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The Topography of Historical Contingency

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Abstract

Starting with Ben-Menahem's definition of historical contingency as sensitivity to variations in initial conditions, we suggest that historical events and processes can be thought of as forming a complex landscape of contingency and necessity. We suggest three different ways of extending and elaborating Ben-Menahem's concepts: (1) By supplementing them with a notion of historical disturbance; (2) by pointing out that contingency and necessity are subject to scaling effects; (3) by showing how degrees of contingency/necessity can change over time. We also argue that further development of Sterelny's notion of conditional inevitability leads to our conclusion that the topography of historical contingency is something that can change over time.

Keywords

contingency, necessity, scale

Introduction

In this paper, we argue that questions about historical contingency and necessity are more complicated than other authors have realized, because the degree of contingency of historical processes is itself something that can change over time. We use metaphors drawn from physical geography to help make this point clear.

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Ben-Menahem suggests that 'contingency' and 'necessity' have special meanings in historical contexts.[1] She suggests that historical contingency increases in direct proportion to sensitivity to initial conditions. A process exhibits historical necessity, or inevitability, when similar outcomes would result from a wide variety of starting conditions. In the limiting case, this means that all possible causal pathways would lead to the same final outcome. Historical processes are contingent when small changes to the initial conditions would make a big difference to the downstream outcome. Ben-Menahem extends these ideas to develop an increasingly sophisticated view of necessity and contingency.[2] For example, she argues that historical contingency and necessity are description-sensitive. Whether two outcomes count as the same may depend on how fine-grained a description of those outcomes we decide to use. She carefully distinguishes historical contingency from chance, and necessity from teleology. She also suggests that the notion of historical contingency is especially useful for understanding human agency in history. And we can do that without getting caught up in the intricacies of the free will debate. The rough idea is that when historical outcomes are necessary or inevitable, those outcomes are insensitive to things that human actors do. But when historical processes are highly contingent, small actions can make a big difference to later results. Thus, Ben-Menahem has developed quite a rich account of historical contingency and necessity. In this paper, we begin with her account and take it one step further by arguing that degrees of contingency and necessity can change with the passing of time. The topography of historical contingency is itself something that can evolve.

It's important to note that Ben-Menahem's sense of 'contingency' is not the only one out there. For example, in a recent discussion of Gould's work, John Beatty argues that Gould thinks of contingency in two different ways.[3] On the one hand, there is what Beatty calls a *causal dependence* sense of contingency, which is roughly equivalent to Ben-Menahem's notion of sensitivity to initial conditions. Beatty also argues that Gould sometimes thinks of contingency as involving unpredictability of later outcomes from earlier conditions – or better, the *causal insufficiency* of earlier states of the system

[1] Y. Ben-Menahem, "Historical contingency". *Ratio*, 10 (1997), 99–107.

[2] Y. Ben-Menahem, "Historical necessity and contingency" in A. Tucker (ed.), *A Companion to the Philosophy of History and Histrography* (Oxford: Wiley-Blackwell, 2009), 120–130.

[3] J. Beatty, "Replaying life's tape", *Journal of Philosophy*, 103, (2006), 336–362.

for later outcomes.[4] For purposes of this paper, though, we restrict our focus to the notion of contingency as sensitivity to initial conditions.

This understanding of historical contingency as sensitivity to initial conditions (and of necessity as insensitivity to initial conditions) can help to clarify some issues in historical science. For example, in paleobiology, Gould has stressed that evolutionary processes are highly contingent.[5] Ben-Menahem argues that her sense of contingency is roughly what Gould had in mind.[6] As a counterpoint to Gould, Simon Conway Morris has recently argued that certain evolutionary outcomes are highly (historically) necessary, and that evolutionary processes tend to converge on those outcomes no matter what the starting points.[7]

In addition, Ben-Menahem's notion of historical necessity is closely related to the notion of underdetermination. Consider the following simple illustration from Sober.[8] A person standing on the rim of a giant bowl drops a ball down the side. The ball will eventually come to rest at the center of the bowl, no matter where along the rim it was released. The outcome is highly insensitive to variations in the initial conditions – that is, to variations in the point of release. One could say that hypotheses about the point of released are underdetermined for a later observer who only sees the ball resting at the bottom. Thus, Ben-Menahem's way of understanding contingency and necessity also has an epistemological dimension.

Figure 1 illustrates Ben-Menahem's notion of historical contingency. Let IC_1, IC_2, IC_3, . . . IC_n be the possible initial conditions that may obtain at time t_0. And let E_1, E_2, . . . E_n be possible effects or states of the system that obtain at some later time. Suppose that some subset of the initial conditions, IC_{E2}, all lead to outcome E_2. That would mean that there is some *in*sensitivity to initial conditions. For effect E_2, it is not possible to isolate or define the initial conditions that produced it other than to specify the broad group of initial conditions IC_{E2}. The operation of the system leaves no traces that can

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4) For further discussion see D. Turner "Gould's relay revisited", *Biology and Philosophy*, 26 (2010): 65-79.

