

The Evolved Apprentice: How Evolution Made Humans Unique

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1 The Challenge of Novelty

1.1 Introduction

Hominins split from the chimpanzee lineage six to seven million years ago, and after a relatively unobtrusive beginning, over the last three million years or so, our lineage has diverged sharply from those of our great ape relatives. Hominins became fully bipedal, dependent on technology and cooperation, and, uniquely, combined a fission–fusion social organization with heavy male investment in their offspring.¹ Life history changed: recent hominins live longer than earlier ones and great apes, and our life history has unusual features (adolescents and active postmenopausal females). Our geographic range expanded massively, as did population size. We moved into many new habitats. Our social organization became complex. We acquired novel cognitive capacities: language, metarepresentation, and perhaps even intuitive physics. In sum, change has been rapid: the early molecular clock dates putting the human–chimp split at about six million years ago were greeted with great skepticism because biologists and physical anthropologists did not believe that such great phenotypic divergence could evolve so quickly. Change has been pervasive: morphology, life history, social life, sexual behavior, and foraging patterns have all shifted sharply away from those of other great apes. No other great ape lineage seems to have undergone such a profound transformation: as far as we know, living chimps and gorillas are broadly similar in habitat and ecology to their ancestors of five million years ago. The hominin evolutionary trajectory is bound to be of interest to us, because it is our trajectory. But a disinterested evolutionary biologist would agree that a striking phenomenon exists here, one in need of explanation.²

There is a standard picture both of the root cause of this evolutionary trajectory and of the kind of agent that evolved as a consequence of this trajectory. The picture conjoins a selective and an architectural hypothesis. The selective hypothesis supposes that hominin fitness came to depend on managing relations with other hominins. No doubt humans, like other primates, sometimes died of accident, disease, and predation. Our ancestors were not free of the typical burdens of primate flesh and bone. But the distinctive feature—the difference-making feature—of hominin selective environments was the intensity of selection, and the kind of selection, imposed by social interaction. Fitness largely depended on patterns of interaction with other hominins. Those who were more successful in forging cooperative relations, and those who were more adept at interacting with their rivals, left more descendants. Our social environment largely—though not exclusively—shaped our cognitive and behavioral evolution. The demands of an increasingly complex social life required an increasingly sophisticated cognitive response. This basic idea—the Social Intelligence Hypothesis—can be developed in several ways. Robin Dunbar, for example, supposed that increasing group size increases social complexity and puts stress on our memory and conflict management time budgets (Dunbar 2001, 2003). That stress selects for more efficient mapping of the social environment and more effective communication. Geoff Miller's model stresses sexual competition (Miller 1997). But probably the most influential variant of this hypothesis derives from Nick Humphrey's Machiavellian model. According to this model, in hominin social worlds every agent is forced to play social chess, trying to leverage as much profit from social interactions as possible while paying minimal costs. Cooperation with others was an essential ingredient for a successful life, but it had to be carefully managed to secure at least a fair share of cooperation's profit. Clearly, as players become more intelligent, social chess becomes more complex, with selection for still greater intelligence (Humphrey 1976). More on this in the next section.

Hominins are distinctively intelligent, then, largely through selection for social intelligence. This selective hypothesis is conjoined to an architectural hypothesis: the famous modularity model. Notoriously, evolutionary psychologists have developed a modular model of the cognitive engine that has emerged from the complex social worlds of hominin evolution (Caruthers 2006; Pinker 1997; Sperber 1996; Tooby and Cosmides 1992). This picture of our cognitive architecture is motivated by the observation that

we solve many day-by-day problems effortlessly, efficiently, and unreflectively. This cognitive efficiency requires special explanation, for we solve many of the routine problems of everyday life only because we are sensitive to many subtle and contextually varying cues. Evolutionary psychologists have followed cognitive psychologists in treating nativist linguistics as a model of the explanation of cognitive competence. Language has seemed a plausible model because nativist evolutionary psychologists take human ancestral environments to pose a set of informationally challenging, recurring, but quasi-independent problems. So, for example, every agent must be able to recognize the norms of his or her social group and to identify acts that would violate those norms. This problem is challenging, as norms are not made obvious by regularities in behavior: you cannot tell what is prohibited just by observing what others happen not to do. There was intense selection on human agents to solve these typical but challenging problems, and as a result we evolved specific adaptations to help us do so. Again, language is a guiding example. Language is a subtle, complex, and abstract communicative system, and our effortless mastery of this system can be explained only by supposing that we come pre-equipped with crucial information about language organization (or so it is often supposed). Other everyday cognitive competences are also informationally demanding. So our effortless mastery of such competences as understanding the minds of others or the norms of our community has a similar explanation. Learning is important. But learning is channeled and shaped by domain-specific, preinstalled information.

