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Article

Embedding algorithms in musical instruments: From automata to artificial intelligence-driven music

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Abstract

This study explores the deep historical roots of algorithmic thinking in music, demonstrating that the design and embedding of algorithms into musical tools predate the eras of computers and artificial intelligence. Across examples ranging from ancient automata to nineteenth-century mechanical musical devices, artisans and musicians constructed mechanisms that embodied musical rules in physical form, thereby formalising processes of repetition, variation and autonomy. By revisiting these historical traditions and examining how past societies conceptualised musical machines, this study provides a historical perspective on recurring issues such as agency, authorship, autonomy and human–machine mediation. Methodologically, the study combines a media-archaeological analysis of historical automata with conceptual inquiry into instrument design, linking pre-digital 'material algorithms' to contemporary intelligent instruments. It examines how the physical embedding of algorithmic procedures has shaped perceptions of musical agency and authorship, while also considering how these historical cases can inform, rather than prescribe, discussions of contemporary AI- and data-driven instruments. In doing so, the study identifies selected continuities and discontinuities between historical musical automata and current algorithmic practices, offering a historically grounded framework for understanding intelligent instruments in the post-digital era.

Keywords: algorithmic instruments; embedding algorithms; intelligent instruments; media archaeology; musical automata

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1. Introduction

The design and embedding of algorithms into musical tools are not novel practices originating in the era of artificial intelligence (AI). Although the tools themselves have changed, the application of algorithmic thinking to music-making has deep historical roots. Long before the advent of digital code and AI, artisans and composers designed and constructed mechanical devices capable of autonomously generating music according to predetermined rules or patterns. These self-playing instruments and mechanical musical devices formalised musical processes and inscribed them into physical mechanisms, thereby embodying early forms of algorithmic thought. Centuries before the emergence of contemporary microprocessor- or machine-learning-driven 'smart' instruments, such historical artefacts already reflected an enduring idea: the embedding of algorithmic logic directly into the material foundation of an instrument. This suggests that musical automation has long involved the material encoding of rules, sequences and performance procedures. Moreover, these historical artefacts provide important points of comparison for understanding how musical procedures have been encoded, automated and interpreted across different technological contexts. Although many of these devices have been studied within organology, media archaeology, music theory and the history of mechanical music, they are not always integrated into contemporary discussions of algorithmic and AI-mediated musical instruments. Revisiting these historical traditions therefore enables an examination of how past societies conceptualised musical machines and how such cases may illuminate recurring questions of agency, autonomy, legibility and machine-mediated performance in the present day.

As a first step, this study examines historical musical devices to explore how they embodied musical rules within physical mechanisms and to analyse the conceptual and aesthetic issues raised by such embodiments. It then poses the following questions: How did historical musical automata materially encode musical rules, gestures and temporal procedures? What conceptual issues do these devices raise for contemporary discussions of algorithmic and AI-mediated music, particularly in relation to agency, authorship, autonomy, legibility and human–machine mediation? Methodologically, the study combines media-archaeological analysis of historical automata with conceptual inquiry into instrument design, linking pre-digital 'material algorithms' to contemporary intelligent instruments.

The remainder of this article is structured as follows. Section 2 traces the historical development of musical automata, beginning with their early origins and theories of musical automation in antiquity (2.1), continuing with the revival and transformation of automata in the Islamic world and Byzantium (2.2), followed by Kircher's seventeenth-century theorisation of mechanical music (2.3) and culminating in the Enlightenment automata that sought to imitate life through mechanical means (2.4). The section concludes with nineteenth-century innovations in mechanical music,

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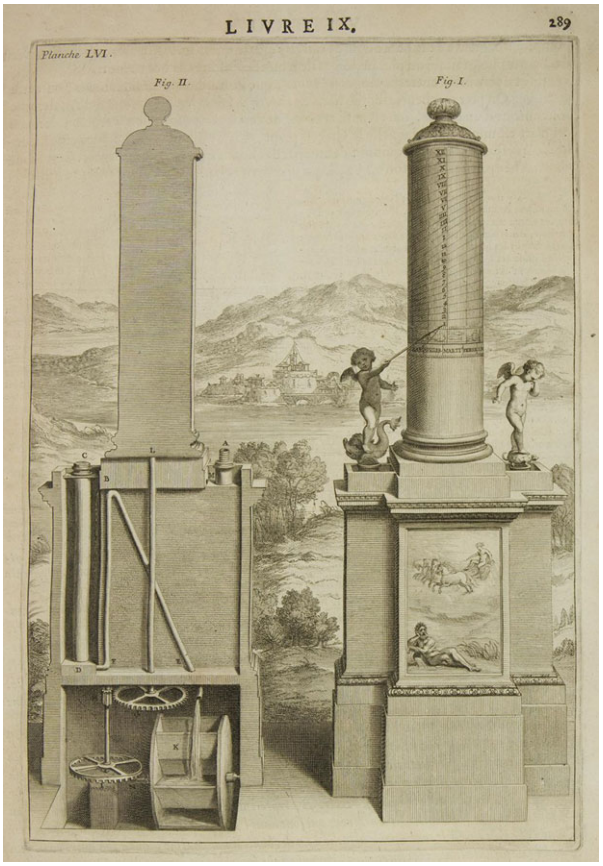


Figure 1. Horloge hydraulique de Ctésibios. *Source*: Vitruvius Pollio, *Les dix livres d'architecture de Vitruve* (1684).

such as barrel organs and orchestrions to advanced automata, including Kaufmann's Trumpet Player, Winkel's *Componium* and Manzetti's Flute-Player (2.5). Section 3 presents theoretical reflections on the agency, autonomy and aesthetics of algorithmic processes in both historical and contemporary contexts. Section 4 considers the contemporary relevance of these historical cases by using them as points of comparison for discussing algorithmic, AI-based, data-driven and sensor-integrated musical tools. Finally, Section 5 concludes by summarising how recurring questions of encoding, agency, authorship, legibility and automation have been reformulated across pre-digital and digital contexts.

