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Linguistics Thesis
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Abstract:
This paper seeks to examine the notion of simplicity and its use in both linguistics and biology. The paper focuses on the Minimalist Program and its attempts to bring biology in line with linguistics, linguistics in line with biology, and both in line with physics. There is a brief description of the areas where minimalism and biology overlap followed by three examples from biology – the Calvin Cycle, signaling in the brain, and reproductive adaptations in rotifers.

Simplicity – The state or quality of being simple in form, structure, etc; absence of compositeness, complexity, intricacy
- The Oxford English Dictionary

Simplicity is such a beautiful concept. It has grace and a restful humility that is hard to describe. The very word simplicity draws from our hearts images of calm landscapes, feelings of peace and quiet contentment. How often in our everyday lives do we call upon simplicity as the guiding principle of our affairs? We search for it, we try and live with it, like it, by its principle, and we use it to differentiate hypotheses – the simplest solution is the best solution. Why is that? What makes simplicity so desirable and so irresistible?

The goal of this paper is straightforward, to examine the concept of simplicity and its use in both linguistics and biology. The conflict between simplicity and complexity has always puzzled me. That one should be seen as more desirable than the other when both ideas interact so productively. Take for example a play where the set and the costumes have been stripped to a minimum leaving the audience with only the text and the talent of the actors to carry the story. In one sense the performance is simple; there are no distractions. A bare stage has its own parsimony, its own elegance. However, if the text is well written and the performers gifted, the resulting presentation will be complex, nuanced. The unadorned stage will complement the intricacies of the text creating in a single instant something which is both simple and complex. This paper is a way for me to explore simplicity and complexity and why they are so important in our thinking. Although I do not think I will reach any satisfactory conclusions, nonetheless, I suspect the journey may have its own rewards.

The philosophical space where linguistics, biology, and simplicity collide with the greatest force appears to be Minimalism. In the first chapter of Linguistic Minimalism, Cedric Boeckx outlines the 'strong minimalist thesis';

"The minimalist program for linguistic theory adopts as its working hypothesis the idea that Universal Grammar is 'perfectly' designed, that is, it contains nothing more than what follows from our best guesses regarding conceptual, biological, physical necessity."[1]

Boeckx immediately qualifies this statement by saying that the hypothesis is probably more than a little overstated. The inspiration for this hypothesis is clearly derived from an appreciation of mathematics and physics. (There are quotes from Planck and Einstein start in the first few pages.) Boeckx reminds us that,

"scientists at all times make the standard gamble that the portion of the world they are investigating can be understood in a simple fashion, that the world is not as 'messy' as it looks, that it shows signs of organization, and that it is governed by laws of general applicability."[2]

Even in choosing the name for their program the minimalists emphasize the importance of simplicity in their philosophy. But what is this simplicity? How can you can you use something as an intellectual pillar without a definition? Norbert

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1 Cedric Boeckx. *Linguistic Minimalism, Origins. Concepts, Methods, Aims.* (New York: Oxford University Press, 2006.) 4.

2 Boeckx, 1.

Hornstein comes to our aid here. In *A Theory of Syntax* he gives us three characteristics of simple systems. First, simple systems should not be redundant. A definition of universal grammar should not include operations that cover the same "empirical territory".[3] Second, keep things sparse. His exact words are "Fewer is better, Ockham is right."[4] Literarily and visually supporting his point with this laconic statement, he goes on to clarify that the things that should be kept sparse are the principles and basic operations utilized by a theory. Third, "in simple accounts the basic operations and principles are natural."[5] Here 'natural principles' are principles which could conceivably be encoded in neurons. For Hornstein, "it is reasonably clear how one could build a merge or copy circuit."[6]

According to Boeckx, the criteria of simplicity is similar to the criteria of economy and to seek simplicity is simply "good natural philosophy" [i.e. science] He gives a quote from David Hume to support this argument; "to multiply causes, without necessity, is indeed contrary to true philosophy."[7] One of the most illuminating quotes that Boeckx gives us in his book is this one from Chomsky 1965,

"There is surely no reason today for taking seriously a position that attributes a complex human achievement [language in this case] entirely to months (or at most years) of experience, rather than to millions of years of evolution or to principles of neural organization that may be even more deeply grounded in physical law"[8]

Minimalism is about the search for a physical basis for language not just in the organism's physical form but also in the physical sciences – the so called laws of

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3 Norbert Hornstein. *A Theory of Syntax, Minimal Operations and Universal Grammar*. (New York: Cambridge University Press, 2009.) 1.
4 Hornstein, 2.
5 Hornstein, 3.
6 Hornstein, 3.
7 Boeckx, 71.
8 Boeckx, 129.

nature. In organizing the philosophical basis for this search Minimalists draw upon certain ideas from biology like emergent properties and exadaptation. Here some confusion arises. Minimalists insist that language evolved too recently to have been streamlined by natural selection -

"A highly modular FL has the sort of complexity that requires adaptation through natural selection to emerge. In addition, adaptation via natural selection takes a lot of time. If there is not enough time for natural selection to operate (and 50,000-100,000 years is the blink of and evolutionary eye), then there cannot be adaptation, nor this kind of highly modular complexity."[9]

Since language cannot be the product of natural selection it must be the result of interactions between multiple cognitive systems in the brain. However, Uriagereka states, in his book *Rhyme and Reason,* that language is not an emergent property. *Rhyme and Reason* is set up as a dialogue between the Linguist and the Other. At some point in the "conversation" the Other brings up the idea of emergent properties and the Linguist responds with "What I don't see is its connection to linguistics."[10]

The concept of emergent properties describes the idea that the whole of a system is in fact greater than the sum of its parts. The arrangement of and interactions between the parts of a system lead to new functions and capabilities. When a serious head injury results in a rearrangement of brain tissue the brain no longer functions appropriately. All the parts are still there but they are not connected properly so they don't work.[11] Biologists use the concept of emergent

[9] Hornstein, 5.

[10] Juan Uriagereka. *Rhyme and Reason, An Introduction to Minimalist Syntax.* (Cambridge, Mass.: The MIT Press, 1998.) 30.

[11] Neil A Campbell and Jane B. Reece. *Biology, Seventh Ed.* (New York: Pearson, Benjamin Cummings, 2005.) 9.

properties to explain how life can be so complex and still be functional. If language is the result of multiple brains systems interacting with each other than it is one of the most emergent of emergent properties.

