Shaping and Being Shaped: Jazz as a Way to Understand Human/ Environment Interaction

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Understanding is often significantly aided with metaphor and analogy. In this paper, we will argue that the process of jazz music provides a powerful analogy for understanding distributed theories of cognition and systems approaches to biology.

Fields like cognitive science and biology often conceive of a difference between "nature" and "nurture"—between organism and environment or between the brain's cognitive process and the environment it thinks in. Distributed theories of cognition and systems biology both propose a unique take on the interaction between "nature" and "nurture," essentially arguing that these two cannot meaningfully be separated. Distributed theories of cognition suggest that cognition is shaped by an interaction between brain and external tools that aid the brain's cognitive process (be it a calculator, cell phone, or paper and pencil). Systems biology similarly conceives of phenotypic development as a deeply interactive process where genotype and environment interact: organisms develop a certain way because of their environments and environments are shaped by organisms.

We believe the metaphor that aids in understanding these interactive approaches to cognition and biology is jazz music, a music which often depends on each musician affecting what the other plays through a process of improvisation. Thanks to its improvisatory element, jazz music is the result of deep interactions between musicians who both affect and are affected by what the other musicians play. In the same way, distributed theories of cognition and systems biology treat the phenomenon they examine (the cognitive process and biological systems) as the result of deep interactions between elements that both shape and are shaped by each other.

Before ending this introduction, we should discuss why we believe it important to analogize theories of distributed cognition and systems biology to jazz. Much research has been done on the importance of analogy and metaphor to human cognition (Lakoff and Johnson 1980; Hofstadter and Sander 2014) as well as the crucial role analogy and metaphor play in academic disciplines. Mathematics, for instance, has deep roots in (and may be impossible for humans to understand without) bodily metaphors, such as > as bigger or more and < as smaller or fewer (Lakoff and Núñez 2000). Economists attempt to illuminate economic exchange with analogies to a marketplace or a zero- (or non-zero-) sum game (McCloskey 1995). The genome is understood by analogy, sometimes as a building block, other times as a blueprint or pure information (Keller 1995).

Why does analogy and metaphor pervade human thought and help us understand otherwise abstract or intricate concepts? Analogy and metaphor help us assimilate new information into our mental schema by highlighting parallels between things that are easier for us to understand (or that we already understand) in order to make sense of what we don't yet understand. For instance, understanding how memory works is tricky, so we may look for analogies that link how memory seems to work to memory storage devices we are familiar with. Memory, Plato believed, could be best understood by thinking of it like a wax tablet that experience can write on. Some minds (with good memories) have stronger wax that can hold symbols longer than others (with weak memories) whose wax is less durable. More recently, psychologists have made analogies of human memory to dual processing computers, where the analogy serves as a conceptual framework for thinking about memory and a hypothesis (human memory works the way computer memory works) to help guide future research (Roediger 1980). No one, of course, believes that human memory *is* a wax tablet, that experience literally writes on that tablet, or that humans store memories exactly the way computers store information, but pointing out possible similarities between human memory and these devices helps us make sense of memory by analogizing what we understand or can easily see to what we don't quite understand or can't easily see.

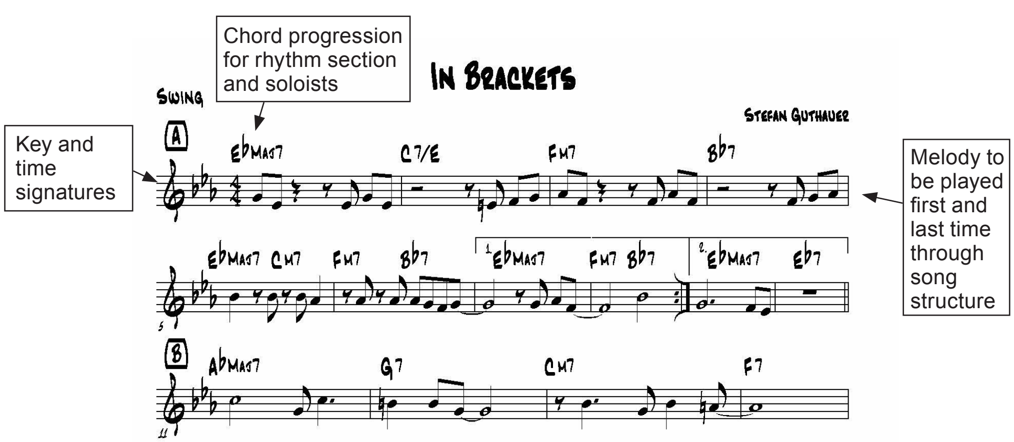
This is our intent in analogizing theories of distributed cognition and systems biology to jazz. The most intuitive way for many people to think about human cognition is as something the brain does, and about biological development as something organisms do. Explaining both of these instead as interactions among parts of a system may be difficult, as such explanations challenge deeply held intuitions. Jazz may provide a more familiar model for understanding a system where the result (the music) is the process of a deep interaction between parts of a system (musicians). This, in turn, may provide a useful scaffold for understanding cognition and systems biology as similarly interactive processes.

