

# Ars Combinatoria

## Mystical Systems, Procedural Art, and the Computer

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"This is a slightly unusual request," said Doctor Wagner, with what he hoped was commendable restraint. "As far as I know, it's the first time anyone's been asked to supply a Tibetan monastery with an Automatic Sequence Computer. . . . Could you explain just what you intend to do with it?"

—Arthur C. Clarke, "The Nine Billion Names of God," 1952<sup>1</sup>

One of the Greek oracles, the sibyl at Cumae, used to write the separate words of her prophecies on leaves and then fling them out of the mouth of her cave. It was up to the suppliants to gather the leaves and make what order they could.

—Charles O. Hartman, *Virtual Muse*, 1996<sup>2</sup>

**B**orges, in the essay "Kafka and His Precursors," suggests that our perception of the present alters our conception of the past, that we can look at texts from the past in a new way, influenced by things we now understand.<sup>3</sup> By the light of the computer, then, we can look anew at a long history of mystical texts and combinatorial systems that reach back to antiquity. Mystical systems involving permutational procedures that purport to reveal a body of hermetic knowledge or that lead to a revelatory exhaustion of all possibilities prefigure the computer's potential to permute and, given rules, to engage in "creative magic" by finding meaning in new combinations. A number of artists in this century, with or without the computer, have explored this realm in their work.

I have searched for examples of three specific types of combinatorial systems. In mathematics, these three types are called permutation, combination, and variation. Each begins with a limited number of items, a set of things. In permutations, the positions of these things are shuffled within the whole set, as in an anagram. For combinations, one can take out any number of elements from the set and put them together in a smaller group. Variations are permutations with repetitions allowed: in variations, one can permute to infinity. The computer, of course, excels at all of these systematic activities.

During this search for examples, certain questions, themes, and comparisons arose. Why are permutations of

abstract symbols so often linked to creation, whether divine or artistic? What is it about permuting letters or numbers that leads to mystical experience? Is this experience born out of the creative transformation that occurs or out of the meditative activity? What role can the computer play as a stand-in for this process? What is the qualitative difference between permutational systems that are intentionally driven, and those systems that are manipulated with chance operations?

Among the themes that have recurred is the notion of total exhaustion; it is often hinted that, if all the possibilities of permutations are exhausted, there might be a revelation or a transformation on a larger scale, or even the end of the world. There is the recurring idea that the numbers 1 or 2 or 3 can give birth to everything there is, to the infinite. The number 1 is often paradoxically equated with the infinite.

Comparing the historic mystical systems to twentieth-century artistic practice with a similar systematic basis presents other questions. Are there larger, more transfor-

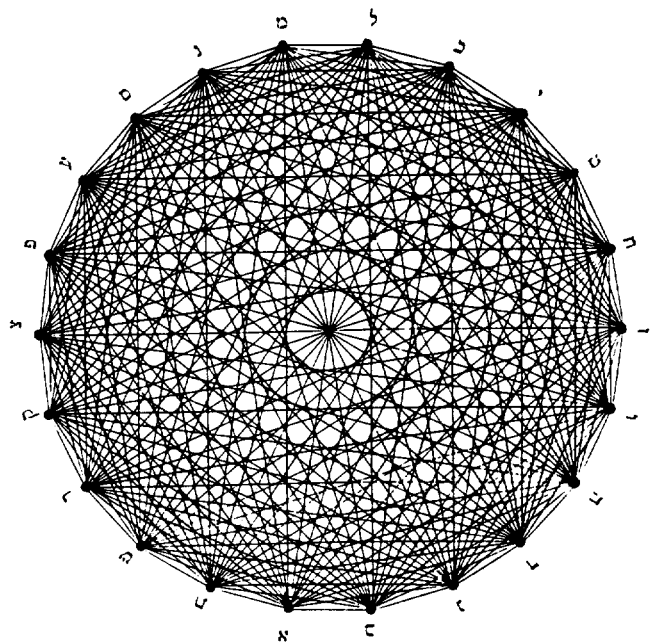


FIG. 1 The 231 Gates of the *Sefer Yetzirah* (from Aryeh Kaplan, *Sefer Yetzirah* [York Beach, Me.: Samuel Weiser, 1990], fig. 4, used by permission).

mational systems, and smaller, more self-contained ones? Why does some procedural work seem more spiritually based, while other work demands to be taken for exactly what it is, pure process? Does the artwork reside in the machine or in what the machine generates? What is so compelling, across the ages, about combinatorial activity?