2. Historical development of musical automata

2.1 Early origins and theories of musical automation

The idea of automating musical performance originates in antiquity, when inventors and philosophers sought to mechanise sound production as part of broader inquiries into natural philosophy and engineering. Ctesibius of Alexandria (fl. 285–222 BCE) is often regarded as a foundational figure in this tradition (Kenny 1932). His inventions, including the *clepsydra* (water clock) and the *hydraulis* (water organ), exemplified how mechanical and hydraulic principles could regulate temporal and sonic processes. The hydraulic clock attributed to Ctesibius is shown in Figure 1. These devices were not merely technical innovations; they also embodied an epistemological stance in which music and time could be formalised and reproduced through mechanical means. For example, later accounts describe Ctesibius as having created an automaton shaped like an animal head, likely inspired by the ritual *rhyton* vessel. Such examples suggest that automata served not only technical functions but also ceremonial and symbolic purposes.

Hero of Alexandria (first to second century CE) expanded this tradition in his treatises *Pneumatica* (Woodcroft 1851), *Automata* and *Mechanica*. He described automated theatres, singing birds and hydraulic organs that staged performances in which sound, movement and visual display were synchronised without direct human intervention. Hero's devices demonstrated an early integration of engineering and performative art, foreshadowing the multimedia and interactive qualities of later algorithmic instruments (Cuomo 2007).

Water clocks, astronomical clocks and clockwork automata also formed rich traditions in both the Islamic world and Europe, and many of these devices combined timekeeping with sound, moving figures and symbolic display. However, the aim here is not to provide a comprehensive history of clockwork automata, but rather to identify selected cases in which time, sound, movement and mechanical sequence were materially organised. Within this limited framework, East Asian examples are relevant because they demonstrate that mechanically regulated sound and movement were not confined to a Hellenic-European lineage. In ancient China, accounts of Ma Jun's third-century hydraulic puppet theatre describe mechanically coordinated performers, whereas the Tang-period water clock associated with Yixing and Liang Lingzan, as well as Su Song's eleventh-century clock tower, combined water power, timing mechanisms, moving figures and percussive sound signals (Needham 1965; Needham et al. 1986). Literary accounts such as the *Liezi* story of Yan Shi's automaton entertainer further suggest the conceptual importance of artificial performers in Chinese reflections on mechanism, embodiment and artifice (Needham 1956: 53–54; Graham 1990). These examples are not treated here as musical automata in the narrow sense; rather, they broaden the historical framework by demonstrating that the material organisation of time, sound and movement was a transregional concern.

2.2 Automata in the Islamic world and Byzantium

During the early medieval period, the legacy of Greco-Roman automata was revived and transformed in Byzantium and the Islamic world. In the Byzantine Empire, Leo the Mathematician (*c.* 790–869) was reported to have constructed a tree of singing birds and other automata for Emperor Theophilos. These devices functioned not only as marvels of engineering, but also as symbolic affirmations of imperial authority and splendor.

In Baghdad, the Banū Mūsā brothers developed, in the ninth century, one of the earliest programmable musical instruments: a hydraulically powered flute organ (Fowler 1967; Hill 1979). A related flute-playing automaton from a later manuscript is shown in Figure 2. Its programmability depended on a rotating pinned cylinder: the placement of pins on the cylinder activated a lever system that opened and closed the flute's holes in a predetermined sequence. In this sense, the pins physically encoded melodic information, functioning as an early form of 'material algorithm' or programmable musical data storage. The device therefore demonstrated that music could be codified, stored and mechanically reproduced, providing a significant precursor to later forms of mechanical sequencing and algorithmic composition.

A later Islamic example appears in al-Jazarī's musical automata, including his musical boat designed for courtly entertainment, in which automated performers generated sound and movement

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Figure 2. A later, related depiction of a flautist automaton in a sixteenth-century Arabic manuscript of a treatise attributed to Archimedes on the hydraulic and pneumatic machinery of water clocks. *Source*: British Library, Add MS 23391, fol. 20v; digital image via Qatar Digital Library.

through water-driven mechanisms and mechanical sequencing (al-Jazarī 1974). These examples further demonstrate that sound, timing and mechanical performance were encoded across multiple Islamic automata rather than embodied in a single isolated device.

2.3 Kircher's Musurgia Universalis and the theorisation of mechanical music

Athanasius Kircher (1602–1680) marks a decisive moment in the intellectual history of musical automata. In *Musurgia Universalis* (1650), he described a hydraulic organ driven by a rotating pinned cylinder – a mechanism already employed in European clock towers – but reframed it within a universal system of music and nature (Kircher 1650). Kircher's hydraulic organ is shown in Figure 3. For Kircher, the automaton was not merely an engineering novelty; it was also an instrument of cosmological demonstration, a tangible manifestation of divine harmony inscribed into mechanical structures.

