repetition either, but we clearly do better than biological mutagenesis here.)

2. We can localize faults in structures, deciding what is at fault, and direct efforts to producing and trying variations at that point. This important point is developed systematically for theory testing in Glymour 1980, but the point is more general as doctors, auto mechanics, software designers,
and a host of others connected with complex technology must know. More can be said about it, but not here.

3. Cost-benefit selection: with the initial genesis of an idea and the formation of a zygote, each undergoes a development, which may abort or be aborted at any stage. Since continued development involves continued commitment of resources (and opportunity costs) any process which can secure accurate assessments of costs and benefits of continuance and act accordingly will in effect contribute to the efficiency of generating variation. If this induces biases in what survives, it is a directive process. It may also be parsed as developmental (or “internal”) selection, but via a higher-order control process.

4. We can learn from past trials, and adjust the “direction” of new variations to improve performance in the light of the effects of past ones.

5. Perhaps most importantly we have structured sets of alternatives for generating simple or compound modifications, and structured ways of searching them (often in material propagules designed for this purpose). Not only do we have catalogs of various kinds, but sections, indices, and (in electronically realized versions) a variety of rich “search tools.” In the richest forms we may formalize and define a “problem space” in which states, starting points, desired endpoints, and allowable moves and their effects are all represented (e.g., Simon 1973). This is closely related to the kinds of combinatorial variation generators characteristic of codes, languages, and other symbolic forms. (This is “higher” culture than the preceding, clearly constitutes rich scaffolding, and this loose category embraces several strata of divergent sophistication and complexity.)

6. Coordinated with the search tools to find alternatives, when they require material embodiments (i.e., books for ideas as well as nails for houses) there must be ways of producing and distributing them. When these are material objects (like screws, fittings, and other machine parts), coordination problems for mass manufacture with interchangeable parts can make these alternatives and their production and distribution infrastructural in character. This feature spans so many levels of varying complexity that it must just remain as a marker for a much larger subject. See also item 10 below.

Next, we consider aspects of scaffolding that tends to entrench variation and leads to accumulation.

Elements that build culture

7. Scaffolding becomes more structure like (less modifiable, and acting asymmetrically as elements that other things are adapted to) as it becomes entrenched.
8. Scaffolding can persist in a maintenance mode, without apparent develop-
ment but entrenched for the preservation of social institutions or for
the efficiency that comes with black-boxing. (Development reappears once
we realize that individuals are recruited, trained, and scaffolded by society
to do this maintenance.) Things that become sufficiently entrenched as to
to become requirements for a wider variety of other things will accumulate
secondary structures and processes for their maintenance.

9. Scaffolding interacts with black-boxing: acquire skills in the use of an
artifact or procedure without knowing in detail how it works, and how to
build or maintain it, thus black-boxing knowledge so that one can use it
without understanding it. One can present scientific laws in engineering
texts for use in “cookbook” fashion, without knowing how they are or were
derived, and one doesn’t need to know how to design or build or fix a car
in order to drive it. The evolution of artifacts so that they can be used with
less maintenance and knowledge of how they work allows one to do things
with fewer cognitive resources, expending them elsewhere. It also allows
(and requires) the differentiation of tasks and work in a society. In this
way more complex cultural elements can be assembled, but their function-
ing presupposes the maintenance of the scaffolding that permitted that as-
cent, and components of the culture become both more distributed and
differentiated. Elements of the culture become more separable, but at the
same time more interdependent. (You buy the car from a firm that has
built, marketed and distributed it (now usually subcontracting large chunks
of this effort), and take it to someone else to fix and maintain it. The evolu-
tion of owners’ manuals has increasingly downplayed the information
necessary to fix it yourself as the frequency of breakdowns for which you
must do so have declined, while the tools and knowledge required have
increased beyond reach.)

10. Entrenchments grow particularly quickly and are particularly far
reaching for elements that become parts of a standing infrastructure.
Water, gas, and power distribution all acquired this status soon after the
beginning of the twentieth century. Telephone, wireless communication
standards (for radio and later for television), and now Internet protocols
place strong constraints on the form of compatible devices, and propaga-
tion of standards. These all become infrastructural by becoming broadly
polyfunctional, used for a wide variety of devices and to serve an even
larger variety of ends, and their presence stimulates a new variety of devices
designed to utilize them, as their use and the standards which must be met
to use them grow in breadth.
Finally, we consider those features that make cultural evolution unusually tolerant of deep changes, and thus make cultures foci for rich and often revolutionary innovation.

Features Allowing Deeper Changes More Easily

11. Probably the most important feature here is vicariousness: To consider a change is not to adopt it. This may range from the “throwaway” options rejected without serious consideration through those requiring more research and detailed planning, up to the production and testing of expensive prototypes and “demonstration projects.” It may not cost much more to develop and explore quite large changes than to explore smaller ones if one is not adopting them, and “exploring” risks much less than “adopting.” In biology, variations are always real: one cannot “consider” genotypes without adopting them. (An organism may be just a trial at the population level, but it does not get another try).

12. One can apply “problem decomposition” to the task of changing a system. Although fixing a component subsystem may impact and require changes spread through the whole system, one can treat the problem of fixing it in isolation, make plausible improvements, and then figure out how the other components must change. This can be repeated for other relevant subsystems. This will not always work, since problems are not always “nearly decomposable” any more than systems are (Simon 1962; Wimsatt 1974), and some modification trajectories may be dead ends. But they often will yield to this approach, and when this is employed at the design stage one can explore and modify deleterious effects of different “macromutations” which would be inaccessible without “vicarious” exploration (item 11 above). This procedure allows construction of solutions that would require a number of modifications to be sufficiently viable, and thus be too improbable to expect in biological evolution.