What follows are several examples, by no means comprehensive, of *ars combinatoria*, or combinatorial art. They are presented in roughly chronological order with one notable exception, the *I Ching*, which is the oldest example of all and is placed just prior to a discussion of some works by John Cage. The examples begin instead with another ancient text, the *Sefer Yetzirah*.

The *Sefer Yetzirah*, or *Book of Creation*, is a mystical Hebrew text. Its origins are uncertain; but it may date as far back as the second century A.D.<sup>4</sup> Its purpose and meaning are equally unclear; it might have been an instructional text for meditative techniques and creative magic, as well as an explication of the book of Genesis. According to the *Sefer Yetzirah*, the world was fabricated by the Infinite One, the *Ain-Sof*, out of permutations of letters and numbers:

*Twenty-two Foundation letters:*

*He engraved them, He carved them,  
He permuted them, He weighed them,  
He transformed them,*

*And with them, He depicted all that was formed  
and all that would be formed.*<sup>5</sup>

By the manipulation of letters, then, the universe was created. The permutational method that was employed by the *Ain-Sof* to create the world is described:

*How?*

*He permuted them, weighed them, and transformed them,  
Alef with them all  
and all of them with Alef,  
Bet with them all  
and all of them with Bet.*

*They repeat in a cycle  
and exist in 231 Gates.*

*It comes out that all that is formed  
and all that is spoken  
emanates from one Name.*<sup>6</sup>

This divine name is the Tetragrammaton, or YHVH, according to the Kabbalists. The 231 “Gates” correspond diagrammatically to the number of lines that can connect the twenty-two letters of the Hebrew alphabet when they are placed in a circle, in other words, the number of two-letter combinations that can be formed (*fig. 1*).<sup>7</sup>

The ten numbers, or *sefirot*, are divine, and they represent ten divine emanations. A diagram called the Tree of Life, derived from the *Sefer Yetzirah* and represented in many different versions over the centuries, shows how the

ten numbers are connected by exactly twenty-two lines, corresponding to the twenty-two Hebrew letters, when placed in a particular arrangement (*figs. 2, 3*).

The mathematical ideas in the *Sefer Yetzirah* continue with an illustration of factor analysis:

*Two stones build 2 houses*

*Three stones build 6 houses*

*Four stones build 24 houses*

*Five stones build 120 houses*

*Six stones build 620 houses*

*Seven stones build 5040 houses*

*From here go out and calculate*

*that which the mouth cannot speak  
and the ear cannot hear.*<sup>8</sup>

The stones appear to represent the letters of the alphabet. The number of permutations that are possible with a given number of letters is the factorial of that number, expressed as  $n!$  or  $1 \times 2 \times 3 \dots \times n$ . The permutations of the entire Hebrew alphabet are  $22!$ , or 1,124,000,727,777,607,680,000.<sup>9</sup> This enormous number must be “that which the mouth cannot speak / and the ear cannot hear.” Or, if the series is continued ad infinitum, the author may be referring to the infinite. So this idea is expressed: from one comes an infinite number of things, or from the Infinite One comes an infinity of matter.

The text of the *Sefer Yetzirah* can also be read in the imperative as instructions, suggesting to the reader a means of creative invention. Permuting the symbols can act as an “operational agent” that could actually produce beings in the world.<sup>10</sup> The skilled mystic can imitate God’s creative ability on a much smaller scale by using the techniques suggested in the *Sefer Yetzirah* as meditative and creative tools. In the Talmud, there is a story about two rabbis who practiced creative magic one Sabbath night and managed to produce a small calf, which they then ate.<sup>11</sup> The myth of the Golem has arisen out of the techniques suggested in the *Sefer Yetzirah*. The Golem is a mute humanlike creature, a robot, which mystics fabricate by using a magical method that includes a systematic meditation on and permutation of numbers and letters.

The *Sefer Yetzirah* was studied and interpreted in later centuries by the Kabbalists, who were scholars and practitioners of Jewish mysticism: their activity flowered in thirteenth-century Spain and France. (*Kabbalah* literally means “tradition.”) Abraham Abulafia was a Spanish Kabbalist with a distinctively systematic approach toward achieving ecstatic mystical experience. He believed that the soul was “sealed” from unity with the Infinite or the Divine, and through specific meditative techniques that lead to ecstatic visions, these seals could be broken. Many of his techniques consist of meditation on and practice of *Temurah* and *Gematria*. *Temurah* is the permutation of letters, often with the Name of God, or Tetragrammaton.