In Kircher's interpretation, the pinned cylinder translated musical order into a repeatable sequence of physical operations, effectively materialising abstract musical rules as mechanical algorithms. By embedding music within his encyclopaedic synthesis of theology, mathematics and natural philosophy, Kircher elevated automata from curiosities of engineering to epistemological instruments. He interpreted the *hydraulis*, for example, as a material embodiment of cosmic harmony, aligning theological and natural-philosophical principles with mechanical design. His theorisation also connected Middle Eastern precedents, such as the

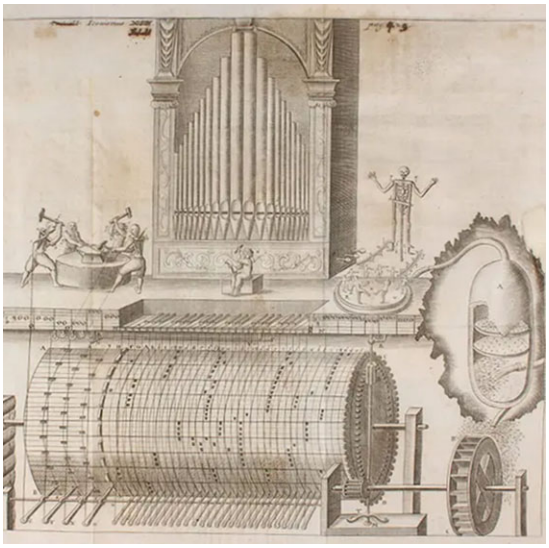


Figure 3. Hydraulic Organ of Kircher. *Source*: Kircher, *Musurgia Universalis* (1650).

hydraulic devices of the Banū Mūsā brothers, with contemporary European practices, situating mechanical music within a transregional history of invention.

Therefore, Kircher's work reveals how mechanical instruments could simultaneously function as tools of entertainment, scientific inquiry and metaphysical reflection. In this sense, his *hydraulis* anticipates modern debates surrounding algorithmic composition, AI and the aesthetics of 'intelligent' instruments, offering an early model of how cultural, theological and technological frameworks converge in the design of automated musical systems (Findlen 2004).

2.4 Musical automata of the enlightenment: imitating life through mechanisms

By the eighteenth century, during the Enlightenment, musical automata had become public spectacles embodying the ideals of rationality, progress and the imitation of life. Jacques de Vaucanson and Pierre Jaquet-Droz developed automata that not only produced sound but also realistically imitated human performers, thereby blurring the boundary between instrument and performer. These inventions functioned as philosophical statements about human reason and creativity, directly engaging with contemporary debates concerning the mechanistic nature of life, as exemplified in Julien Offray de La Mettrie's *L'Homme Machine* (1748).

Jacques de Vaucanson's *Flute Player* (1737) represents a milestone in this regard. Vaucanson's Flute Player automaton is shown in Figure 4. Conceived as a life-sized automaton, it replicated the anatomical processes involved in human flute performance, including finger movement, breath control and lip positioning, through an intricate mechanical design. Its detailed documentation in *Le Mécanisme du Fluteur Automate* (1738) was recognised by the Académie Royale des Sciences as both a technical and theoretical contribution to flute acoustics. For example, the treatise has been regarded as one of the earliest experimental studies of flute acoustics, transforming the automaton into both a scientific apparatus and a public spectacle. For contemporary audiences, the *Flute Player* raised questions concerning agency and authorship; although its performances were preprogrammed,

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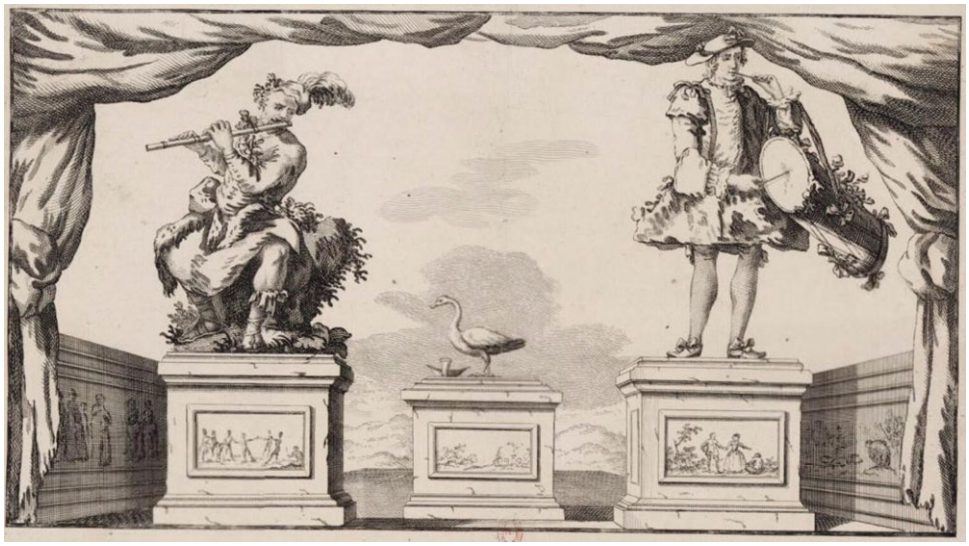


Figure 4. Vaucanson's *Flute Player* Automaton. *Source*: Bibliothèque nationale de France.