5) S.J. Gould, *Wonderful Life: The Burgess Shale and the Nature of History* (New York: W.W. Norton, 1989).

6) Ben-Menahem, "Historical contingency", 107.

7) S. Conway Morris, *Life's Solution: Inevitable Humans in a Lonely Universe* (Cambridge: Cambridge University Press, 2003).

8) E. Sober, *Reconstructing the Past* (Cambridge, Mass.:MIT Press, 1988) cf. in Ben-Menahem, Historical necessity and contingency, 130.

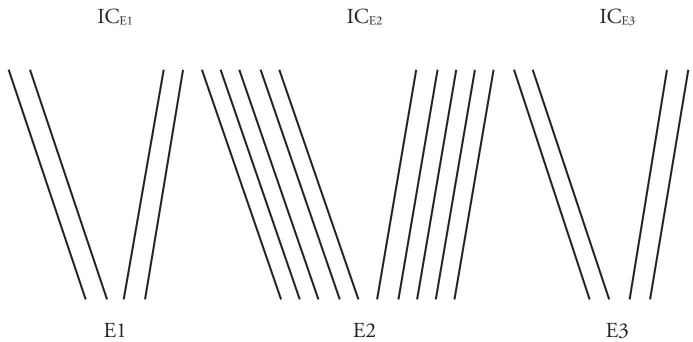

Fig. 1: Illustration of catchment concept and its representation of pathways of necessity and contingency.

distinguish between the initial states within this group. Next, suppose that there are two smaller subsets of initial conditions (IC_{E1} and IC_{E3}) that would lead to two different downstream effects, E_1 and E_3, respectively. What we just said about initial conditions IC_{E2} also applies to these further sets of initial conditions, but with one difference: because these sets of initial conditions (IC_{E1} and IC_{E3}) are smaller, it turns out that effects E_1 and E_3 preserve more information about the earlier states of the system. If effects E_1 and E_3 obtain, then there was a narrower set of initial states from which the system might have evolved. In Ben-Menahem's terms, there is greater sensitivity to initial conditions for E_1 and E_3 then there is for E_2.

Finally, Ben-Menahem's proposal may help to shed some light on the nature of historical explanation. She herself, argues that historical narrative explanations can achieve different effects by emphasizing the contingency vs. the inevitability of outcomes.[9] In a different context, Sterelny has distinguished between robust-process explanations and actual sequence explanations.[10] Robust-process explanations basically show that a certain outcome was going to occur no matter what initial conditions obtained (within a given range of possible initial conditions). Sterelny uses the term "robust" to capture the idea of insensitivity to initial conditions, which is precisely what Ben-Menahem means by 'necessary.'

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9) Ben-Menahem, "Historical necessity and contingency", 127–128.

10) K. Sterelny, "Explanatory pluralism in evolutionary biology", *Biology and Philosophy*, 11 (1996), 193–214.

This paper extends and explores this understanding of necessity and contingency. We use metaphors borrowed from physical geography, especially the metaphor of a catchment, to help think about historical contingency and necessity. We show how Ben-Menahem's proposal can be extended and enriched in ways that go beyond her initial discussion. First, we introduce and clarify the notion of historical disturbance. Next, we proceed to show how historical contingency and necessity, in her sense, are subject to scaling effects. This is related to the point that she herself has made about the description-sensitivity of contingency and necessity, though, as we will show, the issues are somewhat different. Most significantly, we use the catchment metaphor to show how degrees of contingency and necessity can change as processes unfold over time. Finally, we show how these ideas are related to some others in the conceptual neighborhood, such as Kaufmann's concept of the "adjacent possible"[11] and Sterelny's notion of "conditional inevitability."[12]

The Concept of External Disturbance

Our first constructive suggestion is that just as systems can differ with respect to their degree of sensitivity to initial conditions (that is, with respect to historical contingency), they can also differ with respect to their degree of sensitivity to external disturbance. In some cases, a disturbance – even a strong one – might make little or no difference to the later outcome. In such cases, information about the disturbance will fail to be preserved in the later state of the system. It might be tempting to restrict the use of the term 'disturbance' to those external influences that do in fact make some difference to the outcomes of historical processes. However, we will use the term 'disturbance' to refer to any influences that originate outside the system in question, including those that do not affect downstream outcomes. This will make it possible to talk meaningfully about the limiting case of a system that is completely insensitive to external disturbance.

