Introduction

In 2019, the MIT Laboratory for Atomistic & Molecular Mechanics released its first version of the Amino Acid Synthesizer, a musical instrument that operates as a free app on Android smartphones.[1] To create their Amino Acid Synthesizer, Buehler and his team first attributed a tone value to each amino acid—depending on its oscillation frequency—which finally resulted in 20 music notes between F2–C#5.[2] Using this method, every amino acid is sonified and given the potential to compose music via touchscreen. As explained by Buehler et al., this auditory approach furthermore enables an artificial intelligence—here a neural network—to 'understand' the basic construction of proteins: "the neural network has learned the design principles by which certain structural features are generated from the sequence of amino acids, closing the loop between material → sound → material."[3]

Based on the Amino Acid Synthesizer concept where each amino acid is attributed a tonal value, the idea has the theoretical potential to be further elevated by transforming the musical instrument into a musical composition machine—or just music machine—creating symphonies out of the sequence of amino acids in a protein. In this way, proteins give rise to a supposedly natural musical composition. Building on the ideas of Buehler et al, this paper aims to envision a music machine based on a different acid sequence—deoxyribonucleic acid, known commonly as DNA.

The first section of this paper begins with a brief foray into the fundamentals of bio protein synthesis. After having established this fundamental background knowledge, the focus shifts toward the *Quadrille Melodist*—introduced by John Clinton around the year 1865 in London[4]—will serve as a model for this endeavor after. In the second part, the theoretical possibility of a DNA based music machine is explored critically, particularly with reference to its potential for creating 'natural' compositions. Importantly, while the DNA based music machine's conceptual success or failure will prove to be contingent on the Lacanian symbolic quality of the sheets music itself, the feasibility of the concept is not central to this exploration. As will become apparent in the conclusion, pondering the prospect of the DNA Music Machine highlights important questions about what constitutes 'natural' sounds and also helps to reinforce the unique quality of the *Quadrille Melodist* in the world of music machines, past and present.

Protein biosynthesis

In *The Logic of Life* (1970), the geneticist and Nobel Prize winner François Jacob describes heredity as a kind of program that contains the two central characteristics of design and memory. "By 'memory' is implied the traits of the parents, which heredity brings out in the child. By 'design' is implied the plan which controls the formation of an organism down to the last detail."[5] Central to the 'heredity program' is DNA—

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[1] See Amino Acid Synthesizer; see Chandler 2019.

[2] See Buehler *et al.* 2019, p. 7473.

[3] Ibid.

[4] See Braguinski 2019, p. 86.

[5] Jacob 1973, p. 2.

passed on from generation to generation as memory, determining the proteins formed out of amino acids—which essentially takes over all possible biological functions in the cell. The most important aspects of this protein biosynthesis are described below. Since DNA is central to this paper's objectives, it will be dealt with first before also outlining its well-known sibling, RNA.

In *Studies on the Chemical Nature of the Substance Inducing Transformation of Pneumococcal Types* (1944), Oswald T. Avery, Colin M. MacLeod, and Maclyn McCarty experimentally pointed out that the cause of specificity, a biological concept that determines life phenomena, processes and characteristics is found in DNA.[6] According to Jacob, although DNA had been known as a substance in the nucleus for almost a century, it was only the research results of Avery et al. that finally brought together the young field of genetics with the even younger molecular biology—a term coined by physicist Warren Weaver in 1938.[7] According to molecular biologist and science historian Lilly E. Kay, whereas the former understanding of heredity was inextricably linked to Georg Mendel and could only be regarded as *explanandum* [explanatory], Avery et al. introduced DNA as memory for genetic information, making it an *explanans* [explanation]—something of an epistemic clash between the disciplines of genetics and molecular biology.

DNA is fundamentally composed of four nucleotides, which are distinguished by their organic bases adenine (A), guanine (G), cytosine (C) and thymine (T). In 1929, biochemist Phoebus Levene—the originator of the term nucleotide—described the composition of nucleic acids, having previously been introduced by histologist Richard Altmann in 1889.[8] According to chemist Georg Schwedt, a nucleic acid consists of individual nucleotides whereby ribose and phosphoric acid esters form a chain in which a base is bound to each sugar. The best known and most important representatives of nucleic acids are RNA and DNA.[9] In contrast to the ribonucleic acid (RNA)—which will be revisited later in this paper—DNA consists of two discrete quaternary chains connected by the bases A to T and G to C: "This ability of specific base pairing plays a crucial role in the biological function of nucleic acids, the memory, and processing of genetic information."[10] According to the physicist and memory theorist Horst Völz, DNA ultimately holds the decisive data for protein biosynthesis. This data makes it possible to produce a sequence of amino acids based on a specific set of rules and finally form the respective protein.[11] This set of rules will be outline with more detail in the following paragraph.