Figure 5. The Musician Automaton by Jaquet-Droz. *Source*: Musée d'art et d'histoire de Neuchâtel.

many observers responded to the automaton as though it possessed musical autonomy (Riskin 2003).

Pierre Jaquet-Droz and his son Henri-Louis Jaquet-Droz extended this trajectory through automata such as *La Musicienne*, a harpsichord-playing figure that not only pressed keys with human-like gestures but also simulated breathing and expressive movement (Girardier 2020). Jaquet-Droz's La Musicienne is illustrated in Figure 5. Its design incorporated torso swaying and eye movement, emphasising both the expressive qualities of performance and the precision of mechanical control. These automata further complicated notions of authorship and originality, as audiences debated whether the 'creativity' resided in the machine or in its inventors. In doing so, they embodied the aesthetics of mechanical behavior – precise, repetitive, yet uncannily lifelike – anticipating contemporary discussions of algorithmic music and AI-generated performance.

These automata were fascinating not only because they performed music but also because they appeared to generate creative expression, leading audiences to perceive the machines themselves as artistic agents. Much like contemporary generative algorithms raise questions regarding authorship in AI-composed music, eighteenth-century audiences debated whether the creator of an automaton's artistic output was the machine itself or its inventor. *La Musicienne*, in particular, embodied the aesthetics of mechanical behavior: its precise yet graceful movements, unwavering tempo and repetitive accuracy inspired admiration while simultaneously evoking a sense of the uncanny among viewers.

Automata designed for musical performance continued to appear after Jaquet-Droz's *La Musicienne* (Chapuis and Droz 1958). In 1784, an automaton representing Marie Antoinette, a dulcimer-playing figure, was created by the German clockmaker Peter Kintzing (1745–1816) in collaboration with cabinetmaker David Roentgen (1743–1807). The following year, Queen Marie Antoinette purchased the automaton for the Académie des Sciences in France (Kang 2011). Modelled in her likeness, the automaton held small hammers in both hands and used them to play the dulcimer. Its arms moved with motions resembling human joints, and its eyes and head also moved during performance. Hidden within both the figure and the instrument was the mechanical apparatus that enabled its operation.

In India, an automaton capable of producing sound and functioning as a playable instrument, known as *Tipu's Tiger*, was created in 1792. The automaton was commissioned for Tipu Sultan (1751–1799), a ruler of the Kingdom of Mysore. It depicts a tiger

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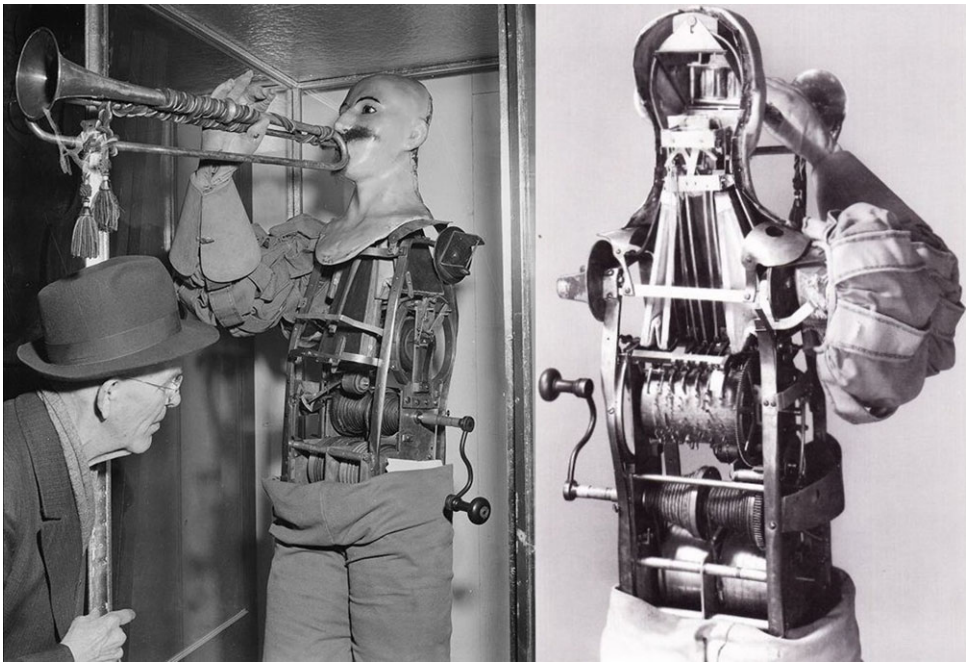


Figure 6. Kaufmann's Trumpet Player. *Source*: Deutsches Museum, Munich.

attacking a European man, with the tiger symbolising the Sultan and expressing hostility towards the enemy represented by the European figure. The man raises one hand as if pleading for help while crying out in agony, whereas the tiger emits growling sounds. Inside the tiger's body, a side panel could be opened to reveal an 18-key pipe organ, allowing the automaton to function as a playable musical instrument.

