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THE PROGRESSION OF ELECTRONIC MUSICAL INSTRUMENTS

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Abstract

This project is an analysis of biological evolution and a mapping of those concepts to the progression of electronic musical devices. All living organisms are comprised of extremely complex components shaped through the random selection of the evolutionary process. The same ideas of design hold true for complex synthetic objects as well. By examining the driving forces behind biological evolution and finding similar concepts behind the cumulative changes of electronic musical devices over time, we will try to locate any parallel developments.

1. Introduction

Before Charles Darwin published his *Origin of Species* in 1859 there was no good scientific theory to explain where we, and all living organisms, came from. Had we always been here? Were we always like this? Where had we come from? Darwin gave us a way to begin to understand these questions through the theory of Natural Selection and biological evolution. Darwinian theories show us that organisms can adapt to their environment by a process of cumulative change, and the main driving force behind this "evolution" is Natural Selection.

All living things, no matter how simple they may appear at first glance, are extremely complicated in comparison to their non-living surroundings. According to a theory set forth by the theologian William Paley in 1802, if one were to find a rock, and ask how it got there, the answer could be quite simple. One might assume it had always been there. However, if one were to find a rabbit, one could not make the same assumption that it had always been there. The rabbit is a complex living organism. It must have evolved from something else over time. We argue that complexity necessitates some type of evolution.

It could then follow that all complexity necessitates some form of cumulative change over time, or evolution, to get to where they are today. This would mean that complex synthetic objects would fall under this rule. Surely complex synthetic (man-made) objects are the result of some type of cumulative change over time, to become more efficient. It is our goal to show that Darwinian theories of evolution do in fact apply to complex synthetic objects, specifically electronic musical equipment.

2. Literature Review

2.1. Biological Evolution

The principles of evolution have been applied to many different processes. The changes that a star undergoes between its "birth" and "death" are often referred to as "stellar evolution." The word can simply mean any type of change, but in a biological sense usually not within the lifespan of one entity. Thus, evolution most often refers to a process of cumulative change in things over time. This cumulative change must take place from one generation to another, that is, descent with modification. No matter what the system that the evolution takes place in, there is always a population (that which is evolving) and some type of slight variation from one generation to the next. The variation must be in at least one, and sometimes even more, of the characteristics apparent in a population. ([2], pg. 4)

Evolution is considered to be composed of two concepts or driving forces. The first of these driving forces is that of environmental change ([4], pg. 25). Every living organism has a specific environment within which it can live. This set of both biological (biotic) and non-biological (abiotic) conditions that determines every possible place where a species can live is known as that specie's *fundamental niche*. Most species however do not ever live entirely throughout one fundamental niche. The set of conditions where a species is actually found naturally is known as the *realized niche*, and is always a subset of the fundamental niche. There are several reasons the realized niche is not the same as the fundamental niche that will be looked at later, such as competition, where one species excludes another from part of the fundamental niche. A specie's fundamental niche is determined by its physical characteristics. For example, a bear would not be well suited to live in an ocean or a desert. Due to this, the bear's fundamental niche does not include these particular environments. Bears have evolved over great lengths of time to be well suited to their particular environment and in which they thrive quite well.

Let us now imagine that a bear's fundamental niche is changed somehow, for example, the temperature drops. This environmental change is going to become a driving force for evolution. The bear species must either adapt somehow to their new environment, or they will perish. There are an infinite number of conditions, both biotic and abiotic, in any given environment that could potentially change in some way. It is easy to see how an environment could somehow be changed. Although not every environmental change will force a change in one particular species, it may in another. When one species undergoes a change, this can in turn become an environmental change for another species, and so on. Because of this it is fairly safe to conclude that evolution is an ongoing process that is never truly complete. What may be beneficial for a species in one particular environment may not be true many years down the road if that particular environment takes on different characteristics.

We can now see how environmental change is a driving force of evolution. When an environment changes a species must adapt to survive. This leads us to the second driving force of evolution, the way in which species go about the actual adaptation. In order to achieve adaptation, there must be some random variation within a species ([4], pg. 25). This variation comes in the form of a mutation, or change in some physical characteristic in an individual within a population. Mutations occur all the time, sometimes for the better, sometimes for the worse. When a species is forced to adapt, it is these mutations that allow that to happen. Mutation causes one inherited and somewhat stable trait to be changed into a different inherited trait. Occasionally this new inherited trait is also somewhat stable, and could better equip the individual to its changing environment. In this case the individual is more likely to survive and reproduce than others in his population, thus adding its more successful mutant gene into that species' gene pool. This is the basis to the theory of Natural Selection. Natural Selection is a combination of a large number of different processes. The main premise, however, is that of "selective discrimination" among individuals in a population ([2], pg. 4).

