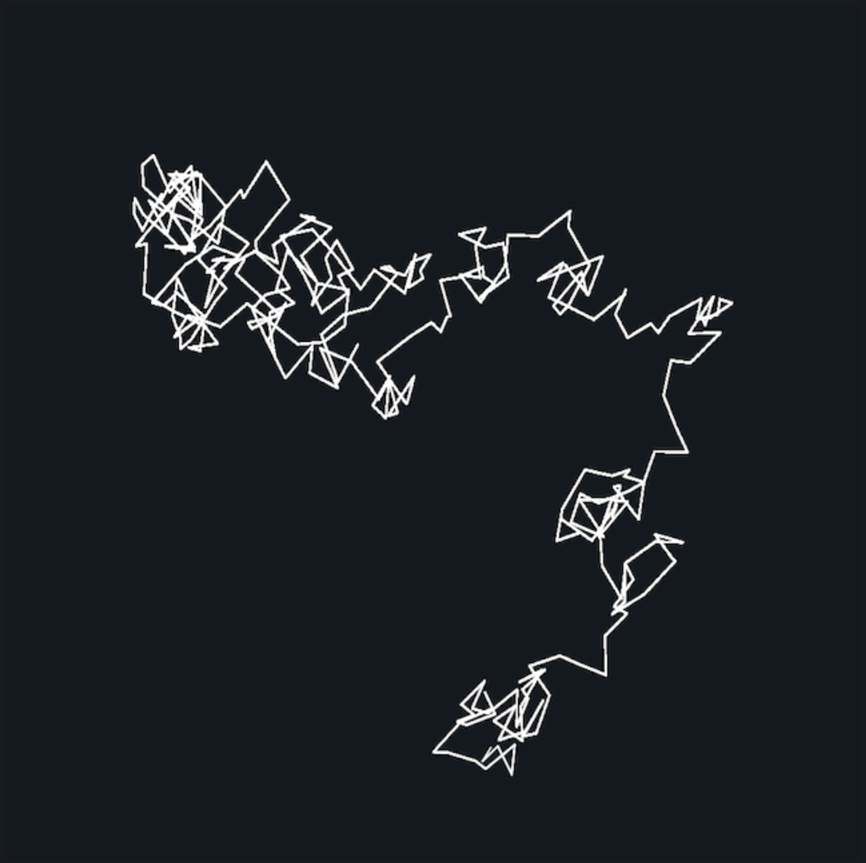
INSTITUTE OF SONOLOGY

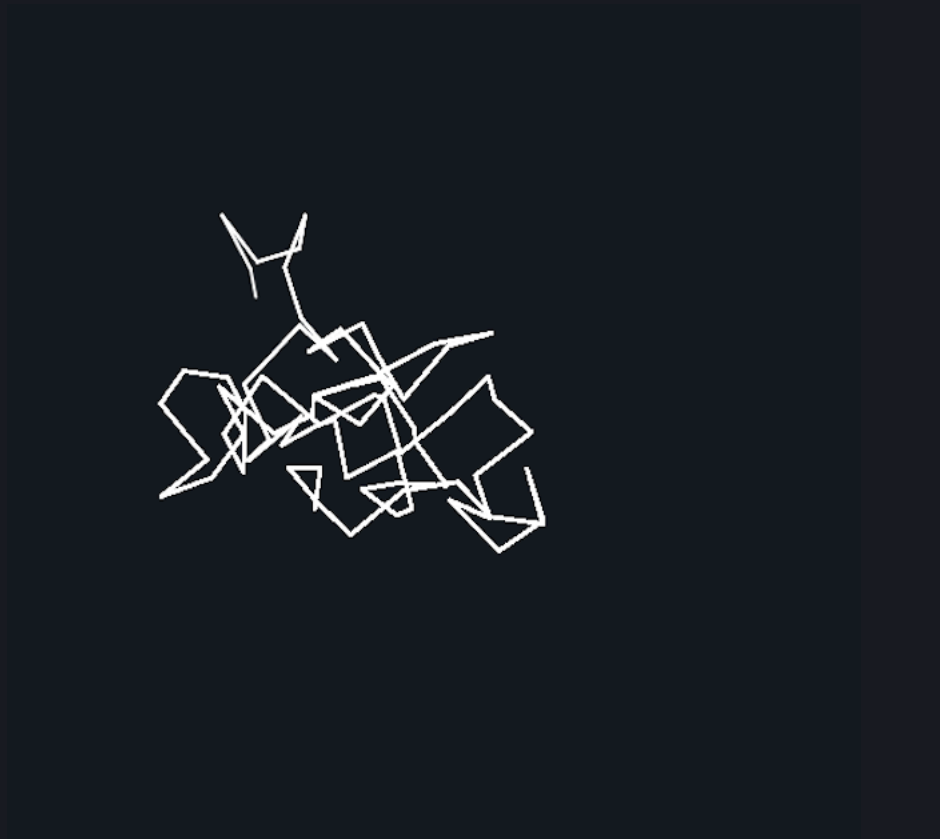
Royal Conservatoire The Hague

History

Composing with Algorithms
http://www.bjarni-gunnarsson.net

Algorithm





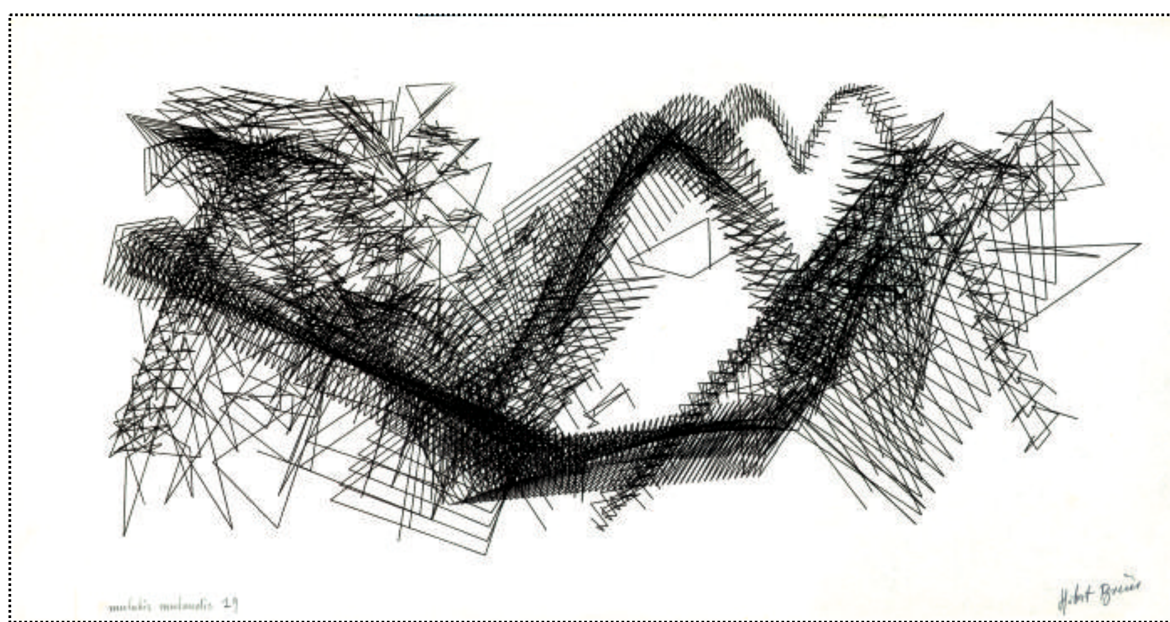
Algorithm a mediation between existing ideas and practical realisations

Algorithmic ***processes*** as implementations to realise an idea or to explore compositional ideas

Boundaries of imagination

"If the composers would have to program each of their ideas for a computer system, they would have to define as accurately as possible what they are looking for. It is to be expected that the computer system will respond with far greater a quantity of propositions answering the definition than the composer's mind alone is either conscious of, or able to imagine. At the same time, it would provide for an exact, step-by-step record of all the proceedings between initial definition and final choice. The composer's choice from the computer's propositions would still remain a highly personal decision, but would be taken in a field which is not limited by the prejudicial boundaries of the choosing person's imagination."