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[11] S.A. Kaufmann, *Investigations* (Oxford: Oxford University Press, 2000) and in S. Kaufmann, "Towards a post reductionist science: The open universe", ArXiv:0907.2492v1 [physics.hist-ph] 15 Jul 2009.

[12] K. Sterelny, "Another view of life", *Studies in History and Philosophy of Biology and Biomedical Sciences*, 36, (2005), 585–593.

Consider a simple model system, such as Sober's example of a ball rolling down the side of a bowl. One can easily imagine disturbances to the system, from a gust of wind that slightly alters the ball's course to a child who grabs the ball and runs off with it. What makes these disturbances is merely the fact that they originate outside the system as we originally described it. Clearly, some disturbances, but not others, will make a difference to the end state of the system. One way to make sense of the idea that a system can be more or less sensitive to a disturbance is to hold the disturbance (e.g. the gust of wind) constant and ask whether that disturbance would make a difference to the outcome in one system as compared with another. (In other words: hold the disturbance constant and vary the system). Another way to make sense of the idea is to focus on a single system and ask how many different kinds of disturbances could make a difference to the historical outcomes in that system. (In other words: hold the system constant and vary the disturbances.) In principle, there could be historical processes that are highly sensitive to disturbances but mostly insensitive to changes in initial conditions, and vice versa.

Ultimately, the difference between sensitivity to initial conditions and sensitivity to disturbance is a matter of how one draws the boundaries of the system in question. In the toy example above, if we count the wind as part of the system, then changes in the direction and speed of the wind will simply count as changes in the initial conditions, and if the wind makes any difference to the outcome of the process, then that will be a case of contingency as understood by Ben-Menahem. Our point is just that outcomes can be sensitive to external influences as well as to changes in prior states of the system. Whether something counts as an external influence, or as part of the prior state of the system itself, depends largely on how we draw the boundaries of the system. And how we do *that* is presumably just a matter of our theoretical interests. This amplifies Ben-Menahem's previous point about the description-sensitivity of historical contingency. Whether a system exhibits sensitivity to initial conditions vs. sensitivity to disturbance is a matter of how much we include in the description of the system. In the extreme case, we might think of the entire universe as a system. In that extreme case, nothing could disturb the system from the outside – except, perhaps, supernatural interventions – and sensitivity to disturbance would not be a live issue.

At this point, we might want to pause to consider a terminological issue. Should we say that sensitivity to initial conditions and sensitivity to external disturbance are both species of historical contingency? Or should we reserve the term 'contingency' for the former? In what follows, we will continue to use the term 'contingency' in a somewhat narrower sense, to refer to sensitivity to initial conditions. But we are aware that some do use the term 'contingency' to include sensitivity to external disturbance. And we acknowledge that the distinction between the two is not a sharp one, since it depends on our own decisions about how to draw the boundaries of the systems we are interested in.

There are cases in historical natural science where this distinction between sensitivity to initial conditions and sensitivity to disturbance might matter. For example, one might think that if an asteroid (or asteroids) had not collided with the earth around 65 million years ago, then subsequent evolutionary history would have looked very different. This would presumably be an example in which a system is sensitive to external disturbance, rather than to changes in initial conditions. This sensitivity to external disturbance may be one thing that Stephen Jay Gould means by 'contingency', in addition to the two senses of 'contingency' that Beatty finds in Gould's work.[13]

The Fine Topography

Let's briefly revisit Figure 1. Although the pathways (or historical processes going form possible initial conditions to possible outcomes) in Figure 1 are represented as discrete lines, it may be more appropriate to think of an indefinitely large number of pathways in each bundle. Taken together, these pathways define a surface that sweeps toward an inevitable endpoint. The image of a funnel, like Sober's bowl, is a useful device for thinking about this. The top edge represents the range of initial conditions, while the hole in the center represents the endpoint toward which anything in the funnel inevitably flows. At the moment, however, the implicit assumption is that the sides of the funnel are smooth. But this assumption is oversimplified, as we will soon see.

Figure 1 represents only the gross topography of historical contingency. Focusing in on the tricky boundary between groups (Figure 2), the importance of the fine topographic detail of historical contingency becomes

[13] Beatty, "Replaying life's tape", 362.