The simplest modern version of this theory is the Single-Gene Model. According to this model, when given a large enough starting population, a species will be variable for any given gene. Let us consider a specific gene in particular, say gene A. The population has a natural high frequency of individuals containing gene A that codes for a certain trait. There will also be a very low frequency of individuals that carry a variation of gene A, by way of a new mutant gene α (an allele, or one variation of the same gene), that causes a variation in the particular trait we are studying. Now imagine that this generation reproduces, and carriers of gene α happen to be better suited to the current environmental surroundings. This will help the carriers of gene α to add more offspring to the next generation than carriers of gene A. If this unevenness in reproductive rate continues for many generations, then the individuals with the more successful gene α will increase in frequency, as those with gene A decrease in frequency. When put in such terms, Natural Selection is thus the differential and non-random continuation of several different genes within a population. This means that Natural Selection occurs if individuals carrying one allele (gene α) reproduce with greater frequency than individuals carrying a different allele (gene A), continually and steadily over consecutive generations ([3], pg. 87-88).

The Single-Gene Model gives us a pretty good idea of how these alleles can change in frequency relative to one another over time. It does not, however, describe why these genes mutate. Every gene plays an important role in determining every physical characteristic that an individual inherits at birth. When one allele is superior to another, it is said to have a selective advantage. Selective advantage then lies within these phenotypic characteristics that various alleles control. A superior allele should then code for a superior phenotypic characteristic that causes its carrier to be better suited to its environment. In other words, individuals carrying the superior allele will have increased survival (viability) and, thusly, increased reproductive (fecundity) rates than those carrying inferior alleles. These two factors are what affect an individual's fitness. Fitness is simply an individual's reproductive success rate, or the average contribution of a certain allele to subsequent generations. Since an individual's fitness depends on the physical traits afforded it by certain genes, fitness is directly related to that individual's selective advantage ([3], pg. 90-91).

The fitness of an individual (and therefore a specific genotype) is attributed to that individual's ability to pass on its genetic material. It does not, however, refer to the specific reasons for the reproductive success of that individual. An individual with high fitness does not always mean it is the most dominant, or well-adapted individual within its population. Although this may be true in most cases, there are a few examples of the underdog in society having high fitness. Such cases are usually attributed to an individual with high fecundity ([3], pg. 91).

Let us look at such a case among salmon. When salmon mate the female lays her eggs and the male will release his sperm when near her and they will join externally in the water. The dominant males, known as 'hooknose' males, reach maturity at age three. The 'hooknose' males are large and fight off smaller males for the right to mate with the females, and hence to pass on his genetic material. The smaller, or 'jack' males reach maturity in their second year, and are not able to fight for mating rights. When mating occurs the 'hooknose' males keep them at a distance. Ordinarily this would mean that the gene for the inferior 'jack' males would not as frequently be passed on to successive generations, and would eventually cease to exist, or exist in extremely limited numbers. This, however, is not the case. The 'jack' males will hide nearby as the 'hooknose' male mates, and when the female lays her eggs, the 'jack' male will sneak in-between the two and release his sperm near the eggs. Although the 'hooknose' male will generally be larger and better adapted to survive in the environment, they take longer to mature than the 'jack' males. This reduces the chance that they will survive long enough to reproduce. As we can see, the 'jack' males may not have a high adaptive value (smaller, less likely to survive as long) compared to that of the 'hooknose' males, but they still have a high fitness, as they are able to pass on their genetic material to successive generations.

Despite some of these exceptions, selection most often favors individuals with phenotypes with high selective advantages. It is important to realize what exactly makes a phenotype favorable. A highly favorable phenotype in one environment may have less of a selective advantage in another environment, or possibly even a selective disadvantage. This shows that the selective advantage of any phenotype, and hence natural selection, is directly related to that phenotype's interaction with its surrounding environment. The peppered moth (*Biston betularia*) is a good example of this. There are two major phenotypes among the species. The wild-type peppered moth has a light gray color scheme, while the melanic peppered moth has a dark color scheme. The wild-type peppered moth has a huge phenotypic advantage in its natural environment on lichen covered tree trunks. The color of the lichen is a light gray, very similar to that of the wild type. The melanic peppered moths do not have this added camouflage, and are very easily spotted by prey. This kept the number of melanic moths very low relative to the dominant wild-type phenotype. Around the time of the Industrial Revolution in England, however, the high amount of soot from factories changed the light gray environment to a black, soot-covered environment. At this point, the dominant wild-type phenotype had come to have a selective disadvantage, while the melanic phenotype gained a high selective advantage. Due to this environment change, the wild-type moths became scarce compared to the melanic moths ([2], pg. 358).