The term exadaptation was coined be the great evolutionary biologist Stephen Jay Gould. Traits often evolve to fit one purpose and then are turned to another purpose later in the organism's history. As Gould wrote "historical origin and current utility are distinct concepts."[12] The minimalists agree that there is a distinct possibility that language is an exadaptation. However, language as exadaptation does not necessarily fit with this concept of simplicity. Exadaptations are some of the messiest parts of biology. In his book Chomsky's Minimalism, Seuren actually uses the inelegance of exadaptation to challenge the minimalist idea that language is in some sense optimal -

"Species and their faculties never start from scratch but patch up their existing structures, adapting them to new functions - a process called exadaptation. For Chomsky, however, the human language faculty is largely exempt from this common and practically inescapable corollary of natural selection. It is presented as a superb technical achievement in its own right."[13]

Clearly there is some disagreement as to how these biological concepts should be used with respect to language. I want to continue from this point with a series of three examples from biology which I think could shed some light on these ideas of exadaptaion, emergent properties, and optimality.

[12] Uriagereka, 49.

[13] Pieter A. M. Seuren. *Chomsky's Minimalism.* (New York: Oxford University Press, 2004.) 32.

Exadaptation at Work: The Calvin Cycle

The Calvin Cycle is responsible for carbon fixation in photosynthesis and is a great example to use when talking about the beautiful untidiness of life and evolution. Photosynthesis can be divided into two major sections – the light reaction and the dark reaction. In Both reactions take place in the chloroplasts. If you take a look at figure 1 you can see that there are multiple chloroplasts per cell. You can also see that the internal architecture of the chloroplast is quite extensive.

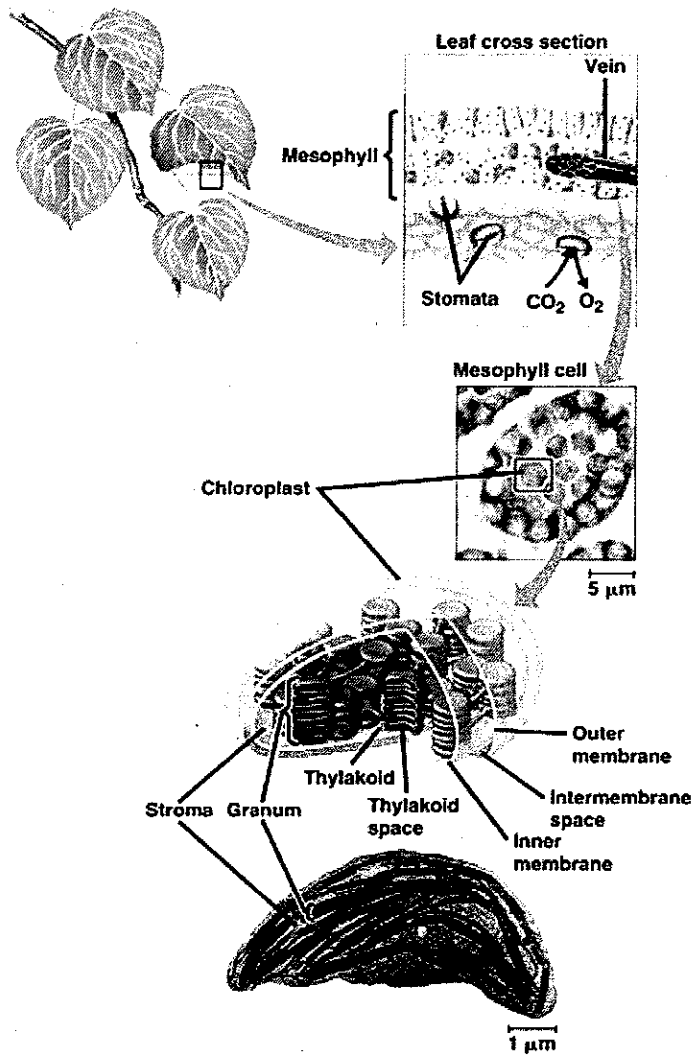

Figure 1. The location and structure of the chloroplast.[14]

The light reaction takes place in the thylakoid spaces. During the light reaction solar energy is converted into chemical energy by storing the energy of an electron excited by a photon[15] in ATP[16] and a molecule called NADPH. The ATP and NADPH

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[14] Campbell and Reece, 183.

[15] The easiest way to think about electrons being excited by photons is to compare the electron and the photon to balls on a pool table. When you hit ball 1 with your cue it begins to move at speed across the table until ball 1 hits ball 2 whereupon ball1 stops moving and ball 2 starts moving. The kinetic energy of ball 1 has been transferred to ball

are then used in the dark reaction, also called the Calvin Cycle. The Calvin Cycle takes carbon dioxide from the atmosphere and uses the carbon to make a sugar called G3P (glyceraldehydes-3-phosphate). G3P can then be used to make all manner of organic compounds including the sugars and starches. Plants make these sugars for their own consumption but happily we can also consume the sugars plants produce.

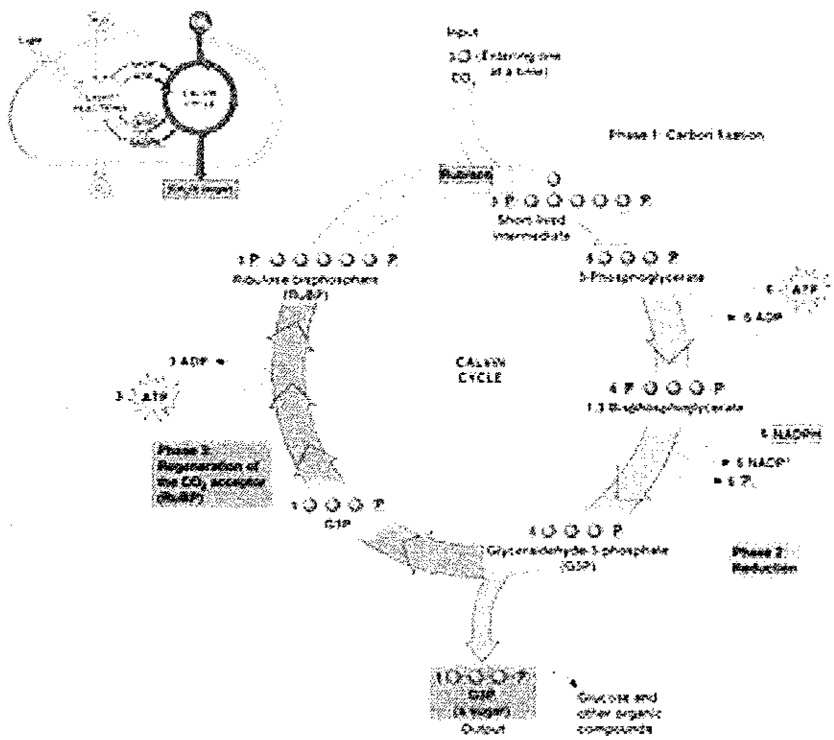

Figure 2. The Calvin Cycle[17]

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2 by the hit. Ball 1 is the photon and ball 2 is the electron. When the photon hits the electron the electron absorbs the energy of the photon.