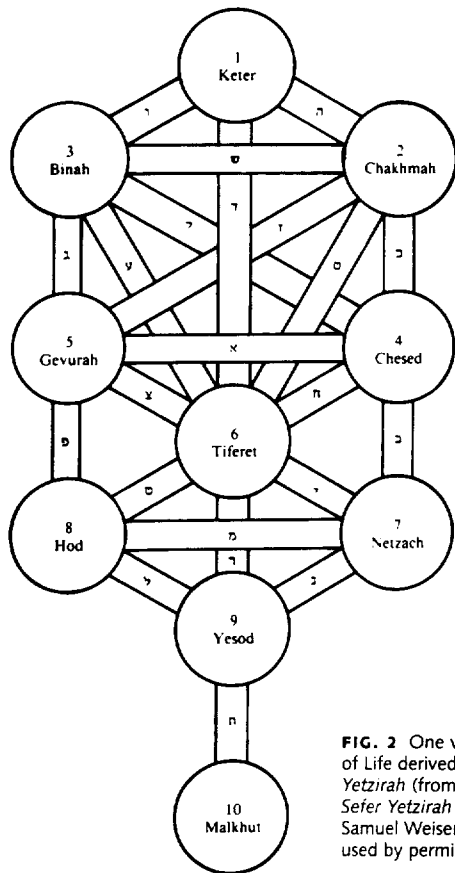


FIG. 2 One version of the Tree of Life derived from the *Sefer Yetzirah* (from Aryeh Kaplan, *Sefer Yetzirah* [York Beach, Me.: Samuel Weiser, 1990], fig. 19, used by permission.)

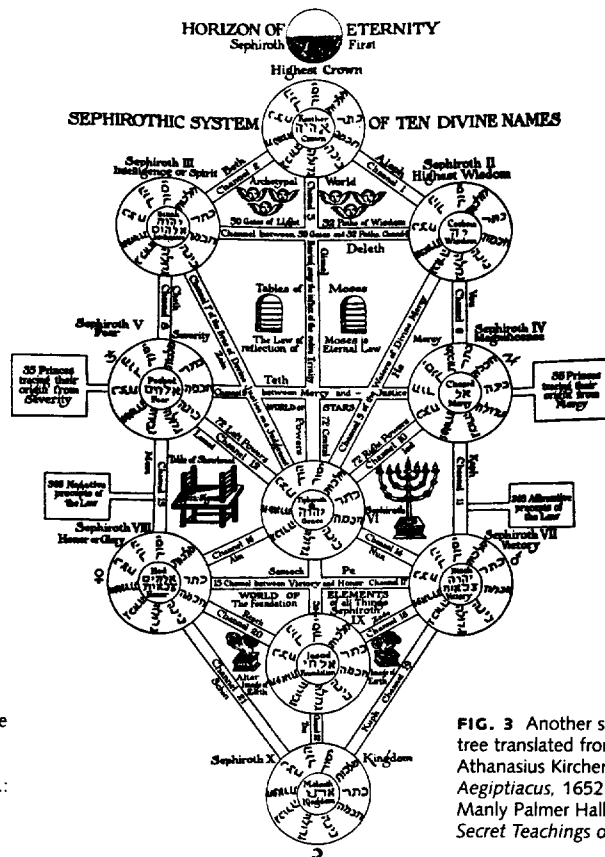


FIG. 3 Another sephirothic tree translated from Athanasius Kircher, *Oedipus Aegyptiacus*, 1652 (from Manly Palmer Hall, *The Secret Teachings of All Ages*).

Each letter of the Hebrew alphabet has a numerical value, so *Gematria* is the calculation of the numeric value of each word by adding up those numbers: the relationships of words are based on their numeric values. Abulafia's "science of combination" describes methods of using these techniques to achieve a heightened state of consciousness. He writes:

*Then take ink, pen, and a table to thy hand and remember that thou art about to serve God in joy of the gladness of heart. Now begin to combine a few or many letters, to permute and to combine them until thy heart be warm. Then be mindful of their movements and of what thou canst bring forth by moving them. And when thou feelest that thy heart is already warm and when thou seest that by combinations of letters thou canst grasp new things . . . then turn all thy true thought to imagine the Name.*