2.2. Complexity

As we have seen, in order for all living organisms to carry out their functions and survive in nature, they must be well adapted to their environments. This potential for evolution makes them extremely complicated. In order for them to remain this way, they must constantly adapt, and maintain their complexity. Simple non-biological objects, however, do not require this ability to adapt to maintain equilibrium with their environment. For instance, no matter how the environment changes a rock will always be a rock, regardless of temperature, humidity, competition, etc. But what differentiates a complex object from a simple object. One could look at this question from our current perspective and answer that non-living objects were simple. This is not the case however. There are many things that are complex and yet not living ([1], pg. 1).

In order to provide a satisfactory answer to this, we will establish a set of requirements that must be met to consider something complex. The first thing that may come to mind is that it must be heterogeneous in composition. There are however many things that are heterogeneous and not complex. A mountain is not complex by our definition, but is comprised of many different things ([1], pg. 6-7).

Another way to describe complexity is through the use of mathematics, specifically probability. If we were to take all the parts that we would consider to make up a mountain (rocks and soil) and tossed them together, they would become a mountain. Any way you threw the pieces together, a mountain will result. This is not the case however with complex objects. If one were to take all the pieces that make up a dog, and threw them together at random, the probability that a dog would result is so small it could be considered impossible. The problem with this approach is that one could make this same argument for the mountain as well. If you took all the components to a particular mountain, say, Mount Everest, and threw all the pieces together, the chances are equally low that they will once again become exactly Mount Everest. It can be said that any particular collection of things is just as improbable as any other. Now consider the combination of a bank safe. It potentially has thousands, even millions of possible combinations, and any one of them could be used as the correct combination. This, however, is not the case, and only one combination of numbers will open the safe. The probability, then, of selecting the numbers at random and opening the safe are the equivalent of throwing together the parts of a computer, and having it actually work. This cannot be said for Mount Everest. If you threw the pieces together, and made a mountain, not exactly Mt. Everest, it would still function as any other combination of parts. There is nothing special about Mount Everest that is specified beforehand, such as with the case of the idea of the computer functioning ([1], pg. 7-8).

One last requirement we will need for complexity is that the functions a complex object carries out that makes it unique, must also help it make a living. You could throw together the parts of a dog, and end up with something else. It may become something that just sits in one spot and drools. It is performing a function, but is not making a living. If it continued in such a fashion it would soon die, and no longer be able to function. With all this in mind we can now piece together a fairly good measure for what we consider to be complex. They must have some pre-determinable attribute that, in all likelihood, would not have arisen by random chance alone ([1], pg. 8-9).

2.3 History of Electronic Musical Instruments

It is important to also gain some insight into the development of electronic musical instruments. An electronic musical instrument is a device that can generate a sound from an electronic source. A German physicist and mathematician by the name Hermann Ludwig Ferdinand von Helmholtz is credited as the originator of electronic musical instruments. He developed an electronically controlled instrument in order to study tone combinations. The "Helmholtz Resonator" used electromagnetism to vibrate metal tines and resonating spheres of glass and metal to recreate complex natural sounds for analysis. It was an

Italian composer, Ferruccio Busoni, who saw its musical potential, as Helmholtz had used it exclusively for scientific endeavors. [32]

Shortly thereafter, variations on the Helmholtz Resonator began to appear as musical instruments powered by electricity. Between the years 1870 and 1915 electronic musical instruments were based on three basic ideas. The first was a rotating metal disc in a magnetic field, known as a tone wheel, which created variations in the electronic signal. The next was a self-vibrating electromagnetic circuit discovered as a result of telephone technology by Elisha Grey. The last technique was simply to use an electrical spark to cause a direct fluctuation in the surrounding air. These three techniques were the standard until the discovery of the vacuum tube. First developed by Lee De Forest, the vacuum tube originally used for radio technology. He later discovered its ability to create sound by way of the heterodyning effect. When two similar radio sound waves of varying frequencies combine, they create an audible sound of lower frequency, equal to the difference in the original frequencies. This effect was used to more easily create sounds electronically. Vacuum tubes were the prominent source for electronic sound production until the development of the integrated circuit in the 1960s. They helped to create easy to use and very dependable electronic musical instruments that helped to popularize them. Since the early 1980s however, electronic musical instruments have become even easier to use and more accessible by the creation of digital synthesizers. These digital synthesizers are controlled through software. As a comparison between biological evolution and the progression of electronic musical instruments is made, several examples of each will be looked at. [32]

3. Methodology

In attempting to map biological evolution to any other type of progression over time, an understanding of biological evolution has to be attained first. The aspects of biological evolution analyzed above were the “driving forces”, or “essentials” that have to be present for a progression to be considered. These driving forces, established by Charles Darwin, are present in all facets of biological evolution and must be present for evolution to occur.

These driving forces include environmental changes and Natural Selection. There have been many improvements to the theory of Natural Selection since Darwin first proposed it in 1859. These enhancements have been looked at in this study, but the main focus is on the most widely accepted, modern theories. The basic concepts behind the modern theory of Natural Selection have been outlined and examples are given for later comparison.