First, we will explain how jazz relies on the kind of interaction that makes it difficult or impossible to separate what each player contributes from the overall music itself. We will argue that each player affects and is affected by what others play in a way where the resulting music becomes more than the sum of its isolated parts. The remaining sections then explain theories of distributed cognition and systems biology as well as how each of these are analogous to the interactive nature of jazz music.

JAZZ AS AN INTERACTIVE PROCESS

Jazz music generally gives pride of place to improvisation within a minimal song structure. In contrast to concert (i.e., classical) music, where musicians generally play from a written-out score telling them what notes to play and how, jazz tends to have a less determinate structure, allowing room for musicians to determine what and how to play. Different "forms" of jazz will differ in how much improvisational freedom they give to musicians—it ranges anywhere from more structured "third stream" that fuses classical and jazz elements, to entirely avant garde free jazz where musicians are free of virtually any preconceived structure. On the whole, though, jazz music tends to feature ample space for improvisation from its musicians.

The balance many forms of jazz strike between preconceived structure and improvisational freedom are best seen by looking at a jazz "lead sheet"—the type of sheet music from which a jazz musician (particularly in a small ensemble) will likely play [image below]. In contrast to the detailed sheet music a concert musician will use, with all notes and inflections spelled out for her, the lead sheet contains a minimal structure: a melody and a chord structure (with sparse dynamic markings) written over a set number of measures. The rhythm section (generally drums, bass, and chordal instruments like guitar or piano) will play the chord progression and repeat it as many times as the song demands (a 12 bar blues chord progression, for instance, may be repeated any number of times, while soloists take turns soloing over it). The melody is generally played the first few times the chord progression is played (what musicians call the "head" of the tune), and each subsequent repeat of the chord progression will feature soloists taking turns soloing over the progression. Finally, the song concludes with a final repeat of the chord progression with the "lead" instrument repeating the melody over the progression one last time.



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This, of course, leaves considerable space for improvisation within a minimal structure. The only things proscribed are the key and time signatures the piece is to be played in, a melody (to be played once or twice at the beginning and end of a song), and the chord progression of the song. All else is generally left up to the musicians to create "in the moment." The rhythm section knows what chord progression to play, but have significant room to improvise; the drummer may have an indication of what kind of groove to play (e.g., a swing, funk, or bossa nova pattern), but can add accents and hits anywhere she feels appropriate; the bass player knows the chord progression to use in constructing her bassline, but can improvise what notes she feels appropriate, and so on. Soloists have even more freedom. They know the chord progression they are to play over and (sometimes) how long their solo is roughly supposed to be, but beyond that, soloists are free to construct the content of their solo "in the moment."

For our purposes, it is most important to see this space for improvisation as a chance for group interaction. Jazz is best seen as an interactive process where musicians improvise together, where each musician improvises, but in a way where each guides and is guided by what the others play. As an example, the piano player may play a chord progression in a particular syncopated rhythm, which the trumpet player may incorporate into her own solo, and the way the trumpet player incorporates that rhythm might inspire the alto saxophonist (who has the next solo) to play in a certain comparable or contrasting style. A drummer who plays a laid back and slightly-behind-the-beat style will likely influence the other musicians to adapt their style to hers, which may encourage her to continue playing the song in that style.

In her study of the workings of jazz rhythm sections (drums, bass, and accompanying chordal instruments like guitar), Monson suggests that "at any given moment in a performance, the improvising artist is always making musical choice in relationship to what everyone else is doing" (Monson 1996, p. 27). The same, of course, can be said of interactions within the rhythm section. Not only might the notes the soloist plays affect the chord voicings and rhythms the accompanists use and vice versa, but what any member of the rhythm section plays might affect what the others choose to play. And what those members play may go on to affect what the other members play, etc.

Monson profiles several ways that different instrumentalists can influence what other instrumentalists might play. Pianists, who accompany the soloist by playing the chord progression of the song, will often be able to tell when other musicians are not on the same page regarding the song (e.g, the bass player seems to be off by one or two beats in the song). In an interview, pianist Michael Weiss describes "a situation where somebody gets lost or not everybody is sure they're in the same place, let's say in a fast tempo, very fast tempo tune. When the piano player plays a chord deliberately on a certain beat, everybody will respond to that more than almost anything else" (Monson 1996, p. 51). Bass players, for their part, can often affect what others in the band play by altering their bassline in various ways: they can, for instance, change the register or octave of their bassline (which may affect the register or intensity other musicians play with) or create a pedal-point, where instead of a walking bass line, the bassist repeats the same note (the pedal-point) over the other accompanists changing chords (Monson 1996, pp. 29-43). About the way drummers can affect, and may be affected by, what other instrumentalists play, Monson writes:

> A particular feel played by the drummer signals the bassist that certain bass lines are appropriate and others are not. Likewise, a particular groove tells the pianist that certain types of comping are expected and others are not. These relationships work in reverse as well. A certain style of comping, or a certain base line will tell the drummer which time feel would be most appropriate. Musicians listen carefully for musical details such as these (Monson 1996, p. 52).