[16] ATP (Adenosine triphosphate) is the molecule that powers every cell. When ATP is broken down into ADP (Adenosine diphosphate) and a phosphate group energy is released and that energy is used for whatever the actions cell requires such as activating proteins. When our cells break down sugars for energy (a process called cellular respiration) they take the chemical energy stored in the sugar and transfer it into ATP.

[17] Campbell and Reece,194.

Now, if you take a look at figure two, you can see each step of the Calvin Cycle. At the top is an enzyme called Rubisco. Remember this enzyme because, for our purposes, Rubisco is the star of the Calvin Cycle. Rubisco brings carbon dioxide into the cycle by adding the carbon from the CO_2[18] to a 5-carbon molecule called ribulose biphosphate (RuBP). This new 6-carbon molecule is the "short-lived intermediate." The "short lived intermediate" then goes through two chemical changes the end result of which is that the 6-carbon molecule becomes two 3-carbon molecules of G3P. The first chemical change (from the intermediate to 3-phosphoglycerate) requires the energy stored in ATP from the light reaction. The second chemical change (from 3-phosphoglycerate to 1,2-biphosphoglycerate) requires the energy stored in NADPH during the light reaction. Once the first half of the Calvin Cycle has occurred three times the cycle has produced six G3P. Five of those six G3P will be used to remake the original 5-carbon molecule, ribulose biphosphate in the second half of the Calvin Cycle. The single remaining molecule of G3P is the output of the Calvin Cycle. You can look upon this molecule of G3P as containing the carbon atoms from each of the three molecules of carbon dioxide.

Do you still remember Rubisco? Rubisco adds the carbon from carbon dioxide to ribulose biphosphate. However, Rubisco is a treacherous enzyme – it has an affinity[19] for both carbon dioxide and oxygen. When the plant cell is short on carbon dioxide, Rubisco binds to oxygen and, in a process called photorespiration,

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[18] Since oxygen is unimportant for carbon fixation the two oxygen atoms from the carbon dioxide are waste and they are released as a molecule of O_2 which makes its way out of the chloroplast and then out of the cell into the atmosphere.

[19] The affinity of an enzyme for a molecule reflects that enzymes ability to bind to the molecule in question.

proceeds to add oxygen to ribulose biphosphate instead of carbon. The resulting 5-carbon intermediate splits into one 3-carbon molecule which can complete the Calvin Cycle and one 2-carbon molecule which leaves the chloroplast and is turned into CO_2. This molecule of CO_2 is now waste; the Calvin Cycle instead of fixing carbon has actually lost carbon and wasted valuable energy to do it. A plant can lose as much as 50% of the carbon fixed by the Calvin Cycle to photorespiration.[20] Why would something so un-advantageous evolve and stick around? Rubisco is one of the most abundant proteins on earth despite its unfortunate affinity for both carbon dioxide and oxygen.[21]

To understand why photorespiration occurs and why evolution has not "fixed" this problem we have to take a look at the situations where photorespiration occur and the mechanisms which plants have evolved to work around these situations. Take another look at figure 1. In the top box labeled leaf cross section you can see three pores in the bottom of the leaf called stomata. These stomata are the pores which allow the plant tissues to exchange gases with the atmosphere. Oxygen goes out and carbon dioxide comes in. However oxygen and carbon dioxide are not the only two gases that can be exchanged through the stomata. On very hot dry days, water also leaves the plant through the stomata. In an effort to combat water loss plants close their stomata. Once the stomata are closed oxygen can no longer leave the plant and carbon dioxide can no longer enter it. As photosynthesis continues, the concentration of oxygen in the plants' cells increases and the

[20] Campbell and Reece, 196.
[21] Campbell and Reece, 194.

concentration of carbon dioxide decreases. Rubisco begins to add oxygen to the Calvin Cycle and photorespiration commences.

Most plants that grow in hot, dry climates cannot afford to lose water but they also cannot afford the high carbon and energy cost of photorespiration. These plants evolved mechanisms to combat photorespiration. C4 plants do not fix carbon with the Calvin Cycle. This does not mean that C4 plants do not use the Calvin Cycle. C4 plants use spatial separation to remove carbon fixation from the Calvin Cycle and from the two-timing grasp of Rubisco. The first cartoon in figure 3 shows the anatomy of a C4 leaf.

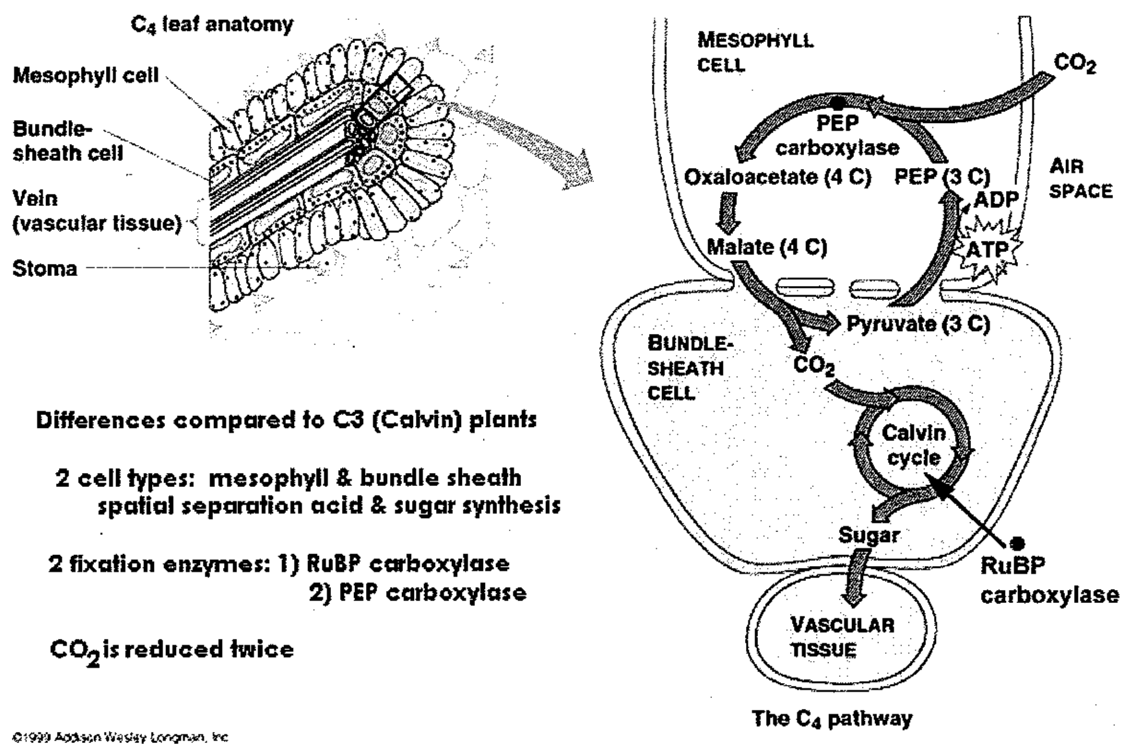

Figure 3. The Calvin Cycle in C4 Plants[22]

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[22] Campbell and Reece, 196.

