# 5 Technical Constraints on the Convergent Evolution of Technologies

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Observed similarities in two distinct technological traditions can be attributable to different causes. The similarities could have been inherited from a common ancestral tradition, in which case the two similar traditions would be *homologous*. Alternatively, the similarities could be the result of the two traditions independently having invented tools with similar forms and/or functions. This latter situation is one of *convergent evolution*.

With respect to lithic technology, the plausibility of convergent evolution depends on the range of stone-tool forms and functions that can be produced. For instance, if prehistoric knappers could have produced an endless range of forms, the coincidental invention of similar tools would be very surprising. In contrast, should the range be limited to but a few forms, we would expect convergence to occur frequently. My premise here is that the range of possible prehistoric stone tools is located in between these two extremes because of technical constraints—those imposed on the morphological evolution of tools by the specific set of techniques used for their manufacture. Not just any form of stone tool can be produced by any single manufacturing technique, and no manufacturing technique can produce any and all forms of stone tools. Given their technical knowledge and the restricted set of tools in their possession, prehistoric societies could produce only limited stone-tool forms.

The study of technical constraints on technological evolution promises more than marking the boundaries between the space of possible and impossible tool forms. By explicitly addressing the impact of manufacturing techniques on the evolution of tools, I aim to expand the evolutionary models set at the level of tool morphology in order to address important factors in the production and convergent evolution of stone tools. I develop a framework for understanding the evolution of manufacturing techniques and their impact on the evolution of tool technology, stone-based or otherwise.

I take that "the paramount goals of archaeological research are constructing and explaining the evolutionary lineages of cultures as they are represented by artifacts" (Lyman 2001: 70). Consequently, the study of convergent technological evolution asks minimally two types of questions, one related to genealogy and the other to process. Solving the genealogy question means identifying the descent relationships (or lack of) between two similar artifact forms by reconstructing their lineages. To solve it, we rely on methods of phylogenetic ordering, meaning that we identify the most parsimonious evolutionary story tracing the heritable transmission of variant tool forms. The use of cladistics to construct phylogenetic trees has been employed to address this type of question (e.g., Lycett 2009, 2011; Mace et al. 2005; O'Brien and Lyman 2003; O'Brien, Darwent, and Lyman 2001).

Here, I limit discussion to process by addressing the causal, effective story behind the forming of technological phylogenies. To solve the process problem, we need to explain how the evolution of some technological traditions happened to converge and what factors, causal or otherwise, shaped this evolution. Addressing the process question means identifying the different mechanisms involved in shaping technological lineages and balancing the causes that led to the specific evolutionary trajectories, including instances of two independent traditions creating similar technological products.

## Morphocentric Models of Technological Evolution

The formal resemblance of tools has long been used by archeologists as a marker of the passage of time and of cultural affiliation (O'Brien and Lyman 2000). Social-learning mechanisms, such as teaching, imitation, and emulation (chapters 3 and 9, this volume) create cultural-inheritance systems that ensure the transmission of information required to reproduce similar tools from one generation to the next. As the transmitted information changes through time, so will corresponding behaviors used to produce the tools and consequently the tools themselves. Overall, we expect a general pattern of descent with modification within the archeological record. The stability of technological traditions is then explained by the faithful transmission of the information necessary to reproduce similar tools, whereas divergence in technological traditions is explained by the transformation of the transmitted information.

Archaeology's prevalent model of the *process* of technological evolution is one that centers on morphological change in artifacts (e.g., Bettinger and Eerkens 1997, 1999; Buchanan and Hamilton 2009; Eerkens 2000; Eerkens and Bettinger 2001; Eerkens and Lipo 2005, 2008; Hamilton and Buchanan 2009; Kempe, Lycett, and Mesoudi 2012; Lycett 2008; Lyman 2001; Mesoudi and O'Brien 2008a, 2008b; Neiman 1995; Schillinger, Mesoudi, and Lycett 2014; Shennan and Wilkinson 2001; VanPool 2001). These "morphocentric" approaches rely on what is probably the most intuitive and simple model of technological evolutionary change one can imagine, yet it is a very stringent one. It makes three assumptions about the nature and process of technological change.