I accept with the standard model that many routine human decisions are cognitively demanding, and that managing cooperation has been a crucial driver of hominin evolution. But in the rest of this chapter I argue, critically, that these cognitive demands cannot be managed by prewired modules. Many of the challenges involve evolutionarily novel features of the environment. I also argue, critically, that the standard model misreads the problem of managing cooperation. I argue, positively, that hominins developed a new form of ecological interaction with their environment, cooperative foraging, and this ecological revolution led to positive feedback between ecological cooperation, cultural learning, and environmental change.³ This feedback dynamic, I argue throughout the whole book, has structured hominin evolution. Our capacity to cope with informationally challenging problems in novel environments (some of our own making)

depends on this dynamic. In particular, it depends on the construction of minds and social environments adapted to efficient, high-volume social learning.

In my view, the standard picture understates the dynamism and connectedness of hominin evolutionary environments. As a consequence, it mischaracterizes the information-using preconditions of a successful hominin life. The questions that hominin environments asked of our ancestors are not quasi-independent. Hominins evolved into social, cooperative foragers. As a result of that economic transformation, foraging practice, technology, social organization, and human demography all interact. For example, the “broad-spectrum revolution” names one striking episode in the human past as our ancestors shifted from relying heavily on hunting large and medium-size herbivores to using a much more extensive range of animal, plant, and marine resources (Stiner 2001; Stiner and Kuhn 2006). This economic transition changed human group size, social organization, technology, and foraging practice. Specialization, differentiation, and population density all increase together. Changes in any one of these variables affect the others.

Moreover, change was pervasive. Hominins evolved in times of increasing climatic variability, and by about two million years ago they had spread far and wide from their original East African epicenter. So the physical environments of our ancestors became more variable and heterogeneous (Finlayson 2009; Potts 1996). Furthermore, and most importantly, hominins became increasingly potent ecological engineers. The hominin footprint on the local environment became ever more marked and more pervasive. Thus by a half-million years ago (perhaps earlier) our ancestors had become effective predators of medium to large herbivores (Foley and Gamble 2009; Jones 2007). This affected how hominins experienced their environment and how selection acted on our ancestors. For example, as weapons, ecological expertise, and cooperation improved, the impact of many predators would decline. But hominin activities also reshaped the environment itself. Very likely, through competition and active persecution, those hunters were affecting the absolute numbers, distribution, and behavior of rival predators. Thus the environments of hominin evolution have been unstable both physically and biologically.

They have also been unstable socially. Group size, the extent and nature of the division of labor, the extent of social hierarchy, and the importance

and nature of interactions with other groups all affect an agent's social world. None of these factors has been constant over the last hundred thousand years. Robert Foley, in particular, has long emphasized the relationship between resource distribution and sexual dynamics. For example, if crucial resources are clumped in rich, predictable local patches (like a salmon run), then one or a few males, by seizing control of resources, can thereby ensure sexual access to the women needing those resources. This resource distribution opens the door to polygyny. In contrast, if resources are pepper-potted unpredictably throughout the environment, women will scatter, chasing those resources, closing the door to polygynous strategies. In my view, human worlds have been heterogeneous psychologically as well as socially and physically: the psychology of other agents has also varied over the last hundred thousand years. The standard model rules this possibility out. If our minds are (mostly) ensembles of (largely) prewired modules, then human nature is largely the same everywhere and when. But we are pervasively and profoundly phenotypically plastic: our minds develop differently in different environments. The extent and nature of this plasticity is controversial, but its existence is not. Humans obviously differ in skills, capacities, and information, and those differences are relevant to social chess. Likewise we clearly have some emotional and motivational complexes whose development is channeled by specific cultures; the response to a perceived insult is very different in a "culture of honour" (Nisbett and Cohen 1996) than in, say, a culture like that of the Faroe Islands, which values social harmony and peacemaking highly (Gaffin 1995). If motivational, emotional, and decision-making mechanisms are indeed plastic in important ways, important differences in human socio-foraging worlds will result in importantly different inhabitants of those worlds.

A central dynamic of human evolution, then, is that while the informational demands on adaptive human action have long been significant, these informational prerequisites are neither stable nor relatively discrete. The standard model is right to insist that many everyday challenges of human social life impose high cognitive loads, and that our response to these challenges is typically competent. Such ubiquitous competence does indeed require special explanation. How is it, for example, that almost all of us master and respond to the norms of our immediate circle? In many cases, this competence does not depend on our being prewired with most of the crucial information needed for adaptive response. We sometimes

blunder; we sometimes overlook the obvious despite repeated exposure. But we often respond competently to novel high-cognitive-load problems.⁴ The standard model overstates the informational independence and stability of the challenges we usually meet. As I see it, then, a key challenge to models of human evolution is to explain competent response to novel problems. The standard model recognizes the centrality of learning to human social life, and different versions of this model vary in the extent to which they appeal to prewired capacities. But to the extent that those models explain competence by appealing to preinstalled information, they are not well designed to explain competence in the face of the new.