13. Scaffolding can become disentrenched without major loss of organization, or locally of organizational support only when replaced “in parallel” using production of material culture, nonmaterial culture, or both via an appropriate substitution. In this it is similar to an evolutionary process for which new generated redundancies (from tandem duplications at the genetic level all the way up) are the primary way of reducing generative entrenchment. For culture, the increase in numbers of parallel channels or means of solution, and consequent disentrenchment of any one of them is crucial. This parallel redundancy is introduced by markets and populational heterogeneity, with learning and borrowing from your competitor generating an expanding redundancy of alternative solutions.
14. There is a natural redundancy for culture. Changing technology—material or ideational—is never instantaneous, so there is always a population of various older machines, procedures, and users. This does several things: Early adopters will have to invest more in learning the new technology (usually in an environment where it is less reliable, less powerful, and less easy to manage), but then they will know unusually well how to help those following them. Those who know the old way as well as the new can “translate” for an extended period of time, and the older technology provides a “backup” when the newer technology fails, which it will do relatively frequently at first. This coexistence of two systems through the transition period can midwife quite momentous changes, which may be relatively minor at first but open entirely new pathways for explosive transformation. (Consider the transformation from penned manuscripts and records to typewriters, to word-processors to desktop computers.) Cooperation within organizations at this level—simple assistance to others in using the new technology—is expected work performance, so even though there are potential “free rider” issues, we are strongly socialized to help, and experience strong disapproval or worse if we refuse. Parallels for biology require kin or group selection, which some writers are unduly suspicious of, but conditions for this kind of interaction for cultural traits are so common as to be endemic.

15. Scaffold can change very rapidly if managed by specialists who know what is necessary to make it transparent to others, often by “black-boxing” it, and using standards to preserve key elements (thus presuming 9 above). If one can find “functional equivalents” for these elements, they too can be replaced, and many new technologies do exactly that. Terms like “backwards compatibility” or “platform independence” in computer software represent exactly this kind of strategy, and permit higher levels of organization to screen off higher levels of function from lower-level details, making deeper changes possible. This is “supervenience” by design (Wimsatt 2001).

Missing from this list are things particular to culture that aid in constructing new variations, and things that aid in evaluating alternatives. Heuristic procedures of model-building (see, e.g., Wimsatt 1987, 2007), or heuristics for making decisions on the basis of very limited information (Gigerenzer et al. 1999) fit here, but exploring them would go beyond the reasonable scope of this chapter.

Almost all of these have in common the use of scaffolding channels, and almost inevitably, the simultaneous use of multiple partially independent channels (independent enough to adapt to different environments and niches, independent enough to support disagreement and competition, in-
dependent enough to interact symbiotically as differentiated complementary elements.

So we see that in humans, generalized notions of reproduction and entrenchment describe processes that interact to produce rich multilayered scaffolding, differentiating multiple channels of cultural inheritance. The existence of multiple channels can lead some of them to differentiate the combinatorial and other features (those listed as 1–15 above, and possibly others) to come to be an informational channel, allowing rapid and massive increases in the speed of evolutionary processes, and possible sources of reflexivity emerging out of close-linked control processes.

Conclusion

We have argued for a middle viscosity account of the nature of culture. Starting from Griesemer’s (2000a) contrast between biological transmission embodying material overlap, and cultural transmission apparently without it, we have attempted to show (1) that cultural transmission is more embodied than it seems at first, and that the ways in which it is embodied, scaffolded, and in consequence, embedded, increases both (2) the frequency and (3) the robustness (hence the accuracy) of successful transmission. Furthermore, scaffolding makes possible the robust transmission of much more (4) complicated and (5) context-sensitive things. This complexity of cultural transmission is just another expression of the complex context-sensitivity of culture, widely noted by anthropologists, and essentially ignored by meme theorists. This complex context sensitivity has frustrated the best attempts so far from the so-called hard sciences to analyze intentionality: it was the “brick wall” of the “frame problem” which bedeviled attempts at Artificial Intelligence two decades ago. This problem is the Gordian Knot of culture: things not having it will not be counted as cultural, and the reticulate complexity of things having it seem to defy further analysis in any other terms. We accept the first, but demur from the second.

The Emergence of Information Channels?

The ways in which cultural transmission is freed from the constraints of material overlap and direct implementation characteristic of biology allow modification of transmitted elements in ways that are decoupled from immediate (and usually negative) consequences. The fact that this modifiability is itself structured by entrenched functional scaffolding allows selective sequential vicarious filtering for efficient removal of many possible
dysfunctional tries. By trying only things that have gone through our richly scaffolded cognitive filters, in which a sequence of successively structured contexts commonly narrow and focus the search immensely, we lower enormously the fitness cost of learning. Functional scaffolding allows trying more alternatives in increasingly refined ways, so that many more successful deep modifications can be produced, transmitted, and successfully integrated. And this ultimately explains the unparalleled lability as well as the cumulative complexity and richness of culture, and at the same time the enormous degree of intracultural differentiation. This all smacks faintly of “Lamarckian inheritance,” but we have gone far beyond that to a much richer vision.

We propose that whenever there appears to be a relatively “free floating” cultural information channel in which any one of an array of messages can be transmitted, either in a preset or easily modifiable form, there is a material propagule or set of propagules (analogous to a Sears catalog), a scaffolding structure or set of structures, or both which permits this freedom, by giving the resources to choose alternatives, and make modifications, often from a specified and sometimes combinatorial set and transmit the resulting messages or consider other possibilities, all without implementing or acting upon their contents. But in addition, there must be a consilience between transmitter and receiver for a message to be comprehensible to the receiver. Scaffolding is required to calibrate the receiver to the source, and in a world without preestablished harmony, successful calibration enabling transmission of messages from a large combinatorial array would require feedback-laden sequential training.

Consider the circumstances under which an information-like channel will appear to “bootstrap itself” to increased reliability and capacity. Without propagules or scaffolding, there is no reason to expect the right sort of consilience to work between transmitter and receiver for cultural systems that can transmit a large (combinatorial) variety of alternative “messages.”

Scaffolding is required in effect to coordinate the receiver to the source, but it seems unlikely that there could be successful coordination without feedback-laden sequential training of the sort that constitutes the imposition or emergence of conventions and standards, or at least routines, of operation. Differently put, without scaffolding, there is no reason to expect the coordinated, concerted conduct of multiple actors in activities that would constitute a social world (Gerson 1998, chap. 2). The cost of conduct would in general be too high.