2.5 New musical machines of the nineteenth century: mechanical instruments and mechanical composers

From the nineteenth century into the early twentieth century, mechanical instruments expanded beyond elite automata into more widely accessible forms of automated performance. Barrel organs, orchestrions and later player pianos brought automated music into both public and domestic spaces, demonstrating the industrial scalability of mechanical performance. The orchestrion, developed by Joseph Vogler and later refined by Johann Nepomuk Mälzel, sought to replicate the sound of an entire orchestra, whereas the player piano transformed domestic music-making by enabling individuals to perform technically complex works through pneumatic roll mechanisms.

Another notable innovation of this period was Johann Friedrich Kaufmann's *Trumpet Player* (1810), which was presented in Dresden in 1812 (Ord-Hume 1973). Kaufmann's Trumpet Player is shown in Figure 6. Shaped like a man dressed in Spanish-style clothing, the automaton used leather bellows to simulate human lungs and could play the trumpet, even producing two notes simultaneously in intervals such as octaves, thirds and fifths. Kaufmann also designed other mechanical instruments capable of orchestral performance, as well as a flute-playing automaton, both of which exemplified the fusion of engineering and music and were regarded as remarkable technical achievements of their time.

Significantly, Dietrich Nikolaus Winkel's *Componium* (1821) marked a transition from mechanical reproduction towards mechanical composition (Riley 2009). The Componium is illustrated in Figure 7. The instrument was publicly exhibited in Paris in 1821 and survives today as a unique artefact preserved at the Musical Instruments Museum in Brussels, highlighting both its historical rarity and conceptual importance as one of the first machines explicitly designed for compositional autonomy. Unlike earlier devices limited to fixed repertoires, the *Componium* incorporated a chance-based mechanism capable of generating endless variations on a theme, effectively embedding a rudimentary generative algorithm into its design. This capacity for autonomous variation positioned the instrument as a precursor to later concepts of generative music, algorithmic composition and machine creativity (Chapuis 1955).

These nineteenth-century innovations illustrate how musical machines evolved from representing human rationality, as in the Enlightenment, towards embodying principles of autonomy, variation and creative agency. In this sense, the *Componium* and related mechanical instruments of the period may be regarded as conceptual antecedents of contemporary AI-based systems, which similarly integrate performance and composition within a single framework.

Following this, another remarkable automaton of the nineteenth century was Innocenzo Manzetti's *Flute-Player* (1849) (Ord-Hume 1973). Manzetti's Flute-Player is shown in Figure 8. Presented at the Great Exhibition in 1851, it depicted a seated man capable of standing, bowing and performing melodies of up to 12 arias on the flute. Driven by a spring-wound mechanism and programmed cylinder, the automaton employed compressed air-tubes, levers and rods to move its lips and fingers with striking realism. Its lifelike gestures – including removing its hat, shifting its gaze and bowing – astonished audiences and embodied the fusion of advanced engineering with musical performance. Manzetti later refined the design so that the automaton could reproduce in real time pieces played on the organ, thereby further advancing the integration of mechanical performance and musical expression.

Collectively, these historical developments demonstrate that musical automata were not merely technical curiosities but also material experiments in delegating musical processes to machines. From Ctesibius's hydraulic mechanisms to Winkel's *Componium*,

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Figure 7. Componium. *Source*: Musical Instruments Museum (MIM), Brussels.

such devices repeatedly raised questions concerning who or what could function as a musical agent, to what extent machines might be said to exhibit autonomy and how mechanical procedures could acquire aesthetic value. These issues, first encountered in mechanical instruments, continue to resonate in contemporary debates surrounding algorithmic and AI-based music.

3. Theoretical reflections: past and present of agency, autonomy and the aesthetics of the algorithm

A defining feature of musical automata is their challenge to the boundary between object and agent. Rather than rehearsing the details of Ctesibius's *hydraulis*, Hero of Alexandria's theatres, or the Banū Mūsā brothers' programmable organ – already outlined in Section 2 – it is more useful here to focus on what these devices meant conceptually. Across antiquity, the medieval Islamic world and early modern Europe, musical automata complicated the distinction between mechanism and performer by producing effects of agency without possessing agency in a modern interactive sense. They therefore raise questions not simply about whether machines 'compose' but about how musical action is distributed among inventors, makers, encoded mechanisms, performers and audiences (Gell 1998).

During the Enlightenment, automata such as Vaucanson's *Flute Player* and Jaquet-Droz's *La Musicienne* intensified these debates. Audiences frequently perceived these machines as autonomous performers, attributing agency to them despite their mechanical determinism. This perception reveals an early form of what later theories describe as the illusion of agency or technological animation (Hayles 1999). The historical fascination with lifelike motion can therefore be interpreted through a posthumanist lens: machines not only extended human capacities but also destabilised