The leaf is divided into two main cell layers – the mesophyll layer and the bundle sheath layer. The bundle sheath layer is encased in the mesophyll layer and because of this has no direct contact with the atmosphere. If you move over to the second cartoon you can see carbon dioxide entering the mesophyll layer where it is fixed by PEP carboxylase (not Rubisco). PEP carboxylase adds the carbon dioxide a 3-carbon molecule called PEP creating a 4-carbon molecule – oxaloacetate. Oxaloacetate is turned into malate (another 4-carbon molecule) and malate is transferred from the mesophyll cell to the bundle sheath cell. In this way the carbon moves from the outer cell layer to the inner cell layer. Once in the bundle sheath cell, malate releases the CO_2 molecule where it is picked up by none other than our old friend Rubisco and incorporated into the Calvin Cycle.

By taking Rubisco and the Calvin Cycle away from the area where gas exchange is taking place and moving them into an inner cell layer the C4 plants have evolved a buffer zone where oxygen can build up without causing a carbon drain. The important thing to note here from the standpoint of evolution is that the problem with Rubisco was not fixed. It was sidestepped. Evolution doesn't go back and fix things that didn't work out in the long run. When Rubisco evolved the atmosphere contained lots of carbon dioxide and very little oxygen – Rubisco's affinity for oxygen was not an issue; it did not affect the survival and reproduction of photosynthesizers. However, the success of photosynthetic organisms led to a huge increase in the oxygen content of the atmosphere (remember oxygen is the waste product of the Calvin Cycle). Suddenly Rubisco's affinity for oxygen becomes dangerous. The decrease in metabolic efficiency caused by photorespiration begins to affect survival rates. But, does natural selection take a step back and modify Rubisco's active site so that it can no longer bind to oxygen? Does PEP carboxylase replace Rubisco in the Calvin Cycle? No, natural selection can't do that. Evolution does not move backwards; it is as far as we know impossible. Instead a new component is added: the enzyme PEP carboxylase is reassigned to carbon fixation and the spatial separation of carbon fixation and the Calvin Cycle is evolved.

Evolution is a messy business and life as the product of millions and millions of years of evolution has become pretty cluttered. Systems are layered upon older systems which in turn rest upon even older systems. With each new convolution organisms gain greater complexity. The more recently evolved something is the more likely it is to be a part of or in the case of behavior the product of the intricate integration of a vast number of smaller systems. These smaller systems all have their own complexities leading down to the molecular orbitals of their molecules. This might seem like a stretch but organic chemistry isn't simple a simple just because it can the interactions it examines can be described by an equation. I know, I had to take the course.

Structure and Function: How Assembly Generates Emergent Properties

Form follows Function. This is something that was drilled into me in Middle School. Although perhaps it might be more accurate to say that form follows function which follows form which follows function and so on, since the confluence of mutation, recombination and natural selection constantly both alters structure to fit function and produces new structures with new functions. Every task executed by a biological entity requires a specific structure and likewise the shape or structure of that biological entity determines its task. In the case of Rubisco a lack of specificity in the form led to a disadvantageous function. But this is just one example out of many potential examples where structure and function are inextricably entwined; take, for instance, cell signaling between neurons.

In the nervous system most inter-cell signaling happens via neurotransmitters. This inter-cell signaling is facilitated by electrical intra-cell signaling. Electrical signals are converted into chemical signals which are then converted back into electrical signals as networks of neurons communicate with each other. Both types of signaling are dependant on physical structure at the cellular and molecular level. If we follow the action at a single synapse we can see exactly how this happens.

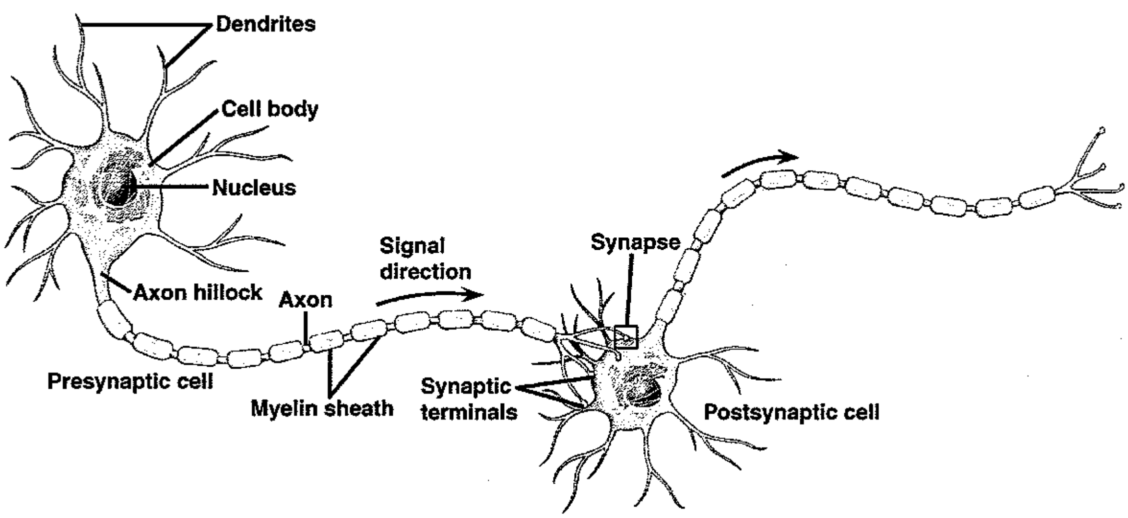

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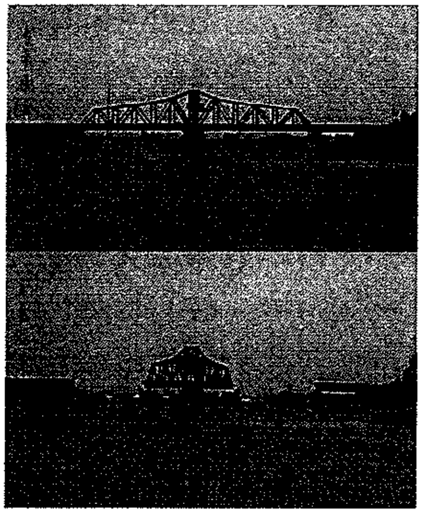
Figure 4. Structure and structural relationship between two generalized vertebrate neurons.[23]