While jazz is not unique in having a style that relies on this type of interplay between musicians, it makes very heavy use of such interplay, as evidenced by the lead sheet above. The less formally structured the jazz, the more each musician is free to shape and be shaped by what other musicians are playing.

Jazz music is the result of individuals improvising within a common formal structure and the interaction among musicians within that structure. In terms of structure, most jazz has a time signature, a key signature, a set of chords that are to be played and soloed over, and a melody that is to be played (at least) the first and last time the chord progression is played. (Some jazz forms, like big band, has more structure than this and other forms, like avant garde "free jazz," has less. Virtually all jazz has at least some type of structure that holds the music together.) Musicians are generally not supposed to deviate from this structure. The drummer knows that the key signature is to be x, the rhythm section and soloists know that the chord progression is supposed to be y, and while each musician may improvise, the improvisation generally occurs within, not beyond that structure.

The musicians themselves also constrain what can (or will) go on in the music. First, the instruments used by the musicians impose their own constraints; there are certain chord voicings that cannot be played on the piano due to how the keys are placed relative to the size of the pianist's hands, and certain note combinations that will be exceedingly difficult to play on an alto saxophone owing to the required fingering. The musicians also bring with them a finite skill set as well as stylistic preferences like key signatures they are most comfortable playing in, "licks" they prefer, and the timbre they produce on their instrument that gives them an identifiable "style." All of these factors constrain what can or will be produced when the musicians play together.

Beyond that structure, though, musicians are quite free in the range of things each can play. The drummer knows that she should play in ¾ time and keep a steady pulse on the ride cymbal and hi-hat, but she is free to plug in whatever fills and accents she likes over top of that. The soloists know the chord sequence (and maybe the stylistic tendencies of their accompanists), but they are relatively free to play whatever note combinations agree with that chord sequence. Where the structure allows interaction by keeping everyone on the same proverbial page, the improvisatory space "beyond" the structure is what allows for the feedback/feed-forward interactions.

Jazz music (except in the case of solo performance) is the result of these interactions. While individual musicians give rise to the music, the music itself is not reducible to" the result of different musicians contributing their distinct parts, because all of the parts are constantly shaped in real time by what the other musicians play. In other words, for instance, if a jazz quartet were to play a song twice—once with one pianist and a second time with another pianist, it is unlikely that the two versions would sound indistinguishable (or close to it) except for a different piano part, unlike how a concerto played once with one oboist and then with another oboist would likely sound almost the same both times. The pianist not only affects her own piano part in the song, but things beyond it such as the mood/energy of the song and how the soloists play their parts.

Nor does interaction between players consist only of causal relations, where one player may influence or cause another to play a certain way. In jazz music there are also constitutive relations, where one player's role is partly constituted by what others are doing. For instance, not only do accompanists (causally) help shape what soloists play, but also form the chordal and rhythmic background in which the solo takes place, becoming, in some way, a crucial (constitutive) part of the solo without which the solo could hardly take place without accompaniment. The drummer and bass player may (causally) affect how the other plays her part, but to some degree, each provides a pulse and groove that the other "locks into;" in that way, the two instruments help to constitute a sound that is greater than either alone and constituted by both.

Jazz relies critically, then, on social interaction and it is difficult or impossible to "reduce" the resulting jazz music to individual contributions from individual musicians. The resulting music is irreducibly social. We believe that jazz's dependence on social interaction can serve as a good analogy for at least two strands of contemporary science and philosophy: distributed theories of cognition and systems approaches to biology. Both of these seek to reframe phenomena that used to be explained reductionistically (cognition, phenotypic development) as irreducibly interactive processes.

DISTRIBUTED THEORIES OF COGNITION

Cognitive science and neuroscience typically conceive of cognition as taking place in the brain, and while these fields may grant that things and environments outside the brain may affect the seat of cognition, the brain is still the sole cognizer (for instance, see Churchland 1986 and Baars and Gage 2007). Proponents of distributed theories of cognition argue that tools and environments that affect thinking should be considered part of the cognitive process. Contra standard theories of cognition, advocates of distributed theories of cognition (DTC) believe that cognition is distributed to include not just the brain, but those things/environments that interact with the brain to perform cognitive tasks.