1.2 The Social Intelligence Hypothesis

Hominin cognitive evolution cannot have been driven mostly by external environmental change, as then we would expect similar trajectories in other species, and that we do not see. Five million years ago, our ancestors were unobtrusive elements of the East African mammalian fauna. We now inhabit essentially every terrestrial habitat, in numbers unprecedented for a large mammal, and we have transformed most of the world's ecologies. The speed and extent of this evolutionary transformation suggest that it has been driven by a positive feedback loop. It is unique; no other great ape lineage is a mirror site, reflecting a similar response to external events. This suggests that the dynamics are internal, though presumably triggered by some idiosyncratic feature of our early history.

According to the standard model, the feedback loop derives from the problem of managing cooperation, a problem that becomes ever more crucial, and ever more difficult, as human agents become more intelligent. As the standard model represents the problem of cooperation, it rests on the strategic aim of enjoying the benefits of cooperation without being exploited by others. Cooperation can be highly profitable, because a group acting jointly can generate a higher return than the sum of each of them acting individually. Collective defense, for example, will typically be far more effective than individual defense. Hominin evolution, among much else, is one long lesson in the profit of cooperation and the power over the world that derives from successful cooperation at and across generations. So cooperation has a potential benefit, but only if the costs of defection can be contained. Cooperative actions are not free, and the benefits

of cooperation often do not fully depend on every agent paying the full cooperation cost. Collective defense can still be successful even if one defender lurks in the rear. These circumstances generate a temptation to avoid the costs of cooperation while collecting the benefits. Thus it seems that in many circumstances, even when cooperation is profitable, it will not evolve. Cooperation cannot persist if free riding is still more profitable. So cooperation will not establish if it is too difficult or too expensive for cooperators to exclude free riders.

This analysis of the “hard problem” of cooperation is reflected in the traditions of both evolutionary models and experimental economics. Much evolutionary modeling of cooperation is based on variations of iterated prisoner’s dilemma themes (Hammerstein 2003). In these models, the rewards of successful cooperation (and those of defection and of trust betrayed) are free parameters to be adjusted as the modeler chooses. The models explore the consequences of different patterns of interaction, the effects of punishment, of error, of group structure, of the effects of the manipulation of rewards and costs. They do not explore the mechanisms that generate the rewards of cooperation. The same is true of experimental economics. For example, in many public-goods games, the central pool that is the reward of cooperation is simply by experimental fiat double the total of the individual contributions. The experimental subjects need to commit to cooperation. But that cooperation involves no collective action or joint problem solving. Rather, these experiments investigate the conditions under which cooperation stabilizes or decays, conditional on the ways the profit of cooperation is divided among the players.

Machiavellian hypotheses thus focus on this cognitive challenge of managing cooperation in an environment in which defection is a threat rather than the problem of coordination, of organizing collective action so that it generates a cooperation profit. Cooperation is so profitable that it eventually became an obligate feature of hominin lifeways. Going it alone has probably not been an option for hundreds of thousands of years. But in such environments, agents must calculate and police reciprocal bargains, scrutinize signals for honesty, decide on disclosure principles, negotiate alliances, decide whether to defect. As other agents become more intelligent, these decisions become more demanding. As cognitive sophistication increases, social environments become more demanding. This selects for further cognitive complexity. Perhaps an initial shift toward cooperation had some

local external cause. It may be that early hominins—australopithecines of three or four million years ago—had to band together cooperatively for protection as their forests turned into woodlands and savannas in a warmer and drier world. At this stage of hominin evolution, cooperation was driven by external, environmental factors. But once cooperation and its management became central to the lives of our ancestors, that established a positive feedback loop between social complexity and individual cognitive capacity.

There is a natural link between the Machiavellian version of the Social Intelligence Hypothesis and a modularity hypothesis, for most candidate modules are tools for social life. If prudent cooperation was central to a successful hominin life, and prudent cooperation was stable only through vigilant mutual scrutiny, we might well expect special adaptations to monitor social exchange and to monitor norms and norm violation. Most obviously, folk psychology will be a crucial resource in cooperation management. It is essential to track the beliefs, preferences, and intentions of others in a world in which partners are necessary, but in which they are at best reluctantly honest and kept so only by sleepless vigilance. Machiavellian versions of the Social Intelligence Hypothesis predict that we have minds with a suite of adaptations for a social life revolving around bargaining, exchange, and honesty assessment. That is just the kind of mind that advocates of massive modularity hypotheses think we have.

Moreover, the cognitive complexity of other agents, and the social complexity that cognitive complexity generates, explain why routine human decision making has a high cognitive load, and hence why everyday competences need to be supported by special tools. We are individually complex agents living in, and contributing to, socially complex worlds. The factors that ramp up the informational demands on routine decisions include the following:

- (i) We have many needs, so trade and exchange are complex, with multiple trade-offs.
- (ii) Many human groups exhibit significant division of labor and specialization, so many humans have lived in groups with significant horizontal differentiation.
- (iii) Many human groups, including some foraging cultures, exhibit significant vertical complexity: individuals form parts of families, which in turn are components of bands, totem groups, and the like. Thus even small-scale traditional societies often have layers of social organization between individual agents and the group as a whole.