Cultural channels must be quasi-independent of scaffolding to be able to transmit any one of the large variety of messages that leads us to call them
channels. But this is only for some purposes: treating cultural channels as independent of scaffolding vastly underestimates the cost of communication. The transmission of cultural elements without material overlap via propagules is likely to be supported by scaffolding with substantial and variegated forms of material overlap: people who have trained together or one of whom has trained the other, who may be working on the same project, using material parts made to the same specifications, from the same manufacturer, working from designs with a long history of successive refinement to work well in applications suitably like this one. An important source of the irreducibly social nature of culture is the functional role that people, as well as artifacts and social conventions, play as scaffolding for others.

When collaborating by e-mail to write this chapter, we do not have to detail the books and training and examples we share, each other’s beliefs, writings, competencies, and interests we know, all contexts fixed and shaped through interactions we have had over the last quarter century. This means that we can often use telegraphic shorthands for our ideas, and do not need to spend long hours elaborating contexts to disambiguate them. But even when we do, the corrections are more readily localized and can often be in shorthand. Thus shared experience functions as a (small-scale) social convention that scaffolds our interactions, and we seem to transmit more than our words can say. This even applies in such “objective” and “public” areas as mathematics, a field in which philosophers have been even less inclined to notice material propagules and scaffolding than other areas of science. We saw in Warwick’s study of the rise of mathematical physics at Cambridge how much common training methods, content, and style were critical to communicating and being able to read textbooks results or do problems constructed at Cambridge—things that did not transport to other supposedly comparably advanced students at the University of London, much less Paris, Göteborg, or the United States.

And below our level of intentional communication, our technology manages multiple layers of black-boxed transformations: the fact that we use the same kinds of computer and same (or laboriously-made-partially-compatible) software, that our e-mail messages are broken into packets, labeled, and sent independently through different routes to be reassembled on our respective mail-servers, and that manuscripts on our hard drives are broken into packets, stored on noncontiguous sectors, and subvisibly assembled in the right order (almost) every time we call them up. That too is scaffolding, and thankfully, almost always invisible to us!

The functional freedom of the channel when the scaffolded developmental context can be taken for granted permits easy and controlled variation
(directed, intelligent, or planned), including freedom to vary relatively deep generative elements of the transmitted message. This happens far more commonly for culture than for biology, but deeper changes are always relatively rarer in either domain than shallower ones. There are various reasons why changes in deep generative elements are not almost always immediately lethal, as would be commonly so in biology: there are vicarious ways of evaluating the effects of the modification without implementing it, and the fact that implementing the message is a separable act that can follow upon evaluation allows us to avoid many certain failures. These modifications are normally in the thing transmitted, and separable from the scaffolding partially responsible for its synthesis and manipulation. That is, the things characteristic of the functioning of the scaffolding are not under modification (at least not on the same time scale), and it is one of the reasons why we call this an information channel that the message can be changed without changing the machinery for transmitting and interpreting it. This has two consequences: first, the “fitness” of a cultural element (material, behavioral, or ideational) is assumed (to a first approximation) not to affect its possibility of transmission and interpretation (or more generally, how it is acted upon by the scaffolding) and (2) implementing or acting upon the message (activity which realizes the fitness of having received the message) is a separable action from its transmission.

But even this cultural “genotype/phenotype” distinction is still too simple, for it suggests that there is a supporting and never modified structure, transmitting a symbolically encoded message (regularized so that it can be systematically produced and modified), and that there is a rigid separation of domains, of scaffolding with material overlap and no modifications during the operation, divorced from “informational” domains without material overlap and subject to modification. It might seem as if scaffolding provides a shelter surrounding a region of free experiment with ideas. But what is instead true is that while the whole structure (or at least a large chunk of it) must be in place for anything to happen, different parts of the scaffolding differentially support different parts or aspects of the conceptual structure being worked on. So in cultural change, we are in a situation of rebuilding Neurath’s boat, but never one of building or rebuilding it from scratch. Indeed there is so much elaborated and contextually focused scaffolding that most of the changes are minimal, quasi-automatic, almost immediately assimilated and invisible semistandard patches. So we have a multiply embedded and entrenched sociotechnocultural scaffolding interwoven and interpenetrating with a multiply entrenched and embedded artifactual-ideational structure with which we are experimenting. Scaffold-
ing is an interactive, not a static structure, and a dynamic account utilizing reproduction and generative entrenchment has taken us through it part of the way toward building a successful account of culture and cultural change.

Acknowledgments

We thank the Konrad Lorenz Institute and its Scientific Director, Werner Callebaut, for making it possible to work together, overlooking the Danube for two crucial weeks in summer 2003. Mark Bickhard’s fortuitous presence boosted our account of cultural scaffolding to a richer one, aided by discussions later that summer with Linnda Caporeal at ISHPSSB. The SOIT seminar at Chicago chose to read Warwick at a fortuitous time to provide one crucial example while Barbara Wimsatt provided another and rich input and feedback on scaffolding. Lisa Lloyd provided helpful comments on the manuscript, as did Emily Schultz who gave important perspectives on cultural anthropology. We have both been scaffolded by Elihu Gerson for a quarter century, who taught us both more sociology than we know, whose gentle comments often ring in our ears, and from whom we have both learned above all not to “delete the work” in our accounts of science. We have been major scaffolding to each other for even longer, and it is a delight to collaborate again after 18 years in writing another paper on cultural evolution. We thank Roger Sansom and Robert Brandon for patience that we know must be finite (on theoretical grounds) but so far has seen no bounds. Griesemer’s research is supported by the Dean of the Division of Social Sciences, College of Letters and Science, UC Davis. Wimsatt is supported by research funds from the Humanities Division and the Big Problems program at Chicago.

Notes

1. “Baby talk,” explicit teaching using ordered or artificially simplified tasks, and so on.
3. To evaluate differential loss of men and women on different career tracks toward high standing positions in the profession, one must disentangle the increasing proportions of women entering medical school in later cohorts (ratios went from about 10 percent in 1970 to nearly 50 percent by 1990), differential losses of men and women from the various specialty and subspecialty tracks, and differential continuing career commitments afterward by men and by women. All three appear to be happening, but Wimsatt’s 1997 study and 2001 follow-up (which gives hard to find longitudinal data) point respectively to the latter two as real phenomena.
4. Most but not all twenty of the professionals were MDs. When only one was an MD, that partner’s career always took primacy, suggesting that financial considerations were important. However, in an earlier pilot study with some couples having an MD and a university faculty member, primacy often went to the academic career at least up through the awarding of tenure, though there too, the higher income of the MD was crucial in allowing hiring of extensive support for child care, cooking, and housekeeping.