While theories arguinthat cognition is distributed in some form or another have long existed (Clancey 2009; Gallagher 2009), the idea gained much attention when Clark and Chalmers published an essay arguing for the idea of the "extended mind" (Clark and Chalmers 1998). They argued that external devices used in the cognitive process count as part of cognition when they perform functions that the brain could potentially have performed. In other words, if the brain had done it, the function would uncontroversially count as part of the cognitive process, leading Clark and Chalmers to argue that the same should be true if that function were performed outside of the brain. In an important sense, this means that cognition should be viewed as an interaction between the brain and certain tools, like calculators or notebooks, that the brain uses in the cognitive process.

Clark and Chalmers illustrated with a thought experiment about Inga and Otto, who both need to remember where the Metropolitan Museum of Art is. Inga has a strong biological memory, so she searches her brain for the address and finds it quite easily. Otto has memory problems, so he writes important things in his notebook, and consults his notebook to retrieve the address. Clark and Chalmers argue that drawing the line of cognition at what occurs in Otto's and Inga's brain is ultimately arbitrary, for in each case information was stored in a network (brain or notebook) and the individual used that network to retrieve the information.

Other examples may be illustrative. Someone can perform the same mathematical calculation using only her brain, her brain with paper and pencil, or her brain with a calculator. In the first of these cases, the brain is a key player, but in the latter two, the cognition seems to consist of an interaction between her brain and the tools in her environment. In another example, research (Lupyan 2012) suggests that verbalizing one's thoughts affects cognition in several ways. Repeating an item's name can aid a person's ability to find that item in her visual field (Lupyan and Swingley 2012). Linguistically categorizing and naming things aids our ability to think about them in various ways that Lupyan calls the Label-Feedback Hypothesis, where our categorization of a thing affects our sense of differentiation between categorized things and other things, which in turn affects our abilities to further differentiate (Lupyan 2012). A third example (Menary 2007) is a phenomenon likely familiar to many writers: that the act of writing has a marked effect on thinking. When a person writes something down, this externalizes and cements a thought so that the the author can look at and examine the thought in a way she couldn't otherwise. In each of these cases, proponents of DTC would argue that some external part of the environment (paper and pencil, verbalized speech, something to write on/with) not only supports or enhances cognition, but becomes part of the cognitive process itself.

To see why, we might take a closer look at one of these examples: solving a math problem with paper and pencil. When a person does this—suppose he is adding three digits to two digits—he uses the paper and pencil to externalize and make visual what would have to be kept in short-term memory. He writes the addends down so that he does not have to hold them in mind while performing the steps of addition. He adds the first column, then writes its sum down (and might carry a remainder to another column) so that he need not hold this (or the addends) in his head while moving to the next column, etc.

There are two ways one can describe this. The first is the traditional way, where the cognition happens in the person's head and the paper is used to write down the results of cognition and serve as a visual aid to each step in the cognitive process. In this view, the paper is an aid to the cognitive process without being part of the cognitive process. In another view, that favored by advocates of DTC, this traditional description overlooks the interaction between the brain and the paper/pencil in a way that makes these difficult or impossible to disentangle. The paper/pencil is part of the cognitive process largely because the existence of these tools causes the brain to operate differently than it would had the problem to be performed only in the head. Also, the paper serves as a storage device in a way that is similar to how short-term memory would if the problem were done solely in the head. The interaction between brain and paper/pencil is so strong and mutually reinforcing that if you take the paper and pencil (or the brain!) away from the equation, the cognitive process looks entirely different. This, in much the same way that parts of the brain interact so deeply that removing one part would drastically affect the entire cognitive process. Proponents of DTC can rhetorically ask what, besides an arbitrary line drawn between the intracranial and the extracranial, makes these two situations meaningfully different.

In the same way that jazz is an interactive process, proponents of DTC argue that cognition is an interactive process. They favor the idea that the calculator or notepad is part of cognition because the interaction between brain and tools are what give rise to the cognition, in the same way as the interaction between musicians gives rise to the shape any particular jazz song takes.

Does the fact that cognition is shaped by brain and tools interacting mean that the tools are part of (rather than an aid to) cognition? Is it best to say the paper/pencil aids the cognition that goes on in the head, or are they so intertwined in the cognition that they become a part of it?

Theorists like Adams and Aizawa (2008) argue against D/ETC on several grounds, but the most relevant one for our purposes is what is known as the coupling-constitution fallacy. They argue roughly that while the paper may aid cognition, allowing or causing the brain to perform certain functions is not strong enough to say that the paper/pencil plays a constitutive role, becoming an actual part of the cognitive process. Robert Rupert (2009) argues similarly that even if we acknowledge the interaction between brain and paper/pencil, there are strong pragmatic reasons (like the success science has already had operationalizing cognition in the brain) to retain our "commonsense" notion that what is going on is the brain thinking with aid from external devices.