To make the genetic information of the DNA accessible for the formation of amino acids, the DNA must first be 'opened' and copied complementarily with nucleotides by

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[6] See Avery et al. 1944; see Kay 2001, p. 77.

[7] See Kay 2001, p. 20, 90f; see Avery *et al.* 1944; see Schwedt 2011, p. 138.

[8] See Schwedt 2011, p. 137f.

[9] Schwedt 2011, p. 139.

[10] Ibid., p. 143 *[translated by the author]*; In 1953, James Watson and Francis Crick pointed out that the structure of DNA forms a double helix. (See Watson & Crick 1953, p. 737).

[11] See Völz 2003, p. 188.

the RNA. This copy is then processed into amino acids in the ribosome. The DNA remains unchanged.[12] Völz contrasts DNA to RNA, explaining that RNA is only single-stranded and relatively short—up to a few thousand nucleotides. Moreover, RNA contains a different sugar (ribose), and T is replaced by the slightly modified U (uracil).[13] In the first phase of protein biosynthesis, called transcription, the DNA is copied from the *messenger RNA* (mRNA), which produces the first ribonucleic acid. The 'messenger' appellation is derived from its nucleotide sequence's determination of the protein to be produced.[14] According to Schwedt, however, the actual information transfer takes place between mRNA codons and *transfer RNA* (tRNA): "Depending on the sequence information, the mRNA provides the correct amino acid to the ribosome for the synthesis of functional proteins."[15] Finally, the tRNA synthesizes the different amino acids in the ribosome from nucleotide triplets in what is called translation. One example would be the amino acid phenylalanine, which is made up of the triplet *UUC*.[16] The protein structure depends on the sequence of the amino acids, which in turn are caused by the nucleotide triplets: "For a protein of e.g. 1000 amino acids, the corresponding 3000 nucleotides can be found in the comparatively very long DNA of 10^7 to 10^{10} nucleotides."[17]

Because each amino acid can be formed out of 4^3 base triplets, this leads to the assumption that 64 different amino acids must exist—at least in purely mathematical sense. In reality, there are only 20 amino acids, which means that one amino acid can be made up of several triplets. According to Völz, this on the one hand corrects errors that have occurred—for instance during the process of copying—and on the other hand, allows a few triplets to initiate start and stop commands, since every amino acid sequence needs a beginning and an end to be able to form a protein.[18] Thus, the base triplet *AUG* triggers the protein biosynthesis; but, it can also occur as the amino acid *Methionine* in the sequence. To complete the progression, base triplets *UAA*, *UAG* and *UGA* conclude the synthesis. This set of rules for protein biosynthesis is considered universal, which is why essentially every organism forms the same amino acid with the same triplets.[19]

In *Who Wrote the Book of Life?* (2000), Kay pointed out that referring the rules of protein biosynthesis as a genetic code is incorrect because from a linguistic and cryptanalytic point of view it is only a table of correlations.[20] Consequently, it is a correlation between triplet(s) and amino acid; however, it has been embedded in the culture as genetic code. Now that the relevant aspects of protein biosynthesis have been

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[12] See Schwedt 2011, p. 141ff.
[13] See Völz 2003, p. 190.
[14] See Völz 2003, p. 190.
[15] Schwedt 2011, p. 144 [*translated by the author*].
[16] See Schwedt 2011, p. 143f.
[17] Völz 2003, p. 189 [*translated by the author*].
[18] See Völz 2003, p. 188f.
[19] See Kay 2001, p. 20.
[20] Kay 2001, p. 19.

described, the *Quadrille Melodist* and its relevance to a proposed DNA music machine can now be properly discussed.