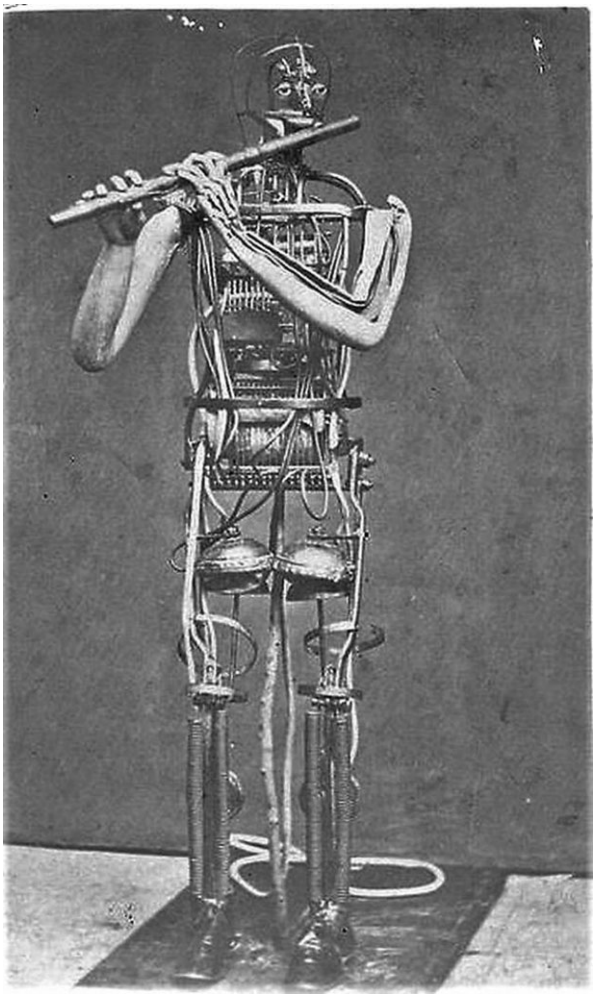


Figure 8. Manzetti's Flute-Player. *Source*: Basilio Catania.

the human–machine divide by embodying forms of 'distributed agency' (Latour 2005).

These cases also foreground authorship as a contested category. In automata, the roles of inventor, craftsman, composer, arranger and performer were often deeply entangled. However, this entanglement should not be understood as cocreation in the same sense as contemporary interactive or AI-based systems. Rather, it demonstrates how musical authorship could be mediated through mechanical design, encoded sequences and the labour of multiple human agents. The *Componium*, with its randomised variations, further complicates notions of creative decision-making, yet it should be understood as a deterministic or rule-bound mechanism rather than an adaptive creative partner. Its significance lies in demonstrating how variation itself could be mechanically encoded, rather than in directly anticipating AI creativity (Magnusson 2019). What began as pinned cylinders or pneumatic rolls re-emerges in contemporary datasets and neural architectures; both materialise musical rules into reproducible forms, raising enduring questions regarding ownership, transparency and authorship.

From this perspective, repetition – once treated as a technical constraint – becomes an aesthetic principle. Just as the monotony of mechanical playback was later reframed as texture or pattern, contemporary generative music and AI systems frequently valorise iteration and variation as creative affordances. This continuity highlights how algorithmic aesthetics depend less on the novelty of

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the machine itself than on the interpretive frameworks – whether the Enlightenment conceptions of nature's laws or posthumanist theories of distributed creativity – through which audiences and practitioners understand them.

In short, historical automata provide more than historical background; they offer a set of cases through which concepts central to current debates may be reconsidered. By placing earlier discussions of agency, autonomy and mechanical authorship in dialogue with contemporary debates on algorithmic and AI-mediated music, it becomes possible to understand 'intelligence' not as a stable property of the machine alone, but as a concept shaped by mechanisms, cultural interpretation and audience perception.

4. Contemporary relevance: historical perspectives on algorithmic and AI-mediated music

Reflecting on these historical cases does not yield straightforward lessons for contemporary AI music. However, it does provide a historical perspective on how musical automation has repeatedly reorganised relationships among instruments, performers, makers and audiences. The following discussion therefore focuses on selected points of comparison, including material encoding, legibility, human intervention and the distribution of musical agency. To avoid presenting these relationships as part of a seamless historical continuum, the comparison is organised around several axes: representation and encoding, storage media, control and feedback, adaptability and learning, degrees of autonomy and interactivity, embodiment and material constraints, provenance and ownership, and social purpose or economy.

From antiquity onwards, musical automata emerged within contexts that combined technical ingenuity with broader cultural, philosophical and symbolic concerns. Ctesibius's *hydraulis* formalised the regulation of sound through physical principles (Landels 1978). Hero of Alexandria's automated theatres integrated sound, movement and spectacle in ways that resonate with contemporary multimodal and sensor-based practices. In the Islamic world, the Banū Mūsā programmable organ demonstrated an early form of data inscription, whereas the singing-bird automata associated with Leo the Mathematician and Emperor Theophilos illustrate the political and symbolic uses of automated sound. Staged within the Byzantine imperial court, their coordinated sound and movement helped materialise courtly splendor, technical mastery and imperial authority. Athanasius Kircher later reframed automata within a cosmological system, highlighting how such devices could serve as epistemic instruments for understanding divine and natural order.

These historical examples should not be treated as direct analogues of current practices, but rather as productive points of comparison. The *hydraulis* demonstrates the regulation of sound through physical parameters; Hero's theatres combine sound, movement and spectacle; the Banū Mūsā programmable organ materially encodes sequence; and Kircher's cosmological framing illustrates how musical machines could be embedded within broader systems of knowledge. Such earlier examples remind contemporary designers that algorithmic instruments are never purely technical artifacts, but are always embedded within wider systems of knowledge, symbolism and cultural meaning. The value of comparison therefore lies less in claiming that historical automata anticipated AI than in identifying recurring problems: how musical procedures are encoded, how control is distributed, how audiences perceive machine performance, and how technical systems reorganise musical roles.

