

Musical Structures and Neural Networks: From Synchronous Polyphony to Algorithmic Ecologies

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Abstract: *This study explores the continuity between musical structures and neural networks, framing creativity as an oscillation between rules and emergence. It examines how generative systems—mechanical or digital—encode style through combinatorial or probabilistic grammars, from eighteenth-century dice games and Kircher’s *Arca musarithmica* to convolutional and deep learning models. Using sources such as *Musurgia Universalis*, *Traité de l’harmonie* and *Opticks*, alongside computational reconstructions, the analysis highlights structural analogies across epochs: stratification, proportion and algorithmic logic as shared principles of art and computation. The conclusion argues that algorithmic ecologies redistribute authorship, turning composition into a dialogue between human intention and machine inference. In this technocultural context, music and AI converge as architectures of meaning.*

Key-words: *Musikalisches Würfelspiel, generative music, algorithmic composition, neural networks, convolutional architectures*

1. Introduction

Imagine a world in which the elegance of a fugue and the structure of a neural network have one thing in common: order emerging from complexity. This study begins with a simple question that has long plagued philosophers and composers, even before the advent of digital algorithms: Can art arise from calculation? The answer unfolds in layers, from the dice games of the Enlightenment to the deep learning systems of today, like a polyphonic texture expanding into an algorithmic horizon.

We will journey through four movements, each resonating with historical and conceptual significance. First, we will revisit the *Musikalisches Würfelspiel*, a playful yet profound game in which eighteenth-century composers encoded style into tables and dice rolls — a proto-algorithm in disguise. Next, we delve into the

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Baroque imagination by exploring Kircher's *Musurgia Universalis* and its mysterious *Arca musarithmica*, a combinatorial machine that promised infinite polyphonies. Studying these manuscripts in their original facsimile editions reveals a world where music was already a laboratory for procedural thought.

The third section bridges the centuries, from Pythagoras's monochord to Fourier's analytical vision, and from Rameau's tonal geometry to Lovelace's prophetic notes on Babbage's engine. Here, we explore the continuity between ars combinatoria and neural networks — a transition from compatibility to probability and from craft to modelling. Finally, we turn to painting and perception, tracing a line from Leonardo da Vinci's proportional grids to convolutional architectures, in which vision itself becomes algorithmic.

2. Methodology

This work combines historical exegesis with conceptual modelling. Primary sources, such as works by Kircher, Rameau and Newton, were consulted in digitised originals to preserve textual authenticity. The analysis is complemented by secondary literature and computational reconstructions, such as Cashner's Haskell implementation of Kircher's algorithm. Rather than treating music and AI as separate fields, this approach seeks structural analogies, examining how systems — whether harmonic or computational — encode meaning through layered relations.

The result is not a nostalgic narrative or a technological manifesto, but an ecology of ideas: a space in which synchronous polyphony and algorithmic ecologies resonate as variations on the same theme — the human desire to formalise creativity and imagine worlds through code.

3. Musikalisches Würfelspiel and the proto-algorithmic logic of eighteenth-century music

Before algorithms became emblematic of digital creativity, music served as an early laboratory for procedural thought. Long before the advent of neural networks and probabilistic models, composers explored systems that prioritized rule-based generation over inspiration. These mechanisms, ranging from dice games to mechanical devices, were not mere curiosities; they posed a question that still resonates today: can art appear from calculation? This section traces the lineage from eighteenth-century musical games to the algorithmic imagination of modern

AI, revealing the ongoing tension between chance and structure, and freedom and constraint.

The musical dice game, or *Musikalisches Würfelspiel*, exemplified this logic through an ingenious combinatorial procedure. Each measure of a minuet or trio was drawn from a matrix of pre-composed variants, with the choice being determined by dice. In the edition published in Berlin in 1792 by Mozart's publisher, Nikolaus Simrock, the game took the form of tables: the columns represented measures and the rows were decided by the dice roll. By concatenating these units, a stylistically coherent piece was obtained. While Mozart's authorship is still disputed, the game's popularity reveals a fascination with 'composition without a composer', governed by the rules of taste and tonal syntax.

Yet chance was never absolute. Each option adhered to a harmonic framework and periodicity that guaranteed cohesion — precisely what Stephen A. Hedges emphasized in his seminal study: 'The success of these games depended less on luck and more on the skill of the designer, who ensured the compatibility of the fragments' (Hedges 1978, 181). The *Würfelspiel* thus appears as a 'machine for permutation', rather than an oracle of randomness.