Quadrille Melodist

The *Quadrille Melodist* was designed as a paper-based system intended to take the work of writing music away from amateur pianists—a music machine, produced in small numbers by the composer John Clinton around 1865 in London.[21] In contrast to the music *box*, which merely performs the same musical piece before repeating the same 'pre-programmed' arrangement, the *Quadrille Melodist* allowed new piano pieces to be freshly composed over and over by following the rules of music theory.[22] "Clinton's method constituted an attempt at mechanizing the compositional process using the theories and technologies of the Victorian era. […] [His] method was planned, rule-based and was communicated in terms that would produce similar results"[23]—as described by musicologist Nikita Braguinski. In an advertisement, it was said: "428 Millions of Quadrilles for 5s. 6d. The Quadrille Melodist, consisting of an almost endless variety of New Quadrilles, composed and invented for the pianoforte, by J. Clinton (Professor in the Royal Academy of Music)."[24] The *Quadrille Melodist* does not play notes directly, but—as suggested by the name—generates quadrilles, a dance-orientated music form.[25] Using this method, it stings together 'unexpected' melodies combinations, which can be played by the pianist. Even if these music compositions are not generated automatically, Braguinski nevertheless speaks of a pre-digital music machine where a human operator is needed:

> Since the *Melodist* mechanizes the logical process of keeping the needed level or musical order […], it resembles more the mechanical calculation machines of the 19th century such as Charles Babbage's Difference Engine than a traditional score. The most important parallel between the Difference Engine and the Melodist is here the underlying conviction that a complex mental process can be subdivided into simple, mechanisable steps.[26]

Next, this paper will consider the question of how this music machine creates the different compositions, beginning with the construction of the Quadrille Melodist.

On first glance, the Melodist conceals its potential as a music machine since it consists of merely a cardboard box containing cards with 'musical fragments' printed upon them. But this music machine breaks with traditional sheet music which had been established since the introduction of letterpress printing and formed as a chronological

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[21] See Braguinski 2019, p. 86f, 91.

[22] See Braguinski 2019, p. 1.

[23] Ibid.

[24] "Advertisement for the *Quadrille Melodist"* in: Braguinski 2019, p. 96, Plate 2.

[25] "Often, quadrilles were adapted from other popular works. The names of the parts that make up the quadrille […] can thus be understood as subgenres in their own right: families of type rather than stable, individual pieces of music. A comparison of quadrilles by different composers shows that they are connected only by their predictable, dance-orientated form and by broader musical features, and not by a universally shared melody." (Braguinski 2019, p. 94f).

[26] Ibid., p. 91.

concept extended across one or more pages.[27] Instead of "a static representation of existing music," which originated with an author, the cards enable, according to Braguinski, a "mechanical production of new pieces."[28] This is due to the structure of the Melodist: it consists of three rows, each row providing seven compartments for the aforementioned cards. In addition to the "short snippets of piano music,"[29] the cards also feature letters which provide positional information. There is thus an interdependency between the respective 'musical fragment' and one of the 21 compartments whereby each compartment is filled with eleven cards—i.e. each card has a strict position in the cardboard box, determined by a letter between A–U.[30] In total, the melodist contains two sets of cards which amounts to 462 cards. The two sets differ not only in terms of the notation and time signatures determined by the quadrille dance, but are also separated from each other very strictly by the position-indicating letter—at least if one wants to use the melodist properly. While one set describes the position of the cards by single letters (A-U), the other set assigns the card to the respective compartment by two identical letters (AA-UU). Besides the letters indicating the positions, there are numbers between 1-11 on the cards.[31] Basically, these are not as important as the position indicated by the letters, rather they serve only for orientation in the individual box and distinguish the respective 'music pieces.' In contrast, the positional information from the letters is essential to the success of the music machine. To illustrate this, this paper will now take a look at the handling of the *Quadrille Melodist* in order that the *lógos* of this pre-digital music machine can become noticeable.

Imagine you have guests to the Quadrillen Dance in your own home and now you want to direct them using piano music. Let us assume that the dance starts with the following card combination: A1 | B1 | C1 | D1 | E1 | F1 | G1.[32] This combination could then be varied to A1 | B4 | C2 | D11 | E1 | F8 | G9, and as long as the cards remain in their assigned letter grouping, the music remains as a harmonious whole. On this point Braguinski emphasizes that "the resulting melodies do hold in themselves a certain aesthetic quality with a lot of chromatic embellishment, grace notes, dynamic change and an occasional harmonic surprise."[33] This form of combinatorics leads to the analogy between melodist and kaleidoscope, which was likely established by Clinton himself:[34] "to offer a logical continuation of a line that begins on one card and ends on another (such as a slope of a mountain), the direction of such lines must be consistent across cards. The same principles also apply to melodic lines printed on individual cards."[35] According to this, each card has a defined beginning and a prescribed end,