(iv) We are long-lived, with good memories, and form long-lasting, high-stakes relationships. Entering into a sexual or social alliance is often a high-risk, high-reward decision.

(v) If Robin Dunbar is right, hominin social worlds have trended up in size. Hominins, increasingly, have needed to keep track of more agents and to map their social relations.

(vi) Sex is complex, as we are social, quasi-monogamous primates with male investment and somewhat concealed female ovulation. Moreover, we live in a fission–fusion society with a sexual division of labor. Males cannot guarantee paternity by direct vigilance of female behavior. Sex is further complicated by partial reproductive cooperation between relatives; for example, by a grandmother caring for her daughter's children.

(vii) We pool information, as well as cooperating to make direct economic gains. So communication plays an especially important role in human social worlds. But not all communication is honest.

(viii) Human social worlds are organized around norms, not just regularities or habits. Violations of norms are often punished, formally or informally, even when the norms are not made explicit.

(ix) Agents are only partially transparent to one another. We signal richly, but some of those signaling systems are arbitrary, referential systems with low intrinsic reliability. We have considerable voluntary control over facial expression, stance, and voice, and so we can partially fake and suppress many natural cues. We have stealth and deception capacities.

Ordinary human decision making, then, takes place in a translucent social world. Often relevant information is available, information that would guide adaptive decision making were an agent aware of it and able to assess its relevance and reliability. But cues are often not perceptually salient. Their relevance is often not obvious, and their reliability is difficult to assess. Our social world is translucent because it is the result of a Machiavellian evolutionary dynamic.

The cognitive challenges of policing the division of collective and cooperative products are real. The problems of deception and defection are not just artifacts of contemporary mass societies. They existed in the social worlds in which the cooperative framework of human life evolved. But defection management is not all that is needed to keep cooperation stable. To be stable, it must also be profitable, and profitable cooperation often requires coordination, and that is often cognitively demanding. Indeed, in

small-scale foraging social worlds, the cognitive problem of effective coordination is *more demanding* than that of detecting defection. The standard picture is right to identify the evolution of stabilized, extensive, obligate cooperation as the core, distinctive feature of hominin selective environments. But that picture misrepresents the task demands on cooperation, for it focuses on explaining how the profit of cooperation is distributed in ways that do not undermine the motivation to cooperate. I suggest (following Calcott 2008b) that a prior question is equally pressing: how does hominin cooperation generate a profit? I begin to answer that question in the next section, and in doing so, I develop the idea that the task demands facing hominins were not just variable over time; they were interdependent.

1.3 Cooperative Foraging

Hominin social complexity has certainly increased. But there has also been a transformation in the ways that hominins interact with, and extract resources from, their environment. The (gracile) australopithecines and early *Homo* were, as far as we can tell, generalist scroungers, subsisting on the proverbial nuts and berries, with the odd grub, slow lizard, and scavenged carcass fragment thrown in. By two hundred thousand years ago, perhaps much earlier, our ancestors were dominating predators.⁵ In sharp contrast to other predators, those hominins often specialized in the prime adults of their target species, typically large ungulates (Stiner 2002). Hominins went from being food to taking food from other members of the predator guild. The shift from marginal scrounging to major predator status most likely took place via increasingly aggressive scavenging. Thrown volleys of rocks would be no great threat to, say, a mobile leopard. But they would genuinely endanger one immobilized by the need to defend a kill. Importantly, the shift to predation preceded the invention of long-distance lethal weapons. We killed large animals before the invention of spear-throwers; bow-and-arrow technology, or poison-tipped weapons (Marlowe 2005). Spears (and perhaps killer frisbees) sufficed.

Later still, probably as a result of living in larger groups and of our increasing ecological footprint, the range of resources that humans harvested expanded greatly. For example, in Europe, by the time the Ice Age was ending, this shift intensified (Stiner 2001). The systematic exploitation of plant-based resources increased. Fish and other marine and riverine resources

became important. Waterfowl and smaller game were taken with specialist equipment. Indeed, in general, this expansion of the resource base is paired with an expansion of specialized toolkits. Foragers developed specialized toolkits and techniques to grind grain and make bread, to harvest water-based resources, and to catch smaller game economically.