5. The extent to which this accumulating knowledge was embedded in practice and in the broader structure of education is revealed in the difficulty found in exporting it to other contexts, not only in France, Germany, and America, but even to other universities in England (Warwick discusses the University of London). This is especially striking since mathematics is taken to be the most context-independent of subject matters. But Cambridge monographs presupposed the background of experience, high technical competence, and detailed mathematical methods taught at Cambridge. Exercises “left to the (Cambridge) reader” might remain unintelligible to a mathematics student elsewhere.

6. There’s a tendency among cultural anthropologists to assume any attempt to build mathematical models of cultural inheritance or evolution will be thin necessarily. We use the term thin, not to subject all mathematical approaches such as dual inheritance models or niche construction to criticism from the thick pole of the spectrum, but to characterize models of cultural evolution in terms of the degree to which they involve rich accounts of development or of culture. Boyd and Richerson’s framework presupposes developmental processes to a significant extent and includes multiple modes of social interaction, but we place our concerns on a continuum between theirs and those of cultural anthropologists of the “thick” description variety. Thus, we seek to reject a categorical distinction between “thick” and “thin,” not to reject mathematical models. We endorse rich characterizations of development and enculturation in the expectation that future progress will naturally include mathematical models to address them within a populational and evolutionary perspective. But for generalizable theory we must commonly (though not exclusively) seek robust qualitative predictions over detailed quantitative ones (Levins 1966; Wimsatt 1981b). But we also think it essential to mine detailed case studies for intuitions about what matters, and particular interactions not covered in general theory. Most “thick” description advocates seek particularistic qualitative accounts and resist attempts at generalization.


8. Brumann (2002, 509) argues that part of the purpose of a thick concept of culture was to establish a division of labor between sociology and anthropology and traces this to Talcott Parsons. An analogous division of labor between genetics and embryology led to the theoretical inadequacies that evo-devo is attempting to repair.
9. To clarify, we explore cultural evolution here mainly in terms of examples and problems arising in the rich, “thick” case of human culture, but we are not satisfied either to assume culture applies broadly, if thinly, to a wide variety of social organisms or to define culture so as to apply only to humans. Medium-viscosity theories like ours aim to leave it an open question how widely the concept of culture applies (without the easy reductionism of “thin” models). We acknowledge the “thickness” of the concept, but at the same time insist that “thick” does not mean “unanalyzable.” A plausible candidate for “medium viscosity” descriptions of culture would be Gaddis’s (2002) discussions of the “fractal” character (the relevance of detail on multiple spatial and temporal scales) of historical descriptions, explanations, and analysis. (These would be produced by successively nested entrenchments of kluged contingencies of broadening scope with a “random fractal” order like those used to generate realistic looking river deltas and mountain ranges (see, e.g., generation by “successive random additions” of perturbations of successively smaller scale in Turcotte 1997, 153). This need not be either hierarchical or regular, unlike the more widely known self-similar fractals that have a snowflake-like homogeneity. (Thanks to Emily Schultz for noticing this ambiguity.) Gaddis urges that we draw on the new historical, chaotic, and fractal physical sciences for methodological intersections with the human sciences. Something that interfaces with rich mathematical theory from another science while not sacrificing the demand for cultural richness should qualify as “medium” in our terminology. One striking characteristic of human intentional action is that it can causally couple these diverse spatial and temporal scales frequently enough to matter. Similar interactive multilevel structures are also common in biology (Wimsatt 1994). The operation of generative entrenchment over time predicts such a macroscopic fractal order of nested contingencies on all scales in biology, and if we are right, in human history (Wimsatt 2001).


11. Rationalization “in the economist’s sense of doing more with the same resources, or the same work with less resources,” see Gerson, forthcoming.

12. In balloon construction, single vertical framing members went from basement to roof, leaving vertical air shafts inside walls. In platform construction, each floor was built separately and sealed off from the floors below. The earlier design presented a fire hazard, since flames could propagate unimpeded (and hidden) from the basement to the attic up these shafts. Flames could rise in a platform building only by burning through floors (or spiraling up stairways). For similar reasons platform homes were more economical to heat (Thornton 2002, 16–18).

13. Sears was one of at least six companies to produce mail-order houses in the early decades of the twentieth century. The others include Sears’ chief competitor in the housing arena and the first to offer kit houses, Alladin; their chief competitor in catalog sales, Montgomery Ward; and also the Bennett, Loizeaux, and Gordon–Van
Tine lumber companies (Thornton 2002, 20; this invaluable source mentions all but Bennett and Loizeaux).

14. Odling-Smee, Laland, and Feldman (2003, 192) state that “Niche construction is an ontogenetic process” but this does not make their account a theory of development. Development is treated in their theory as a black box that “allows individual organisms the opportunity to gain sufficient energy and material resources from their environments to survive and reproduce. It thereby both contributes to the building of the next generation of a population of organisms in the conventional manner and causes changes in the niche-constructing organisms’ own selective environments’” (pp. 192–193). In this minimal use, niche construction interacts with ontogeny too nonspecifically to derive a theoretical structure for its character or interactions.

15. We accept their perspective, but our elaboration of a particular kind of niche construction leads in such very different directions with different tools and explanatory foci as to be almost orthogonal to their approach. We believe that our accounts are broadly consilient, and expect that the whole story for culture will require both. See also Gray 2001 and Griffiths and Gray (2001) for efforts to integrate niche construction into developmental systems theory.

16. Perhaps the fact that we can sometimes successfully separate Siamesed twins but cannot do so for the coffee with cream is misleading: the biologist would point to the much richer and more multidimensional forms of interconnectedness possible for the twins. We suggest that the same is true for material and ideational culture: in some ways it is so easy to separate them that we fail to recognize the violence done to both by the result.