First, it is generally assumed that the stone-tool manufacturer produces a tool with a certain form because he or she has a mental representation—sometimes referred to as an "ideational unit" (e.g., O'Brien, Lyman, Mesoudi, and VanPool 2010)—that specifies what the final product—the "empirical unit"—should look like:

> [A] manufacturer of, say, projectile points, thinks of his intended creation using ideational units: "I need a 6-inch-long point that is 2 inches wide and has 60-degree notches instead of the usual 40-degree notches." Those units—inches and degrees—cannot be anything else but ideational because we cannot "see" or "feel" them. The manufacturer then uses ideational units to create the object and can also describe the object using ideational units. The actual specimen that he creates—a 6-inch-long projectile point—is an empirical unit in that it can be seen and felt. (O'Brien et al. 2010: 3798)

Implicit here is the idea that should the mental representation of the intended tool be altered, the resulting final form of the manufactured tool would vary accordingly. To build on O'Brien et al.'s example, should the manufacturer intend to produce a projectile point that "has 60-degree notches instead of the usual 40-degree notches," he would, in fact, produce a projectile point that has those characteristics. Consequently, morphocentric models track the transmission of variation in stone-tool form, since what one intends to produce is what one effectively produces. The specific means of production are typically abstracted away, what I have referred to elsewhere as the *congruence assumption*: variation in the mental representation of tools' final form maps isomorphically on the morphological variation of the produced tools (Charbonneau 2015a).

Second, mechanisms introduce variation in stone-tool lineages. In morphocentric models, it is typically assumed that errors in the social-learning process alter the form of the tools. The main variation-generating mechanism of technological evolution is that of the accumulation of copying error, or ACE (Eerkens 2000; Eerkens and Bettinger 2001; Eerkens and Lipo; 2005, 2008; Schillinger, Mesoudi, and Lycett 2014). According to the ACE model, novel variation in technological traditions reduces to slight quantitative variations in artifact form that are introduced by the imperfections of human cognition and, as far as techniques are involved, by slight (generally unconscious) mistakes in the manufacturing of tools. For instance, one may misjudge the actual size of a tool one is copying, or one might imperfectly recall the shape of the tool one is copying. Eerkens (2000; see also Eerkens and Bettinger 2001; Eerkens and Lipo 2005, 2008) found that cognition-based copying errors typically alter a morphological character's value by about 5 percent, irrespective of the quantitative character's absolute value. Just as technological traditions are assumed to persist from one generation to the next through the transmission of information about the form of the tools, the variation necessary to fuel the evolutionary process is itself introduced by errors in copying stone-tool forms.

Third, morphocentric models generally assume that tool morphology changes but slightly from one generation to the next. For instance, any morphological differences between a model tool and its copies that are less than or around 5 percent—that is, within the copying-error threshold—can be understood as a gradual change of this kind (Charbonneau 2015a). Consequently, if two different tools are part of the same technological lineage, yet diverge by more than 5 percent in some of their morphological characters, the assumption of gradual morphological evolution implies that we should observe a series of transitory forms linking the two tools, all within the error threshold from one another. The dissimilarity in morphology expected from copying errors is thus expected to give us a measure of the evolutionary distance between any two tool forms.

## Novel Forms, Intermediate Forms, and Impossible Forms

Morphocentric models have proven to be invaluable in many case studies. However, these models deal strictly with the evolution of morphological characters of final tool forms, and only those characters that vary on a continuous quantitative dimension. Here, I identify additional aspects of tool morphology that need explanation, such as novel forms, intermediate forms, and impossible forms (chapter 2, this volume). Developing evolutionary models that satisfactorily account for the historical change of these additional forms requires us to attend to the techniques involved in their production. After discussing these additional forms and the importance of technical and material constraints in their making, I develop a general modeling strategy dealing with these constraints, thus complementing the morphocentric approach.