Another interesting element of this debate for our purposes is how far DTC theories might extend the bounds of cognition. If elements in the external environment that play a crucial role in cognition can be called parts of cognition, where should be line be drawn? Some (like Clark and Chalmers) take a conservative approach arguing that external tools can only count as cognitive if (a) the person has reliable access to them, (b) the person can be said to have ownership of those items, and (c) that the items take over roles that could have occurred in the brain. Some argue that these criteria are too conservative (Menary 2012) or arbitrary (Rupert 2012). Others (Gallagher 2008; Jaeghe et al. 2010; Menary 2013) argue for more liberal modes of DCT in various ways by arguing that even social institutions like the scientific community, legal, and educational institutions interact enough with brains to be considered part of cognition. By their lights, it is difficult to see how the smartphone that allows me to access a GPS service is part of my cognition (because I own it) but the GPS cloud and the community of drivers contributing traffic updates to it (neither of which I own) are not part of my cognition. Those who argue for more liberal interpretations of DTC might also find it difficult to understand why items can only count as part of my cognitive process if they replicate what my mind could have done on its own; why not *anything* that aids cognition?

We do not intend to resolve or weigh in on either the constitution/coupling problem or the problem of where to draw the bounds of cognition. We just want to note that both seem to stem from the common issue of how much interaction with a brain is sufficient to mean that something is now part of the cognitive process. The more we learn about the brain, the more we discover that cognition consists of modules within the brain interacting with each other. Thus, if cognition is an interaction between or among modules in the brain, it doesn't seem a stretch to think that extracranial items interacting with those modules could also be considered part of cognition. Yet, most of the debate around the merits of DTC and "how far" reveal how difficult (critics would say problematic) this step is to make.

Advocates of DTC describe the interaction that produces cognition in the same way one might describe the interactive process as jazz. Suppose the cognition in question involves writing a paper using a word processor (Menary 2007). Just as with jazz, this situation contains constraints (imposed by the word processing program, the brain, and the ability of the brain to interact with the program) with substantial room within those constraints for interdependent interaction. Each brain is constrained by its structure, defining what it can (and can't) do, and the cognitive process is also constrained by what environment the cognition is operating in. In this case, the word processor has certain abilities and limitations that govern how one can interact with it.

Yet, within those constraints, the brain and environment have ample room for interaction. For instance, knowing the capabilities of the word processor may affect the brain's thought process.[1] Seeing the written words on the screen may prompt thinking on where to go next which in turn affects what gets written down next, etc. About this situation (thinking affects what gets written, and what gets written affects subsequent thought), Menary (2007, p. 628) argues the following:

1. All the components in the system play an active causal role.
2. They jointly govern behaviour in the same sort of way that cognition usually does.
3. If we remove the external component the system's behavioural competence will drop, just as it would if we removed part of its brain.
4. Therefore, this sort of coupled process counts equally well as a cognitive process, whether or not it is wholly in the head.

We believe points 1 and 3 to be highly analogous to jazz. 1 finds its analogy in the interactive nature of jazz music. In the same way that the soloist and accompanist (or players in a rhythm section) interact with each other in a way that affects all involved, the word processor and the brain interact with each other to such a degree that they both affect the cognitive process. Point 3 is analogous to the thought experiment in the previous section meant to show that each musician, if removed, would deeply affect how the song was played. Removing the word processor from the process of writing has a similar effect to removing, say, the drummer or alto saxophonist from the grouping of musicians.

Points 2 and 4 are less applicable to the jazz setting, but for a potentially instructive reason: 2 and 4 center around the idea that what elements are part of the cognitive process is not always clear in any given case. Whether the word processors we are using to type this article (or the internet, which has helped us find information that contributed to the paper) are part of our cognition may be a matter of dispute. But whether any of the jazz musicians who contributed to a resulting jazz song are part of the jazz music would not be in dispute. If Menary or others want to make the case that the word processor is part of the writer's cognitive process, he must tell a story to argue the word processor's importance to the cognitive process in a way that no one would have to tell a similar story about the importance of the flutist's solo to the jazz tune. We accept that as "jazz" describes the interaction and its result, all of the musicians involved contributed to the process interactively.[2]

Yet, discussions about DTC center around precisely those types of discussions; all will (we hope) admit that the word processor plays a large role in shaping the writing process, but the question is still asked whether the word processor is part of the cognitive process or just an aid to the cognitive process.

Why do these discussions occur in the domain of cognition but not in jazz? Admittedly, there is one aspect of DTC that may not be analogous to the domain of jazz. In DTC, there is one necessary component to cognition to which all others play a supporting role: the brain. Clark notes that "in taking extended cognition seriously, [we need not] lose our grip on the more or less stable, more or less persisting core biological bundle that lies at the heart of each episode of cognitive soft assembly" (Clark 2008, p. 116). Without the bass (or any other) player, the jazz will surely sound different, but jazz can still be played. Proponents of D/ETC argue, though, that removing the brain from the process—unlike removing the word processor—means the process is no longer cognitive. The brain, they argue, may not be a sufficient condition for consciousness, but it is a necessary one in a way that is not analogous to jazz.