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[27] See ibid., p. 87f.
[28] Ibid., p. 87
[29] Ibid.
[30] See Braguinski 2019, p. 88f.
[31] See ibid.
[32] As this is an example, only the first row of the Quadrille Melodist is described. However, the dance extends over all three rows.
[33] Braguinski 2019, p. 89, note 7.
[34] Braguinski 2019, p. 92.
[35] Ibid.

which connect to the surrounding cards.[36] In this way, the rules of a musical composition can finally be kept. If we now consider the possible combinations for a set of cards, we find that, contrary to the 428 million quadrille promised by the advertisement, there are a total of 11^{21} = 7,400,249,944,258,160,101,211 possible pieces of music.[37] For Braguinski, this incorrect indication of possibilities in the advertisement indicates that the *Quadrille Melodist* would have be sold mainly to musicians with little musical or mathematical knowledge.[38]

Consequently, the Melodist makes it possible to play new quadrilles indefinitely—monotony becomes a vain venture. Since each card is located in a fixed position within the cardboard box, the musician can exchange the individual 'musical fragments' in the slot while playing and, thus, evoke new music: "For the player, it is possible to play the quadrille dance in the same combination, with only slight changes, or with a fully new arrangement of cards."[39] It is precisely the melodist's capability of composing while the music is played on the piano which leads Braguinski to set it apart as a music machine from, for example, the *arca musarithmica* combination box designed by Athanasius Kircher or the *Musikalische Würfelspiel* [musical dice game][40]: "The time component is crucial in this case. In a temporal artform such as music the speed of operation determines whether the tool can be used live, or whether it presupposes a period of preparation. Thus, while the mathematical structure of the *Würfelspiel* resembles the core elements of the *Melodist*, its status as a tool is different."[41]

Having established the basic knowledge of protein biosynthesis and describing the creation and use of the *Quadrille Melodist*, the DNA-based music machine can now be presented in the following section.

DNA-Based Music Machine

At a concert in January 1981, biologist Mary Anne Clark and botanist K.W. Bridges presented their work *Inflections: Musical Interpretations of DNA Data*—probably one of the first works to associate sounds with DNA.[42] Similar to the previously discussed Amino Acid Synthesizer, a sonification of DNA or proteins takes place here; a transformation rule between DNA, and its respective proteins together with tones that are "pleasantly unusual but quite listenable"[43]; an assignment between two different (language) systems; basically, a code. If one disregards the fact that the musical notation traced back to

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[36] A certain exception are the cards at the beginning and end of a row. Nevertheless, due to their notation, these can only be used at the respective positions.

[37] See Braguinski 2019, p. 90.

[38] See Braguinski 2019, p. 90.

[39] Ibid., p. 88.

[40] The *Musikalische Würfelspiel* is associated with the composer Wolfgang Amadeus Mozart, who published an instruction for composing waltzes by means of two throws postmortem in 1793. (See Braguinski 2019, p. 91). The basic principle, i.e. composing using dices, can be traced back to the composer Johann Philipp Kirnberger and his 1767 publication *Der allezeit fertige Polonoisen- und Menuettencomponist*. (See Kirnberger 1767).

[41] Braguinski 2019, p. 91.

[42] Dunn & Clark 1999, p. 27.

[43] Ibid.

Pythagoras is already a code for phonetics, it becomes clear that the pure encoding of DNA into audible acoustics alone does not lead to a composition that follows the rules of music theory, even if that structure—that is, the *lógos* of the *bíos*, the biology—seems so promising.[44] Yet according to musicologists Perter Wicke, Kai-Erik and Wieland Ziegenrücker, a musical composition in the "artificial European" sense is "the result of a musical idea (artistic inspiration) and its technical elaboration based on melody, harmony and form, compositional technique, instrumentation, etc."[45] Consequently, it is not enough to simply sonify DNA, amino acids, or proteins to design a music machine that corresponds to the quadrille melodist. Furthermore, it must be clear that the DNA-based music machine presented below is a transformation rule, an assignment between amino acid and 'small' compositions. This code represents a correlation between the 'DNA' system and the system of 'musical notation,' the phonetic code. In context of the DNA-based music machine's presentation, the *Quadrille Melodist* characteristics are also clarified once again in turn.