(Herbert Brün)



Algorithm

A set of well-defined steps for solving a particular problem.

Term derived from the name of the Persian mathematician ***Muhammad ibn Musa al-Khwarizmi*** who introduced algebra to western mathematics.

An algorithm proceeds from an ***initial state*** and executes ***operations*** defined for each step until none is left and an output has been made.

Could refer to a ***method, procedure, operation*** or ***technique***.

Pseudocode

Pseudocode is an informal language used for specifying algorithms.

Example (for making music)

- **INPUT:** Length, Sounds, Durations and Intensities.
- **VARIABLES:** ListOfEvents, CurrentLength
- **LOOP:** Until duration has been filled:
  - Choose random sound S
  - Choose random duration D
  - Choose random intensity I
  - Create event E from S,D and I
  - Add E to the ListOfEvents
  - Increase the CurrentLength by D

Guido d'Arezzo

Established the framework for traditional music notation.

In 1026 he used ***rule-based methods*** for composing music.

Created ***lookup tables*** for translating vowels to notes.

The vowels come from a Latin text.

A vowel could correspond to several pitches. Compositional ***choices*** had to be made regarding which pitches to choose.

Guido d'Arezzo

A table determines the compositional ***rules*** and therefore the possible music created.

g3	a3	b3	c4	d4	e4	f4	g4	a4	b4	c5	d5	e5	f5	g5	a5
a	e	i	o	u	a	e	i	o	u	a	e	i	o	u	a

Vowel ***lookup table*** for translating vowels to pitches.

Kircher

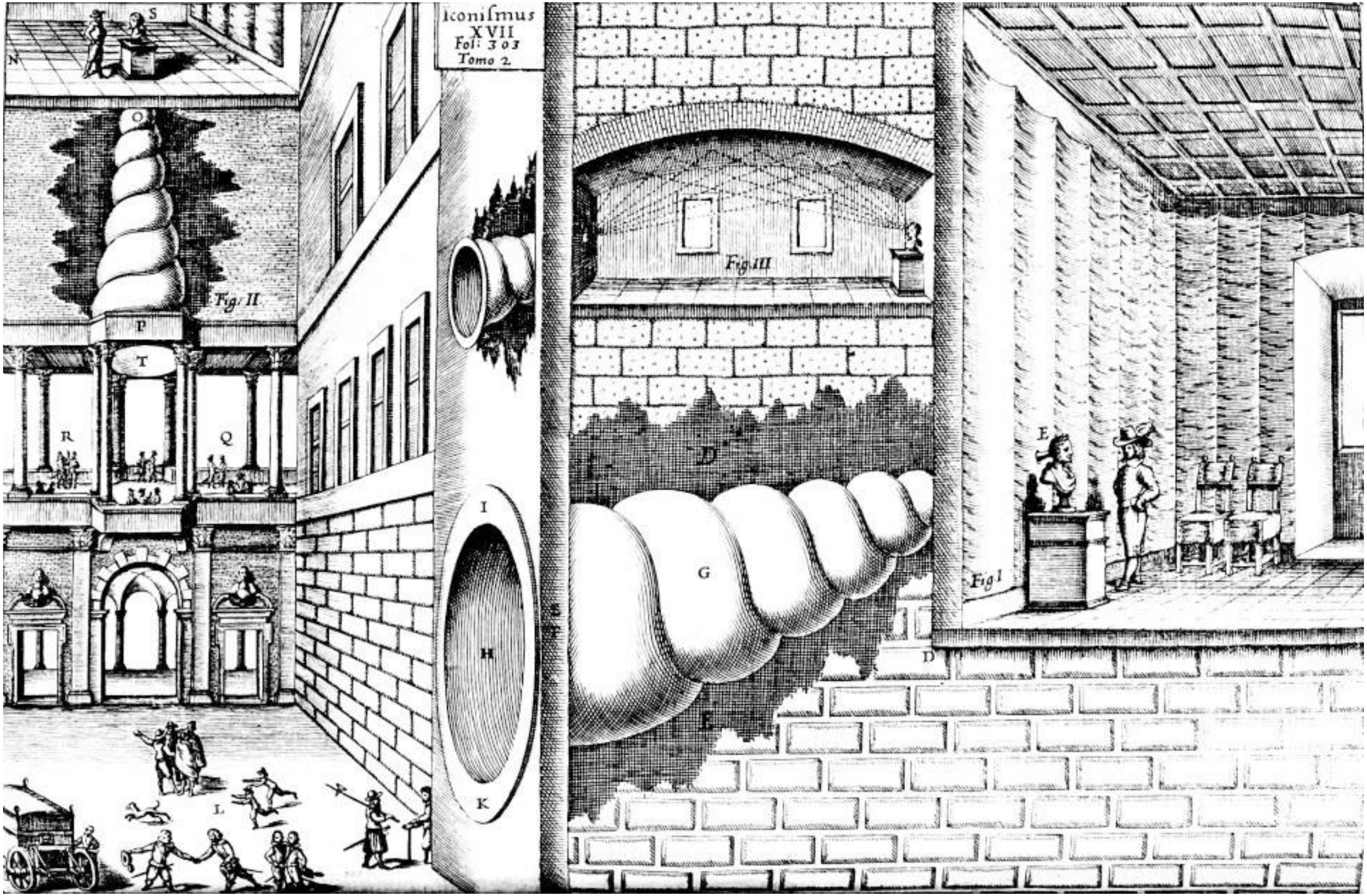
Athanasius Kircher (1602–1680)

- Combinatorial tables: pre-composed fragments combined systematically.

- Rule-bound procedures: deterministic schemes, not true randomness.

- Counterpoint as system: step-by-step execution of rules.

- Anticipated music as a rule-based process, not just inspiration.



ATHANASIUS KIRCHER, A Talking Statue, ?PHONURGIA NOVA?, 1673.

Mozart

Used musical dice games to generate compositions from pre-composed materials (1787).

Different versions of each measure ware pre-composed and the dice rolled to determine how these would occur in a piece.

A ***table of rules*** is used to look up which measures to use after a dice roll.

For some steps only a certain measure was possible not matter what the dice roll outcome was.