I take these shifts in ecological role to be a clear historical signal of the invention and establishment of a new lifeway, built around a new mode of foraging. By two hundred thousand years ago, and most probably much earlier, hominins had evolved into social foragers.⁶ Such foragers depend on harvesting high-value but heavily defended resources. The regular exploitation of those resources (at tolerable risk loads) depends on some mix of (i) rich, targeted ecological information (so, for example, tubers are a rich carbohydrate store, but they must be found, recognized, detoxified, processed); (ii) cooperation; and (iii) technology. Typically all are needed, though the exact mix will vary with time, place, and target. Hunting large animals is intrinsically risky, and it required technology to be integrated with a detailed understanding of the prey, its capacities, habits, and likely reactions, and to skilled, coordinated group hunting. Truly lethal weapons are needed before individuals and small groups can take large and dangerous prey. Neanderthals, like sapiens, were effective hunters of medium to large prey (d'Errico and Stringer 2011), and their use of heavy spears is known from the archaeological record of about 400,000 years ago (Thieme 1997). So it is likely that the common ancestor of our species and the Neanderthals was also an effective social forager, though it is possible that the sapiens and Neanderthal lineages evolved in parallel from a less adept ancestor.

On this view of hominin evolution, as with Machiavellian models, cooperation is central to our evolving cognitive capacity. But our conception of the informational challenge changes. Cooperative foraging (and especially cooperative hunting and cooperative defense against predation) requires coordination, and thus communication. Cooperative hunters must plan and coordinate before targeting potentially difficult and dangerous targets, especially if there is task specialization. But even if there has been advanced and expert planning, on occasion not everything will go according to plan. Agents will have to react on the fly, sometimes in novel situations, and often with imperfect information. They will make high-stakes decisions under time pressure, based on their reading of the physical and biological context and on their expectations of others' reactions, and with rather

limited prospects for communication and consultation. No doubt those fast-response decisions often failed. But they were good enough, often enough, for lifeways based on cooperative foraging to establish and spread, and that is impressive in itself, for these are high-load, high-stakes decisions. Hunting and killing large animals with a sharp stick is no easy project. Both the risks and the rewards are great. These are large, concentrated resource packages. But catastrophe is just a moment's inattention away.

Hominin life, then, came to depend on the rich resources that cooperative foraging delivers. In turn, cooperative foraging demands care, coordination, and skill. In the next section, I explore one aspect of skill: its dependence on social learning.

1.4 Cooperative Foraging and Knowledge Accumulation

Cooperative foraging is one key transition in hominin evolution. Such foraging is a profitable but demanding form of life, for the profit of joint foraging typically depends on effective coordination, often in far from ideal circumstances. Agents must often make decisions when distracted, under time pressure, in danger, and with obscured lines of sight, often in noisy or confused surrounds. The decision-making environment is at best informationally translucent. I suggested in the previous section that hunting large game cooperatively with limited technology depends on effective coordination and the use of transient target information. But it also depends on a rich understanding of stable features of the physical, biological, and technological environment. For example, Kim Shaw Williams (2011) shows that tracks, scats, browse marks, and other physical signs of passage are rich with information for the prepared mind and eye. If the surface is suitable, a tracker can read information about the identity, direction, and time of travel of local fauna, and there is as well much information to be had about the interactions among them (this information is beautifully illustrated, in a European context, in Ennion and Tinbergen 1967). Foragers do have prepared eyes and minds; they are expert natural historians of their local patch. Typically much of this information is acquired culturally; for example, a striking set of photos in Morrison 1981 shows Aboriginal children learning how to recognize different tracks by being shown how to reproduce them. So a second cognitive precondition of cooperative foraging is the existence of a flow of information across the generations. Cultural

learning of this kind can begin and can become important without the active cooperation of the source of information. Agents leak information in their everyday activities. Moreover, they often adaptively structure the learning environment of their young as a by-product of their own utilitarian activities. However, I argue that high-volume, high-fidelity cultural learning depends on informational cooperation between source and sink (the target to whom information flows) in an appropriately organized environment. It depends as well on specific perceptual and cognitive adaptations, probably of the source as well as the sink.

Sometime between about 120,000 and 50,000 years ago, human cultures began to resemble those known from the ethnographic record. By 50,000 years ago, humans had diverse toolkits: they exploited a wide range of materials in their technology, made complex tools, exploited many natural resources for food, buried their dead, had distinct local styles, and made objects that appear to be decorative rather than directly utilitarian. In the jargon of archaeology, they were “behaviorally modern.” Behaviorally modern human cultural worlds depend on high-volume, high-fidelity cultural learning. The elaboration of technology (and thus of technique) depends on a group being able to retain the cognitive capital it inherits, occasionally adding an innovation to it, then transmitting that enhanced capital to the next generation with high fidelity. Indeed, it is arguable that behaviorally modern humans differ from their predecessors just through the establishment of social environments in which high-volume, high-fidelity social learning is robust (more on this in chapter 3). But earlier humans also depended on quite high-volume, high-fidelity social learning. Exploiting high-risk, high-return resources is itself a signature of the capacity to preserve and transmit informational resources. The Neanderthals who regularly exploited elk and other large European ungulates, and the Middle Stone Age Africans who specialized in similar targets, were skilled and knowledgeable. So, for example, Neanderthals brewed adhesives for their hafted weapons out of birch bark, using processes that depend on a surprisingly precise control of temperature (Nowell, forthcoming; d’Errico and Stringer 2011). Expertise and cooperation compensated for limited technology. Likewise the ancient tuber and corm harvesters depended on much hard-won information, if underground storage organs really were important resources from *erectus* on. Fruits are designed to be eaten. But plants do not welcome herbivore consumption of their storage organs, and

hence they are protected both mechanically and chemically. It takes a well-informed mind to find these organs, extract them, and make them edible by soaking, cooking, and the like.⁷