From today's perspective, these procedures may seem basic, yet the principle behind them — combining predefined units under strict constraints — anticipates the generative logic of contemporary algorithms. While eighteenth-century dice determined the succession of measures, neural networks now figure out the succession of probabilities across billions of parameters. The essence of the process stays unchanged; it is only its scale that has changed: from finite grids to probabilistic abysses, and from controlled chance to algorithmic prediction. Nevertheless, the same structural tension persists that between freedom and constraint, and between play and the law of composition.

This historical analogy invites broader reflection: generative systems, whether mechanical or digital, use within a dialectic of determinism and emergence. Mozart's dice game encoded stylistic norms into a finite matrix, while modern AI embeds them into high-dimensional spaces where creativity is simulated through statistical inference. In both cases, automation redistributes authorship, shifting agency from the individual to the system of rules, whether inscribed in tables or embedded in code.

4. Prototypes of the musical algorithm: From combinatorial devices to algorithmic imagination

The concept of creating music using combinatorial rules dates back further than

Mozart. In his 1650 work *Musurgia Universalis*, Jesuit polymath Athanasius Kircher introduced the *Arca musarithmica* — a box containing inscribed tablets that could produce polyphonic music when combined according to specific rules. Inspired by Ramon Llull's combinatorial techniques, Kircher conceived of an apparatus for 'mechanical composition', a materialised algorithm capable of generating countless configurations through permutation. Recent scholarship, such as Andrew A. Cashner's digital reconstruction using Haskell, confirms the operational logic of the *Arca musarithmica* and highlights the continuity between Baroque procedural thought and contemporary generative systems.

A century later, printed musical games proliferated. In 1757, Johann Philipp Kirnberger published *Der allezeit fertige Polonoisen- und Menuettencomponist*, a game that enabled anyone to compose polonaises and minuets by throwing dice. In 1758, Carl Philipp Emanuel Bach described an exercise in double counterpoint 'without knowing the rules' — a striking example of procedural thinking. By 1780, Maximilian Stadler's *Table pour composer des minuets et des trios à l'infini* signalled the ambition to create an 'infinity' of variants within a controlled harmonic system, anticipating the aleatoricism of the 20th century. These devices transformed composition into a combinatorial process where freedom played within the boundaries of the norm and are conceptual ancestors of today's generative networks.

This genealogy intersects with broader intellectual projects. In his *Traité de l'harmonie* (1722), Jean-Philippe Rameau reorganised musical knowledge on 'self-evident principles' of mathematical origin, translating nature's order into homophonic syntax — a geometry of notes governed by immutable laws. At the same time, Leibniz conceived of a *mathesis universalis*: a universal calculus that would unify logic, combinatorics, and symbolic manipulation. These two tendencies — Rameau's tonal system and Leibniz's algebra of thought — did more than simply codify knowledge; they also prepared the cultural emergence of 'code' as a language of forms, including in art. Creativity became a structured process, formalisable and ultimately mechanisable.

The fascination with rules and permutations persisted. While Rameau and Leibniz conceived of an algebra of harmony and thought, Ada Lovelace translated it into the logic of computation. In her 1843 notes on Menabrea's article, she wrote: "If the fundamental relations of pitched sounds in the science of harmony and musical composition were susceptible to such expression and adaptation, the engine could compose elaborate and scientific pieces of music of any degree of complexity or extent" (Lovelace 1843, 694).

Although programming mechanisms outlined the prototype of algorithmic logic by the nineteenth century, the first analogue computer predates the

Industrial Revolution in the form of the Antikythera Mechanism. This ancient astronomical device used interlocking gears to calculate celestial movements, anticipating the symbolic architecture of modern algorithms.

5. From dice to deep learning: Musical structures in algorithmic ecologies

How are the dice games of the eighteenth century connected to today's generative models? In both cases, style acts as a probability distribution applied to choices, with cadences, periods and motifs unfolding under controlled entropy. Dice games encoded this distribution manually in tables, while neural networks infer it statistically from vast corpora. The intention remains the same: to produce credible variation within grammar.

However, the difference is decisive. While Johann Philipp Kirnberger ensured coherence by preselecting phrases, modern models optimise target functions across spaces holding billions of parameters, generating sequences that merely sound stylistically authentic. Historically, the Enlightenment's *ars combinatoria* was a 'machine of taste', while today's artificial intelligence is a 'machine of probability'. One relied on taxonomies of craft, while the other relied on latent inference from data. One presupposed predefined compatibility, while the other performs a statistical transfer of style — a concept that did not yet exist.