17. There is yet another course than considered here. This characterization of Weismannism assumes that inheritance is only in the biological germ line, not in either the biological or cultural soma or anything else we are forced to recognize. But the multilevel hierarchical Weismannism discussed in Griesemer and Wimsatt (figure 1), and in Callebaut 1993, 427–429, assumes the possibility of other hereditary channels with other (entrenched, and thus stable) germ line like lineages with their own somas, thus recognizing a genotype-phenotype-like relation for cultural objects. This is a useful perspective for some purposes, though it is probably best seen as a predecessor of the development here in terms of reproducers and entrenchment. The use of reproducers gives more powerful tools for determining when and how we should recognize temporal patterned series as autonomous or semiautonomous lineages.

18. No modern biologist would do otherwise, and some theorists closer to the biology (e.g., Boyd and Richerson 1985) just develop a populational theory without special note. Philosophers sometimes reify theories as idealized abstract types (appropriate for some analytic purposes) but then act as if they were just a single lineage of improving theories. Hull (1988) demonstrates that this will not do any more for culture than it will for biology. We argue below that the nature of cultural inheritance gives an additional role for populations as units.
19. When comparing the intelligence of New Guinean hunter-gatherers and modern Europeans, Jared Diamond (1997) suggests that the primary action of biological selection on human populations since the dawn of agriculture and the origin of growing permanent settlements was immunological: resistance to the diseases we have acquired mostly from our domesticated animals and nurtured in the close quarters and larger population sizes, which generate epidemics. Durham’s (1992) treatment of malaria and sickle-cell anemia in West Africa shows rich interactions of historical migrations, rainfall and malaria incidence, linguistic groups and other cultural patterns, agricultural practices and different primary crops in different regions, which paradigmatically illustrate what “thicker description” approaches in biocultural evolution can do. The few documented counterexamples to this “disease thesis” (for example, a gene conferring extended lactose tolerance in Northern European animal herders) illustrate how little genes affect or constrain culture directly. Yoghurts, kefirs, and cheeses all provide culturally mediated ways of reducing the lactose in dairy products widely used (and likely originating) elsewhere, and are not less successful in Northern Europe where the gene giving extended lactose tolerance occurs at a higher frequency. Avital and Jablonka (2000) make similar arguments showing that genes-only explanations of culture fail to account for many details of behavior and behavioral transmission in birds and mammals—details that are better explained by social learning and direct transmission of “behavioral traditions.”

20. More exactly, we suppose a time scale long enough for substantial cumulative cultural change but short enough that there has been no significant genetic change affecting culturally relevant traits. Except perhaps for genetic loci affecting disease resistance, this seems a good approximation for cultural changes over the last ten to twenty biological generations, and thus for the time since the Copernican Revolution.

21. The semiconservative replication mode of DNA is sufficiently important to make redundancy a third type. The unreasonably high stability of the genes was a driver of important creativity in attempts to understand them in the first half of the twentieth century.

22. Linnda Caporael’s (1997) repeated assembly in core configurations model is mindful of development, is group/social focused, and is both top-down and bottom-up in approach.

23. For culture, it is as though we would have to solve all of the complexities of developmental genetics and transmission genetics together before we could get usable information from either. But transmission genetic techniques and their molecular genetic descendants were essential to locating and isolating the genes used in developmental genetic analyses. Analogous problems may exist for determining what can be a meme.

24. This argument applies only for those elements of the process that are conscious, so a potentially important exception here is the role of the acquisition of tacit knowl-
edge of all kinds. Reber (1993) argues that mechanisms for acquiring it are phylogenetically deep, likely pervasive in other processes, and that both the knowledge and how we acquire it are not readily open to conscious inspection, so its extent and importance are likely underestimated. His account of tacit knowledge draws heavily on generative entrenchment to make predictions about its character and mode of action (chapter 3), so we may be able to analyze it with our tools, even if we can’t make it conscious!

25. This is, roughly, our social network amplified by our technology, in which we have many new “one-way” connections like movies, radio, and television.

26. Recent work in biology shows that genetic inheritance is multichannel as well. Epigenetic inheritance processes help regulate gene expression but operate, and are transmitted, in parallel to the transmission of DNA. Genetic inheritance cannot function without them because it requires the regulated gene expression of development in the parent to occur (Jablonka and Lamb 1995). In general, it is hard to see how complex, hierarchically organized life could have evolved without the emergence of multiple inheritance processes (Maynard Smith and Szathmáry 1995; Jablonka and Szathmáry 1995; Griesemer 2000c).

27. In “Hierarchical multilevel Weismannism,” cultural transmission involved multiple channels, and roughly, any aspect of phenotype could be taken as an element to be transmitted. But speaking of a channel involved transmission of a smaller generative set that (in context of other operating channels) could be used to generate the rest, as an axiom set could be used to generate the theorems that follow from them. Then the generative set became “heterocatalytic” and genelike (Wimsatt 1981b), and the whole adaptive structure resulting from their elaboration became phenotype-like. But this picture did not sufficiently recognize the richness of interaction of these different phenotypes.

28. Activity and germ-linedness are not necessarily coupled. There can be active replicators that are not germ-line (in somatic cells) and germ-line replicators that are not active (germ-line “genomic parasites”). But these separations are themselves products of the evolution of developmental organization and must be explained, not assumed in definitions, especially since the separation of germ and soma has a very patchy phylogenetic distribution (Buss 1987).

29. This might stem from the view that since all features of the cell trace back to genetic activity, at one time or another genes determine everything. But this does not give us genetic determinism. On Laplace’s classical definition, in a deterministic system, from a totally specified state of the world at a single moment one could predict the state of the world arbitrarily far forward or retrodict arbitrarily far backward in time. But to make the parallel argument work, at any given time, we would have to include operating cells and relevant larger multicellular, environmental and social contexts to predict the behavior of the genes. So the imagined genetic determinism does not satisfy Laplace’s definition.
30. We do not accept Dawkins's view that genes are the sole or even the fundamental difference makers in development, but we grant him that assumption for the sake of formulating the view of reproduction. Griesemer (2000a, 2000b, 2000c, 2002, 2003) develops the argument without granting that assumption.