### Novel Forms

Studies dealing with processes of tool evolution concern the evolutionary change of tools' morphological characters. Both the copying-error mechanism and the notion of gradual evolution assumed by the morphocentric models are bound to quantitative morphological characters—those that can be quantitatively defined (e.g., size, side angles, and thickness). Consequently, morphocentric models rely on quantitative character spaces to model technological evolution—that is, a set of dimensions, each corresponding to a specific quantitatively describable morphological character of a tool that the archeologist is interested in. In such morphospaces (McGhee 1999, 2007, 2011; chapter 2, this volume), the range of possible values a given character of this sort can take is usually given by a subset of real numbers or, when more relevant, a subset of natural numbers. A specific tool form, then, is located in a morphospace at the intersection of all its modeled characters' values (O'Brien and Bentley 2011; O'Brien et al. 2016).

Morphocentric models were not built to deal with the generation of novel morphological characters. Indeed, the copying-error mechanism is bound to transform only the value of a tool's morphological character, and for this to happen that character needs to already exist. Copying-errors cannot, however, explain why that character was present in the first place, as the mechanism has no stated capacity to generate novel morphological characters. In other words, copying-errors is a variation-generating mechanism for *pre-existing, quantitative characters*.

Consider, for instance, the invention of Paleoindian fluted points in North America. A fluted tool is "a bifacial piece from which an elongated flake has been removed along the longitudinal axis, in order to thin one or both faces, without reaching the edges" (Inizan, Reduron-Ballinger, Roche, and Tixier 1999: 136). These modifications of projectile points were not obtained by gradual removal of increasingly elongated flakes through the same techniques used to shape the projectile point in the first place. Rather, following Crabtree (1966), they necessitate their very own special version of pressure flaking. Inizan et al. (1999) identify the production of flutes as requiring a "special technique" of channel flaking (see also Whittaker 1994).

Since morphocentric models were not built to deal with the invention of novel morphological characters, technological convergence at this level calls for an extension of the models. Indeed, in its current form, the morphocentric explanatory strategy is constrained in dealing strictly with cases of homological evolution and cases of parallel evolution for *shared quantitative characters*. Morphocentric models can explain how two homologous characters came to be so similar: the character itself and its specific value in the two novel traditions were inherited from a common tool ancestor that already had that same morphological character, and one with a value similar to that of its descendants. Morphocentric models can also deal with cases of parallel evolution, but only if shared characters converged on the same quantitative value after having first evolved in different directions. For instance, a process of disruptive selection followed by a process of stabilizing selection on copying errors could lead two traditions sharing a common ancestral form to evolve a specific character value in opposite directions and then bring them back around to the same value. However, in both cases, the presence of the similar quantitative character is assumed, not explained.

## Intermediate Forms

The archeological record is populated by partial forms—incomplete, broken, or discarded tools—but morphocentric models are concerned primarily with the evolution of a tool's final form and the specific values that its morphological characters assume. The models are not designed to deal with intermediary forms that a tool takes while it is being manufactured, nor do they account for the manufacturer's mental representations of what forms the tool under production takes at each intermediate step of its production. Moreover, the specific sequence of intermediate forms needs to be taken into account for a complete explanation of final, functional forms, as important evolutionary processes and changes may affect the transitory forms that link a blank core to a functional stone tool. The materials involved in the production of tools tend to follow structured manufacturing patterns of change. This means two things: first, variation in the intermediate forms can have downstream effects on the final form of the functional tool; and second, similar forms can be produced by variant manufacturing routes—that is, the sequence of intermediary forms may vary yet land on the same final, functional morphology.

There are different ways that variation in the manufacturing sequences can be introduced without affecting the general morphology of the resulting tool form. First, two manufacturers may hold different mental representations of the morphological form that some intermediary steps should take, yet they may share similar mental representations of the final form the artifact should take, and thus produce such similar forms. Variation in the mental representations of the desired intermediary steps can be transmitted and serve as the basis for alternative technological traditions. Second, as the manufacture of a stone tool is a fragile process, accidents can happen. The different ways that these manufacturing errors can be solved are, in themselves, specialized techniques. However, different technological traditions—different in terms of the strategies they adopt to solve manufacturing mistakes—may not show up in the final morphological characters that typically are of interest in morphocentric models. Flake scars are studied by archeologists, but they typically are absent from morphocentric models. The same applies for the marks left by the use of manufacturing strategies to deal with the idiosyncrasies of the raw materials, such as strategies to correct knapping errors or to rejuvenate and reshape old tools.