Thus, while not an exact analogy, the interaction of jazz can certainly help explain how proponents of DTC view the interaction of the brain and external tools to form cognition. Jazz musicians interact to form jazz music in a way where removing any of the musicians affects the resulting song, which renders each musician an inextricable part of the music-making process. This is much the same as how a word processor, paper and pencil, or calculator interacts with the brain in a way where removing the external tool would deeply affect the process of cognition, possibly enough to render the tool itself part of the cognitive process.

PARALLELS TO BIOLOGY

Similarly, there are parallels within biology that further demonstrate the kind of mutually coordinated activities we see in jazz, in that biological systems are the result of deep interactions between organisms and environments, each affecting how the other develops. Organisms shape environments and environments shape organisms in a way that, just like with jazz and DTC, make the variables difficult if not impossible to fully disentangle.

One example of such interactions between organisms and environment is the coordination of individual, independent myxameobae cells into slime mold. Myxameobae have two basic forms: individual cells and a sexually reproducing "slug" form. When there is plenty of food around, the myxameobae live as single cells, but if food becomes scarce, they coordinate their actions to form a slug that will crawl across the landscape, eating and searching for a place where it can send up spore stalks to spread its spores into the wind in the hopes that the spores will find food elsewhere. Of interest to us is how the cells coordinate into the slug form.

When a mxyameoba begins to starve, it begins to release a chemical called cGMP, a common signalling molecule in biological organisms. Myxameobae have receptors for cGMP on their surface; the more receptors that attach to cGMP, the more likely the cell is going to move in that particular direction. That means that the higher the cGMP concentration in the environment, the more likely the cell will move in that direction. The more cells that are starving, the more cGMP is released into the environment, meaning the cells will move in the direction of more cells. As a result, the slug form tends to be quite varied in its actual structure, rarely looking like a single solid slug, but looking like a network or having various textures, stretching and moving across the environment in various ways. Once enough of these cells accumulate, a macroorganism emerges which can be seen very easily by the naked eye. In fact, they can be several inches or more across, spreading across forest floors, logs, etc.

With the myxameobae releasing this cGMP into the environment, drawing them toward each other, one should ask exactly where the single celled organisms end and the polycellular organism in the slug form begins. To what degree is the environment itself part of the slime mold? One can also ask to what degree is the cGMP a "tool" the cells are using to accomplish their goals. Lack of food results in the release of cGMP into the environment, and this molecule then causes the organisms to move in the direction of highest concentration of that molecule. Is the molecule part of the emergent organism? The coordinator? What, really, is the difference? It is a product of the organisms, a tool of the organisms, and an exteriorized part of the organisms, the purpose of which is to coordinate the actions and interactions of the single cells to create the slug form so that more food can be acquired more quickly and easily, and the organisms themselves spread to other environments to protect at least some of them from complete starvation.

Moreover, the myxameoba also release more cGMP the more cGMP they run into. This contributes to coordination in a positive feedback loop. The more cGMP there is in the environment, the more they move toward it, and the more they release. That allows them to come together, to seek each other out and coordinate their actions. And all of this is done through something released into the environment. Each myxameoba directs and is directed by each of the others in the environment.

This process is analogous both to DTC and the interactions among jazz musicians. Just as there is no obvious or non-arbitrary way to decide where the single-celled becomes the poly-celled organism, it is often hard to tell when an aid to cognition is so central to cognition that it becomes part of cognition. When an author writes down an idea, he has externalized the idea so that he can now look at the idea as an external observer, which may cause him to reject or expand on the idea in a way he wouldn't have could he not have written the idea down. Is the paper and the fact that the idea can be written down an aid to cognition or part of the cognition? LIke with the cGMPs relation to the slug, it seems hardly to make a difference: the paper and brain (and hand as the intermediary) function in a feed-forward loop, the one shaping and being shaped by the other.

This also fits with how jazz often operates, as can be seen when a band spontaneously changes a tune's pulse, which generally starts with one player deciding to change her pulse, which gradually influences others to follow suit. As an example, a jazz tune in a typical 4/4 time signature is usually played with a "full-time" pulse, where each of the four quarter notes are equally emphasized: 1 2 3 4, 1 2 3 4. Yet, sometimes musicians (usually in the rhythm section) can choose to change the tune's pulse, maybe by bringing in a "half-time" pulse, where one only emphasizes two of the four quarter notes: **1** 2 **3** 4, **1** 2 **3** 4. When one musician changes the pulse this way, other musicians will often pick up on this change and decide to modify their approach similarly; for instance, a bass player may change her walking bassline from four notes per measure to two notes per measure to line up with the half-time pulse. As new musicians decide to adopt the half-time pulse, other musicians are more likely to follow suit until all musicians are now playing in this half-time pulse.