31. One might stabilize more of the environment if one went down to a smaller propagule of cells rather than all the way to a single cell. But Grosberg and Strathmann argue that going to more exposed single cells better escapes transmission of mutations and parasites which might survive better in one or another cell of a semi-protected propagule to destroy descendants of the whole propagule later. See Griesemer et al. 2005 for further discussion.

32. Indeed, thirty-some years ago, it was easy for otherwise penetrating students of the history of genetics to have underestimated the contemporary power of Morgan’s criticisms in this paper. John Moore introduced the reprinting of Morgan’s paper in 1972 with the comment (p. 123) that “This article is not especially important for any intrinsic merit—the arguments are not very convincing—but in a few years its author’s name was to replace that of Mendel as the principal formulator of genetic theory.” Historical scholarship on Morgan’s developmental views and the appreciation by geneticists and evolutionists alike of the importance of development have changed the landscape dramatically since 1972.

33. On the mutual dependencies of embryological and genetic explanations, the notion of tracking processes of development and transmission, and their changing historical relationships, see Griesemer, forthcoming.


35. Once upon a time, department stores were icons of urban rather than suburban living.

36. Modern catalogs themselves have complex organizational scaffolding aids to help the customer find what they want, and often to discover what they need. The latter requires an explicit educational function, often supplemented by technical experts available by telephone or e-mail. The Cole-Parmer scientific catalog serves to equip laboratories, and to aid in the construction of often one-of-a-kind research equipment. It thus seeks to offer a general problem-solving toolbox for configuring laboratories, but also aids for how to use it. Even sophisticated scientists need this kind of help. Grants require itemized budgets well before the laboratory is configured. And paralleling the offering of Kit houses by Sears, catalogs offer both individual and bundled systems, solving problems of compatibility of which the customer may not even be aware. The Cole-Parmer 2003–2004 catalog is 2,096 pages plus 300 special pages including 100 pages of indexes. It includes (1) specialized supplies, (2) whole systems as well as modular parts for building various (often prototyped) systems, (3) multiple elaborate indices, (4) color coded keys, (5) other finding aids, (6) four pages of introduction to how to use the catalog, (7) A 100-page
supplementary catalog of new products released within the last year. The informa-
tion load is daunting. Catalogs and yellow-page sections of the telephone directory
are now increasingly offered on CDs, or directly on the internet. This both reduces
production and mailing costs and allows much more powerful electronic search
functions, but assumes that the potential customer has an appropriately configured
computer. Not sure? The friendly internet offers to download on command the soft-
ware it determines you need to read the latest state-of-the-art catalogs. That is distrib-
uted intelligence!

37. Becker contrasts his sociologist’s notion of culture as a resource for people in
groups to use “in order to coordinate their activities” (1986, 13) with that of anthro-
pologists who take culture to be a system of independently existing patterns that
make societies possible. Extending Becker to our multilevel context, it’s social
groups all the way down: society—that is, groups whose members’ activities are
coordinated—is a precondition for evolution at any level. But we also accept the
anthropologist’s insight that culture is emergent, even if not independent of social
order. (We thank Elihu Gerson for referring us to Becker’s essay.)

38. Becker’s wonderful and lucid story of his experiences as a “Saturday night musi-
cian” is a case in point. It would be hard to be a pickup piano player if pianos were
not present in clubs (Gerson, personal communication, January 29, 2006). But in the
hands of some theorists, this is the immediate prelude to claim that (therefore! sic!)
we do not need explicit representation of artifacts in the theory, which should be for-
mulated in terms of ideas, conventions, or practices (e.g., Boyd and Richerson 1985;
Richerson and Boyd 2004). We disagree fundamentally: for a theory of cultural evo-
lution, the pianos must receive representation on equal footing with piano players,
and with their conjoint activities in social contexts, in order to analyze the gener-
tive and reproductive aspects of developing cultural systems.

39. One might object that the move to superindividuals is to change the category of
the question, but we think not, or at least not automatically. We certainly speak
of the culture of a firm, and allow for it to change. And issues about the phylogenetic
origin of culture (for the first time, in the evolutionary history of Homo) are dif-
ferent than questions about the differentiation of cultures (which many of the latter
represent), but only in the same way as the (mesoevolutionary) origins of language
diffs from the microevolution and speciation of languages.

40. Of course, the “same” scaffolds may act or be capable of acting as reproducers in
some contexts, and not in others, just as with organic lineages.

41. Compare this to the role of enzymes in a cell: enzymes make reactions more
likely (and thus more rapid) than they otherwise would be without them. This anal-
ysis distinguishes the enzyme from the reaction system it belongs to and assigns the
action or role to the enzyme, even though the action could be said to be of the col-
lective. The enzyme that flexes so that a substrate is bound is like the proverbial “arm
raising” in action theory: the arm behaves and the person acts. Similarly, we say that
the system, rather than its parts, develop. As Levins (1974) notes, this changes the
dynamics, and effective organization of the cell, by creating near-decomposability
(Simon 1962) and connectivity along new lines. Usually, enzymatic activity in me-
tabolism is described as contributing to self-maintenance or growth. But in func-
tional terms, self-maintenance and growth serve development and development
serves reproduction (Griesemer 2000a, 2000b, 2000c). Reproduction is of a complex
organized system of parts, so “action” is something assignable only to systems or
processes.

42. This kind of perspective is not inconceivable: economist Kenneth Boulding, an
early advocate of cultural evolution, used to delight in remarking to staid audiences
of the late 1950s that “a car is just an organism with an exceedingly complicated
sex-life.”