Later, as the process culminates, he writes: "Thy whole body will be seized by an extremely strong trembling, so that thou wilt think that surely thou art about to die, because thy soul, overjoyed with its knowledge, will leave thy body."<sup>12</sup> And a disciple of Abulafia writes that his teacher tells him,

*My son, if you would devote yourself to combining holy Names, still greater things would happen to you. And now,*

*my son, admit that you are unable to bear not combining. Give half to this and half to that, that is, do combinations half the night, and permutations half the night.*<sup>13</sup>

Contemporary with Abulafia, and not far away, Ramon Llull was born in Majorca in the thirteenth century. Llull was a Christian mystic and a Neoplatonist. After receiving a vision on a mountaintop in which he saw the "Dignities" of God revealed to him as elements in all creation, Llull devoted himself to developing a truly eccentric and original combinatorial system of letters and revolving wheels. What is called Llull's Art is a kind of self-contained logic. He devised the Art to prove systematically the reality of universal Christian truths and to serve his missionary purpose of converting Jews and Muslims by demonstrating these truths. The Art is enormously complex, but put simply, it employs letters of the alphabet as symbolic notation for Divine attributes; the letters are placed on revolving wheels and can then be mechanically combined with other data in order to solve problems. Llull believed his Art could be applied to all fields of knowledge and was therefore a truly universalist system.<sup>14</sup> In Llull's own words: "We have employed an alphabet in this art so that it can be used to make figures as well as to mix principles and rules for the purpose of investigating the truth" (fig. 4).<sup>15</sup>

Llull's Art has often been described as a precursor of

modern symbolic logic and the computer, "a prototype of an expert system."<sup>16</sup> It depends on a user, or "artista," who can mobilize the structure to apply it to specific questions. Werner Künzel, a Berlin philosopher/computer scientist, has translated Lull's *Ars Magna* into a DOS program, which is available on the Internet.<sup>17</sup>

Lull's thought was enormously influential in the centuries to follow, especially in the Renaissance. Frances Yates says, "The European search for method . . . began with Ramon Lull."<sup>18</sup> In the seventeenth century, Athanasius Kircher was singularly influenced by Lull and expanded the *Ars Magna* into his own *Ars Magna Sciendi*. Lull's influence continued to René Descartes and to Leibniz, the father of symbolic logic, who developed his own *ars combinatoria*. By this time, the purpose of *ars combinatoria*, in the examples I have found, was moving away from the mystical or universalist and toward systems for symbolic logic, semantic invention, or pure process and play. This shift seems qualitative, from the mystical to the formal.

An example of this more purely formal approach to the combinatorial arts is found in games for musical composition in the eighteenth century. Music, with its abstract notation, lends itself directly to recombination. These *musikalische Würfenspiele* or musical dice games consisted of a number of musical elements that could be recombined via a formal structure and the random function of throwing dice to select the elements. The results needed to adhere to a particular musical form such as a polonaise. The first *musikalisches Würfenspiel*, written by Johann Philipp Kirnberger in 1757, recombined phrases of six to eight measures. The possible new musical compositions are  $11^{14}$ , far too many ever to listen to. Other composers used measures or smaller units for recombination. C. P. E. Bach used individual notes as the units and developed a lengthy process of ordering them through random selection. Mozart and Haydn also composed for dice games, each using a slightly different "program."<sup>19</sup> (Mozart's dice game, too, has been translated for use on the computer.<sup>20</sup>) And a new element has entered: chance. The dice game is not an intentional system, but a system driven by a random function (fig. 5).

Also in the eighteenth century, Jonathan Swift wrote a parody of systematic thinking in *Gulliver's Travels*, where he describes an imaginary permutational machine (fig. 6). The "professor" in the story has been described variously as a caricature of either Leibniz or Lull. When Gulliver visits the Grand Academy of Lagado, he is shown an amazing device "for improving speculative knowledge by practical and mechanical operations." The mechanism consists of a frame holding square blocks:

*These bits of wood were covered on every square with papers pasted on them. and on these papers were written all the*