First, historical musical automata can be examined in relation to the expansion, organisation and display of musical possibilities, although these functions should not be assumed to have been the primary motivations of all makers. Many documented automata served as displays of wonder, technical virtuosity, courtly spectacle, patronal prestige, timekeeping or natural-philosophical reflection, whereas later mechanical instruments such as street organs, music boxes and barrel organs contributed more directly to broader musical circulation and access. In the present, algorithmic composition applications for non-specialists and AI improvisation systems raise related – but distinct – questions concerning access, technical capacity and the mediation of musical expertise. Similarly, pre-twentieth-century examples of composition for mechanical instruments should be understood as selective engagements with specific devices rather than as evidence of systemic transformations in musical practice or pedagogy.

Historical instruments also invite reflection on the problem of embodied legibility, rather than offering direct design principles framed simply in terms of transparency versus black-boxing. The relevant issue is not merely whether a mechanism is visible or concealed, but whether the relationships among mechanism, gesture, control and sound can be meaningfully understood and acted upon by performers and audiences. Vaucanson's *Flute Player* and Jaquet-Droz's automata concealed much of their internal machinery and therefore cannot be described as transparent in a strict technical sense. Their human-like forms instead produced a type of performative legibility; audiences could recognise gestures of breath, touch, posture and expression even though the underlying mechanisms remained largely inaccessible and non-modifiable. Likewise, nineteenth-century automata such as Kaufmann's *Trumpet Player* and Manzetti's *Flute-Player* demonstrated how mechanical design could balance sonic complexity with lifelike expressivity, reminding us that the aesthetics of transparency and concealment have long been negotiated. Contemporary designers similarly must determine how legible an algorithm's operations should be to performers and audiences. Although visualising algorithmic processes may enhance understanding and engagement, concealment may instead focus attention on sonic output. However, visualisation alone does not guarantee legibility. For contemporary AI-based instruments, legibility also depends on editable parameters, clear mappings between input and output, information regarding data provenance and feedback mechanisms that enable performers to intervene meaningfully in the system.

Another point of comparison concerns the extent of human intervention. Historical instruments ranged from fully automatic devices – such as spring-wound mechanisms that operated autonomously – to later hybrid forms such as the player piano, particularly in late nineteenth- and early twentieth-century contexts, in which performers could partially shape expressive nuance. Contemporary designers must likewise consider the balance between autonomous generation and human interaction. Allowing performers to adjust stylistic parameters in real time can merge mechanical precision with human expressivity.

The historical record further demonstrates that music automation rarely replaced human musicians entirely; rather, it generated new musical roles and practices. Although player pianos displaced certain theatre pianists, jazz musicians also learned from piano rolls and used them as tools for developing new techniques. Historical comparison can therefore complicate contemporary fears that AI will simply displace musicians, although present-day AI systems operate under very different economic, legal and technological conditions. From a *longue durée* perspective, each stage of musical automation – whether in antiquity, the Enlightenment or the industrial era – provoked comparable anxieties. In many cases,

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machines transformed musical practice by redistributing roles, skills and forms of access rather than by eradicating existing practices altogether. This suggests that the contemporary challenge concerns not only replacement but also the conditions under which AI systems redistribute creative agency, labour and control. These historical cases do not provide a simple ethical lesson for AI music. They do, however, demonstrate that musical automation has repeatedly redistributed roles among makers, performers, arrangers, audiences and machines. This historical perspective cautions against treating technological change either as inevitable replacement or as uncomplicated augmentation. For contemporary AI-based instruments, the central ethical questions concern who controls the system, whose musical data are encoded, how authorship and credit are assigned, and whether performers are able to intervene meaningfully in the system's operations.

In this context, transparency refers not only to the visualisation of algorithmic processes but also to operational explainability, data and model provenance, controllability and auditability. These dimensions matter differently for performers, audiences and rights holders. Performers require editable mappings and feedback mechanisms; audiences require ways of understanding how machine-generated output is produced; and rights holders require documentation of training data, consent, attribution and credit. Contemporary AI-assisted music practices, such as *Flow Machines* and artist-led voice-model projects including Holly Herndon's *Holly+*, demonstrate that augmentation depends not simply on the presence of a human within the workflow, but on whether the system preserves actionable control, documents data provenance and provides mechanisms for consent and attribution (Sony Computer Science Laboratories 2020; Herndon 2021).

Just as pinned cylinders and piano rolls served as repositories of musical knowledge, contemporary training datasets and model architectures function as archives of stylistic information. In both cases, aesthetic outcomes are shaped not only by performers or machines but also by the design choices embedded within the medium itself.

This study does not propose an unbroken or linear genealogy from automata to contemporary AI music. Rather, it advances a comparative historical framework for examining how different technologies have encoded musical procedures, distributed agency and shaped perceptions of musical authorship. Although historical automata and contemporary AI systems differ significantly in their technical operations, social contexts and degrees of adaptability, comparing them can clarify how questions of agency, authorship and automation have been reformulated across different technological settings.

The comparison is therefore organised around concrete axes such as encoding schemes and storage media, control architectures, timing and synchronisation, authorship and arrangement labour, degrees of interactivity, provenance and ownership, and the transition from deterministic mechanisms to statistical, adaptive and networked systems. By articulating these connections within contemporary debates on AI music, this study contributes a long-term historical perspective that situates current data-driven instruments in relation to earlier forms of musical automation and algorithmic aesthetics.