Like with the cGMPs, a feed-forward loop begins, where the more members adopt this half-time pulse, the more each musician responds to her environment (where others are playing this pulse) by adopting the new pulse. While the process is certainly less deterministic than the single-celled organisms who produce cGMP, each musician's choice to adopt the half-time feel or not depends largely on what other musicians are doing. Thus, it becomes difficult to suggest that any member of the band decided individually to adopt the half-time pulse, because each musician is taking cues from other musicians and giving other musicians cues.

Another example from biology involves the mechanism of RNA editing, where environmental effects cause nucleic acids to be inserted into the RNA. What we call "environmental effects" are really in fact molecules or the addition of energy in the form of photons or vibrations that are then transformed by proteins in the cell membranes to chemical reactions on the inside of the cell membrane that are, typically, the beginning of a chemical cascade that ends with a particular internal change. This internal change can be the turning on or off of a gene, the alteration of RNA (messenger RNA to make a protein, an RNA enzyme, or one of various other kinds of RNA) already created by an active gene, or the transformation of a protein already made by the RNAs. The internal mechanisms of the cell are thus so fundamentally influenced by the environment that it becomes difficult to truly separate the two. To return to the specific example of altered RNA, the RNA coded by the DNA is altered so that the new RNA is different from the original gene. Environmental factors affect the kind and degree of additions and subtractions of nucleic acids to the RNA to make the new molecule that will in turn make a protein that allows the organism to best respond to the environment. Obviously, altering already-existing proteins is the fastest response, altering RNA is a medium response, and turning genes on and off is the slowest response to the environment, and each of these are going to be needed for different environmental factors, depending on the adaptive needs of the organism.

In other words, genes and gene products interact with the environment in complex ways. Genes are turned on and off in reaction to chemical signals within the cells, which are themselves initiated from chemical or physical forces from the environment. The simplest model would be for a chemical in the environment to attach to a protein on the cell surface, which in turn sends a chemical signal to a gene regulatory protein, which in turn switches a gene on to produce a mRNA that in turn produces a protein that can either provide a structural or enzymatic reaction to the environment.

But this simplest model is in fact a rare occurrence in nature, and typically only in the simplest of organisms, like bacteria. As noted above, there are actually many different ways a cell can react to the environment that essentially act as extensions of the genetic code of the DNA. For example, there can be what is known as alternative splicing of RNA molecules. The RNA molecule in question is entirely coded by the DNA, but it can be cut and rearranged in different ways based on environmental signals indicating which RNA product is required. That is, the DNA produces a large number of these RNA molecules, which then will alter (through self-splicing) or be altered (by RNA-splicing structures within the cell) based on the changes in the environment signalling what is needed. This makes the cell more responsive to the environment, since the RNA simply has to be cut and pasted in a certain way rather than completely created. In addition, there is also a mechanism known as RNA editing, where nucleic acids can be inserted into the RNA. Thus, the RNA coded by the DNA is altered so that the new RNA is different from the original gene. Again, environmental factors affect the kind and degree of additions and subtractions of nucleic acids to the RNA to make the new molecule that will in turn make a protein that allows the organism to best respond to the environment. Where is the "genetic code" therefore held? In the chromosomes? In the chromosomes and the cytoplasm? Or in the chromosomes, cytoplasm, and environment?

Another way to see the interaction of genetics and environment to the phenotype is to look at the role of both in sculpting behavioral traits. By definition, behavioral traits are traits governing behavior, which is a reaction to the environment. For any behavioral trait (and most which have been studied are heritable to some degree, having a genetic component), there will be what scientists call a reaction norm: a spectrum of ways that trait can express.

As an example, of the most studied (and most controversial) traits shown to have a genetic element is general cognitive ability (*g*), where researchers estimate has anywhere from a heritability of .3 (weak heritability) to .8 (strong heritability) (Croston et al. 2015). Any individual will have a certain reaction norm of ways their *g* could develop: for purposes of simplification, a floor and ceiling below or above which their IQ (which measures *g*) cannot go. But how *g* expresses owes quite a bit to epigenetic and environmental factors (like the attachment formed between mother and child, environment the child is raised in, or the education she receives) (Bjorklund 2006).

To make the line between where nature ends and environment begins harder to draw, humans and other animals have the capacity for niche construction: the shaping of one's environment to best fit the traits one has. We can imagine a child whose genome makes a high IQ (measuring *g*) more likely than a lower IQ. That child may show intellectual promise in school such that teachers give the child extra practice on activities that enhance the child's IQ. The child may also gravitate toward the type of intellectual activity that would raise IQ over time. Thus, the environment may affect how the child's *g* develops, but the child also acts on her environment, arranging it (deliberately or not) to best suit (and potentially raise) the child's *g*. Kim Sterelny has convincingly argued that humans engage in cultural niche construction by creating environments for our children (from house to schoolhouse) that shape human intelligence (Sterelny 2007, 2012).