The production of similar forms might in fact go through divergent manufacturing routes. Variation in the intermediate forms found in the archeological record may not only serve to show that two similar forms were produced by different manufacturing techniques—thus explicitly showing that the two technological traditions in fact diverge in their manufacturing techniques—but also identify important commonalities in the production of different tool morphologies. In other words, examining the intermediate forms under production can allow us to observe convergence and homologies not only at the level of the final morphological form of tools but additionally at the level of their production techniques. In fact, two final forms may largely differ morphologically (according to the accumulated copying-error metric), yet share important similarities in their intermediate forms and production techniques.

## Impossible Forms

Taking into account the manufacturing techniques also allows the study of forms that are not found. The manufacturing techniques available to prehistoric tool makers also delimited the boundaries between possible tool forms, regardless of whether they are actually observed in the record, and impossible forms (chapter 2, this volume). By possible forms, I mean those shapes that could be produced through the use of prehistoric knapping techniques, and by impossible forms those that could not. Consider the trilobate arrowhead, defined by Delrue (2007: 239) as "an arrowhead that has three wings or blades that are usually placed at equal angles (i.e., c. 120°) around the imaginary longitudinal axis extending from the centre of the socket or tang." As far as I could find, there are no stone-based trilobate arrowheads. In contrast, ivory, antler-based, and metal trilobate arrowheads have

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been found (Delrue 2007). This absence is surprising at first, given the functional advantage of the trilobate arrowheads over two-bladed (bifacial) ones:

> From an archer's point of view trilobate arrowheads are generally more accurate than flat, two-bladed ones. Arrowhead blades act as aerodynamic surfaces, and two-bladed heads are larger and more easily affected by crosswinds than trilobate ones with the same mass. The use of more than two wings (three or four) increases the weight and stabilises the flight of the arrow, two good reasons to use multi-winged arrows. (Delrue 2007: 245)

If Delrue's functional account is correct, then the reason why stone arrowheads were limited to the bilobate form cannot be stated in terms of functional constraints. Trilobate arrowheads have proved to have important functional advantages over bilobate ones, so it is surprising that the trilobate morphology was not exploited to produce stone arrowheads. The morphocentric model can explain this absence only by claiming that it is a historical accident no arrowhead tradition evolved a trilobate shape. However, the most plausible reason for the absence of lithic trilobate arrowheads is simply that one cannot produce such a shape by traditional knapping techniques. This has to do with the constraints imposed by the conchoidal fracturation process exploited by traditional flintknapping techniques. When a knapper produces such fractures on a core through percussion or pressure, the fissures travel roughly parallel to the surface of the core until they reach one of the core's surfaces. Knapping trilobate arrowheads would necessitate that fractures stop somewhere halfway through the core and then come back toward the hammered platform's surface, which contradicts the physical nature of the fracturing process.

## Theoretical Technospace

Here I draw on some of my previous work (e.g., Charbonneau 2015a, 2015b, 2016) and that of others (e.g., Mesoudi and O'Brien 2008c) to develop a basic framework for an evolutionary model of technical change—that is, a model of the evolution of hierarchically structured techniques involved in the production of tools. Although I am interested mainly in stone-tool manufacturing techniques and their impact on convergent evolution, the model can readily be extended to techniques involved in the production and evolution of other kinds of tools and cultural material products (e.g., pottery, adhesives, clothing, and buildings) and even to culturally transmitted structured behaviors that do not produce material outcomes (e.g., dance routines, rituals, and, arguably, language). The specific formal framework I adopt is directly inspired by *models of the morphogenesis of form*, or *theoretical developmental morphospaces* (McGhee 2007; chapter 2, this volume). My objective is to offer conceptual and formal tools to examine the different mapping relationships between the evolution of manufacturing techniques and their effects on the evolution of stone tools. The framework offers the additional benefit of allowing straightforward representation of technical constraints and, for the present discussion, of different levels of technological convergence and homology.