While Clinton 'merely' operated according to the theories of melody, harmony and form—as well as the quadrille dance itself—the *lógos* of the *bíos*, in contrast, sets a metaphorical framework for the development of a DNA-based music machine right from the beginning of the conception. Technically, there are twelve 'base tones,' which is why the four organic bases of DNA alone are not sufficient to think of a music machine. Equally unsuitable would be the encoding of the 'base tones' on one of the 64 base triplets as this would break with the composition rules as a sequence within the RNA. The individual amino acids seem to be the most promising. However, on the one hand, the twelve 'base tones' cannot easily be divided among the 20 amino acids—as is the case with the amino acid synthesizer where certain tonal values occur twice. On the other hand, this would also break with the theories of melody, harmony and form—which is why this type of coding is only suitable for sonification purposes. Even a reduction of tones by fixing on one scale could not be adequately encoded due to *lógos* of the *bíos*. Although a harmonic melody would be created, it would lack rhythm and/or metrics, for example. More importantly, however, a single melody is not yet a full composition. Consequently, the DNA-based music Machine avoids individual notes or note values and instead works with 'musical fragments,' such as small pieces of piano notation following the example of the *Quadrille Melodist*. Each amino acid and the start and stop commands are assigned an individual 'tiny' composition. The intention is to create 'natural' compositions based on protein biosynthesis, i.e. compositions defined by the *lógos* of the *bíos*.

As previously noted, a protein consists of a beginning and an end, as well as a sequence of amino acids of which there are 20 in number. Therefore, a total of 22 pieces have to be composed. The length of these compositions is irrelevant, in contrast to the

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[44] "It seemed to me that DNA's relatively simple alphabet of four coding elements that form just 20 'letters' (amino acids), which in turn combine to form the basis of all earth life, had to be rich with structure and very likely would resonate with the inner maps of humans, who are built upon this code." (Dunn & Clark 1999, p. 27).

[45] Wicke *et al.* 2007, p. 381 *[translated by the author]*.

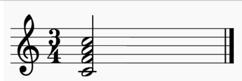
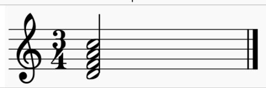
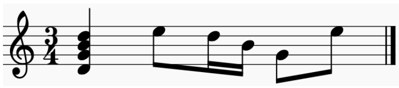
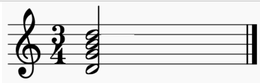
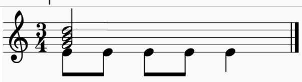
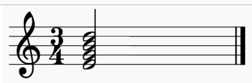
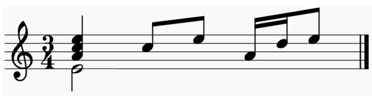
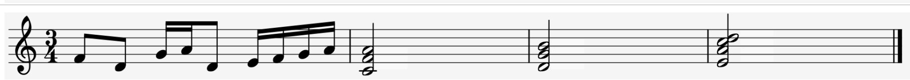
Quadrille Melodist, which is limited due to the confines of the cardboard box—a piece of music which is too long would simply not fit into the box. The pieces of music printed on the *Quadrille Melodist's* cards follow an order running from left to right. Consequently, each card follows on from the previous card, thus respecting the rules of composition. Even if, for example, dissonant note values appear, these lead to consonant note values according to musical composition theory.

In the case of the conceived DNA-based music machine, the lack of a defined sequential order poses a problem. If you want to develop a music machine that produces compositions using protein biosynthesis, it must be clear that neither the length of the amino acid sequence is known, nor the number or position(s) of the individual amino acids that are used. This has implications for the composition of each musical 'fragment' per se. Only the beginning and the end of the amino acid sequence can be encoded in a defined way, since those base triplet commands start or stop the synthesis and are, thus, already determined in each protein regarding their position. Consequently, each amino acid has to be assigned a composition that can be connected to the other 'pieces of music'—both at the beginning and the end of the 'pieces.' The compositions of the start and stop triplets, on the other hand, only need to be connectable to the encoded 'musical pieces' of the amino acids on one side, depending on whether the start or stop command is involved.