Mozart

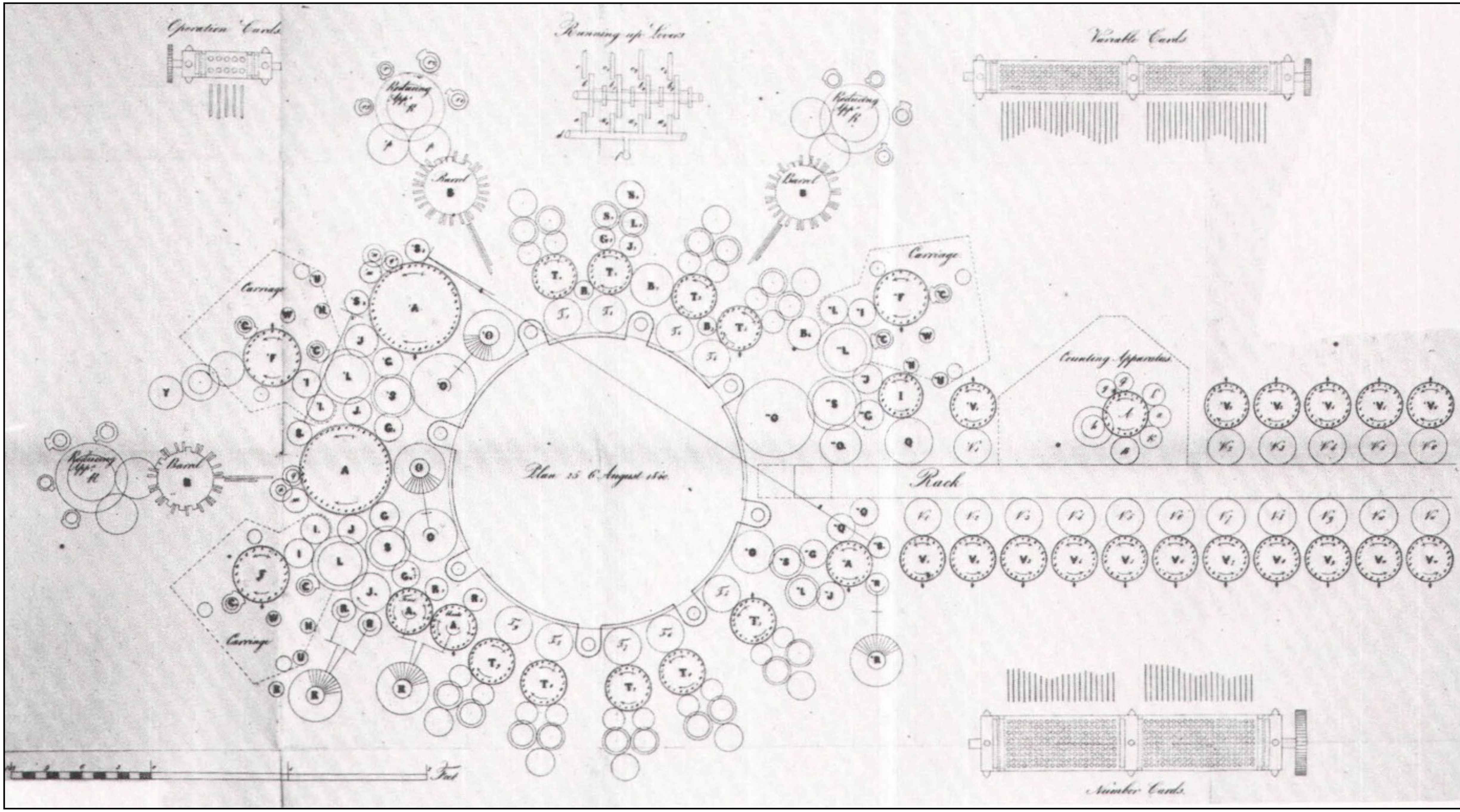
	I	II	III	IV	V	VI	VII	VIII
2	96	22	141	41	105	122	11	30
3	32	6	128	63	146	46	134	81
4	69	95	158	13	153	55	110	24
5	40	17	113	85	161	2	159	100
6	148	74	163	45	80	97	36	107
7	104	157	27	167	154	68	118	91
8	152	60	171	53	99	133	21	127
9	119	84	114	50	140	86	169	94
10	98	142	42	156	75	129	62	123
11	3	87	165	61	135	47	147	33
12	54	130	10	103	28	37	106	5

Table of rules used to select specific measures given a certain dice roll

Ada Lovelace

"[The Analytical Engine] might act upon other things besides number, were objects found whose mutual fundamental relations could be expressed by those of the abstract science of operations, and which should be also susceptible of adaptations to the action of the operating notation and mechanism of the engine… Supposing, for instance, that the fundamental relations of pitched sounds in the science of harmony and of musical composition were susceptible of such expression and adaptations, the engine might compose elaborate and scientific pieces of music of any degree of complexity or extent."

Analytical Engine



The proposed design for the ***Analytical Engine***, a mechanical general-purpose computer designed by Charles Babbage. Mid-1830s

The Schillinger System

Joseph Schillinger developed a method of composition based on ***mathematics*** and ***algorithms*** in 1946.

Not bound to a style and was aimed at helping the composer to generate material instead of limiting him within a closed system.

The publication consists of two volumes and a total of 1640 pages.

"My system does not circumscribe the composer's freedom, but merely points out the methodological way to arrive at a decision. Any decision, which results in a harmonic relation, is fully acceptable. We are opposed only to vagueness and haphazard speculation."

The Schillinger System (1946)

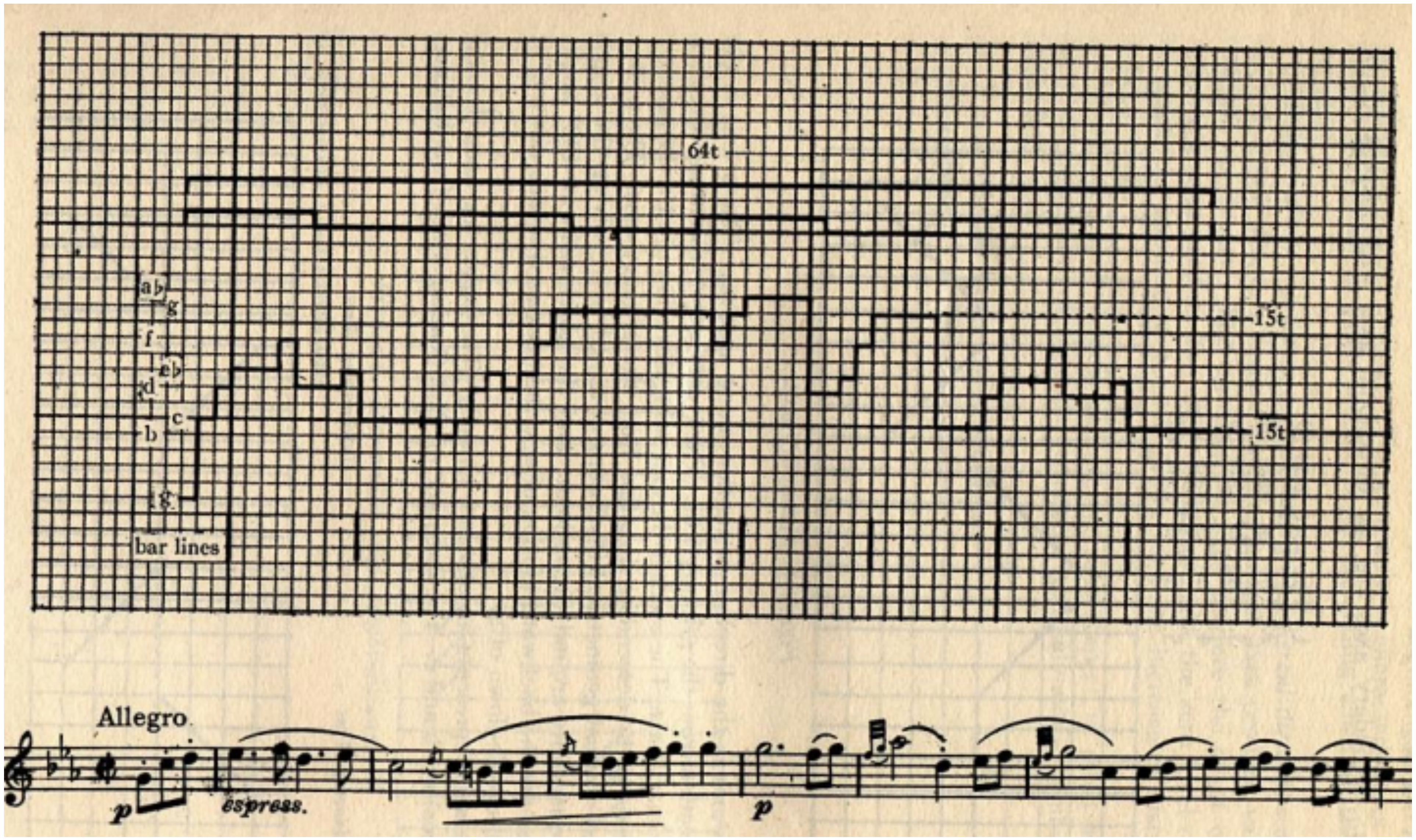
Comprehensive **mathematical method** for rhythm, melody, harmony, and form.

Used **permutation**, **combinatorics**, and **geometric transformations**.

Deterministic: rules + input → predictable musical output.

Bridge between pre-computer rule systems and later algorithmic formalism.

Schillinger



Barlines at the bottom of the graph. The ***pitch names*** on the left side, where each pitch falls on the y-axis of the graph. The lines above the melodic graph represent ***period***, ***measure***, and ***phrase divisions***.

Schillinger

B. Composition of Density-Groups

As we have mentioned before, the choice of p and t, or of S and T as density units, depends on the degree of refinement which is to be attributed to a certain particular score. For the sake of convenience and economy of space, we shall express dt as one square unit of cross-section paper. In each particular case, d may equal p or S, and T may equal t or mt. Yet we shall retain the dt unit of the graph in its general form.