The idea, then, is that positive feedback links social foraging and intergenerational social learning. Intergenerational learning provides much of the informational fuel that makes social foraging successful, and the rewards of social foraging support the life spans and expensive metabolisms that make extensive intergenerational learning possible. A skeptic might concede that once humans are behaviorally modern, high-fidelity, large-bandwidth, cross-generational social learning plays a central role in human lives and societies. However, this is a relatively recent feature of hominin history (the challenge runs), and hence social learning in positive feedback with collaborative foraging cannot be a crucial driver of hominin evolution. Cross-generational human learning became a central part of human lives only after human minds, bodies, and social worlds had largely evolved.⁸ In support of this deflationary view of cross-generational social learning, a skeptic might legitimately point out that until the last hundred thousand years or so, hominin technology seems to have been very conservative, with a small, slowly growing toolkit. Hominins may have innovated, but if they did, those innovations rarely became the new standard practice within the innovator's community. In a world in which children reliably absorbed parental lore, we should expect to see a less-conservative material culture, for children would inherit an information platform from their parents as a basis for further improvement

Unsurprisingly, I disagree. The capacity *to add* regularly to cognitive capital by reliably preserving and amplifying innovation may be relatively recent. Even so, the reliable *preservation* of expertise is ancient. Around 400,000 years ago, humans were using material technology that could not have been reinvented anew each generation, helped only by some minimal prompting by the elders. Making stone spearheads is a difficult art, with multiple processing stages. Control of shape is increasingly difficult as the target to be made becomes smaller, if it is symmetrical, and if one dimension is elongated. Yet the technology 300,000 years ago—so-called mode 3 technology—required close control of shape in working relatively small artifacts (Foley and Lahr 2011).⁹ Likewise, the natural-history expertise essential to cooperative foraging could not be rebuilt every generation without substantial informational input from the previous generation.

Both hominin minds and hominin social environments are adapted to the social acquisition, use, and transmission of ecological and technological expertise. Without such adaptations of minds and social environments, life as a social forager could not have evolved.

Social foraging, then, is informationally demanding over short time frames through the requirements of joint and coordinated action. It is informationally demanding over longer time frames because it rests on a reservoir of skill and expertise. Moreover, social foraging requires the *integration* of ecological, technological, and social information. A group of foragers putting a hunting party together needs to appreciate both their local ecology and the capacities of their partners. The same is true of on-the-fly decision making. For example, effectively responding to an emergency requires agents to integrate what they know of the situation—the level and nature of the threat, the lay of the land, the potential responses—with their knowledge of their social partners. Agents responding to a threatened attack need to understand who stays calm, who panics, who is a hothead. Moreover, they need to factor in the physical condition of their partners. The right response to injury, fire, or flood depends on specific local circumstances and on the abilities and frailties of those who face emergency. Response cannot be too stereotyped. No doubt social foragers quite often made poor decisions in response to crisis. But the world of 150,000 years ago was much more dangerous than it is now (setting aside the danger posed by humans), and so the persistence of this lifeway in that dangerous world shows that social foragers often responded appropriately to the unexpected. The basic structure of human life history, with its extended periods of juvenile dependence, requires that on average, mortality is low once adulthood is reached (as we will see in sec. 4.3). The evolution of human life history patterns is hard to date, but researchers generally agree that by the time of the erectines (around 1.8 million years ago), a significant shift from ape to human life history patterns had occurred. This extension of life history (humans live a good twenty years or more longer than chimps) shows that while social foragers had many dangers to negotiate, they usually did so successfully. The assembly, integration, and intergenerational transmission of social, ecological, and technological information have deep roots.

A quick review of progress to date is in order. Like others, I think the expansion of cognition in the hominin lineage is intimately connected to the expansion of cooperation in that lineage. But in contrast to the usual

defection-management perspective, I see the key cognitive preconditions of cooperation as being those necessary for coordination and effective joint action. In a complex and risky environment, profitable cooperation depends on more than trust, on more than the confidence that you will not be ripped off. It also depends on teamwork, with a mutual awareness of one another's abilities, and on integrating this social information with appropriate information about the world: the target of joint action. Once these conditions were met, joint action was profitable. Indeed, it became increasingly profitable as target information and technology were harnessed to improved coordination. The evolution of coordinated action depended on improving capacities to coordinate and on improving, harnessing, and retaining for the next generation information about foraging targets and techniques. Critically, once this form of cooperation is established, it triggers a positive feedback loop between environmental change, ecological cooperation, and cross-generational learning. Cooperation increases the pace of environmental change, and the nativist solution to the problem of high cognitive load is increasingly restricted to special cases.