The second of these driving forces, that of environmental changes, was defined in regards to biological evolution. The impacts these changes have, and the many forms they may take were considered. Examples were also given for many possible cases that were deemed relevant to our study. We explored the idea of defining living organisms as being complex. An explanation of complexity was given, how it can be applied, and why it is relevant.

At this point we set out to develop a theory describing the evolution of complex man-made artifacts. Once our theory has been fully developed we need to establish a historical background to test it against. We must decide how well our hypothesis holds to the actual progression of the electronic musical hardware we have researched and point out important similarities and discrepancies. After we reference our theory to facts we must draw conclusions as to whether or not our theory holds true. If so, how closely, and how do we account for differences? Once we make a decision we must discuss the implications of our conclusions, and what they could mean.

4. Analysis/Results

4.1. Theory of Evolution

We must now form some type of theory by which complex objects undergo cumulative change over time in order for the change to be referred to as evolution. It would be unreasonable to believe that the exact same rules and processes that govern the evolution of biological organisms apply to complex synthetic objects. For example, while synthetic objects can and are reproduced by man, they do not directly create their own offspring. Likewise, as competition can exist between competing products within a market, they do not directly compete with one another. As you can see, this means that ideas such as the fitness of a species, or product, can be applied, they must first be modified to account for such differences. Rather than compare and contrast complex synthetic objects with biological organisms, we will rather attempt to show how a few consequences of evolution can be used as proof of evolution.

The first of these consequences is that of diversity. Darwin's theory would predict that through the process of natural selection and reproductive variability, the number of species, including past and present, must continue to grow as species adapt to their environments. This is evidenced by the fact that there are over 1.5 million distinct species of plants and animals that have currently been documented. We believe that just as species adapt and diversify, synthetic objects do as well. For example, ancient man used rocks as tools, and learned to better shape them over time to perform a specific task. These tools were used as an early hammer, and as further modifications were made, such as adding handles, a variety of tools developed. Today there are hundreds of variations of the hammer. This vast diversity among types of hammers is due to the necessity for change and the evolutionary process that resulted ([6], pg. 1-3).

Diversity is one consequence, but more importantly is that of continuity. Diversity alone does not prove an evolutionary process has occurred. One cannot simply show a primitive stone tool and be able to say that a modern day hammer evolved from it. There must be several continuous steps that show a continuous progression. Just as man did not evolve in one step from early ape-like ancestors to the modern human, the hammer too had many intermediary species that facilitates and evolutionary process ([6], pg. 30-32).

As we have shown, these are the consequences of evolution. We will try to show how these apply to complex synthetic objects as well. The driving forces are still present. In the case of man-made artifacts environmental change simply refers to market demands for products, factored by social, cultural, and economic changes rather than those of climate, vegetation, etc. The selection process is also different from biological evolution, but still very present and rather than undergoing the process of

Natural Selection, they undergo more of an artificial selection. This process is still based on environmental changes (social, cultural, economic), but is done artificially by man. Products with a high fitness (have a high demand in the current market) have a higher chance of being reproduced, just as occurs by the Natural Selection process. We now have a theory set up with diversity and continuity being our gauge for the presence of evolution. Let us now apply these indicators to the historical background of electronic music equipment to determine if evolution has indeed occurred as is believed.

4.2. Diversity

Showing diversity throughout the history of electronic musical instruments is not as straightforward as it may seem. There is no one instrument that led to a variety of similar instruments further along the progression. It can be shown, however, that a single concept led to several instruments of a similar theme at many points during the series of developments and improvements of the electronic organ and synthesizer. In a broader sense, the concept of diversity is demonstrated repeatedly throughout the development of the electronic organ. The discovery of the main concepts, such as the *heterodyning effect*, led to large bursts of concurrent, but different developments in electronic music. The heterodyning effect is the effect that occurs when two, slightly varying, high radio frequency sound waves combine and create a lower audible frequency equal to the difference between the two radio frequencies.

One of the first uses of the heterodyning effect appears in the instruments created by Jörg Mager. Between 1921 and 1930, Mager created the Electrophon, the Kurbelsphäraphon, the Sphaerophon and the Partiturophon. As stated above, all of these instruments were a variation on a heterodyning tone generator based instrument, but each had different methods of input. Inventors like Mager experimented with various input formats from wheels and knobs to buttons and full keyboards. At this time period, *polyphonic* (the ability to create multiple sounds at once from one source) instruments were nonexistent, so if the creator wanted to allow multiple sounds concurrently, each sound had to have its own input device. Many inventors used one or two knobs, or button boards, but there were some that had as many as 5 keyboards with the limiting factor being the musician and his ability to use many keyboards simultaneously. [12]