Under such conditions a scale of density-time relations can be expressed as follows:

$$D = d,\ D = 2d,\ \ldots\ D = md$$
$$D^{\rightarrow} = dt,\ D^{\rightarrow} = d2t,\ \ldots\ D^{\rightarrow} = dmt$$
$$D^{\rightarrow} = dt,\ D^{\rightarrow} = 2dt,\ \ldots\ D^{\rightarrow} = mdt$$
$$D^{\rightarrow} = dt,\ D^{\rightarrow} = 2d2t,\ \ldots\ D^{\rightarrow} = mdnt$$

The above are monomial density-groups. On the graph they appear as follows:

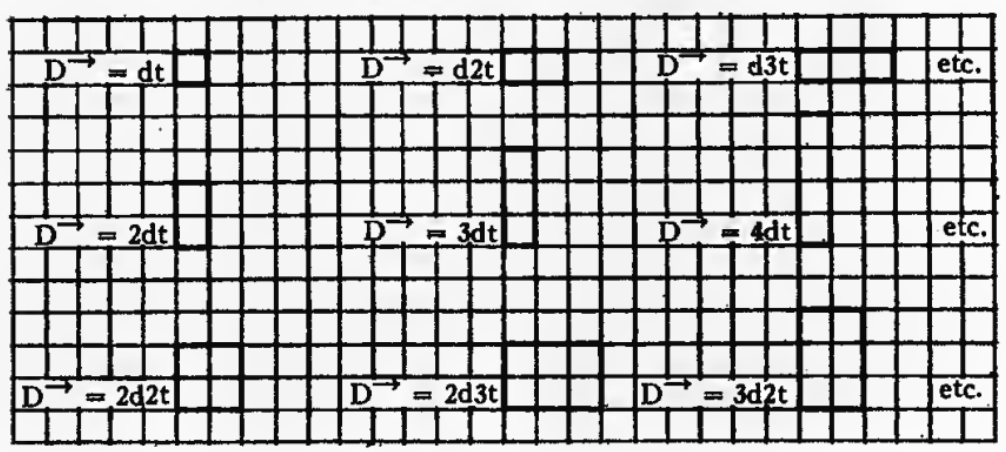


Figure 130. Monomial density-groups.

Binomial density-groups can be evolved in a similar way:

$$\Delta^{\rightarrow} = D_1^{\rightarrow} + D_2^{\rightarrow};\quad D_1^{\rightarrow} = dt;\quad D_2^{\rightarrow} = 2d2t;$$
$$\therefore \Delta^{\rightarrow} = dt + 2d2t$$

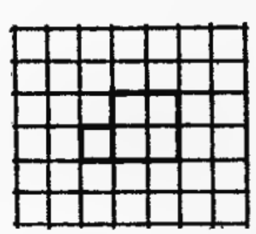


Figure 131. Binomial density-groups (continued.)

Non-identical converging axes, often containing resistance: $\frac{b}{c}$ and b ÷ 0 ÷ c

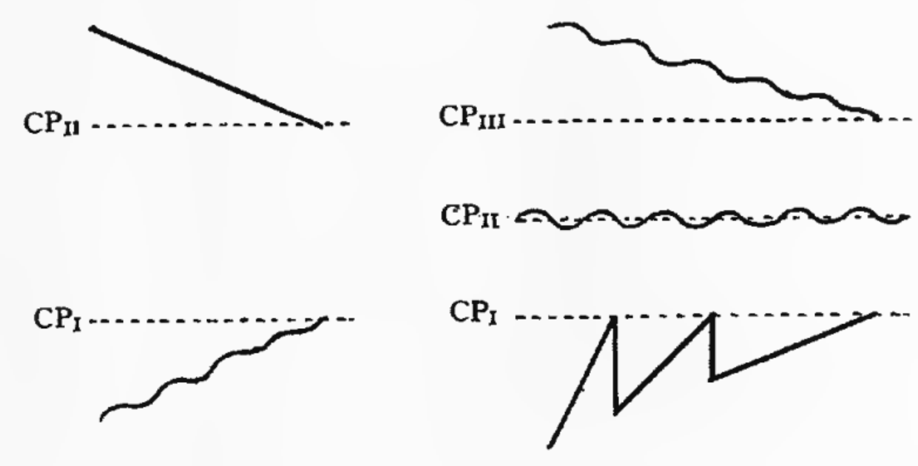


Figure 73. Non-identical converging axes.

For more extreme cases, convergence of many parts.

7. Instrumental Resources:

(a) *density:* low; medium; high; in extreme cases, variable density of the following forms:

direct:

delayed:

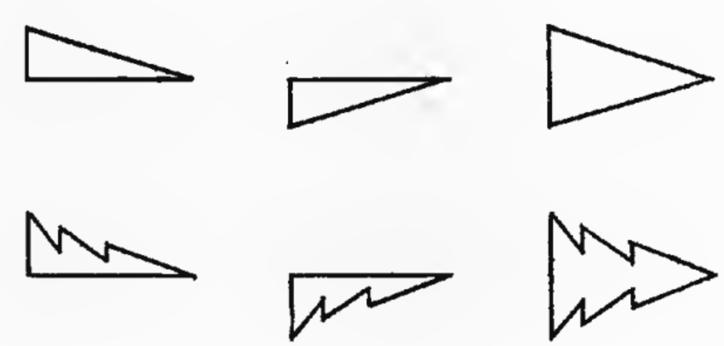


Figure 74. Variable densities.

Conlon Nancarrow

Composed **directly** onto **player piano rolls** (punched by hand).

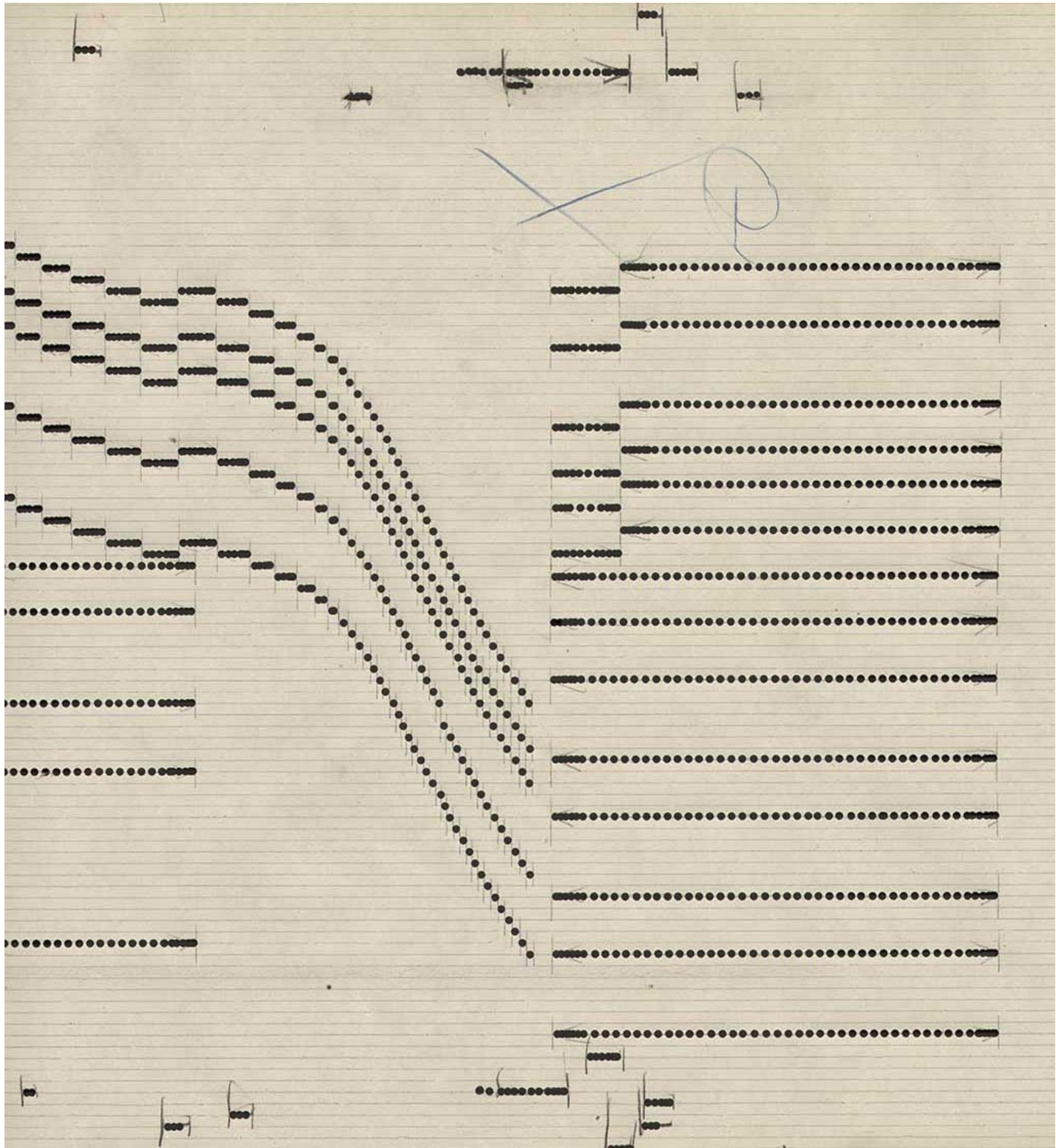
Explored extreme rhythmic **complexity**: tempo canons, accelerations, irrational ratios.