43. For example, if humans regularly built new automobiles by scavenging some key
parts of old ones and adding in new parts to supplement the old, then there would
be relations of material overlap between old and new such that automobiles
would have genealogies. Suppose further that the new parts are produced by scaffold-
ing operations of the human builders in which templates are constructed from dam-
aged old parts and modified to facilitate production of new parts that fit together
with the scavenged old parts. Then the materially overlapping parts would be play-
ing a developmental role in helping to confer reproductive capacity on the offspring
automobile. But just this happens in economies like that of Cuba (and rural America
today—see Harper 1987)! In the “hot rod” communities of the 1950s and 1960s, this
proceeded so far as to generate a new manufacturing framework. There were pre-
ferred cars to modify (e.g., 1930s Ford V-8’s, and late 1960s Chevys), and engines
and carburetors to switch. As the movement took hold, “third-party” suppliers
emerged to provide parts that initial one-of-a-kind trials had shown to be promising
and imitation had generated a demand and an opportunity. (These ranged from
mountings to allow the substitution of specific nonstandard components up to
whole bodies and different engines in various tunings). These manufacturers scaf-
folded the individual hot rods thus produced, and the hot rodders that produced
them. Manufacturers even emerged which would take cars delivered directly from
the original manufacturer and modify them according to various standardized per-
formance and accessory specifications, to be delivered to the customer who had or-
dered the final product “as new,” with warranty in place. The Ford “Cobra” was one
such well-known example—so well known that it (and its niche congeners) were
reviewed in sports car magazines, listing specifications, performance (against more
commercially standard models), price, and manufacturer (with address). This, like
racing, was encouraged by manufacturers like Ford and GM to enhance their image
with customers who would favor their standard production numbers.

44. Hutchins’s Navigation team from chapter 1 of Cognition in the Wild fits this
framework like a hand in a glove, though it is richer still, and also involves develop-
mental agent scaffolding.
45. Hughes (1987) describes in detail the development, entrenchment, and shaping of societies in the evolution of large technological systems, such as electrical grids. The latter were modeled on gas distribution, which was in turn modeled on water distribution (Basalla 1987).

46. This seems a safe estimate, given Sears’ 75,000 and the involvement of two other large competitors (Aladdin and Ward’s) and at least three smaller ones.

47. Cornell’s Student Union, Willard Straight Hall, is the subject of one such revealing but affectionate story—retold in Wimsatt 2007, chapter 12.

48. We have kept the link between generative entrenchment and its measurement deliberately loose. The appropriate operational measure could vary with the mode of organization of the system, the representation of it we are using, and the tolerances we should use for registering a change as significant. The range of things affected if we change an element in a system may depend on how it is changed, and by how much, and under what circumstances (conditions on other parts of the system and its environment), and of course on what it is connected to. Then too, the reach of the damage arising when a component fails may propagate across normally separate functional systems in unanticipated ways, and commonly does so in catastrophic failures. A DC-10 crash at takeoff at Chicago’s O’Hare Airport twenty-five years ago resulted from a failure in a bolt in an engine mount on the left engine. The engine ripped out of the wing, disabling hydraulic lines to flaps and ailerons on that side, and with this loss of control the plane crash was inevitable. (The DC-10 can fly with one engine out, even if lost on takeoff, but not without controls.) Controls were subsequently redesigned with additional redundant hydraulic lines. But no one would suppose it to be part of the function of the bolt to maintain their integrity. So it is better to speak of a family of measures of generative entrenchment, and how sensitive conclusions are to the measures chosen for the purpose at hand. Schank and Wimsatt (1988) compared different measures of generative entrenchment in their simulations of (idealized) evolving gene control networks, and found that their (particular) conclusions were robust across very different measures.

49. Wimsatt and Schank 1988; Wimsatt 2001. This famously does not happen for species or higher taxa, but only for aspects of their design architectures. See Van Valen’s (1973) “Red Queen” hypothesis: lineages do not get any better at surviving. Their environments are constantly degrading because all of their competitors are escalating too and “You have to run as fast as you can just to stay in the same place.”

50. These are “physical” conditions. In any complex construction project a series of legally mandated inspections must be performed at key stages of the construction. Thus water, gas, and electrical inspections must come after framing, but before the wallboard, and for good functional reasons.

51. The stereotypical house falls short of the richer dynamical reality. Organisms are constantly being rebuilt, even as they develop and evolve. The same could be said for
our organizations and institutions, and on the dwelling perspective, for our houses, as occupied and maintained. (To recognize this is to recognize that the relevant unit is larger than the physical house.) Such dynamic organization requires even more of the kinds of organizational forms of this and the following note.

52. Such modular structures in cultural systems show crucial elements of biological design that have been ignored by philosophers—design for robustness and redundancy, and the ability to handle imprecision and local contradictions, which let systems deal with failure and stress, and age gracefully. Philosophers’ buildings and machines would be like the famous “One Hoss Shay” of Oliver Wendell Holmes’s 1858 poem—a structure that ran perfectly for 100 years without scratch, wear, or aging, and then collapsed into a pile of dust—presumably at the appearance of the first contradiction. These are all connected. See Wimsatt 1981a, reprinted in Wimsatt 2007.

53. Griffiths and Knight (1998) offer a “parity argument” to suggest that channel and informational signal coming from a source are symmetrical: they can each be viewed as serving the function of the other, so neither can be privileged as “the information” (see also Griffiths 2001; Griffiths and Gray 2001). Moreover, they claim, the relevant causal relation to explain the transmission of information from source to receiver over a channel is “systematic dependence” of the state of the receiver on the state of the source—that is, they offer a statistical criterion for causal connection to bolster their parity argument. This assumption clearly needs to be reexamined, but the issues are more complex than discussed here. (Thus, does prior communication of the structures necessary to decode signal from channel violate their “systematic dependence” assumption for all subsequent messages? Does the knowledge of how it will work by those who set up the channel violate this?)

54. Consider a set of detectors at a receiver that are tuned to different characteristic frequencies in the Fourier decomposition of a single complex wave carrying information from a source. There is no physical separation among the components of the wave until the interaction at the detectors, which are parts of the receiver, (where they will produce physically separable outputs) and not parts of the channel conditions. FM transmission involves similar principles to combine signal with carrier wave, transmitting them together as a modulated carrier signal, and then “demodulating” at the receiver to separate signal from carrier. If one could decide in advance what the bandwidth of each channel was, there is no reason why such a design could not be used for multiple channels sent at once as part of the same (very wide bandwidth) transmission signal. (Thus if one wanted to combine five voice channels assigning 20 KHz to each, adding 100 KHz of bandwidth to the carrier frequency, and making the modulating frequencies 0–20 KHz for the first signal, 20–40 KHz for the second, and so on, their composition should allow a unique demodulation of the five signals at the other end).