The synapse is the point of connection between two neurons and it is where an electrical signal becomes a chemical signal. In Figure 4 the cell on the left has four

[23] Campbell and Reece, 1014.

synapses with the cell on the right. That leftmost cell is called the presynaptic cell and it is the cell where the electrical signal we are following originates. The electrical signal travels down the axon of the presynaptic cell in the direction of the red arrow. In the case of neurons the electrical signal in question is generated by the movement of positively charged ions into the cell. When a neuron is in its resting state (i.e. not transmitting an electrical signal), the inside of the cell can be said to have a slight negative charge. When a neuron is activated, large quantities of positive ions enter the cell causing the inside of the cell to have a positive charge. The positive charge travels along the axon from the cell body to the synaptic terminals. Once this positive charge reaches the synaptic terminals it causes voltage-gated Ca^{2+} channels to open. Voltage-gated Ca^{2+} channels are proteins that span the cell membrane. The have a pore in them that is shaped specifically to let only Calcium ions through. These voltage-gated channels also have a "voltage sensor", an area of the protein that responds to changes in charge. When the cell is in its resting state the pores of these voltage-gated Ca^{2+} channels are closed. However, when the voltage sensor detects a change in charge it causes a conformational change in the protein which opens the pore and allows Ca^{2+} ions to flow through the channel.

All proteins have a structure, a shape that defines the function they play in the cell. Most proteins have multiple conformations of their structure where the addition of energy or some other trigger can cause the protein to move some element of its structure to a new position. This leads to a change in function (usually the protein moves from an inactive to an active state). A good visual analogy to use when thinking about conformational changes in proteins is a swing bridge.



Whether the bridge is open or closed it is still the same bridge, but in each conformation it can perform a different function

Figure 5. The Little Current Swing Bridge in Little Current, Ontario.[24]

The influx of Ca^{2+} ions causes little packages of neurotransmitters called synaptic vesicles to fuse to the cell membrane of the presynaptic cell and release the neurotransmitters into the synaptic cleft, the space between the presynaptic and postsynaptic neurons. If you take a look at figure 6 you will notice that the synaptic terminal and the postsynaptic cell never touch. The neurotransmitters diffuse across the synaptic cleft where they come into contact with ligand-gated ion channels. Ligand-gated ion channels are in many respects similar to the voltage gated ion channels we encountered earlier. They are proteins which span the cell membrane and contain a pore which allows the passage of certain ions from one side of the membrane to the other. However, unlike the voltage-gated ion channels, ligand-gated ion channels are not sensitive to charge. Ligand-gated ion channels have a receptor site which is shaped to bind expressly to one particular signaling molecule.[25] The ligand-gated ion channels in the postsynaptic membrane of a neuron have receptor sites that are specific for different neurotransmitters.

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24 "Little Current Swing Bridge." *Wikipedia*. http://en.wikipedia .org/wiki/Little_Current_Swing_Bridge. Accessed March 3 2010.

25 Ligand – A molecule that binds specifically to a receptor site of another molecule (Campbell's Biology – Glossary)

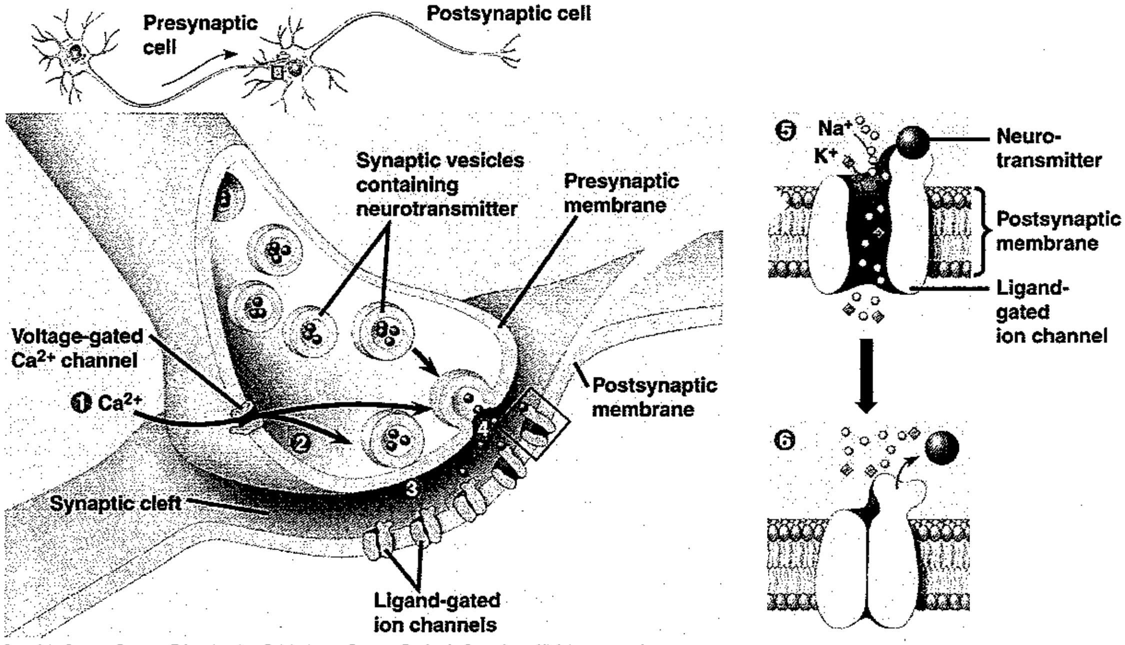

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Figure 6. Neurotransmitter release at the synaptic terminal.[26]

An ion channel with a receptor site for glutamate will not respond to the release of acetylcholine and vice versa.[27] Once the neurotransmitters have diffused across the synaptic cleft and bound to the receptor sites on the appropriate ligand-gated ion channels those ligand-gated ion channels will undergo a conformational change which will open their pores and allow positively charged ions like Na^+ and K^+ to flow into the postsynaptic cell (See figure 6). This influx of positive ions, if it is big enough, can cause a chain reaction which causes the positive charge to move down the axon of the postsynaptic cell. Thus, the electrical signal from the presynaptic cell became a chemical signal which crossed the synaptic cleft and became an electrical signal again. Our postsynaptic cell has now become a presynaptic cell. The electrical signal which travels down the axon of our erstwhile postsynaptic cell will reach the synaptic terminals of said cell causing the release of neurotransmitters and sending the signal on to a new

[26] Campbell and Reece, 1022.
[27] Glutamate and acetylcholine are both common neurotransmitters.

postsynaptic cell. [28]

Though there are many parts of this process that I could go into further detail about. I would like to return for a moment to release of neurotransmitters from the synaptic vesicles into the synaptic cleft because this process is extremely exciting and a great example of the relationship between structure and function at the molecular level. The process undergone by the synaptic vesicles is called exocytosis[29]. There are four major proteins involved in this instance of exocytosis, Synaptotagmin, Synaptobrevin, Syntaxin, and SNAP-25. I know these are a lot of names which all sound vaguely similar but just bear with me.