Rule-based procedures: **systematic transformations** of rhythm and pitch.

Music often unplayable by humans, but exact for machines.

Seen as a precursor to computer music: **hand-coded algorithms** for a mechanical instrument.

Conlon Nancarrow



Serialism

After World War II, several composers continued to develop the serial technique invented earlier by Arnold Schönberg.

A general tendency was to extend the serial principles to organize time, timbre and dynamics. The series would function as a ***unifying element*** (or algorithm) controlling every detail of a composition.

Transformations such as ***transposition, inversion, retrograde and permutation*** serve to vary the the base series.

Brings forward issues such as ***formalization, total control, parametric spaces*** and ***compositional dimensions***.

Serialism

Pierre Boulez composed his Structures 1a during a single night in 1951, applying the serial principles to pitches, durations and articulations.

Automatic procedures applied to ***predetermined material*** could thus generate entire compositions.

Structures 1a

"I wanted to eradicate from my vocabulary absolutely every trace of the conventional, whether it concerned figures and phrases, or development and form; I then wanted gradually, element after element, to win back the various stages of the compositional process, in such a manner that a perfectly new synthesis might arise, a synthesis that would not be corrupted from the very outset by foreign bodies—stylistic reminiscences in particular."

(Boulez, 1986)

Pierre Boulez – Structures Ia (1951)

Written for two pianos.

Total serialism: pitch, rhythm, dynamics, articulation all derived from one series.

Procedural rules: transformations (inversion, retrograde, permutation) applied systematically.

Automatic generation: once rules are set, material unfolds with little intuitive choice.

Aim: eradicate convention, rebuild music from pure parametric control.

Karel Goeyvaerts

Attended the Darmstadt New Music Summer School, was a friend of Stockhausen and composed music using ***serial technique***.

Held that ***sine waves*** are the most purest of sounds and an important discovery for composing music with.

His composition nr 5 is made only of sine tones and relations among the parametric values are derived from the arithmetic series of the numbers **1 to 11**.

Each parameter value derived from mathematical relationships

The structure of the piece is essentially generated from numerical control tables

Computers

Computers become available during the postwar years (40s, early 50s).

Large, complex, limited and difficult to access in the beginning.

Early machines often had an integrated loudspeaker, called a '***hooter***'. It was used by various groups of people to make music. It was based on impulses.

Different '*hooter tunes*' ware realized but little of quality or with lasting effects on computer music.

Mark 1

Mark I was the world's first commercially available general-purpose electronic computer (Manchester).

Mark I's instruction set included a ***hoot*** command, that enabled the machine to give auditory feedback to its operators. The sound generated could be altered in pitch, a feature which was exploited when the Mark I made the earliest known recording of computer-generated music in 1951.

Alan Turing in 1951 described the 'hoot' instruction (applies impulse to loudspeaker diaphragm).

These experiments are not considered having artistic impact or influence the design of later music software.

Caplan, Prinz

1955, he wrote hooter-based music-playing routines

As demo, the *Wilhelmus* (Dutch national anthem) could be played

Caplan wrote ***music-generating routines***

- based on Mozart dice game
- machine not fast enough (composed down an octave)
- only used melodic lines

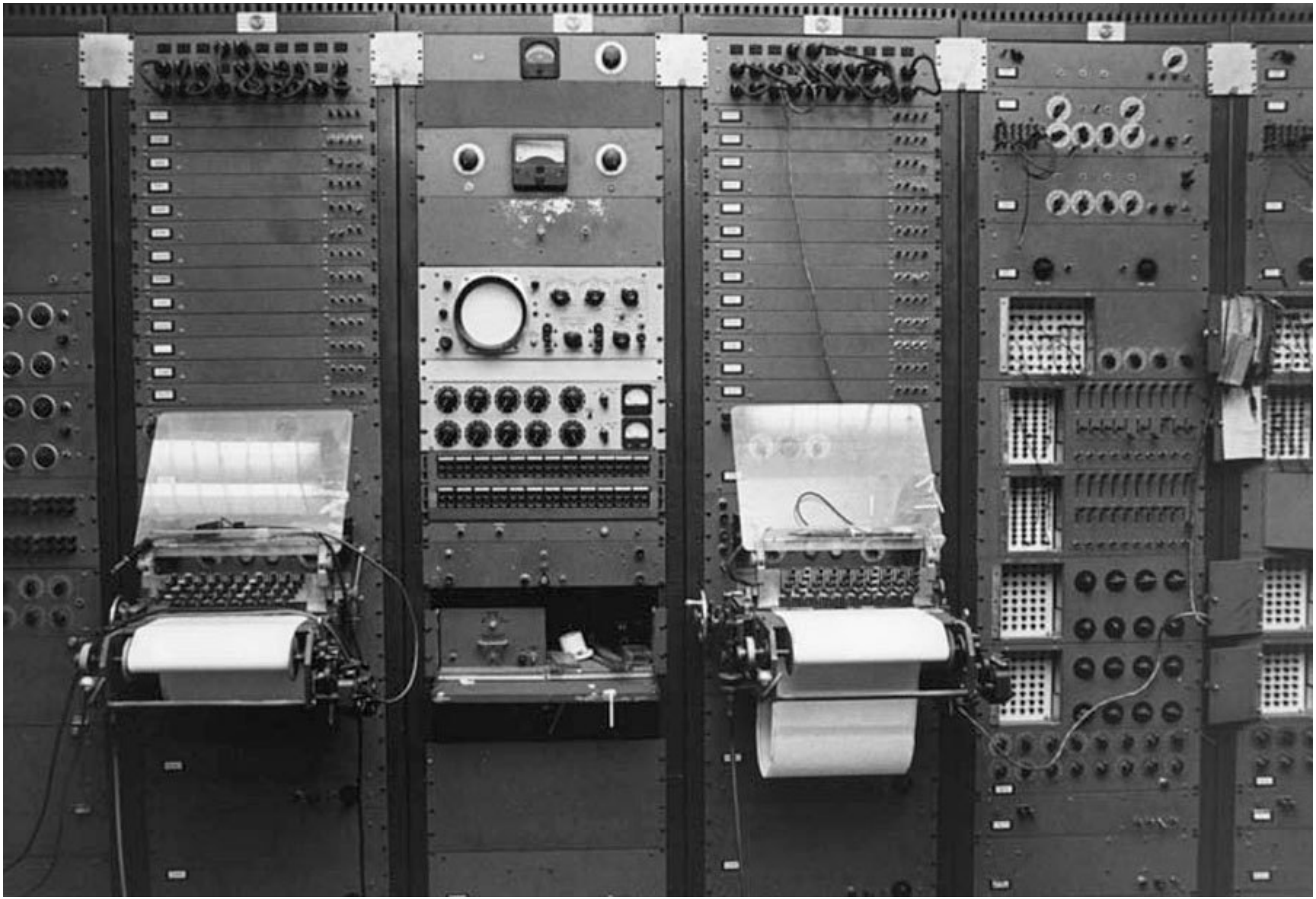
Perhaps can be considered a computer-aided algorithm composition system and predates Illiac Suite.