55. One can defend Simon’s analysis at this point by pointing out that he was talking about forming structures through aggregation, not by development, and that his
justly famous argument required at least some intrinsic stability of the subassemblies. The real processes that we consider require invocation of both aggregation and articulation operations, and differentiation and developmental ones.

56. This simultaneous presence and interaction of substantial resistances or insensitivities along some dimensions and remarkable highly context-specific sensitivities in others is a deep conceptual requirement (though not yet sufficient) to speak of cognitive agency.

57. We have used quotes here because we would actually reject these terms. But generative entrenchment can explain the phenomena which innateness is invoked to explain (and much more) without the antidevelopmentalist biases and paradoxes produced by the latter (Wimsatt 2003).

58. This contrast is easily misunderstood. Most cultural mechanisms permitting deep changes have biological analogues. But new possibilities with cognition and culture significantly amplify their effects.

59. There is no common metric for comparing their speeds, since it is not clear what we would compare with what—no “cultural code” whose sequence could be compared for rates of substitution with the genetic sequence. But no one would accept an analysis that had the opposite result. So we can try to get more clarity by analyzing the mechanisms involved, which must be part of any such solution. Both biological and cultural evolution actually proceed at a wide range of rates. Boyd and Richerson (1985) note that early methods of tool making (“point technologies”) persisted unchanged for hundreds of thousands of years. And the transmission of oral tradition is practiced in such a way as to resist change, and does so for spans covering centuries—easily long enough to encompass the industrial revolution. On the other side, significant bacterial evolution can happen in a few days. So maximum (or minimum) speed alone is not the issue.

60. This case is interesting because it shows that culture need not be transmitted horizontally. Agricultural practices were apparently transmitted from parents to offspring, but as cultural traits, not as biological ones, even though having the cultural trait clearly impacted biological fitness through the increases in numbers of children the practices engendered, and the interference competition agriculturalists generated for hunter-gatherers by clearing forests that housed most of their game species and diverse edible plants.

61. Herkimer 1952 is a rare find of this type, self-baptized an “Engineer’s Illustrated Thesaurus.” It is a deliberate attempt to give engineers a wide variety of designs of given categorical types to solve kinds of problems. It contains 8,000 figures—drawings of mechanisms—representing kinds of solutions (with different side constraints) that an engineer designing an artifact can look to for ideas. (Hughes (1989) argues that patent office volumes were frequent resources in the workshops of American inventors of the late nineteenth and early twentieth centuries.) The “The-
saurus’ idea deliberately exploits the concept of functional (near-) equivalents. Her-kimer says that such collections of commented drawings are not new, but that the particular way he has organized them (first by function, and then subdivided by broad mechanical type), is new and especially useful.

62. Latour (1987) points out how new innovations become “black-boxed” as they become entrenched as part of the procedural “furniture.”

63. There is a partial biological analogy here in unexpressed variations that may accumulate and be expressed in other circumstances via means such as heat-shock proteins, DNA-methylation, and pseudogenes, but these we defer for another time.

64. Loss of scaffolding does happen and must be kluged on the fly, usually with substantial effort and more modest standards for success. Schultz (2005) discusses Zentella’s (1997) story of Puerto Rican transnational migrants as they navigate New York while learning ESL and maintaining contact back home. Globalizing forces can even disenfranchise “migrants” remaining at home, revealing the rich scaffolding we count on, and once again confirming the maxim that we learn how functional systems work by seeing how they break down. These cases with adaptation on smaller scales to failures of social support are just as important for understanding culture as the romanticized “progressive” changes of science and technology.

65. New technologies commonly show a rapid growth of alternatives, with a subsequent reduction of variation as some of the variants become dominant. This “bottom heavy clade” is common for new adaptive radiations. Thus, just a generation after the invention of the internal combustion engine, then still in its early adolescence, Page’s (1918, 30–32) book on aviation engines has a three-page (partially overlapping) classification of 66 engine types, including a diagrammed double-row rotary engine (not found in a total review of aircraft in the first world war; it presumably existed in prototype form only), and a new phylum—a six-cycle engine (like discovering cyanobacteria). Both are nonexistent, indeed unknown today, as are many of these types. Only a few have (much transformed) modern descendants.

66. Clarification: Take item (2) in this list of conclusions as frequency of successful transmission of a message somewhat like that intended, (3) as a measure of the dispersion of successful messages from the exactly correct message, supplemented by the ease of recovery of essentially the whole message from partially degraded instances of transmission, (4) as true because of the possibility of transmitting accurately a number of message parts (possibly from different sources) that have to be assembled correctly to produce the complex whole, and (5) that in the context of scaffolding skills and learned prior knowledge, message parts are successfully disambiguated in ways that are computationally local though possibly semantically global, showing context dependence in the first and context relevance in the second.

67. Simpler things, like sticks and stones used incidentally in a game, that would not count as cultural may be counted as such within the context of a cultural system, just...
as viruses can count as living in some extended sense in terms if their relations with the living things that they parasitize and transform.

68. Indeed the only potential causes left of consilient senders and receivers are traditional information flows over channels and correlations induced by development in a common persistent environment. Neither of these is a plausible explanation for the organization of receivers of any organizational complexity: both are too low bandwidth to generate culture of any but low viscosity—that is, the “thin” culture of transmitted memes such as “preferences.” Haugeland’s (1998) essay “Mind Embodied and Embedded” makes extensive use of the distinction between high and low bandwidth in distinguishing between information channels and embodiment, suggesting a deeper resonance between our views.

69. So the genetic code machinery is not typically modified by changing the message. Essentially this was first noted by H. J. Muller in 1922, when he argued that transmission genetics must use distinct causal pathways from gene expression because mutations that caused diverse and serious disruptions of phenotypic function were all equally heritable. The operation of the telegraph and telephone are similarly independent of or invariant over the contents they transmit. Though each of them could be modified by the appropriate message sent and acted on, they commonly are not, and their proper function depends on this fact. This fact was relied upon by biochemists who exploited rare mutations that did change the genetic code machinery to work out the code itself (see Schulman and Abelson 1988).

70. This idealization ignores embodiment and social embedding of the performing structures and processes. There are some purposes and perspectives for which this is a useful idealization, and this disembodied compartmentalization fits some systems better than others.

References