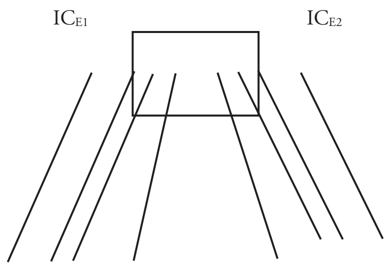

Fig. 2: Close-up of 'problematic' zone where measurement accuracy is less than difference between catchment divides.

clearer. At some point between groups IC_{E1} and IC_{E2}, there will be a set of initial conditions that are extremely sensitive to disturbances. If undisturbed, these initial conditions will result in E_2, but a slight disturbance will alter their pathway to that of E_1. Notice that in the figure, the pathways at the edge of each bundle are at a more acute angle. This represents the more sensitive nature of these pathways. They do not dip as steeply towards either E_1 or E_2, but instead are nearly vertical, implying that the historical processes may easily be diverted (by external disturbances) from their otherwise inevitable endpoints. The idea here is that even when different initial conditions will all generally lead to the same outcome – that is, the conditions in set IC_{E2} all lead to effect E_2 – some of those initial conditions might well leave the system more sensitive to external disturbance. A system's degree of sensitivity to external disturbance could itself be something that is sensitive to variations in the initial conditions of the system. There might be cases in which we could say: If things had been very different in the past, then the subsequent historical processes would have been more/ less sensitive to external disturbances. This way of combining the notions of sensitivity to initial conditions and sensitivity to external disturbance represents an important extension of Ben-Menahem's ideas. We propose to use the term *tipping point conditions* to refer to a set of initial conditions that would, barring external disturbance, lead to a given outcome (here, E_1), but which also send the system down a historical pathway that is highly sensitive to disturbance, where even a small disturbance would result in outcome E_2). Using the topographic metaphor, we might say that these tipping point conditions define the edges or ridges of the topography of historical contingency. Pathways in these locations are highly sensitive, at least initially in their development, to slight disturbances, as these will shift their end point with relatively little "effort." Moreover, the sensitivity to disturbance can diminish over time. As these pathways get closer to their endpoint, it may take a greater disturbance to alter their trajectory.

There is a limit to how accurately initial conditions can be stated or measured. The box covering the pathways in Figure 2 represents the measurement accuracy of a particular method of distinguishing between initial conditions. The box covers a great number of pathways. This is intended to signify the fact that our existing means of measuring or identifying initial conditions may lead us to count many (slightly different) possible initial conditions as the same. This means, in turn, that which set of initial conditions serves as the "tipping point" between the two possible outcomes (E_1 and E_2, in the above example) will depend, in part, on what system of measurement we use, or what level of description we adopt.

This last point is closely related to Ben-Menahem's observation that historical contingency and necessity are description-sensitive.[14] It is possible to give finer-grained vs. coarser-grained descriptions of both initial conditions and outcomes. In many cases, the degree of contingency of the historical processes will depend on the level of description of the initial conditions and/or the outcomes. To give one example of this, in his review of Conway Morris's book, *Life's Solution*,[15] Kim Sterelny points out that there is a problem with some of Conway Morris's illustrations of convergent evolution.[16] Consider human agriculture vs. the "agriculture" practiced by some species of ants. Is this an example in which the same trait has evolved twice (or in which evolution has led to the same outcome from different starting conditions)? That depends. If we describe the trait in a very coarse-grained way, as Conway Morris does, this looks like a case of evolutionary convergence. However, it we give a finer-grained description, and agriculture and human agriculture look like different traits.

14) Ben-Menahem, "Historical necessity and contingency", 124–125.
15) Conway Morris, *Life's Solution: Inevitable Humans in a Lonely Universe*.
16) Sterelny, "Another view of life", 593.

Description Sensitivity *vs.* Scaling Effects

Historical contingency and necessity are description sensitive because what counts as the same initial conditions and/or outcomes can be sensitive to how those conditions and/or outcomes are described. Contingency and necessity are also subject to scaling effects, and this is a slightly different issue than description sensitivity. To borrow an example from Ben-Menahem, it may be largely inevitable that a general wins a battle with a particular strategy.[17] The general would still have won, using that strategy, if many other initial conditions had been different. When we look at the battle at such a large scale, or from such a high-altitude perspective, there seems to be very little contingency in the outcome. However, if we were to study the battle on a smaller scale, we might find a great deal of historical contingency. For an individual soldier, the slightest change in earlier conditions could make all the difference between death and survival. In the aftermath of the battle, the general might think: Our side would have won, even if earlier conditions had been very different. But the individual soldier, at the smaller scale, might think: if conditions had been just a bit different, I could well have died. The victory was largely inevitable, though this particular soldier's survival was contingent. Yet the soldier's survival is, in some sense, a part of the larger victory. We are talking about the same historical events in both cases, while focusing on different temporal and spatial scales.

We want to emphasize that this scale-dependence is not the same phenomenon as description sensitivity. Description sensitivity has more to do with whether two possible outcomes (or possible initial conditions) count as the same. For example, it might be that victory for one side was inevitable. But 'victory' is a fairly coarse-grained term. We might distinguish different types of victories, and at this finer-grained level of description, it might turn out that a victory-of-a-certain-type was not inevitable. Yet even as we shift from coarser- to finer-grained descriptions, we are still operating at the same spatial and temporal scale – namely, at the level of the battle as a whole.