RCA Synthesizer

The first ***programmable*** electronic synthesizer with paper-tape to control analog sound production (1955). Composer entered data as punched hole patterns.

- Input: paper tape (flexible, maximum control time: 4 minutes)
  Input format was note/event oriented
- 2 channels that a common bank of sound sources: white noise generator and 12 oscillators
- Output to speakers but also cut directly to disk

RCA Synthesizer



RCA Synthesizer

Algorithmic aspects

Event-oriented programming: each punch tape symbol encoded musical parameters.

Deterministic control: once the tape was prepared, the machine executed exactly what was specified.

Parameterization: pitches, durations, dynamics all specified numerically → strong link to serial procedures.

Constraint: limited memory/tape length (max ~4 minutes).

Music N (1957)

- First to use ***unit generator*** concept where synthesis networks are designed by passing a signal through a series of unit generators
- ***Instrument*** is basic program which takes the parameters of a note and generates the appropriate samples
- Unit generators: oscillators, envelope generators, mixers, filters
- ***Score*** definition: notes containing parameters for instruments
- Note paradigm still dominants computer music
- Parametrized: notes (events) described with a series of ***parameters***
- Sound transformations considered '***effects***'
- Punch cards in, tape out, tape -> da converter

Music N

Unit generators: modular building blocks (oscillators, filters, envelopes) combined like algorithms.

Orchestra/Score model: instruments(rules) + event lists (data).

Parametric control: every note/event described by numerical parameters.

Symbolic to sound: abstract rules translated into digital audio samples.

Encouraged algorithmic thinking: composers wrote processes, not performances.

Lejaren Hiller

Trained as chemist and realized the first computer-generated composition, ***Illiac Suite*** (1956-1957) with fellow chemist Leonard Isaacson at the University of Illinois.

Saw music as related to ***information theory*** where a piece was like extracting ***order out of chaos*** using rules.

His algorithms often used random numbers tested by rules that determine succeeding steps. The resulting data would then be transcribed to musical notation.

Lejaren Hiller

Each of the four movement of ***Illiac Suite*** uses different algorithms.

Hiller wrote an article in the ***Scientific American*** describing the piece and computer music which generated much feedback.

"Music is . . . governed by laws of organization, which permit fairly exact codification. (. . . it has even been claimed that the content of music is nothing other than its organization.) From this proposition, it follows that computer-composed music which is "meaningful" is conceivable to the extent to which the laws of musical organization are codifiable."

Illiac Suite

Rule-based generation: compositional rules were encoded as logical conditions.

Stochastic choice: random numbers provided variation within constraints.

Filtering process: the computer generated many options → rules decided what was acceptable.

Output: notation (string quartet score), not sound.

Lejaren Hiller

The ***ILLIAC I.*** computer

University of Illinois

Hiller moved to the music department and founded the Experimental Music Studio.

Composers interested in working with computers and electric sound later joined, for example ***James Tenney*** and ***Herbert Brün***.

Tenney realized compositions with software by ***Max Mathews***, became a composer-in-residence at Bell Labs and was interested in applying ***stochastic*** procedures to composition.

Brün was interested in ***designing processes*** and listen to the result instead of imaging a sound and trying to create it. To discover what music could be when computers are available.

James Tenney

- Influenced by his study with Lejaren Hiller
- Research composer at Bell Labs 1961-64
- Dissatisfaction with timbre in ‘purely synthetic electronic music’
- Psychoacoustic experiments that resulted in random amplitude and frequency modulations
- Wanted to separate compositional procedures from note generation
- Dialogue (1963) is between tone and a band of noise
- Stochastic control over timbral, durational, and pitch parameters

James Tenney

Tenney, *Dialogue* 1963

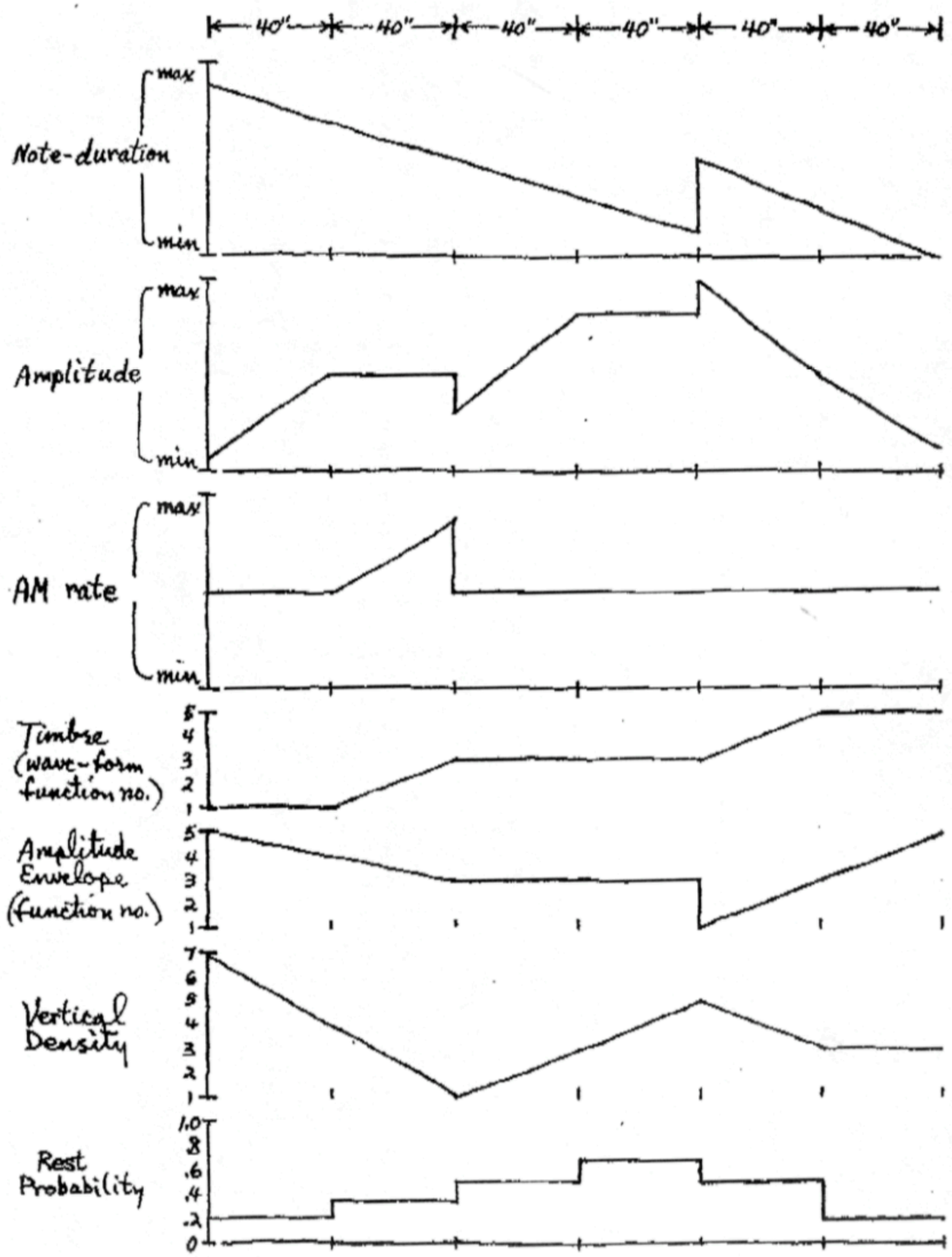


Figure 11a. Parametric Means for *Dialogue* (tonal stratum).