Let us assume, for example, that a protein consists of three amino acids.[46] The starting triplet is ATG, followed by the amino acids cysteine (UGU), phenylalanine (UUC), and tryptophan (UGG). The sequence is completed by the stop triplet UAA. While the start triplet ATG only needs to be connected at the end and the stop triplet UAA only at the beginning of its short composition, the compositions of the amino acids cysteine (UGU), phenylalanine (UUC) and tryptophan (UGG) need to be connected to the other compositions both at the beginning and at the end. Therefore, the 'musical fragments' of each amino acid attributed to it were composed as well as the commands start/stop in D major—easy to understand for everyone—consisting of 8 note values and as few octaves as possible. This *Amino Acid to Sheet Music Code* (see page 9) allows the rules of composition to be respected, no matter which amino acid follows the next.

Since there are 20 amino acids—each with its own unique composition, which can appear at any point in the work except at the beginning and end—there are $1 + 20^n + 1$ possible compositions. The protein beta-globulin, for example, consists of a total of 146 amino acids plus one beginning and one end. Consequently, this protein has a total of 148 'musical fragments' which can be traced back to the *Amino Acid to Sheet Music Code* (see p. 10ff). Furthermore, because the *Amino Acid to Sheet Music Code* can be transferred to the codon table, a composition can be evoked using single-stranded RNA, regardless of whether it is a useful protein.

[46] This is just an example; the protein described here does not exist.

Amino Acid	Sheet Music	Code
Alanine (Ala)		A
Arginine (Arg)		B
Asparagine (Asn)		C
Aspartic acid (Asp)		D
Cysteine (Cys)		E
Glutamine (Gln)		F
Glutamic acid (Glu)		G
Glycine (Gly)		H
Histidine (His)		I
Isoleucine (Ile)		J
Leucine (Leu)		K
Lysine (Lys)		L
Methionine (Met)		M
Phenylalanine (Phe)		N
Proline (Pro)		O
Serine (Ser)		P
Threonine (Thr)		Q
Tryptophan (Trp)		R
Tyrosine (Tyr)		S
Valin (Val)		T
START		Z
STOP		Y

The Amino Acid to Sheet Music Code

1. Letter	2. Letter				3. Letter
	Uracil	**C**ytosin	**A**denin	**G**uanin	
Uracil	Phe	Ser	Tyr	Cys	**U**racile
	Phe	Ser	Tyr	Cys	**C**ytosine
	Leu	Ser	**STOP**	**STOP**	**A**denine
	Leu	Ser	**STOP**	Trp	**G**uanine
Cytosine	Leu	Pro	His	Arg	**U**racile
	Leu	Pro	His	Arg	**C**ytosine
	Leu	Pro	Gln	Arg	**A**denine
	Leu	Pro	Gln	Arg	**G**uanine
Adenine	Ile	Thr	Asn	Ser	**U**racile
	Ile	Thr	Asn	Ser	**C**ytosine
	Ile	Thr	Lys	Arg	**A**denine
	Start / Met	Thr	Lys	Arg	**G**uanine
Guanine	Val	Ala	Asp	Gly	**U**racil
	Val	Ala	Asp	Gly	**C**ytosine
	Val	Ala	Glu	Gly	**A**denine
	Val	Ala	Glu	Gly	**G**uanine

The Supposed Genetic Code

1. Letter	2. Letter				3. Letter
	Uracil	**C**ytosin	**A**denin	**G**uanin	
Uracil	N	P	S	E	**U**racil
	N	P	S	E	**C**ytosine
	K	P	**Y**	**Y**	**A**denine
	K	P	**Y**	R	**G**uanine
Cytosine	K	O	I	B	**U**racil
	K	O	I	B	**C**ytosine
	K	O	F	B	**A**denine
	K	O	F	B	**G**uanine
Adenine	J	Q	C	P	**U**racil
	J	Q	C	P	**C**ytosine
	J	Q	L	B	**A**denine
	Z / M	Q	L	B	**G**uanine
Guanine	T	A	D	H	**U**racil
	T	A	D	H	**C**ytosine
	T	A	G	H	**A**denine
	T	A	G	H	**G**uanine

The Sheet Music Code in Codon Table

ATG	GUG	CAC	CUG	ACU	CCU	GAG	GAG	AAG	UCU	GCC	GUU	ACU	GCC	CUG	UGG	GGC	AAG	GUG	AAC	GUG
Z	T	I	K	Q	O	G	G	L	P	A	T	Q	A	K	R	H	L	T	C	T