In battles and other historical processes, different degrees of contingency and necessity, as well as different degrees of sensitivity to disturbance, can be identified at different scales and different levels of descriptive

[17] Ben-Menahem, Historical contingency, 107.

resolution. We just described a case involving contingency at smaller scales but historical inevitability at larger scales. But the reverse can also occur. It could turn out, for example, that a particular soldier's death in the battle is largely inevitable. That soldier dies under a great many variations of initial conditions. That could be true, for instance, if the soldier happens to be in a unit that gets called upon to make a hazardous attack – a unit that takes heavy casualties no matter how the rest of the battle goes. This lower-level historical inevitability is compatible with a high degree of contingency at larger scales. It is entirely possible that if conditions had been just a bit different – if the fog had burned off a few minutes earlier, or if the other side's reinforcements had arrived a few minutes later – the outcome of the battle as a whole would have been entirely different.

Thus far, we have extended Ben-Menahem's ideas in two ways: first, by distinguishing sensitivity to external disturbance from sensitivity to initial conditions, and second, by pointing out that historical contingency is scale-relative. In the next section, we go on to develop what we take to be the most important extension of her ideas.

The Catchment Metaphor

Although it may seem counterintuitive at first, we want to suggest that degrees of contingency and inevitability can change as events unfold. Earlier we suggested in passing that degree of sensitivity to external disturbance can increase or decrease with the passing of time. We think that the same might be true of historical contingency and necessity, and we propose to illustrate this by developing the topographic metaphor.

Imagine a system involving increasing inevitability: Initially, at the edge of each bundle of initial conditions, there is greater contingency and greater sensitivity to disturbance. As events unfold, pathway bundles become more deeply entrenched and increasingly interrelated. The ability of an individual act or event to move the individual or the pathway bundle towards a different outcome can diminish over time. This is analogous to the increasingly entrenched channels that result as one moves from the divides of a catchment towards the main channel.[18] Notice that a battle could be like

[18] For discussion in relation to landscape evolution see R. Inkpen and D. Petley, "Fitness spaces and their potential for visualizing change in the physical landscape", *Area*, 33, (2001), 242–251.

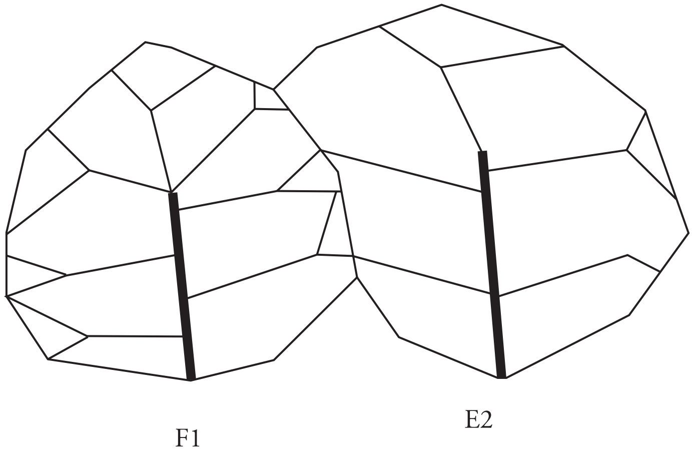

Fig. 3: Entrenchment of channel in network.

this. In the early stages, small events or differences could make a big difference to the outcome, but victory for one side might become more inevitable as events unfold.

At the base of a catchment is an entrenched channel that eventually flows out of the catchment at a single point (Figure 3). From any point in the catchment, it is a downhill trajectory to both the channel and the outflow point. Water that starts out (say, as precipitation) anywhere in the catchment will inevitably end up at the channel and the outflow point. A catchment is the topographical version of the funnel example that we used earlier. Wherever you start in the catchment, the final outcome or effect is always the same. In Figure 3, the lines represent the more deeply entrenched pathways. The pathway from any starting point (or initial condition) can be rapid or slow, depending on the detailed topography of the catchment. A rapid pathway across a steep slope will differ in character from a pathway across a shallower slope where there are numerous slope storage areas. There may also be entrenched sections of the catchment to which many pathways converge. These are represented in Figure 3 by thicker lines. Once the water is captured by one of these more entrenched channels, its path through the catchment is highly constrained. Outside of these channels, pathways can be more influenced by contingent events, although they still flow or move towards the final exit point. At the boundary between the catchments, where the initial conditions are what we earlier referred to as tipping point conditions, water could flow into either of two catchments. The slightest disturbance could make the difference between two outflow points. As the water descends the sides of a catchment, it becomes increasingly difficult to divert the water from its pathway toward the exit point.