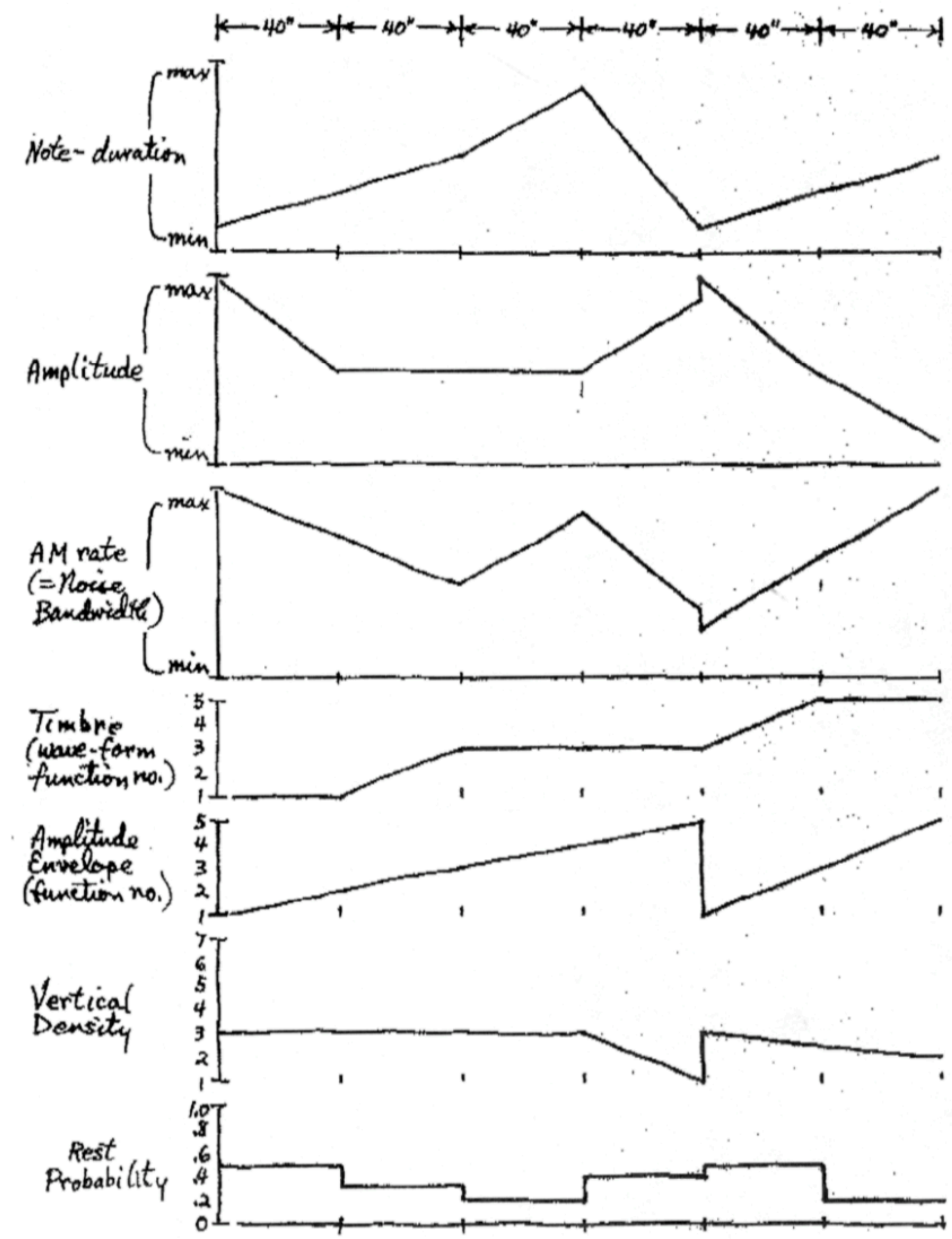


Figure 11b. Parametric Means for *Dialogue* (noise stratum).

Tones

Noise

James Tenney - Dialoge (1963)

Xenakis

Worked initially as architectural assistant for Le Corbusier in Paris.

Applied ideas from architecture in music for example in ***Metastasis*** (1954) where long continuous glissandi create sonic spaces.

Criticized total serialism for destroying itself by complexity where the methods resulted in "*nothing but a mass of notes in different registers*".

Xenakis

Proposed ***"stochastic" music*** where the organization of materials is based on probabilities. First used in ***Pithoprakta*** (1956).

The use of statistical methods resulted in a formal approach to composition creating a compositional model for the "*fundamental phases of a musical work*".

Xenakis

Developed a computer algorithm ***ST*** (1964) which was implemented by IBM in Paris and used to generate a family of different pieces.

Used various other algorithms for composing music such as:

* ***Markov Chains***
* ***Screens*** (granular synthesis)
* ***Strategy games***
* ***Boolean algebra***
* ***Set theory***
* ***Brownian motion***
* ***Cellular automata***

Gottfried Michael Koenig

Implemented his first compositional program, ***Project 1*** in 1966 at the Institute of Sonology in Utrecht.

Enables to investigate a simple ***compositional model***.

Parameter values are choses between ***regular and irregular*** on a scale from 1 to 7.

The result of the program is the output in a form of a score table. The ***interpretation*** of the table data and the transfer to notation is very important.

Gottfried Michael Koenig

Implemented ***Project 2*** in the 60's. It is based on defining a database of parameters and a structure formula for selecting and combining those parameters.

Variants of the same structure could be made.

Gottfried Michael Koenig

Selection principles for treating musical material:

* ***Sequence*** (a series of values)
* ***Alea*** (random)
* ***Series*** (random with repetition check)
* ***Ratio*** (weighted random)
* ***Group*** (repeated random)
* ***Tendency*** (random with changing boundaries)

Pierre Barbaud

Algorithmic music as the rational spirit of ***modernity***, whose goal was *"to submit the appearance of sound events to calculation, to demolish what is conventionally called 'inspiration,' to replace the mystical passivity of the composer in the presence of the 'muse' with lucid and premeditated activity."*

Founded the ***Groupe de Musique Algorithmique de Paris*** (GMAP), joined by Roger Blanchard, Jeannine Charbonnier, and Brian de Martinoir in 1960. The group produced a collective composition , ***Factorielle 7***, which was one of the first computer-generated scores. The piece was built around 5040 ($7! = 1 \times 2 \times 3 \times 4 \times 5 \times 6 \times 7 = 5040$) combinations of a twelve-tone row, devised using aleatoric techniques.

Pierre Barbaud

Barbaud sets in motion a ***musical process*** which runs its course without intervention. No ad hoc modifications of the musical output; if it is found aesthetically insufficient, the composer must ***adjust*** the "*controls*" of the generative algorithm and then let it run

```
'DEBUT''REEL'FA,QA,RA          ◊
'ENTIER'NK,NC,NKK   ◊
'REEL''TABLEAU'L0,L1,L2,L3$(0:319)$,CAN$(0:3,0:99)$,
CAN2$(0:3,0:99)$,
ENS,FON,SEC,TIE,QUA,QUI,SIX,SEP$(0:49)$     ◊

'PROCEDURE'LECTURE(L3) ◊ 'REEL''TABLEAU'L3 ◊ 'DEBUT'
 'ENTIER'M,K      ◊ K:=DONNEE ◊
'POUR'M:=0'PAS'1'JUSQUA'K'FAIRE''DEBUT'
      L3$(M)$:=DONNEE      ◊
'FIN' ◊ 'FIN' ◊

'PROCEDURE'MARIE THERESE(L0)◊'REEL''TABLEAU'L0◊
'DEBUT''REEL'A,X,QN,RN       ◊       'ENTIER'L,M,N,P       ◊
     M:=0◊N:=0◊P:=0◊L:=DONNEE◊
ORG: A:=L0$(M)$◊X:=(A-ENT(A))×1000◊
     'SI'X=FON$(P)$'ALORS'CAN$(L,N)$:=1
     'SINON''SI'X=TIE$(P)$'ALORS'CAN$(L,N)$:=3
     'SINON''SI'X=QUI$(P)$'ALORS'CAN$(L,N)$:=5
     'SINON''SI'X=SIX$(P)$'ALORS'CAN$(L,N)$:=6
     'SINON'CAN$(L,N)$:=7◊
     M:=M+4◊'SI'M>NKK-7'ALORS''ALLER A'ENDE◊
     N:=N+1◊QN:=ENT(N/2)◊RN:=N-QN×2◊
     'SI'RN=0'ALORS'P:=P+1◊'ALLER A'ORG◊
ENDE:'FIN'◊
```

Cage

"Music which should be allowed to grow freely from sound at its very grass roots, for methods of discovering how to 'let sounds be themselves rather than vehicles for manmade theories, or expression of human sentiments."
(1957)

Applied ***chance procedures*** to his music for example with the *I Ching*.