## Building a Theoretical Technospace

A theoretical technospace is the technique-centered analog of tool morphospace. However, instead of defining the dimensions of the space by the values of quantitative morphological characters that stone tools possess, the dimensions are defined by the different variant states that their manufacturing techniques can take. This implies that we need to first define what a technique consists of and how techniques can vary. From these, I derive a formal representation of technical variation—that is, the technospace proper. The technospace is intended to map all imaginable techniques, possible and impossible. This contrast with *empirical spaces*, which are defined by the range and diversity of observed stone-tool variants. Not only are empirical spaces limited to observed forms, but they need to be continuously redrawn as novel variants are discovered (McGhee 1999).

## Techniques as Hierarchically Structured Behaviors

For our current purpose, a technique consists of the specific recipe of decisions and actions as it is enacted in the production of a stone tool (Mesoudi and O'Brien 2008c). Tools are not produced merely by imagining them. A tool manufacturer needs to effectively engage body and mind into actions and deal with materials (and generally other tools) in order to produce a desired final product. A proper understanding of the evolution of techniques must give a central role to these factors (Charbonneau 2015a, 2016).

The hierarchical structure of techniques can be decomposed into assemblies of actions serving intermediary subgoals, each of which must be satisfactorily completed in order for the manufacturer to successfully produce the intended end-product form. These subgoals represent cognitive decisions of how to proceed and whether a specific intermediary manufacturing step has been properly achieved and what to do next. Subgoals can be nested under higher-level subgoals, with the whole structure ultimately resulting in the total hierarchical structure of decision-and-action assemblies that characterize the technique. The main goal of a technique is to produce the intended tool form. All lower-level subgoals are means to satisfy this master goal. The hierarchical structures of techniques are thus functional structures (Charbonneau 2016), which are typically depicted as tree diagrams (figure 5.1).

An important perk of adopting a concept of technique that is hierarchically structured is that it allows us to identify the different kinds of technical variation and thus metrics of evolutionary distances between technical variants, while at the same time allowing us to systematically map technical variation onto artifact morphological variation. We can already identify two main types of differences characterizing technical variation: variation at the level of the actions and variation at the level of the decision nodes, what I refer to as action-level variation and hierarchy-level variation, respectively (Charbonneau 2015b).

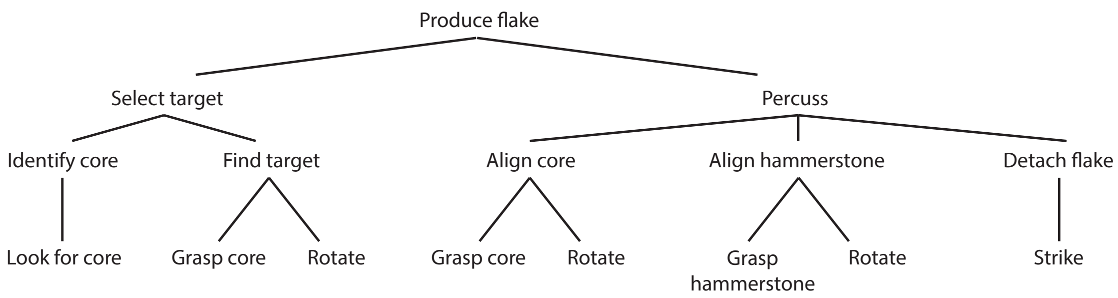


**Figure 5.1**
The hierarchical structure of the basic flaking unit (after Stout 2011).

## Action-Level Variation

Specific actions recruited in the production of a tool serve as the atomic units of technical variation. Actions can vary in two ways. First, they can vary in a discrete manner. A specific action can be replaced by another kind of action (e.g., replacing the grasping of a hammerstone by the pushing away of the hammerstone), or specific actions can be added or subtracted from a technique. Alternatively, actions can vary "internally," through an alteration of the specific value or state that the action takes (e.g., percussing a hammerstone at a 45-degree rather than a 60-degree incidence angle). Between two otherwise identical techniques, both types of action-level variations consist in the difference of at least one of the action units of the two techniques. Different mechanisms can produce these variations. Errors creeping in the imitation of a string of actions or of a specific action assembly can serve as an instance of action-level modification process, as one action could be misinterpreted for another (e.g., hit hammerstone on core at 45 degrees of incidence instead of 50 degrees). Alternatively, a specific action could be intentionally modified.