This fascination with combinatorial devices reappears in eras that seek universal rules of meaning. Lull combines theological concepts; Kircher manipulates tables; Rameau codifies harmonies; Leibniz formulates an algebra of thought; and Lovelace imagines a machine of symbols. These operational fiction boxes, wheels and tables — all convey the same idea: that intelligibility can be simulated procedurally. Music, with its precise relationship to numbers, becomes the best testing ground. As Joseph Fourier observed, 'Mathematical analysis is as extensive as nature itself; it defines all perceptible relations... and discovers the hidden analogies which unite them' (Fourier 1822/1878, 7) — a statement that resonates with the algorithmic logic underlying both harmonic systems and modern AI.

From the gallant dice of the pre-classical era to the neural networks of today, rule-assisted composition reflects a continuity: the desire to simulate meaning through form. While *Musikalisches Würfelspiel* proposed a playful grammar of style, contemporary models propose a probabilistic grammar — a shift from compatibility to deduction and from craft to modelling. In this symbolic arc, music ceases to be merely a testing ground and becomes a laboratory for creativity. The question is no longer whether the machine can 'compose', but how do we redefine

composition when code becomes an artistic language and the algorithm a new way of imagining form.

The algorithm itself has roots in simple ratios discovered by Pythagoras through vibrating strings. Intervals such as the octave (1:2), the fifth (2:3) and the fourth (3:4) are expressions of physical order, not aesthetic conventions. Pythagoras observed that string length decides pitch, and that ratios between string lengths produce stable intervals. His monochord — a single string over a resonating box with a movable bridge — turned sound into an object of mathematical enquiry.

According to tradition, the idea came about by chance. While passing a blacksmith's workshop, Pythagoras noticed that certain hammer blows produced harmonious intervals. Upon analysing the weights, he discovered simple ratios. This led him to hypothesise that harmony is governed by proportion. However, what we call 'sound' is a combination of frequencies — an invisible chord revealed by Fourier analysis. Any pitch consists of a fundamental frequency and harmonics. Among the first sixteen harmonics, the fourth, fifth and sixth form the major triad. The macrostructure of harmony is inscribed within the microstructure of sound, providing evidence that the algorithm precedes composition.

The same logic applies to painting. White light, seemingly uniform, decomposes into spectral colours — from red to violet — through Newton's prism, mirroring harmonic analysis in acoustics. Just as the ear unfolds sound into overtones, the eye unfolds light into chromatic components. Both processes reveal an underlying architecture of perception that is governed by ratios and periodicities rather than sensory immediacy. Vision and audition are algorithmic syntheses that translate physical signals into structured experiences. Art, whether sonic or visual, appears as a code of imminent complexity, organising nature's continuum into discrete forms. From tonal geometry to the colour spectrum, aesthetic order reflects a computational logic that predicts the generative principles underlying contemporary algorithmic creativity.

6. From Fourier to Schenker: Stratifying meaning in algorithms and art

Just as Fourier analysis decomposes sound into harmonics, Schenkerian analysis breaks music down into hierarchical layers, from the melodic surface to the tonal foundation. Similarly, convolutional neural networks do not 'see' an image as a whole; they break it down into levels of complexity, from contours and shapes to textures and semantic patterns.

For Heinrich Schenker, music is an architecture of depth, with each layer resting upon the earlier one, meaning appearing through reduction. This logic is like the way neural network's function: each layer extracts features from the preceding one, building a web of activations that leads to recognition. In both cases, meaning is not conveyed by the surface, but by the invisible relationships between the layers.

Therefore, convolutional networks are not merely tools for visual processing; they are modern forms of harmonic analysis applied to images. They interpret an image not as a sum of pixels, but as a stratified composition — a kind of 'visual music' where perception results from an algorithmic architecture of meaning.

Just as sound conceals an invisible geometry, Renaissance painting conceals a silent network of proportions — a structure that, as Charles Bouleau revealed in *The Secret Geometry of Painters* (1963), is the hidden scaffolding of art. Masters did not only paint with a brush, but also with a compass, constructing spaces governed by ratios rather than arbitrariness. Musical intervals such as the fifth and fourth become spatial proportions.

This transposition of harmonic order into visual geometry suggests premodern algorithmic thinking; the painter did not improvise but composed instead. Each element was placed within a symbolic coordinate system in which proportion was the keystone. Leonardo, Botticelli and Dürer all employed the Golden Section as an organisational principle, not merely aesthetic, but ontological. The formula $\phi = (1 + \sqrt{5}) / 2$ was not just a constant, but the signature of harmony.