In the quest to develop polyphonic instruments, inventors used a multitude of methods. By this time, inventors had established how to make sound and how to make it sound the way they wanted it to. The next step was to allow the musician to be able to make these sounds with different notes at the same time. One method that worked was using the same technology for making sound over and over again for each button pressed on the keyboard. As one can imagine, while this method worked, it was difficult to implement due to the physical size of the components available at the time. In spite of this, several methods were attempted. One of these methods was created by Hugo Gernsback and used in his Pianorad. Each of Pianorad's 25 oscillators had a small speaker built into the large loudspeaker on top of the device. This method, while successful at creating polyphony, was neither practical nor economical. [13]

Another early successful attempt at polyphony was Armand Givelet's and Eduard Eloi Coupleaux's Orgue de Ondes. The "Wave Organ" had an oscillator for each key, therefore allowing for polyphonic sound, but at the cost of its enormous size. The goal of polyphonic sound in a small package eventually became a standard, as opposed to a novelty, with the invention of the transistor and its introduction into electronic music. [14]

The modern sampler also has its roots in the development of electronic musical instruments as far back as the mid 1930s. The "singing keyboard" of 1936 played electro-optical recordings of audio waves on 35mm filmstrips that were triggered by a key press. The Mellotrons and Chamberlins of the

1960s used similar technology with magnetic tape under each key. These instruments had three tracks on each tape allowing for more variety during play. In the early days of electronic music, this method was simply a different way to obtain sounds from key presses, but they ultimately led to an entirely different type of device: the sampler. [26], [27]

With electronic organs and samplers already on the market, inventors looked to use their technology for yet another type of device that would add to the experience of the organ. First the Sideman in 1959 and then the Donca-Matic DA-20, an improvement on the Sideman, provided rhythmical accompaniment to the musician. Both devices use rotating discs with adjustable speed for tempo to accomplish their goals. The Donca DE-20 later replaced the Donca-Matic DA-20, which was an all-electronic solid-state model. The DA-20 would end up being the first instrument for the Korg Musical Instrument Company, which would later become a giant in the electronic music hardware market. [28], [29]

4.3. Continuity

Continuity is easiest to show in the sequence of instruments that span the time between the invention of the Theremin and Robert Moog's creation of the first Moog synthesizer. In this time period, the concentration seemed to be on creating electric organs. Mechanical organs, as in pipe organs, were already a standard in music, but because of their large size, could not be moved. The invention of the Theremin by Leon Termen proved that a relatively small electronic device could indeed create musical tones. The goal was then to be able to control those sounds with keys and not with hands and a pair of antennas.

Attempts at this goal actually started before the Theremin was created. These devices were electro-mechanical devices that used a combination of mechanical parts, as in gears, and electronic parts to create the desired sounds. One of these instruments was the Telharmonium, created by Thaddeus Cahill and patented in 1897. This monstrous machine was 60 feet long, weighed 200 tons and cost $200,000. The Telharmonium was essentially a collection of 145 modified dynamos employing a number of specially geared shafts and associated inductors to produce alternating currents of different audio frequencies. These signals were controlled by a multiple set of polyphonic velocity sensitive keyboards (of seven octaves, 36 notes per octave tunable to frequencies between 40-4000Hz) and associated banks of controls. Sound was first projected using acoustic horns built from piano soundboards. In later models a telephone network was used to generate the sound. The Telharmonium was never greatly accepted by the public, probably because of its large size. The underlying principles, however, were used in the Hammond Organ, which came about in the early 1930s. [7]

The principles on the Telharmonium were also used in the Choralcello, which was similar to the Telharmonium, but much smaller in size. The Choralcello was developed from 1888 to 1908 before it was presented to the public in Boston, MA. It used a similar electromagnetic tone wheel as the Telharmonium, but also used a set of electromagnetically operated piano strings. There were not many models of the Choracello sold, but many continued to be used up until the 1950s. [8]

One of the first departures from the mechanically driven instruments was William Du Bois Duddell's Singing Arc in 1899. At the time, London used carbon arc lamps to light the streets. These lamps were inefficient and also created a constant humming. Duddell was the physicist appointed to solve this problem, and in the attempt, noticed that the humming would change pitch as different voltages were applied. Duddell attached a keyboard to several arc lamps to control the voltage to the lamps and created a musical instrument. The idea was never very well received and Duddell never even filed for a patent on his device. [9]

In 1915, Lee De Forest, who is credited with inventing the vacuum tube that we know today, created the Audion Piano using vacuum tubes. The Audion Piano was a simple keyboard instrument but was the first to use a beat-frequency (heterodyning) oscillator system and body capacitance to control pitch and timbre. It used a single triode valve per octave, which was controlled by a set of keys allowing one note to be played per octave. The output of the instrument was sent to a set of speakers that could be placed around a room giving the sound a dimensional effect. De Forest planned a later version of the instrument that would have separate valves per key allowing full polyphony -- it is not known if this instrument was ever constructed. [10]