Used a set of "*charts*" with entries for sonorities, rhythm and dynamics.

Cage

Worked with Hiller on ***HPSCHD*** (1967-69) for seven harpsichords, fifty-one tapes of computer generated music and slide projections.

Cage generalized his procedures in 1982 into computer algorithms with Andrew Culver and used later in his life.

Cage

“Formerly, when one worked alone, at a given point a decision was made, and one went in one direction rather than another; whereas, in the case of working with another person and with computer facilities, the need to work as though decisions were scarce—as though you had to limit yourself to one idea—is no longer pressing. It's a change from the influences of scarcity or economy to the influences of abundance and—I'd be willing to say—waste.”

John Cage (interview during the composition of HPSCHD)

HPSCHD

Performance of ***HPSCHD*** at the Assembly Hall of Urbana Campus, University of Illinois.

David Tudor

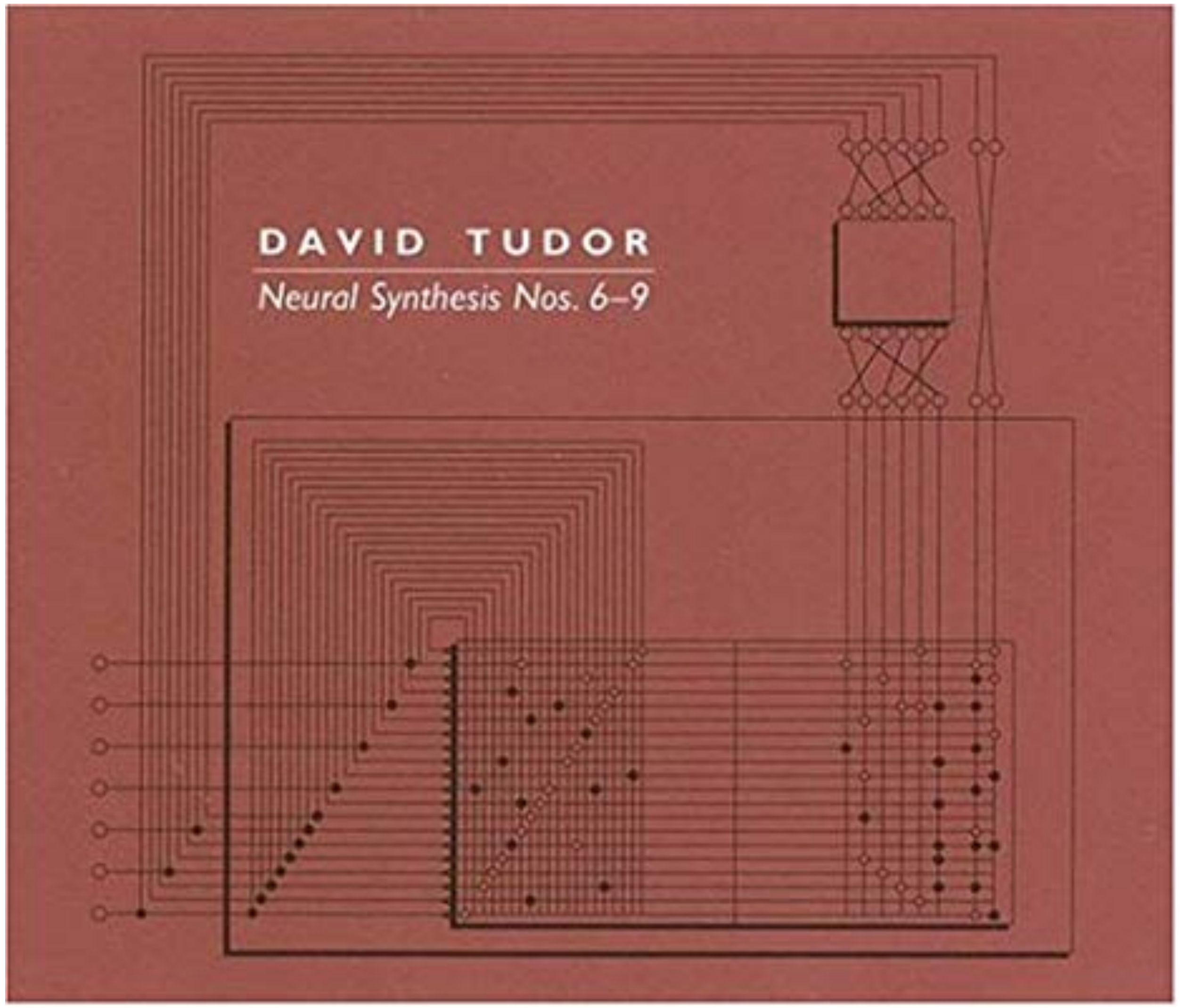
Neural Synthesis combines music, electronics, and the inspiration of biology through a custom hybrid synthesizer.

The neural-network chip forms the heart of the synthesizer. It consists of 64 non-linear amplifiers (the electronic neurons on the chip) with 10240 programmable connections. Any input signal can be connected to any neuron, the output of which can be fed back to any input.

Neural Synthesis relies upon an overlaying process exposing different levels of the source material.

David Tudor

The space of possible interneuron configurations is so large that it is difficult to reproduce the behavior of the synthesizer, which can evolve sound on its own over time. Searching for the regions of configurations that produce captivating sound becomes the challenge.



The League of Automatic Music Composers

Collective of electronic music experimentalists from San Francisco and active in the early eighties. Used network models with computers for live performance.

"*We approached the computer network as one large, interactive musical instrument made up of independently programmed automatic music machines, producing a music that was noisy, difficult, often unpredictable, and occasionally beautiful.*"

Brian Eno

"Since I have always preferred making plans to executing them, I have gravitated towards situations and systems that, once set into operation, could create music with little or no intervention on my part. That is to say, I tend towards the roles of planner and programmer, and then become an audience to the results"

Music for Airports (1978) uses tape loops of different lengths causing evolving patterns due to phasing. The vocal-only piece repeats its first note every 23 seconds, the next one every 25, the third every 29 and so on.

Brian Eno

Released ***Generative Music 1 (1996)*** using only SSEYO Koan, a generative software to create the music he describes as ever-different & changing.

Hopes for three kinds of music: ***live, recorded and generative***.

David Cope

"*I envision a time in which new works will be convincingly composed in the styles of composers long dead. These will be commonplace and, while never as good as the originals, they will be exciting, entertaining, and interesting.*" (1982)

Cope created software that produces output in the ***style*** of various composers. Software that attempts to ***replicate***, not create.

His method uses ***pattern matching*** and ***style databases***.

Music theory or artistic work?

Composition or Music Theory

In algorithmic composition much discussion has been on how to program software that generates "plausible" results that appear to be in a ***certain style*** or to ***emulate a composer***.

One belief states that computers should "learn" a musical structure and then reproduce it. The idea itself ***prevents invention*** but ***encourages copying*** of ideas.

A possible confusion is between the ***different goals*** of ***composition*** on the one hand and ***music theory*** or ***artificial intelligence*** on the other.

"Ultimately, the limitation with the computer is only the limitation of the imagination itself. Perhaps our imagination is not yet open enough or vast enough to know exactly what to do to exceed our limitations. I think that this is one of the reasons why someone like Xenakis was interested in a program like the Gendyn program; he wanted to be surprised. He wanted to do something in which he had some control over the process, but in which the results would go beyond what he could possibly imagine. The question of how to use one's imagination but not be constrained by its limitations is a central one in regard to the use of the computer in creating music."

(Gerard Pape, 2003)

Exercises

Exercises

A process where a synth is played using a beta distribution for pitches and stutter pattern for duration where each duration occurs four times.

A process where pitches variate between random (using either a uniform or an exponential distribution) and predefined ones.

A process that plays two synths at the same time where each one has has a different rhythm pattern and amplitude trajectory.

A process that plays chords of three notes each where each note in the chord has a different amplitude set.

A process that will generate a random pitch and repeat it for a number times until it generates another one.