In one sense, the degree of inevitability in the catchment system has not changed. It was always inevitable that the water would exit the catchment at a given point. But if we "zoom in" and focus on the finer topography – that is, if we focus on a smaller scale – it does seem that there is quite a lot of contingency in the upper portions of the catchment. Very small changes to the landscape in the upper portions would make a difference to the pathway that the water takes as it descends. But by the time we get to the bottom of the catchment system, small changes to the landscape will make far less difference to the water's pathway.

The catchment itself, however, is not a static entity. The topography of the catchment can change due to external disturbances or internal deformation (e.g., erosion). External shocks can alter the shape of the catchment; think of an earthquake that changes the course of a river. The pathways that water takes through a catchment can themselves alter the landscape. For example, when multiple pathways converge to form a single channel, the water can form valleys and gorges. In a catchment, the outcome is always, in a sense, inevitable: water always flows toward sea level. However, if we go with a slightly finer-grained description of the possible outcomes, it turns out that which outcome is inevitable can change over time. Consider the simple question of where a certain river meets the sea. During a certain historical period, it might be inevitable that water draining from a catchment exist to the sea at a certain location. But as the topography of the catchment evolves over time, the river might change course, and sea levels might rise or fall.

Consider next the nature of a river at its mouth. A simple single channel is not necessarily the end point of a river. Deltas, such as the Mississippi or the Niger, have an intricate and dynamic network of small channels that form the end of the river. These channels are relatively shallow and change their characteristics over time. Although the mouth of the river can be defined in general terms and is geographically constrained, the exit point for a specific channel can be spatially variable.

We might think of models such as Sober's ball rolling down the side of a bowl, or our own catchment imagery, as models of historical processes. These models highlight certain features of the historical processes that we are interested in – namely, their contingency and necessity, in Ben-Menahem's sense. But we can also readily imagine how the models might change over time. In fact, the topography of a catchment *does* change over time. As the topography of a catchment changes, so too will the historical contingencies and necessities associated with the water's passage through it. If we are right about this, then it might not be enough to ask how much contingency or necessity there is in historical processes. We might also want to investigate how the topography of historical contingency/necessity has changed over time.

Others have, of course, used the topographic metaphor as an aid to thinking about evolution. Wright used the idea of an adaptive or fitness landscape to visualize the fitness of different biological variations.[19] (One could focus either on genetic or phenotypic variations.) The horizontal dimension represents either genetic or phenotypic variability, while the vertical dimension represents fitness. A peak in the adaptive landscape represents a specific variant, or a cluster of variants, that would have a high degree of fitness relative to a given environment. Natural selection can be conceptualized as "pushing" populations up these fitness peaks. Many other theorists since Wright have used spatial metaphors for thinking about evolutionary change. Some have expanded the idea to include multidimensional landscapes.[20] Theoretical morphologists sometimes talk of morphospaces, or multidemnsional spaces in which each dimension represents variation with respect to some morphological trait.[21] One can then think of the evolution of a lineage as tracing a path through such a multidimen-

[19] S. Wright, "The roles of mutation, inbreeding, crossbreeding and selection in evolution" in *Proceedings of 6th International Congress on Genetics, Volume 1*, (1932) 356–366.

[20] S. Gavrilets, "Evolution and speciation in a hyperspace: the roles of neutrality, selection, mutation, and random drift" in J.P. Crutchfield and P. Schuster (eds.), *Evolutionary Dynamics: Exploring the Interplay of Selection, Accident, Neutrality, and Function* (Oxford: Oxford University Press, 2003), 135–162; S. Gavrilets and J. Gravener, "Percolation on the fitness hypercube and the evolution of reproductive isolation", *Journal of Theoretical Biology*, 184, (1997), 51–64.

[21] G.R. McGhee Jr., *The Geometry of Evolution: Adaptive Landscapes and Theoretical Morphospaces* (Cambridge: Cambridge University Press, 2007).

sional morphospace.[22] Our approach in this paper fits into this tradition of using spatial metaphors to think about historical change. What's new about our proposal is not the use of the landscape metaphor, but rather the use of it to help think about the degree of contingency/necessity in historical processes.

The catchment metaphor may have some other interesting applications. Consider, for example, the distinction between *parallel* and *convergent* evolution. Parallel evolution occurs when two closely related species evolve in similar ways in response to similar environmental pressures. Sterelny offers as one example of this the evolution of drought resistance in two species of eucalyptus trees.[23] He observes that "the space of evolutionary possibility for these sister species will itself be similar, for they largely share their morphology, physiology, and reproductive biology" (p. 588). If summers get drier, the two species will respond in similar ways. Convergent evolution, by contrast, occurs when distantly related lineages evolve similar adaptations over long periods of time spent in similar selective environments. The classic example is the evolution of winged flight in insects, pterosaurs, birds, and bats. Figure 4 is an illustration of parallel evolution. The two species occupy the same main channel but follow slightly different pathways within this constraining channel. Convergent evolution is illustrated by Figure 5, where a lineage crosses over into a new catchment at some point in its evolutionary history. Any species crossing over into this catchment will inevitably end up at the same morphological "place."