Leon Termen created the Theremin in 1917. While this instrument was not a keyboard instrument, others to create the first synthesizers would later use its concepts. Leon Termen was a cellist and electronic engineer who took what was then considered the problem with using the heterodyning effect for musical purposes and used it as a control mechanism for a musical instrument. When a body approached the vacuum tubes that were being used, the capacitance of the body caused variations in frequency. Termen wanted to free the performer of the keyboard and fixed intonation. The sound produced was monophonic continuous tone in which the performer controlled pitch with one hand and volume with the other. Termen later produced variations on the Theremin, one of which had a keyboard to replace the loop and antenna. [11]

The Electrophon, Spharaphon, Partiturophon and the Kaleidophon were all developed by musician Jorg Mager between the years of 1921 and 1930. The first of the series, the Electrophon was, like the Theremin, a heterodyning tone generator based instrument. A handle that was moved across a semi-circular dial creating a continuous glissando effect was used to control it. There was a later improvement that added more filters to improve the timbre and to avoid the continuous glissando. This version was called the Kurbelspharaphon. The Sphaerophon was another version that replaced the handle with a pair of short-keyed monophonic keyboards. The short keys allowed the player to use both at once creating a duophonic tone. The Partituophon was similar to the Sphaerophon, but with four, and later, five keyboards. This allowed for four and five voice playing, but each voice had to have its own keyboard, making it more difficult to play. It was because of this that the keys were so small. The Kaleidophon was completed in 1939, and most of the information available on it is word of mouth only. All that is known of this instrument is that is was "an electronic monophonic instrument with 'kaleidoscopic' tone mixtures". [12]

In 1923, a radio technology journalist set out to create a polyphonic electronic music instrument and created the Staccatone as his first attempt. It was not until he paired up with Clyde Finch from the Radio New Laboratories in New York that he truly succeeded. Together they built the Pianorad in 1926. The Pianorad had 25 single LC oscillators for every key in its two-octave keyboard giving the instrument full polyphony. It can be seen here that at this point in time, inventors had devised various ways to create sound electronically and the focus was starting to drift towards making polyphonic instruments that more closely resembled the piano in musical abilities. [13]

In 1929, the Orgue des Ondes appeared as a cheap replacement for pipe organs. Developed by Armand Givelet and Eduard Eloi Coupleaux, who had previously worked on a monophonic instrument, the Orgue des Ondes, or Wave Organ, removed the need for microphones by connecting straight into an amplifier or radio transmitter. The organ had over 700 vacuum oscillator tubes to give it a pitch range of 70 notes and ten different timbres. There were most likely over 1,000 vacuum tubes for oscillators and amplifiers. The Orque des Ondes eventually lost popularity due to the superiority of the American built Hammond Organ. [14]

The Hammond Organ was designed and built by ex-watchmaker Laurens Hammond in April of 1935. Hammond created the Hammond Organ Company in Evanston, Illinois and soon the Hammond Organ became extremely popular in the leisure market for organs. The Hammond used technology that related directly to Cahill's Telharmonium, but in a much smaller package. The Hammond organ generated sounds in the same way as the Telharmonium, the tone wheel and the tone generator assembly consisted of an AC synchronous motor connected to a gear train which drove a series of tone wheels, each of which rotated adjacent to a magnet and coil assembly. The number of bumps on each wheel in combination with the rotational speed determined the pitch produced by a particular tone wheel assembly. A Hammond console organ included two 61-key manuals; the lower, or Great, and upper, or Swell, and a pedal board consisting of 25 keys. The concert models had a 32-key pedal board. Hammond also patented an electromechanical reverb device using the helical torsion of a coiled spring, widely copied in later electronic instruments. The Hammond was a success as a home entertainment instrument and also saw success in Jazz, Blues ad Rock until the late 1960's. [15]

It was around this time, from the mid 1930s into the 1940s, that more and more instruments were using vacuum tubes as their primary method of sound generation. In the preceding years, many other methods were explored, but as the vacuum tube became more commonplace, it was noted that instruments could be made smaller and less complicated by using vacuum tubes. Vacuum tube-based organs, like instruments that came before, were mainly grouped into monophonic and polyphonic, but as the technology was improved upon, monophonic keyboard instruments were built and used less and less.

The Hammond Organ Company created the Novachord in 1939, and it was Hammond's first tube-based instrument. The Novachord used 169 vacuum tubes to control and generate sound and had a seventy-two-note keyboard with a simple pressure sensitive system that allowed control over the attack and timbre of the note. The sound was produced by a series of 12 oscillators that gave a six-octave range using a frequency division technique. The Novachord was one of the first electronic instruments to use this technique, which later became standard in electronic keyboard instruments. The Hammond Organ Company also developed the Solovox in 1940, which was a less complicated, and monophonic, vacuum tube instrument. It was considered a keyboard attachment instrument and was intended to accompany the piano with organ type lead voices. The Solovox was able to create a range of string, woodwind and organ type sounds and was widely used in light music of its time. [16], [17]

In 1945, the first hints of a modern synthesizer appeared in the form of the Hanert Electric Orchestra built by John Hanert for the Hammond Organ Company. The Electric

Orchestra was described as an "Apparatus for Automatic Production of Music" [17].