1.5 Life in a Changing World

Hominins have not evolved in a stable world. As Rick Potts (1996, 1998) and Clive Finlayson (2009) emphasize, the world of hominin evolution has been increasingly climatically unstable: the Holocene is an aberrant stretch of stability against a shifting background. Likewise Pete Richerson has recently argued that much of human evolution should be understood as a response to climate, both to its increasing instability before the Holocene and to its anomalous stability since (Richerson, forthcoming; Richerson and Boyd 2002). But more important still, cooperative foraging is such a powerful mode of interacting with the environment that it directly and indirectly transformed the hominin environment and thus the ways in which selection acted on our ancestors.

Cooperation (perhaps in conjunction with other adaptations) has allowed the hominin lineage to penetrate new regions and habitats. Hominin environments have become increasingly variable across space as hominins have become increasingly widespread ecologically and geographically. Moreover, cooperative foraging has an increasingly heavy ecological and physical footprint over time. The populations of target species are depleted.

Predators become increasingly rare, wary, or both. These environmental effects also create coevolutionary opportunities for species that will eventually domesticate, and for scavengers of various sizes (rats, mice, cockroaches, lice). We experience new pathogens as we change our mobility, residence patterns, and population size. Landscapes are altered. Australian Aborigines, for example, have long used fire as a tool both to clear underbrush, making game more accessible, and to induce a flush of grass growth, encouraging their target species to return to their hunting grounds. These altered fire regimes, with much more frequent burning, have had dramatic long-term effects on Australian landscapes (Bliege Bird et al. 2008; Pyne 1998).

So the direct effect of social foraging is significant and cumulative as environmental change becomes more rapid and intense. That was especially true once innovations were more reliably preserved, transmitted, and built on, for then individual and collective effects on environments increase. Consider again the elaboration of the control of fire, from true hearths and earth ovens to container-based cooking, pottery, and other technology that depends on the control of heat. These developments increasingly altered humans' experience of their environments. The same is true of clothing (Gilligan 2007), shelters, watercraft, and tools and weapons. But the evolution of social foraging had profound effects on the social environment as well, by both selecting for and making possible (through an increased period of juvenile dependence) increases in the fidelity and volume of cultural learning (Carey and Judge 2001; Kaplan et al. 2000; Robson and Kaplan 2003). Elaborated social learning almost certainly evolved because of selection for utilitarian expertise, and that in itself would change social life as children became more interested in adult activities, and adults more tolerant and communicative. Indeed, it has even been suggested that elaborated social learning has led to a distinct form of social hierarchy based on esteem and prestige. Esteem and deference are the price the less able pay to experts for access to their expertise (Henrich and Gil-White 2001). But once evolved, those capacities changed social life in even more profound ways as they were exapted for other purposes, including machinery for social cohesion. Once social learning became central to human psychology and social life, other important changes in human social life followed, as groups began to consciously and publically identify themselves as groups. Public symbols in various forms—song, ritual, physical symbols, public art—are

part of the machinery through which group cohesion and identity emerge. Mere regularities become entrenched as customs and norms; they become markers of who we are, not just of what we happen to do. These symbol systems depend both directly and indirectly (via the technology needed to make them) on elaborated cultural learning. Music and ritual, too, are transmitted socially, but once established, they profoundly change social lives (Mithen 2005).

The effects of social foraging on demography and group size also increase the pace and intensity of environmental change. All else being equal, improving the efficiency with which humans extract resources from their environment will result in an expanding population and an increase in group size. Larger groups preserve informational resources more reliably, for learners have more expert models from whom they can pump information, and expertise is less likely to be lost by unlucky accident. But as Haim Ofek argues in *Second Nature*, size makes the benefits of specialization more available. There is a market for special skills, so larger groups can divide labor more finely. Ofek conjectures that fire keeping was the first form of labor specialization. If he is right, that specialization preceded behavioral modernity. But as the returns of social foraging increased, especially after behaviorally modern humans began to depend on the efficient harvesting of many different resources, among larger groups there would have been important incentives for specialization. If specialists are more likely to successfully innovate in their field of specialization, as seems likely, positive connections will develop between elaborating social foraging, increased group size, and the rate of innovation.