## Hierarchy-Level Variation

Whereas in the case of action-level variation, two techniques differ only in terms of their specific sequence of actions, hierarchy-level differences are set at the level of the decision structure of the techniques. In such cases, not only would the hierarchical structure of the techniques differ, but so would the sequence of the subservient actions. Hierarchy-level modification mechanisms alter subassemblies of a technique's structure. Subassemblies thus can be added, subtracted, concatenated under a new node, or even reshuffled. Two techniques can even be combined together to produce a novel technique (Charbonneau 2016). In all, mechanisms for hierarchy-level modification are those capable of modifying an existing technique by altering it at the level of its decision subassemblies, including its master goal.

## Theoretical Technospace Defined

Based on these considerations, we can define a theoretical technospace as the set of all imaginable techniques—that is, all techniques that vary either at the level of their sequence of actions, at the level of their hierarchical structure, or both. Having specified the different kinds of transformation that techniques can undergo, we can construct an abstract space by which all techniques have as neighbors another technique that can be obtained through the operation of any one modification mechanism. In a theoretical technospace, each coordinate point represents a different technique variant, varying either by its precise sequence of actions, by its decision structure, or both. A population undergoing technical evolution can then be represented by a cloud of points exploring the technospace, with each particle of the cloud representing a single individual located at the coordinate of the technical variant he or she possesses. A population moves through technospace by modifying its existing techniques through either action-level or hierarchy-level modification processes.

## Technical Constraints

Technical constraints were defined above as constraints imposed on the morphological evolution of tools by the specific set of techniques used for their production. We saw that certain tool forms were possible, in that they could be produced by a given set of techniques (e.g., bilobate arrowheads through prehistoric knapping techniques), whereas others were not (e.g., trilobate arrowheads through the same manufacturing techniques). Theoretical technospaces allow us to represent these constraints as boundaries delimiting the space of possible and impossible tool morphologies, given a specific set of manufacturing techniques. However, as many tool forms can be produced by different techniques, and as different techniques can produce different forms, it is simpler to represent technical constraints on tool forms directly in a technospace. Technical constraints on tool form then become functional constraints on technical variation, where a functional technique is understood as one that can effectively produce its intended, final tool form, as defined by its master goal.

Among all conceivable manufacturing techniques, only some will prove capable of producing the tool form they were intended to produce. By producing a functional form, I mean that a technique with a specific structure is capable of being successfully enacted, such that a manufacturer can go through each step of the technique by satisfying all of its subgoals; that the technique has a clear, recognizable end result; and that the technique, when enacted properly, satisfies its master goal. Dysfunctional techniques, then, are those that fail to satisfy any one of those three conditions. Moreover, we can assume that dysfunctional techniques—those that fail to produce an intended result—will typically fail to be socially transmitted to the next generation, as they offer no functional end result to those enacting its recipe. This is analogous to cases in which a specific developmental regime of an organism leads to an unviable or sterile form (chapter 2, this volume). Consequently, regions of technospace inhabited by dysfunctional techniques of this sort will remain generally empty, as any venture into the dysfunctional regions of technospace will fail to perpetuate itself. For instance, using a stone to produce hard-hammer percussion on the edges of a brittle material (e.g., chert) in order to shape a handaxe is a functional technique. In contrast, trying to shape a similar handaxe but hitting a face instead of an edge will fail to produce conchoidal fractures on the core and will likely result in breakage. In technospace, the former technique will be located inside the boundaries of functional techniques, and the latter will fall outside. By examining which techniques are capable of producing their intended end results and which ones do not, and by identifying the factors involved in shaping the boundaries of these constraints (cognitive, bodily, instrumental, and/or material factors), we can then map the set of techniques that are functionally realizable and those that lead to dysfunctional results.