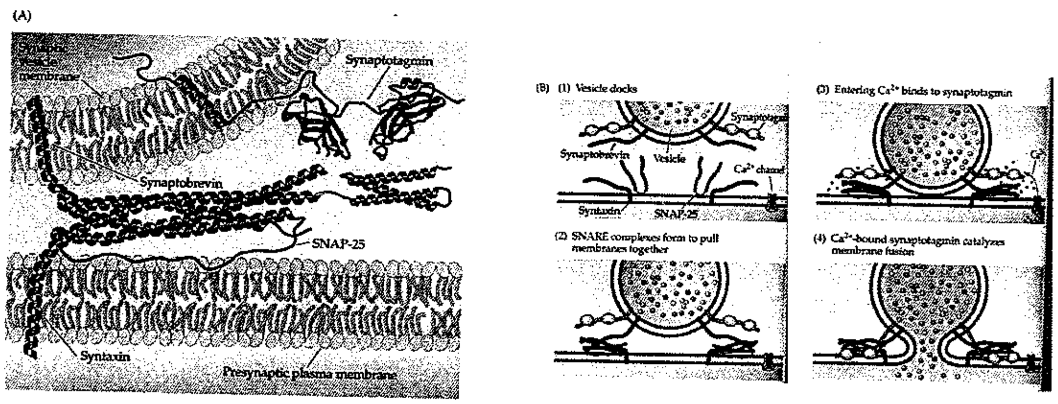

Figure 7. Molecular mechanisms of neurotransmitter release during exocytosis.[30]

The proteins Synaptogamin and Synaptobrevin are attached to the vesicle containing the neurotransmitter to be released. The proteins Syntaxin and SNAP-25 are attached to the membrane of the cell. If you look at Figure 7 you will notice that

[28] For more detailed information on nervous systems see Chapter 48 in Cambell's Biology or Neuroscience by Dale Purves et al.
[29] Exocytosis describes any process wherein a vesicle fuses to the cellular membrane and releases its contents outside the cell
[30] Dale Purves, George J. Augustine, David Fitzpatrick, William C. Hall, Anthony-Samuel LaMantia, James O. McNamara, Leonard E. White, Editors. *Neuroscience, Fouth Ed.* (Sunderland, Mass.: Sinauer Associates, Inc., 2008.) 104.

Synaptobrevin (blue), Syntaxin (red), and SNAP-25 (green) all have large sections that appear as spirals in the cartoon. These spirals are called helices. The shape of the helices allows them to overlap and create a tether for the vesicle which holds it close to the membrane of the cell. When the calcium ions enter the synaptic terminal the ions bond to sites on Synaptogamin. The change brought about in the conformation of the Synaptogamin by binding to the calcium ions brings the vesicle into direct contact with the cell membrane leading to the fusion of the two membranes. When this happens the vesicle essentially folds outward releasing its store of neurotransmitters into the synaptic cleft to transmit the chemical signal to the postsynaptic neuron.[31]

In the end all biology is about structure. Since language must have a basis in our biology, there must be physical structures which correspond to the abstract representations of language we have developed through years of indirect study. However, I am not sure we can expect those physical structures to be directly analogous to our theoretical conception of language. If language is truly an emergent property than it is made up of both actual physical systems and the interactions between those systems.

Optimality and Creative Solutions: Reproduction in Rotifers

When I think about optimality. I always think about it in terms of a comparison. Given a choice among a multitude of possibilities the optimal option is that one which is most efficient or least damaging. I know that in mathematics there are very specific ways one can optimize a situation and I think that these tools can translate well to certain parts of biology. For instance in looking at wing or fin shape, seeing whether or not they are optimized for aero or hydrodynamic efficiency. However, some parts of biology do not

[31] If you want more detailed information on neurotransmitter secretion see pgs 102-107 in Neuroscience, Purves et al.

allow for such clear distinctions between the most advantageous characteristics and less advantageous characteristics. Sometimes evolution throws a curve ball and out of nowhere comes a preposterous phenotype that just doesn't fit into the system. But whether or not it fits into the system is not the point. The point is that the phenotype is successful.

Figure 8. A photograph taken through a light microscope of a common rotifer from the genus Philodena.[33]

The phylum[32] Rotifera contains a collection of microscopic animals noted for their complex jaws and the ciliary wheel organs that give them their name (from Latin, rota meaning wheel and ferre meaning to bear so a rotifer is a wheel bearing animal.) The phylum contains approximately 1,817 species divided among 34 families, 5 orders, families, 5 orders, three classes are Sesonidea, Monogononta, and Bdelloidea.[34] Rotifers are a great phylum to look at when studying the stranger solutions to evolutionary problems. The classes Monogononta and Bdelloidea have evolved entirely different yet

[32] One of my strongest memories of seventh grade is from my ecology class. The teacher was eccentric to say the least. He kept a menagerie of animals in the classroom included a remarkably active tortoise, a diffident box turtle, and a small flock of cockatoos. In addition to teaching us how to dissect a perch and care for eels, Mr Minsky also made sure that we knew exactly how to classify a species - Kingdom, phylum, class, order, family, genus, species. He taught us an acronym to remember them by - Kids Play Chess On Florida's Greatest Shore. (Although I was perhaps more influenced by my brother's rather more amusing version - Koala's Pee Constantly On Foreign Government Statutes)

[33] Sorensen, Martin Vinther. "Rotifera." *Grzimek's Animal Life Encyclopedia.* (Online. Accesed 12 March 2010.) 259.

[34] Sorenson, 259.

equally effective methods for dealing with the same problem.