The Synthesizer was an instrument for composition and synthesis of electronic music similar to the later RCA Synthesizer and other coded performance machines. Instead of using punch paper tape like the RCA Synthesizer, the Hanert Synthesizer had a moving mechanical scanning head that moved over a sixty-foot long table covered in eleven inch by twelve-inch paper cards. The paper cards held the characteristics of the sound (pitch, duration, timbre and volume) stored in the form of graphite marks that were 'read' by direct electrical contact of the scanning head. Hanert's method allowed for a great deal of flexibility, as marks could be added to the cards with a graphite pencil and the cards could be arranged in any order.

For years, inventors and musicians explored many variations on the monophonic vacuum tube keyboard instrument. Some inventors turned their focus to simulating other instruments like the trumpet or saxophone, while other inventors developed machines that created sound effects for movies and TV. Other inventors turned to more unorthodox music and used electronic instruments to try to pioneer a new style of music. The end result of all this exploration and inventing was a much better understanding of the underlying technology that would eventually lead to the synthesizer.

In the years 1947 through 1949, Harald Bode, who would prove to be one of Robert Moog's influences in developing his synthesizers, built the Melochord. The Melochord was a monophonic keyboard instrument based on vacuum tube technology with a keyboard that used pitches derived from the traditional equal-tempered 12-note scale with switches extending the 37-note range from three octaves to seven. A foot pedal allowed overall control of the volume and a novel, electronically operated envelope shaper could be triggered for each key. A later version incorporated two keyboards; the second keyboard being able to control the timbre of the other, a technique used in subsequent modular type synthesizers. Although the Melochord suffered technical drawbacks, it was to play an important role in the development of modern analog synthesizers. In 1961 Harald Bode, recognizing the significance of transistor-based technology over valve-based synthesis, wrote a paper that was to revolutionize electronic musical instruments. Bode's ideas of modular and miniature self-contained transistor-based machines was taken up and developed in the early 1960's by Robert Moog, Donald Buchla and others. [18]

Many recognize Raymond Scott as the person who made Robert Moog and his synthesizers a possibility. Moog worked for Scott when he was developing instruments of his own and eventually inspired Moog to create his. One of Scott's first inventions was the Clavivox, built in 1952. The Clavivox started its life as a Theremin built by Moog himself. Moog, at the time, was building Theremins with his father and selling them. Scott took this Theremin and removed the pitch antenna, and in its place put a keyboard. Further developments distanced the Clavivox from its roots quickly as Scott realized that there were more elegant ways of controlling an electronic circuit. Much of the sound-producing circuitry would actually closely resemble the first analog synthesizers made by Moog in the 1960s. [19], [30]

In 1952, two electronic engineers employed at RCA's Princeton Laboratories invented the RCA synthesizer. This synthesizer was similar to the Hanert Electric Orchestra in that it was programmable. The RCA used a punch-paper roll on which the composer predefined a complex set of sound parameters. This allowed mixing of generated sounds and shaping of the sound with dividers, filters, envelope filters, modulators and resonators. The mkI used twelve vacuum tube oscillators to produce sound and the mkII used twenty-four. While the RCA Synthesizer never fulfilled its inventors' expectations, its novel features were an inspiration for a number of electronic composers during the 1950s. [20]

There were other variations on this method of first "programming" the music onto some medium. One such example were The Composer-Tron, built in 1953, which allowed the composer to "draw" the music in the form of patterns and shapes on a surface with a grease pencil which was then read by a cathode ray tube. Another similar method was Oramics, developed by Daphne Oram in 1959. Oramics was the method of "drawing" the music onto a set of ten sprocketed synchronized strips of 35mm film, which covered a series of photoelectric cells that in turn generated an electrical charge to control the sound frequency, timbre, amplitude, and duration. A third such device was the Siemens Synthesizer developed from 1959 to 1969 by Helmut Klein and W. Schaaf at Siemens Halske in Germany. Like the RCA Synthesizer, the Siemens used paper rolls as a method to program the music into the machine prior to playing. Later, a visual input device and other types of input devices were added to the unit. [21], [22], [23]

1957 brought music and computers together for the first time; a union that time would prove to be a long and successful relationship. Max Matthews, from Bell Laboratories, developed MUSIC 1, which was soon replaced with MUSIC II running on an IBM 704 and written in assembler code was the world's first computer synthesis program. MUSIC III was written in 1959 for the IBM 7094, which marked another prosperous union; music and the transistor. The MUSIC series finally ended in 1968 with MUSIC V written in FORTRAN for the IBM 360. [24]