Finally, Stuart Kaufmann's notion of the adjacent possible also has some connection to questions about historical contingency and necessity. The catchment metaphor may help to illustrate those connections. The rough idea is that only some regions within a larger state space – namely the adjacent ones – are accessible from a given location in that space. One way to think about this is by contrasting a catchment with a delta. To begin with, imagine water flowing through a catchment toward an exit point. As the

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[22] K.J. Niklas, "Effects of hypothetical developmental barriers and abrupt environmental changes on adaptive walks in a computer-generated domain for early vascular land plants", *Palaeobiology*, 23, (1997), 63–76; K.J. Niklas, "Evolutionary walks through a land plant morphospace", *Journal of Experimental Botany*, 50, (1999), 39–52; K.J. Niklas, "Computer models of early plant evolution", *Annual Review of Earth and Planetary Sciences*, 32, (2004), 47–66.

[23] Sterelny, "Another view of life", 588.

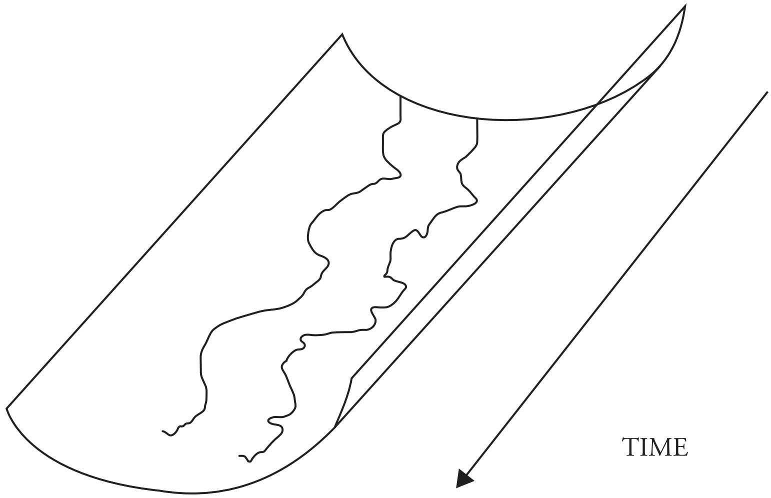

Fig. 4: Illustration of parallel evolution. Channel constrained by factors such as environment, morphology, physiology and reproductive biology.

water gets closer to the exit point, the regions of the catchment that it could still go on to occupy get smaller and smaller. By contrast, as the water flows into a delta, new possibilities seem to open up. It could go down any number of different channels, and follow any number of different routes to the sea. In the former case, the range of adjacent possibles gets smaller and smaller with the passing of time; in the latter case, the range of adjacent possibles seems to increase. Intuitively, historical necessity involves a decrease in the range of the adjacent possible states of a system; historical contingency is just the opposite.

Conditional Inevitability

Sterelny introduces a notion of conditional inevitability, which at first glance seems very close to our idea that degrees of contingency/inevitability can change over time. In response to Conway Morris's defense of evolutionary convergence, Sterelny argues that evolutionary history might be "conditionally robust," or conditionally convergent. The rough idea is that a certain evolutionary outcome might *become* inevitable at a certain point in evolutionary history. To give one example, Conway Morris seems to