This geometry is not just a technique; it is a code and a precursor to the layered logic of convolutional networks. Just as convolutional neural networks analyse images through successive filters, Renaissance painters constructed compositions through layers of meaning, centres of gravity and visual equilibria. In both cases, belief is the outcome of algorithmic processing, whether human or artificial.

7. From proportion to belief: Painting, neural networks, and the algorithmic horizon

Just as Renaissance painting was a geometry of the spirit, today's convolutional neural networks (CNNs) are architectures of belief. Just as Fourier analysis separates sound into harmonics and Schenkerian analysis reveals structural depths in music, CNNs do not 'see' an image as a whole; they decompose it into layers. In both cases, meaning appears through stratification.

CNNs operate through filters that extract compositional features such as edges, contrasts and shapes. Each layer detects a level of complexity, from simple contours to composite structures, culminating in semantic recognition. This hierarchical process mirrors the way painters built their compositions, progressing from sketch to detail and from geometry to expression. Just as Leonardo used proportional grids to guide the viewer's gaze, CNNs use attention mapping to find salient regions. In both cases, belief is algorithmically directed: what we see is what is activated.

In classical painting, the figure and the ground are not just aesthetic elements, but interdependent semantic components. In neural networks, these blocks become mathematical yet preserve compositional logic; each layer builds upon the earlier one, adding meaning and context. Therefore, painting is not only a source of inspiration for AI, but also an ancestral model of visual networks — a stratified architecture of significance where the algorithm is less an invention than a revelation.

This logic of stratification and interdependence extends beyond belief. It is also clear in the structure of blockchain, where each block of information is validated and connected within a decentralised network. Just as visual composition constructs meaning through internal relations, blockchain constructs trust through algorithmic coherence. From Leonardo's grids to neural networks and chains of numerical blocks, the algorithm acts as a bridge across epochs.

Just as white light conceals the spectrum of colours and the first harmonic carries within it the entire history of music, the algorithm is not an 'intruder' in art, but rather the fundamental frequency without which order cannot exist. As Newton observed, 'Nothing more is requisite for producing all the variety of colours and degrees of refrangibility than that the rays of light be bodies of different sizes...' (Newton 1704, 237). In painting, as in music, proportion precedes expression and feeling emerges from an ordering structure, not arbitrary impulse.

Today, neural networks do more than recognise forms; they recreate the world through layers of meaning and deep activations. They do not replace human vision — they extend it. They do not compete with inspiration; they map it. The algorithm is not a limitation, but an opportunity — a bridge between what we see and what we can understand. A new ecology of meaning is taking shape between the sacred geometry of the Renaissance and the digital architecture of the present, where art, science and artificial intelligence resonate in harmony rather than excluding one another.

The future will not be defined by data alone, but by vision. In its subtle form, the algorithm is a means of perceiving the world and its implications, and of predicting what is to come. The technocultural revolution is not a hypothesis, but

an ongoing process — a living code written in real time with every image, word and choice.

8. Conclusion: From synchronous polyphony to algorithmic ecologies

The trajectory from eighteenth-century dice games to deep learning architectures reveals a profound continuity: creativity has always balanced freedom and constraint, chance and structure. What began as a playful grammar of style in the *Musikalisches Würfelspiel* evolved into probabilistic grammars embedded in neural networks — systems that infer rules from data rather than imitating them. Music, with its intrinsic link to numbers and proportions, anticipated this shift, from Pythagorean ratios to Fourier's analytical vision and from Rameau's tonal geometry to Lovelace's computational prophecy.

Today, algorithmic ecologies extend this logic beyond sound, shaping perception itself. Convolutional networks organise vision as harmony organises tone, and blockchain codes trust as counterpoint codes coherence. These architectures do not abolish art; they redistribute authorship, transforming composition into a dialogue between human intention and machine inference. The algorithm, far from being an external imposition, emerges as a latent order — a structural horizon where art, science and technology converge.

Speaking of 'musical structures and neural networks' acknowledges a shared epistemology: both organise complexity through layered relations and seek meaning in patterned variation. From synchronous polyphony to algorithmic ecologies, the question is no longer whether machines can create, but how we inhabit a world in which creation itself is a distributed process — an interplay of codes, ratios and visions. In this unfolding technocultural landscape, the future of art will be shaped not only by data, but also by our ability to interpret, imagine and resonate within the architectures of possibility.

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