In 1963, the age of the modern analog synthesizer began with the development of the Moog Synthesizer. Robert Moog started his career by building Theremins and selling them and at the same time, began absorbing ideas about transistorized modular synthesizers from the German designer Harald Bode. Moog began to manufacture his synthesizers in collaboration with composers Herbert A. Deutsch, and Walter (later Wendy) Carlos. The success of Carlos' album, "Switched on Bach", which was recorded entirely on Moog Synthesizers, launched Moog from the electronic avant-garde community, as most previous instruments of this type had been, into the popular music community. With this leap came purchases made by such names in popular music as The Beatles and Mick Jagger, which only helped to increase the credibility of Moog's products. Unfortunately, Moog's company did not last the decade for companies such as Roland and ARP took Moog's ideas and created more complex and more cost-effective products. Moog later started another company named Big Briar and returned to building Theremins, but in transistor form. What Moog did for the industry was set the standard for analog synthesizers for years. Many companies came and went and built and sold synthesizers in the likeness of Moog's products opening the doors for an entirely new sound that found a home in modern music and entertainment. [30], [25]

In agreement with the definition of continuity, the series of inventions that led to the development of the Moog synthesizer follow a smooth progression. At no point was there a leap in the technology of electronic organs that led directly to the analog synthesizer. Throughout the history of the electronic organ and analog synthesizer, there are many examples of inventors using ideas from previous instruments to build upon and improve for their invention. One example of this is the Hammond Organ that used principles from the Telharmonium, built almost 40 years earlier, to generate its sound. The Hammond used these principles in more of an electronic form, as opposed to the mainly mechanical form of the Telharmonium, but used the principles nonetheless. Another such example can be found with the Moog itself. Robert Moog studied the work of Harald Bode, who built the Melochord, and used his ideas in developing his synthesizers.

5. Conclusions

It is once again important to stress that we cannot directly compare the theories of biological evolution to that of complex synthetic objects, namely electronic musical equipment.

What we do intend to do however, just as Darwin himself had done, is to use the historical record as evidence evolution has indeed occurred. As the realm of products in the world of complex synthetic objects continues to grow, diversity has been shown to be quite substantial. If there were no evolutionary process present, we would witness a loss of diversity. This however is certainly not the case. Since the year 1790, the United States has issued over 4.7 million different patents. A majority of these patents can be viewed as an "individual species" comprising a realm of man-made artifacts. Compared to the previous number of 1.5 million known species of plants and animals, it can be assumed that the diversity of the complex synthetic world is equally as great ([6], pg. 2).

This is also evident among electronic musical equipment, as can be seen by the various models of instruments available today on the market. One can see here, from the above examples that once inventors and musicians discovered ways to make music from electronic devices in the form of organs, they began to use that technology and branch out into other areas of electronic music. While these instruments were not electronic organs, and some did not require a person to interact constantly with the device, they still used the same technology employed in electronic organs to make sounds. Vacuum tubes, oscillators, tone wheels, and later transistors were all used in these various devices, but to create a different type of sound. Diversity can also be seen down at a lower level with the similar techniques and methods that were used to create instruments that were mostly the same, but with small variations, providing the industry with many ways to create electronic music.

We feel that the historical record shows quite convincingly that there is ample proof of continuity existing within the progression of electronic musical equipment. This subsequently suggests that it is not simply a progression, rather a form of evolution. Most importantly is that no single invention or idea can be found having no predecessor of some sort. Every new model is some variation or combination of earlier models or components. A very clear "family tree" of sorts can be constructed with all appropriate links.

In all we have concluded our research has a strong indication that technological advancements and progress not be viewed in the traditional sense of occurring in hopes of achieving some ultimate goal. This rather suggests that the progression follows an evolutionary pattern similar in design to that of our current ideas of biological evolution. What this means is that this progression occurs rather to adapt the product (or particular "species" of instrument) to its current environment within the market of other competing products. Similar to biological evolution this suggests that there is no true ultimate goal; rather it is an ongoing process to adapt. There is some concern that since adaptation occurs via Artificial Selection, that it is through design, and not a process of random variation. Although these products are designed based upon similar products, not all instruments created are best suited to the market (environment). What this means is that several products, or "species", appear on the market, but only the ones best suited to the current market survive. Mutation does not play such a large role in Artificial Selection as it does in Natural Selection, and this is one of the major differences we must be aware of when comparing the evolution of biological and artificial species.

One advantage complex synthetic objects have is due to their selection process and reproduction methods. Changes as a result of the Artificial Selection process can occur much faster than those produced through Natural Selection and thus random variation. They can occur over a few generations or even from one generation to another. This is a major reason that the number of species observed is much larger for complex synthetic objects over a much smaller timeframe. Ultimately we believe that although differences are present between biological evolution and the progression of electronic musical equipment, it is nevertheless evolution.

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