Rotifers inhabit a wide variety of aquatic and semi-aquatic environments, these include everything from freshwater ponds (where rotifers are the most prolific) to damp moss and melt-water on glaciers.[35] Many of these habitats are subject to swift and devastating changes. Gladyshev and Meselson describe the common habitats of the rotifers as "ephemerally aquatic" which sums up the problem of rotifer survival quite nicely.[36] How can an aquatic organism survive once all the water has disappeared? The answer is in some form of protected dormancy. Monogonant rotifers achieve this state by producing a resting egg.

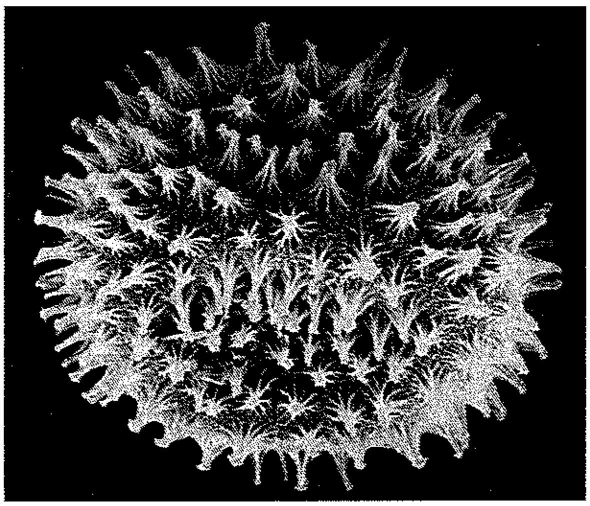

Figure 9. This is a picture of a Monogonont resting egg taken using a scanning electron microscope.[37]

Monogonont rotifers have both a sexual and asexual phase in their reproductive cycle. When they reproduce asexually they essentially clone themselves. The process is

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35 Sorenson, 260.

36 Eugene Gladyshev and Matthew Meeselson. "Extreme Resistance of bdelloid rotifers to ionizing radiation." *PNAS* 105.13 (2008): 5139.

37 Roger Pourriot and Terry W. Snell. "Resting Eggs in Rotifers." *Hydrobiolgia* 104.1 (2004): 217.

called parthenogenesis.[38] In parthenogenic reproduction eggs are produced via mitosis which means that instead of containing only one set of chromosomes the mitotic egg contains two just like any other cell. This mitotic egg then goes on to divide and work its way through all the stages of development without fertilization. The cell already has two copies of the genome; fertilization is unnecessary.

When Monogononts reproduce sexually they produce a resting egg. The resting egg is the diploid[39] result of fertilization. It is covered by a thick, opaque shell which is spherical or ovoid. The shell protects the fertilized egg from not only the elements but even from the action of digestive enzymes should the egg happen to be eaten.[40] The eggs can lie dormant a very long time, in some cases for years, waiting until the right conditions arise. When the right conditions do arise the egg will hatch and continue its life cycle. This is a highly successful strategy for dealing with an inconstant environment. Not only do the Monogononts get to hide out during the bad times, the occasional bout of sexual reproduction is hugely important for the maintenance of genetic diversity and healthy genomes.[41]

The Bdelloid rotifers have their own highly successful and incredibly cool method for dealing with the same environmental issues. Bdelloid rotifers only reproduce asexually. This is a big deal. Why is it a big deal, what makes this unusual? After all bacteria only reproduce asexually, right? Well, both wrong and right. It is true that bacteria reproduce asexually but it is not true that they don't have sex. Reproduction and

[38] Sorenson, 262.
[39] Diploid cells have two sets of chromosomes. (Haploid cells have only one set of chromosomes)
[40] Purriot and Snell, 216.
[41] Purriot and Snell, 220.

sex are actually separate things.[42] Sex is about genetic exchange. Bacteria exchange genetic material in a process called conjugation but they reproduce by mitosis. Rotifers cannot undergo conjugation. They appear to be totally asexual. Asexuality usual means extinction. Asexuals are successful for a geologically brief period before they vanish. This caused biologists to think that asexuality was "an evolutionary dead end."[43] However, Bdelloid rotifers have been around for 35-40 million years and they have done without sexual reproduction for tens of millions of those years.[44] Also, this is not just one isolated species and outlier. The class Bdelloidea contains at least 360 species. What is different about these rotifers? Why are they a flourishing, successful class of organisms? The answer lies in their adaptations for drought survival.

Bdelloid rotifers are able to desiccate themselves, dry themselves out, in a process called anhydrobiosis, "a state of suspended animation."[45] When they are in this state they can literally be blown by the wind and if they happen to land in a suitable environment they rehydrate and begin anew. This sounds easy and simple, trust me, its not. Desiccation is extremely dangerous. Most organisms that undergo desiccation can only survive the process during a mostly dormant larval stage (like the resting egg). This is because desiccation causes extensive DNA breakage. It can essentially shred your chromosomes.[46] Bdelloid rotifers can survive desiccation at any point during their life cycle. This is mind-blowingly weird. (And yes, that is the technical term.) The Bdelloid

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42 Olivia Judson. *Dr. Tatiana's Sex Advice to all Creation.* (New York: Henry Holt & Co., 2002.) 217.

43 Judson, 216.

44 David Mark Welch and Matthew Meeselson. "Evidence for the evolution of bdelloid rotifers without sexual reproduction or genetic exchange." *Science* 288 (2000): 1211.

45 Judson, 230.

46 Gladyshev and Meselson, 5139.

rotifers can do this because they are tetraploids with an extensive system for repairing DNA breakage.[47] Haploid organisms have one set of chromosomes per cell, diploid organisms have two, and tetraploid organisms have four. The rotifers use the many extra copies of their genes as templates for their DNA repair system. This DNA repair mechanism is something that we do not currently understand but it seems to be able to repair breakages in the DNA as well as to correct mutations caused by radiation.[48] The desiccation allows rotifers to avoid difficult environments leading to less selective pressure, and thus less need for genetic exchange. The DNA repair mechanism allows rotifers to combat the harmful mutations that would inevitably build up over time.

Here is another successful and amazing solution to the problem of "ephemerally aquatic" environments. Both solutions are efficient in different ways. Sexual reproduction can be a huge waste of resources so in this area the Bdelloid solution is best But sexual reproduction is so much simpler than the massive cellular apparatus involved in desiccation and DNA repair. Seen in this light the Monogonanats have the preferable solution. How do you choose between them? Well, you don't. They exist. They are nature. Why waste your time deciding which is better when they both work. Choosing the optimal solution won't give you much insight into how that solution solves the problem. Why search for some universal, guiding principle of nature in your philosophy when nature is right there for you to look at.