GAU	GAA	GUU	GGU	GGU	GAG	GCC	CUG	GGC	AGG	CUG	CUG	GUG	GUC	UAC	CCU	UGG	ACC	CAG	AGG
D	G	T	H	H	G	A	K	H	B	K	K	T	T	S	O	R	Q	F	B

UUC	UUU	GAG	UCC	UUU	GGG	GAU	CUG	UCC	ACU	CCU	GAU	GCU	GUU	AUG	GGC	AAC	CCU	AAG	GUG
N	N	G	P	N	H	D	K	P	Q	O	D	A	T	M	H	C	O	L	T

AAG	GCU	CAU	GGC	AAG	AAA	GUG	CUC	GGU	GCC	UUU	AGU	GAU	GGC	CUG	GCU	CAC	CUG	GAC	AAC
L	A	I	H	L	L	T	K	H	A	N	P	D	H	K	A	C	K	D	C

CUC	AAG	GGC	ACC	UUU	GCC	ACA	CUG	AGU	GAG	CUG	CAC	UGU	GAC	AAG	CUG	CAC	GUG	GAU	CCU
K	L	H	Q	N	A	Q	K	P	G	K	I	E	D	L	K	I	T	D	O

GAG	AAC	UUC	AGG	CUC	CUG	GGC	AAC	GUG	CUG	GUC	UGU	GUG	CUG	GCC	CAU	CAC	UUU	GGC	AAA
G	C	N	B	K	K	H	C	T	K	T	E	T	K	A	I	I	N	H	L

GAA	UUC	ACC	CCA	CCA	GUG	CAG	GCU	GCC	UAU	CAG	AAA	GUG	GUG	GCU	GGU	GUG	GCU	AAU	GCC
G	N	Q	O	O	T	F	A	A	S	F	L	T	T	A	H	T	A	C	A

CUG	GCC	CAC	AAG	UAU	CAC	**UAA**
K	A	I	L	S	I	**Y**

A Musical Composition of Beta Globulin. Coding of Amino Acids

The genetic code of beta-globulin comes from: Dunn, John / Mary Anne Clark, “Life Music: The Sonification of Proteins”. In: *Leonardo*, Vol. 32/1 (1999), p. 28.

A Musical Composition of Beta Globulin. Musical Notation.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Conclusion

This paper's exploration began with the *MIT's Laboratory for Atomistic & Molecular Mechanics* and their Amino Acid Synthesizer as a point of embarkation. Taking their approach further, the conception for the *DNA-Based Music Machine* has attempted to incorporate the *Quadrille Melodist's* system of 'musical fragments' with hope of achieving a 'natural' composition. At a cursory glance, the two may appear to be quite similar in function; both are made up of 'tiny' compositions. But upon critical inspection, the *DNA-Based Music Machine* misses the goal of producing 'natural' compositions. This is because the individual 'musical fragments' attributed to each amino acid had to be composed beforehand; therefore, they are the product of a person's mind and are, thus, removed from the 'natural.' Consequently, the author of the 'tiny' compositions would have a claim to the authorship of any work provoked by protein biosynthesis, similar to Clinton, who would claim authorship of any composition created via quadrille melodist. However, even though the authorship of the composition lays on the human hand, Mother Nature can be seen as an arranger at least.

Moreover, the question arises to what extent the *DNA-Based Music Machine* can be described as a music machine. On closer inspection, it is clear that the core of the *DNA-Based Music Machine* is a transformation rule. This is much closer to the *arca musarithmica* or the *Musikalischen Würfelspiel* because the *Quadrille Melodist* stands out above all through its ability to be used at the same time its composition is being played on the piano! Like the machines contrasted to the *Quadrille Melodist*, the *DNA-Based Music Machine* cannot replicate this function; only when the amino acid sequence or at least the sequence of the individual bases of the single-stranded RNA is known can this music machine can be used. Consequently—and with reference to Braguinski—the *DNA-Based Music Machine* should by no means be called a music machine. Nevertheless, the picture of a *DNA-Based Music Machine* evokes a highly exiting form of composition, reminiscent of the didactics of Joseph Schillinger.[47] Therefore, every 'tiny' composition is limited by the condition that it must be connectable with the next 'piece of music' which makes composing these 'musical snippets' a playful challenge.

Even if the discovery of the 'natural' music machine was not achieved, it can nonetheless be concluded that the concept of the *DNA-Based Music Machine* has made it possible to emphasize the unique nature of the *Quadrille Melodist*. Furthermore, a new form of playful composition was envisioned, as well as another way of sonifying proteins which builds upon the pattern of previous studies.

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[47] See Dunn & Clark 1999, p. 27; see Brodsky 2003, p. 51.

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