In sum, feedback loops form between individual cognitive capacity, social organization, and the pace of environmental change. Environmental change, in turn, is important because the informational requirements on adaptive action vary as the environment varies. The right choice often depends on specific features of the environment. As humans have lived in such variable environments, many high-load problems cannot be solved by prewiring information into human heads. Our genes cannot predict the kind of world in which we will live. That has been true for at least 200,000 years, probably longer. The spread of variation across space and time is large. In some cases, we may have access to adaptively salient information by being prewired with the much of the information we need (or with partially specified schemes allowing learning to fine-tune such prewired

capacities). The physical properties that govern mechanical interaction between stone, bone, and other hard materials are important to our lives as tool-assisted foragers, and we have some evidence that these physical principles are difficult to grasp. Chimps learn to manipulate their environment by trial and error, but they do not automatically generalize from one setup to a causally similar one (see Povinelli et al. 2000, though this interpretation is controversial; see Herrmann et al. 2007). These mechanical principles are common to, and adaptively important in, all human environments, and so humans may well be pre-equipped with information about mechanical causation (Pinker 2007). But this model does not export to most other competences. Even if we confine our attention to humans before the invention of farming and domestication, humans have experienced and adaptively responded to ecological challenges as varied as hot inland deserts (central Australia), extreme seasonal variation (the high Arctic) tropical rain forests (Africa, Central America), shallow tropical seas (the Indonesian archipelago), and large-game specialization (the African savanna). While some principles of biology and naive physics are constant across the ecological challenges those environments pose, the constant features are extremely coarse-grained. Most of what these different peoples need to know will be *specific* to their circumstances.

Moreover, ecology, demography, social structure, and specialization interact. The differences in ecology ramify. These foraging peoples live in different social and psychological worlds, not just different ecological worlds. The problem of novelty cannot be contained to a single domain. Changes in ecology and demography are reflected in changes in specialization, stratification, and investment in high-fidelity cultural learning. These in turn affect the social and psychological judgments an agent must make. For example, the problem of trust changes as we shift from relatively homogeneous and intimate social worlds to those in which differentiation and exchange play a more central role. As social stratification becomes important (and grave goods hint that some forms have deep roots), social and sexual decision making has ever higher stakes, as the differences between winners and losers become more marked. Defection and deception become serious dangers (more on this in sec. 6.3). As group size increases, or as interactions with other groups become more common, interactions with relative strangers grow in importance. For example, the social worlds of the complex foraging societies of the Pacific Northwest, organized around salmon

exploitation, differed greatly from those of the Australian Aborigines of the first twenty thousand years of their occupation (Brumm and Moore 2005; Habgood and Franklin 2008; Keen 2006; O'Connell and Allen 2007). The societies of the Pacific Northwest had a highly developed technology and intricate systems of public symbols; they were densely populated, with marked social stratification. The early Aboriginal world had low population densities with small, scattered groups; a limited technology; and few signs of social stratification and public symbol use. Yet many were sexual gerontocracies with extraordinarily elaborate norms of sexual access (Keen 2006). The problems of social navigation and mind reading in ancient Australia differed from those of the Pacific Northwest.

In sum, then, the organizing theme of the next few chapters is the problem of novelty and the idea that we solve that problem by being able to accumulate and use cognitive capital. The story of hominin evolution is not the story of the evolution of specialized, innately structured modules. Nor is it a story of a key innovation and its consequences. As we will see over the next few chapters, it has often been suggested that the ape–hominin divergence is due to a specific adaptive breakthrough in our lineage. Three recent suggestions include fire and cooking, the use of weapons, and cooperative breeding. These were important, but the model I develop here emphasizes positive feedback loops between many aspects of hominin life, for the hominin adaptive complex involves many features that are novel to, or greatly exaggerated in, our lineage. These include technology, various forms of ecological cooperation, and a transformed and complex social life. I suggest that these hominin specializations began to evolve early, perhaps around the australopithecine–habiline transition, and with change becoming more marked with the origin of the erectines (perhaps around 1.8 million years ago). In many respects, the dates remain conjectural. More important, these hominin novelties coevolved in positive feedback loops, or so I argue. There is no master adaptation whose origin explains the rest.

In chapter 2, I introduce a basic model of accumulation and apply it to the broadest outline of the evolution of hominin social learning in chapter 3. In that chapter, I illustrate the explanatory power of the basic model by using it to explore a range of puzzling phenomena in archaeology, including Neanderthal extinction. I link information sharing to other forms of cooperation in chapter 4. Chapters 5 and 6 elaborate the basic model by linking it to issues in signaling, trust, and communication. I remarked in

section 1.2 that the defection problem is overemphasized in some models of human evolution. But it is important, and chapters 5 and 6 explore the connections between cooperation, communication, and the suppression of cheating. Many forms of late hominin cooperation depend on trust: on an agent's capacity to make credible threats and promises. Credibility, in turn, has been seen as a signaling problem, the problem of ensuring honest communication between the trustworthy in the face of the threats of deception. So these chapters explore the mechanisms that make honest communication possible, and the mechanisms that often make it possible to trust the promises and threats of others. The basic model of social learning built in section 2.3 focuses on the evolution of the capacity to transmit skill and expertise across the generations, so chapter 7 extends that basic model by applying it a broader range: the intergenerational transmission of norms and ideology. The discussion of cooperation and threats to cooperation in chapters 4, 5, and 6 focuses on interactions within local groups or communities. Chapter 8 takes up the issue of relations between groups and the idea that cooperation within human groups depends on cutthroat competition between them. I am skeptical, and I explain why. The chapter ends by identifying important open questions, and with a final overview.