## Mapping Technological Variation onto Morphological Variation

### Final Forms

By mapping a specific technical variant onto the material results a technique produces when successfully enacted, we can systematically map technological variation onto possible tool forms. The same kind of reasoning allows us to experimentally examine how varying a technique will effect change on the intended end result. This is what replicative studies of stones tools have been investigating, with a caveat. The caveat is that actualistic studies typically start their investigation with existing tool forms and then reverse-engineer the forms into the sets of techniques that could have produced them (e.g., Crabtree 1966, Pelegrin 2012). The investigation of theoretical technospaces allows us instead to take as a basis a specific technique and examine which forms it can produce, if any. In fact, existing research does just that, not by taking techniques as a basis of study, but rather by examining the effects of varying specific key factors in the realization of manufacturing techniques (e.g., Braun, Plummer, Ferraro, Ditchfield, and Bishop 2009; Dibble and Pelcin 1995; Eren, Lycett, Roos, and Sampson 2011; Eren, Patten, O'Brien, and Meltzer 2014; Magnani, Rezek, Lin, Chan, and Dibble 2014). By combining the use of theoretical technospaces and actualistic studies, we can map variation in technical behaviors with the variation observed in the archeological record.

### Intermediate Forms

The same logic applies to the study of intermediary and retouched forms. The specific forms of the intermediary products can be located in specific regions of morphospace, just as final forms are. However, instead of mapping the final form with the fully enacted technique, we can map a partially enacted technique to the intermediary form it produces. The same goes with retouched forms, but with completely enacted techniques plus rejuvenation steps. The technospace model explicitly represents the process of manufacture at each step of its realization, including the morphology of the untouched core that will be processed. Together with the mapping of technological variation and morphological variation, we can represent the specific morphological trajectory that a tool under production takes. That tool can thus be represented by a trajectory of intermediary forms in morphospace as its manufacture goes on, concluding on the final morphology of the tool. In addition, the regions of morphospace where intermediary forms tend to agglomerate may differ from those regions where final forms find themselves. Technospaces allow us to examine analytically which regions of morphospace are typically represented by intermediary forms.

## Convergence in Technospace and Beyond

Here I discuss two types of convergent evolution—accessibility convergence and deep convergence—that are set at the level of the manufacturing techniques rather than at the level of a tool's shape.

### Accessibility Convergence

Accessibility convergence refers to the manner in which manufacturing techniques and variation in technospace relate to the morphology of stone tools and its variation. Two similar tool forms can be produced by different manufacturing techniques. We can refer to such situations as a case of *accessibility convergence*—situations where two different techniques share important similarities in the regions of tool morphospace onto which they map. The techniques themselves need not be similar to any degree; they need only to be able to produce (or access) similar tool forms (figure 5.2). Two techniques can thus be understood as accessibility convergent when they share overlapping regions in morphospace.

Consider the following example. Several Maya eccentrics have "holey" shapes: they are flaked, round bifaces with a hole in the middle, similar to a doughnut (e.g., Joyce 1932). Two alternative explanations for the invention of these eccentrics involve taking into account changes in manufacturing techniques. One candidate technique consists of grinding a nonhomogeneous core with an exploitable nonbrittle inclusion (e.g., soft limestone [G. Iannone 1993, personal communication]). Alternatively, one could produce holes in a homogeneous core by using a lapidary drilling technique involving, for instance, a bow drill. The latter technique may have been borrowed from the use of similar techniques used to drill shells and beads and adapted to lithic materials. For this technique, one needs to find the right kind of material to produce the eccentrics. For these alternative techniques, developing the knowledge required to identify promising cores and mastering the perforating skill both depend on the acquisition of novel technical knowledge and expertise.