5. Conclusion

Across different eras and cultural contexts, musical rules and procedures have been inscribed into physical mechanisms in diverse ways. Shaped by each period's scientific knowledge, technological capabilities and artistic imagination, these devices demonstrate how music-making could be partially delegated to material systems and how such delegation raised questions concerning performance, authorship and agency.

Several recurring issues emerge from the examination of these historical automatic instruments. First, self-playing instruments blurred the traditional boundary between performer and instrument, transforming perceptions of whether a machine could possess agency. Audiences who encountered Vaucanson's *Flute Player* or Jaquet-Droz's automata sometimes regarded the machines as performers – or even composers – praising or criticising their 'performance' and thereby raising new questions concerning authorship. These reactions provide important historical points of comparison for present-day debates on copyright and creative ownership in algorithmically generated music.

Second, these machines reveal early forms of machine-mediated musical production, although they should not be equated with contemporary human–AI cocreation. Eighteenth-century examples, such as Mozart's K. 608 and K. 616 and Haydn's works for the *Flötenuhr*, demonstrate selective compositional engagement with mechanical organs and clockwork instruments rather than evidence of interactive cocreation (Ord-Hume 1973). Composers, arrangers, craftsmen, pin-cutters, roll editors and operators all worked within the affordances and limitations of automatic organs, pinned cylinders and later piano rolls, thereby distributing musical labour across human and mechanical systems. Because most of these devices executed fixed or semi-fixed programmes, this distributed agency should be distinguished from the adaptive, real-time interaction characteristic of contemporary AI-based systems. Historical automatic instruments are therefore better understood as precursors that clarify earlier forms of distributed agency rather than as direct prototypes of contemporary interactive algorithmic or AI-based systems.

Third, the development of music automation foregrounded the aesthetics of repetition and variation. Systems such as early music boxes and barrel organs, which repeated predetermined melodies, transformed technical constraints into aesthetic features by emphasising regularity and pattern. In the nineteenth century, Winkel's *Componium* addressed the monotony of repetition by introducing a chance-based variation algorithm capable of generating unpredictable musical sequences. This represented a pioneering attempt to produce varied musical flow from limited material and provides a valuable historical point of comparison for later probabilistic composition techniques and concepts of generative music.

Fourth, historical automatic instruments illustrate the evolution of encoding media for storing and transmitting musical knowledge beyond the written score. Pinned cylinders and perforated paper rolls physically encoded musical information in ways that are conceptually parallel to contemporary Musical Instrument Digital Interface (MIDI) data and algorithmic code. Commentary on machine performance has long contrasted mechanical precision with the perceived absence of human expressivity – an enduring debate that continues to resonate in current discussions of AI-generated music and its alleged 'lack of emotion'.

Embedded algorithms are never neutral; they script gestures, styles and roles. Historical automata already redistributed labour among composers, makers and machines, whereas contemporary concerns regarding dataset provenance, consent and attribution extend these questions into the domain of AI. Transparent documentation, opt-in data practices and clear crediting protocols can help render algorithmic instruments more accountable

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rather than treating them as opaque substitutes for human creativity.

Viewed through this historical lens, algorithmic automation in music can be understood not as a phenomenon unique to the digital era, but as a recurring concern that has assumed different forms across changing technical and cultural contexts. Recognising both continuity and rupture allows contemporary AI music tools to be understood in relation to earlier forms of automation while also acknowledging the distinctiveness of data-driven, adaptive and networked systems. Although some later mechanical instruments broadened musical circulation and participation, contemporary intelligent instruments raise related – but distinct – questions concerning access, technical mediation, expertise and the limits of human–machine interaction.

Historical precedents also invite renewed attention to legibility and interactivity in instrument design. Although Vaucanson and Jaquet-Droz concealed the internal complexity of their mechanisms to produce wonder, contemporary creators may instead choose to visualise algorithmic processes or expose them through interfaces that engage audiences more directly. Moreover, the historical coexistence of automatic and human-operated devices provides a useful point of comparison for contemporary systems that negotiate autonomy, control, feedback and performer intervention.

Finally, in the post-digital era, discourse surrounding music and art has increasingly focused on the division of roles and the changing relationships between humans and algorithms. The historical exploration undertaken here provides such discussions with a long-term perspective, deepening our understanding of how artistic forms adapt to technological change. Historical automatic instruments did not wholly replace human performers; rather, they fostered new musical cultures and transformed the roles of musicians. This suggests that contemporary AI music technologies should be examined in terms of how they reshape creative processes, social roles and forms of agency, rather than through a simple opposition between replacement and creativity. In this sense, algorithms are better understood as mediating systems whose creative significance depends upon design, use, control, attribution and social context.

In conclusion, by placing the history of musical automata in dialogue with contemporary debates on algorithmic and AI-mediated music, this study offers a historical perspective on the changing relationships among composers, performers, machines and audiences across both pre-digital and digital contexts. The historical insights presented here provide valuable reference points for understanding the creative interaction of humans and machines within the contemporary music-technology environment and may contribute to shaping an interdisciplinary discourse on the future directions of musical art. The aim is not to collapse historical automata and contemporary AI systems into a single continuous lineage, but rather to demonstrate how recurring questions of encoding, agency, authorship, legibility and automation have been reformulated across changing technological, institutional and audience contexts.

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