We should note that the structure at work with traits and reaction norms is similar to the structure of jazz and distributed theories of cognition. In an earlier section, we discussed how jazz generally has a certain form to it best represented by the lead sheet, which instructs the musicians on such things as the key and time signatures as well as the chords which make up the song and the melody of the song's first and last repetition. DTC has some fixity to its structure also, defined by the capacities of the brain(s) and environmental tools available. This is analogous to a reaction norm, where the genome sets a limit on the number of ways a trait can express. Yet, as with jazz and DTC, everything beyond those fixed limits is made up by the deep interaction of organisms and the environment.

CONCLUSION

Where the standard account of cognition sees cognition as something the brain does, distributed theories of cognition depict cognition as something the brain and external tools do in interaction. Where standard accounts of biological development depict organism and environment as discrete variables, systems biology see organisms and environment as inseparable because involved in a deep interdependence. Paper and pencil, word processors, and calculators are such a part of cognitive processes that it is potentially arbitrary to draw a line between the work done by the brain and that done by the "external" tools. SImilarly, when mxyameoba release cGMP, causing other mxyameoba to move toward each other to form a slug, it may become arbitrary to draw a line between the organism of the slug and the environment that gave rise to its formation.

Jazz music involves the same type of deeply interactive process, where each musician's choices are both affected by their responses to other musicians and help affect other musicians' subsequent choices. A musician may change their style of play in response to something another musician did, and in so doing affect what the other musicians decide to play, as when a soloist's choice to move to a higher register affects accompanists' choices to move to that higher register, potentially fueling the soloist to play even higher. In cases like these, it is difficult to explain the resulting music by analyzing each musician's isolated part, because each part shaped and was shaped by the other parts. No musician's part can be explained separately from the environment surrounding it.

This is where we see the analogy among jazz, distributed theories of cognition, and systems approaches to biology. In each of these domains, the resulting phenomena—respectively, the jazz music, cognitive process, and biological development—arises by an interaction that makes it impossible or arbitrary to explain any part of the system without reliance on the interaction between it and other parts of the system.

The dominant intuitions in cognitive science and biological science is to treat what look like separate variables as variable: there is the brain's process and the tools surrounding it, the organism and the environment surrounding it. It is often hard to see how crucial the interaction between brain and tools or organism are to shaping the results because these interactions are, in a sense, hidden from view. I can see a person thinking and see her using the calculator, but I cannot "see" how each shapes what the other does. I can see the person's behavioral traits and the environment the person is in, but I must infer how the traits shape the environment and how the environment shapes the traits. Thus, the variables appear separable precisely because they appear separable while much of the interaction between them remains hidden from obvious view.

One reason jazz provides a good metaphor, then, is that the interaction is, in a real sense, there for all to hear and is often recorded. One can listen to a jazz record and hear many of the interactions we've described in this paper. One can hear that the drummer's rhythm, the pianist's chord voicings and the trumpeters' tone effect the feel of the overall song, which in turn affects how each musician plays. One can hear a drummer's shift to a half-time groove was likely affected by another musician's phrasing (using half notes rather than quarter notes), which in turn affects other musicians' decisions to adopt the same half-time feel. Unlike watching the person thinking with a calculator (where the variables are evident but the interaction is hidden), jazz music allows us to hear the interaction, sometimes quite vividly.

This, we think, makes jazz an ideal metaphor to provide a conceptual base with which to understand the projects of distributed theories of cognition and systems approaches to biology. All three domains depict systems where the results of the system comes from a deep interaction of the system's parts, where the parts interact by both affecting and being affected by other parts simultaneously.

NOTES

1. This is clearly illustrated by thinking about the difference in an author's thought process when using only a typewriter versus using a word processor. In the former situation, the author likely knows that the writing will have to be done more or less chronologically and that moving a passage from one spot to another (cut and paste) will be difficult or impossible. With a word processor, it is much easier to write down thoughts "out of order" and order them later that may not be possible with a typewriter. Thus, the medium and its anticipated capabilities may affect how the brain processes a task.
2. In fairness, some writers go beyond arguing that the musicians alone contribute to the jazz music. Myers (2013) has argued that changes in record technology (e.g. limitations on how long a record could be) as well as cultural and geographical climate have had substantial effects on the sounds of jazz. Several books have been written profiling landmark jazz records and the conditions under which they were recorded, partly ar-

guing that these conditions substantially affected the resulting sounds (e.g. Kahn 2000; Kahn 2002). These arguments are more analogous to discussions about whether the books in my office or the internet are a part of my cognitive process.

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