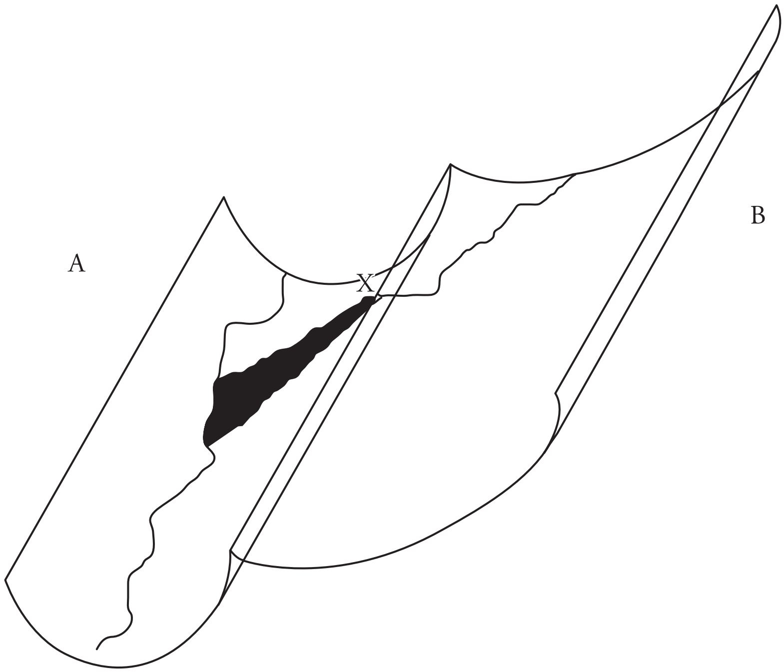

Fig. 5: Illustration of convergent evolution. Channel B crosses into channel A at X and the shaded area represented the potential pathways from X to the channel in catchment A for the species. Note the much lower divide for channel B implying that the species in that channel has developed into a section of the catchment where constraints on the future development of the species lessen. This process is analogous to river capture in drainage development.

think that the evolution of intelligence is in some sense inevitable. Given enough time, natural selection will eventually produce intelligence in different groups (e.g. primates, cetaceans, corvids). One possibility that he does not seriously consider is that this evolutionary outcome was not always inevitable, but that it only became inevitable at a certain point in evolutionary history – say with the evolution of the tetrapod body plan. Using Sterelny's language, we might say that the evolution of intelligence was conditionally inevitable, or inevitable given the evolution of the tetrapod body plan. This is very close to saying that the degree of contingency/

inevitability in evolution is itself something that can change over time. Sterelny is, in effect, saying that an outcome that is not inevitable to begin with can become so.

Indeed, Sterelny's notion of conditional inevitability is easily illustrated using the catchment metaphor. Think of a raft floating down a river, approaching a delta. Early on in the process, it is not a foregone conclusion that the raft will exit the river to the sea at a given point *p*, because the delta system presents it with numerous possible exits. But the raft's exiting at a certain point p might be conditionally inevitable. Given that the raft goes down a certain channel at a certain point in the process, there might be no other possible exit points left.

It's a little puzzling that Sterelny introduces the idea of conditional inevitability without also acknowledging the possibility of conditional contingency. It could well be that some outcomes become contingent only when certain points are reached in the historical process. Consider, by way of example, the fate of an endangered species. As long as the population remains above a certain size, the persistence of that species will remain fairly insensitive to changes in local conditions. An especially dry summer, or an unusual food scarcity will not drive the species to extinction. We might vary these and other local conditions and get the same outcome – the persistence of the species – every time. But once the population declines below a certain number, differences in outcomes – persistence vs. extinction – could become highly sensitive to small changes in local conditions. Beyond that point, if the species does persist, we might want to say that the happy outcome was highly contingent upon local conditions being just right. In this sort of case, the outcomes (extinction vs. persistence) are contingent, but that contingency is itself conditional upon a decline in abundance. The decline in abundance is itself an historical process. So there might be a sense in which contingency increases as abundance declines.

We therefore agree with Sterelny about the importance of conditional inevitability, but we see the need to take this idea a bit further. First, we also need to countenance conditional contingency. And second, once we see that the relevant historical conditions (such as, in the above example, species abundance) may change gradually over time, we are led towards the conclusion that the degree of contingency/inevitability of the later outcomes is itself something that can change over time.

It might be useful to rethink the debate between Gould and Conway Morris in terms of this conclusion that the topography of historical contingency can change. As noted earlier, Gould thinks that evolutionary history is highly contingent. Conway Morris, on the other hand, holds that evolution is highly convergent, and that some outcomes (including the evolution of intelligence) are pretty much inevitable. Sterelny is right to take Conway Morris to task for ignoring the possibility that an outcome might only be conditionally inevitable. The argument that we have developed here suggests that this criticism might be carried a bit further. It turns out that *neither* Gould nor Conway Morris has taken seriously the possibility that the landscape of contingency and necessity is itself something that can undergo historical change. This omission is problematic. After all, once one acknowledges that the topography of historical contingency can change, then it becomes an empirical question just how that topography has in fact changed.

Conclusion

Drawing upon Ben-Menahem's notions of historical contingency and necessity, we have suggested that historical events and processes can be thought of as forming a complex landscape of contingency and necessity. We think that this topographical metaphor – as well as more specific metaphors, such as that of the catchment – can prove useful to historians and natural scientists.

We have also suggested three different ways of extending and elaborating Ben-Menahem's concepts: (1) By supplementing them with a notion of historical disturbance; (2) by pointing out that contingency and necessity are subject to scaling effects; (3) by showing how degrees of contingency/necessity can change over time. We have also argued that further development of Sterelny's notion of conditional inevitability leads to our conclusion that the topography of historical contingency is something that can change over time.