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47 Jae H. Hur, Karine Van Doninck, Morgen L Mandigo, and Matthew Meeselson. "Degenerate tetraploidy was established before bdelloid rotifer families diverged." *Mol. Bio. Evol.* 26.2 (2009): 382.
Gladyshev and Meselson, 5141.
Eugene Gladyshev, Matthew Meeselson, and Irina R. Arkhipova. "Massive horizontal gene transfer in bdelloid rotifers." *Science* 320 (2008): 1213.

48 Gladyshev and Meselson, 5141.

Alan: (describing other people) They chop down trees, they drive busses or they play games.
Jon: Yes, that's very important –they play games.
Alan: Now, *we* also play games, but we as philosophers play language games. Games of language. Now when you and I go onto the cricket pitch, we do so secure in the knowledge that a game of cricket is in the offing. But when we play language games we do so rather in order to find out what game it is we are playing...[49]

When I began writing this paper I thought I might reach some form of closure. I might discover the truth about simplicity or maybe find out that there was true justification for its use as an arbiter of scientific fact. In included the above quote from Beyond the Fringe's sketch on philosophy because I feel like it most accurately describes what I was able to do. I now know that the questions I asked are questions that it would take a lifetime to answer, maybe more than one. I also know that looking into those questions only left me with more questions. For example when Hornstein says it is reasonably clear to see how one could build a merge or copy circuit. What does that mean? I don't see it. It is not reasonably clear to me. Although I agree with the idea that ultimately language has its basis in neural circuitry, if language is an exdaptation then operations like Move might be some property of our cognition that is not necessarily for language, only used by language. We don't know what this operation might look like in other aspects of cognition. We are no longer just generalizing within language but across a large portion of our intellectual capacity. This brings up all sorts of frustrating questions for me, like whether or not language creates reason or whether an aptitude for logic generates

49 Alan Bennet, Peter Cook, Jonathan Miller, and Dudley Moore. *The Complete Beyond the Fringe.* (London: Souvenir Press Ltd., 1987.) 50.

the symbolic power to develop language, and even how we define our capacity for abstraction in relationship to the cognitive potential of other animals.[50] (On a bad day these questions keep me up at night chewing on my own doubts.)

Also, disentangling language evolution must be much more difficult than tracing the lineage of any other trait. Language evolves in two dimensions. There is the biological evolution of language, where we must confront the questions of adaptation, exadaptaion, natural selection, not to mention the questions of emergent properties and the physical nature of consciousness. Language is also affected be a kind of cultural evolution. We all know that language changes over time. We have dead languages, living languages, pidgins and creoles. Sounds change, vocabularies shift as words are created, borrowed and lost. I suspect that this sort of change is unrelated to the biology of language. I think it has much more to do with the narrative of human history, maybe with changes in culture or context. It is true that you can apply many of the concepts used to explain biological evolution to aspects of this cultural evolution. When populations of the same species are isolated from each other by a geographic barrier they tend to diverge. This can be due to the process of genetic drift[51], or to selection pressure from the different environments, or any other number of factors. If two languages are isolated by a geographic

[50] If you are interested in the neurobiology of this debate you can type episodic memory or semantic into a database like Pubmed and you will be inundated with articles arguing for and against the presence of these types of memory in everything from rats to primates.

[51] Genetic drift describes the unpredictable changes in the gene pool of a population due to the fact that populations are finite. When you flip a coin 10,000 times you are likely to get very close to 5000 heads and 500 tails, but when you flip a coin only 10 times it would not be unprecedented to get 8 heads and only 2 tails. It is the same with populations. The larger the population the less chance there is of a deviation from the predicted genetic ratios among that populations offspring, but no population is infinite so some variation is inevitable (Campbell, 460)

barrier they are likely to change in different ways and at different rates. However, despite their similarities biological evolution and cultural evolution differ it at least two crucial ways. The first is that biological evolution can be traced back to genetic changes while the cultural evolution of language is dependent on a more diffuse set of variables. The second is that the cultural evolution of language can be volitionally motivated. That is that we as speakers can make conscious choices about language use which can then be transmitted to future generations.

I think that one of the Minimalist Programs most admirable goals is trying to separate the biological evolution of language from the cultural evolution of language. The search for universal principles which can be applied cross-linguistically is a great way, perhaps the only way (though I hope this is not the case) to elucidate those parts of language which are the result of our biology and not our culture. There is this sense that the cataloging of these universals will result in some synchrony between the fundamental principles of biology and the fundamental principles of language. Though I do not have the expertise to make a truly cogent judgment about the validity of this idea, I think that there still may be a few problems.

I did learn a few important things about my own thinking over this process. I discovered that I am an old fashioned sort of biologist, and I don't have to move with the times. In her book *A Feeling for the Organism*, Evelyn Fox Keller tells a brief anecdote about the pace of modern science. Sometime in the early 80's

Barbara McClintock, a brilliant cytogeneticist[52], asked a group of graduate and post-doctoral students in Harvard's Biology Department to remember "to take the time and look." Those graduate students responded that they would love to take the time but they feared that it was impossible. They argued that "the new technology of molecular biology [was] self propelling. It [didn't] leave time."[53] Barbara McClintock was a scientist whose career spans some 70 years during which time she saw the molecular revolution in Biology begin, sweep through the field like a wildfire, and in the end leave no part of Biology unchanged. Her request "to take the time and look" comes as a response to the altered focus of biology after the molecular revolution. It is a request we could do worse than to consider. For me, this drive towards simplicity in biology and even in linguistics finds some of its modern roots in the years of the molecular revolution. But despite this driving force for natural laws and simplicity, I still want to take time and look.

In the end I think I have reached the convergence of two dogma's. I am unwilling to accept the possibility that the intricacies of life can be boiled down into a few simple and universal rules and minimalists are unwilling to accept the possibility that a confluence of random events without an underlying guidance system can lead to order. I am about to end my ramblings, but before I go I would like to leave you with this thought from a great writer and biologist, Lewis Thomas.

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[52] Cytogenetics - The study of cytology and genetics in relation to each other; *esp.* the study of the behavior and properties of chromosomes as the constituents of cells that determine the hereditary properties of an organism. (Definition from the OED) Cytology and cytogenetics are no longer a very active disciplines because the study of the DNA as the genetic code has taken over from the study of the chromosome.

[53] Evelyn Fox Keller. *A Feeling for the Organism, The Life and Work of Barabara McClintock.* (New York: W. H. Freeman & Co., 1983.) 206.

Thomas once wrote, "The only solid piece of scientific truth about which I feel totally confident is that we are profoundly ignorant about nature."[54] Most days I know exactly how he felt.

[54] Lewis Thomas. *The Medusa and the Snail, More Notes of a Biology Watcher.* New York: The Viking Press, 1979. Print.

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