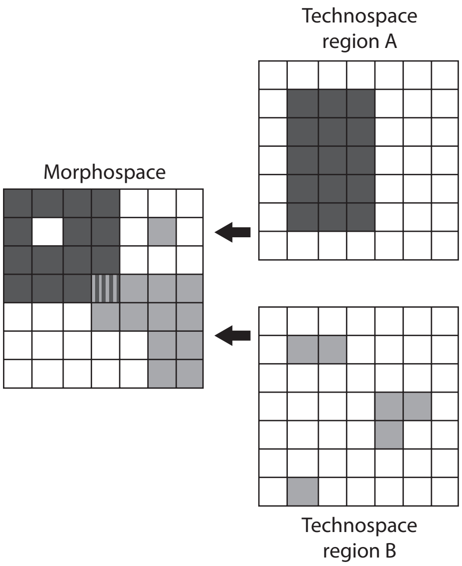


**Figure 5.2**
Diagram showing two techniques located in different parts of technospace (regions A and B). Techniques found in the two regions may nevertheless map onto tool forms that are close to one another in morphospace, and they can even overlap. The forms producible by the techniques in region A are represented by dotted squares, and those by the techniques in region B by hatched lines squares. Blank squares in technospace represent technical variants that do not produce any functional results. Gray squares in morphospace are forms that cannot be produced by any of the examined techniques. The black square in morphospace represents a tool form that the techniques in both regions can produce. Assuming an ecological advantage to forms situated inside the box with heavy lines, we should expect convergent evolution in form.

Consider that two different technological traditions could independently invent perforating techniques, but different ones. One tradition may innovate by discovering that the grinding of heterogeneous cores can lead to producing a hole in the core, whereas another one discovers that drilling techniques used to perforate shells can be adapted to lithic materials. Whether or not the two traditions in fact produce similar eccentric forms, they share the potential of stumbling upon similar shapes. Thus, the independent invention of similarly shaped eccentrics could be expected (and would be more probable) simply because the two techniques share the same potential of producible forms. In terms of technospace, the regions of morphospace that both techniques can access overlap to a large degree (Charbonneau 2015a). Using technospaces to identify the technical constraints imposed by different manufacturing techniques also allows us to identify which regions of morphospace both techniques can access, and on which region of morphospace they can converge.

## Deep Convergence

Paying attention to the evolution of manufacturing techniques also allows us to distinguish between homology and convergence at the level of the tools' morphologies and homologies and convergences at the level of manufacturing techniques. Two technical traditions can be said to be deeply homologous if they share a manufacturing technique that they inherited from a common ancestor that also possessed that same technique. In contrast, two traditions that have similar manufacturing techniques yet did not inherit them from a common ancestor will be deeply convergent.

In the case of "holey" Mayan eccentrics, should two traditions have independently stumbled upon the same technique to perforate the cores (e.g., by independently discovering that grinding away an inclusion in the core can produce a hole), we would have a case of deep convergence. In contrast, should the two traditions have inherited the same technique from a common ancestor, we would be in a situation of deep homology. Another interesting scenario would be that two traditions inherited from a common ancestor the same bow-drilling techniques for beads and shells, but then each tradition independently transferred that technique to the modification of stone materials (chapter 2, this volume).

Of course, being capable of producing a hole need not lead to similar shapes in manufactured tools. Neither deep convergence nor deep homology—nor deep parallel evolution, for that matter—depends on the morphological similarity of the produced tools. Indeed, this is because of the possible disassociation between technical and morphological traditions. The information concerning a tool form can be transmitted independently of the specific technique used to produce that form. In other words, morphological lineages need not be congruent with technological lineages.

## Conclusion

It is not enough to recognize whether morphological similarity is the product of convergence or of homology. One also needs to explain why convergence occurred. I have argued that morphocentric models, the main approach to explaining the process of technological evolution, are not designed to deal with some key questions regarding the archeological record and the evolution of technological traditions. I showed the importance of addressing how manufacturing techniques constrain both the production and the evolution of tool form. Doing so exposes how the issue of technological convergence is in fact a multilayered process, one in which homologies and analogies are not restricted to similarities in form but also to similarities in the techniques used. I have developed the notion of deep convergence to deal with cases of independently invented yet similar techniques, and that of accessibility convergence to deal with cases of different techniques capable of producing similar forms. Finally, I have offered a basic framework to operationalize the study of technical variation and technical evolution and their impact on the archeological record.

Further work is required, if only because the framework can prove its usefulness only by being operationalized and effectively used to address specific empirical problems.

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