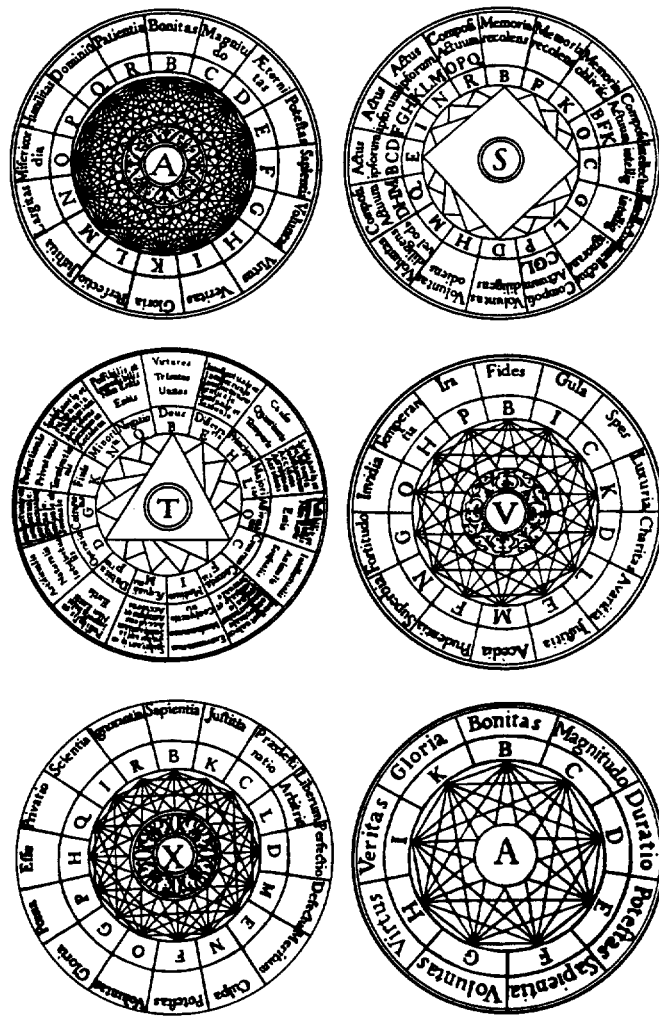


FIG. 4 One adaptation of Ramon Lull's 13th-century combinatorial wheels (from the *Enciclopedia universal ilustrada*, Barcelona, 1923).

*words in their language . . . but without any order. . . . The pupils . . . took each of them hold of an iron handle, whereof there were forty fixed round the edge of the frame, and giving them a sudden turn, the whole disposition of the words was entirely changed. [The professor] then commanded six and thirty lads to read the several lines softly as they appeared on the frame; and where they found three or four words together that might make part of a sentence, they dictated to the four remaining boys who were scribes . . . the professor showed me several volumes in large folio already collected, of broken sentences, which he intended to piece together, and out of those rich materials to give the world a complete body of all arts and sciences.*<sup>21</sup>

In the nineteenth century, there was a great deal of activity in the realms of mathematical logic and probability theory leading toward the idea of the computer. George Boole and Charles Babbage each brought the world closer to what would eventually become this ultimate (or at least

Ex. 2a  
Zahlentafel.  
Table de Chiffres.

	A	B	C	D	E	F	G	H
2	70	14	104	192	25	143	18	107
3	10	64	100	12	149	30	161	11
4	33	1	160	163	77	156	108	172
5	36	114	8	35	111	39	137	44
6	104	150	47	71	117	52	132	120
7	165	152	112	15	147	27	73	102
8	7	81	131	37	21	125	49	115
9	142	106	40	62	43	140	23	82
10	22	62	86	132	120	22	143	83
11	85	45	20	158	82	123	78	48
12	145	27	6	121	46	67	63	16

Ex. 2b  
INSTRUCTION

To compose, without the least knowledge of Music, Country-dances, by throwing a certain Number with two Dice.

- 1) The Letters A--H, placed at the head of the 8 Columns of the Number-Table, show the 8, times of each part of the Country-Dance, viz. A, the first, B, the second, C, the third, &c. and the Numbers in the Column under the Letters show the Number of the time in the Notes.
- 2) The Numbers from 2. to 12, show the sum of the Number that can be thrown.
- 3) For instance, in throwing for the first time of the first part of the Dance, with two Dice, the Number 6, one looks next to that Number in the Column A, for the 105<sup>th</sup> time in the Notes. This time is written down, and makes the beginning of the Dance. — For the second time, for instance, the Number 8, being thrown, turn to the same table Column B, and the Number 81, shall be found. This time is put next to the first, & one continues, in this manner till the eight times shall be thrown, when likewise the first part of the Dance shall be finish'd. — The sign of repetition is further plac'd & the second part begun.

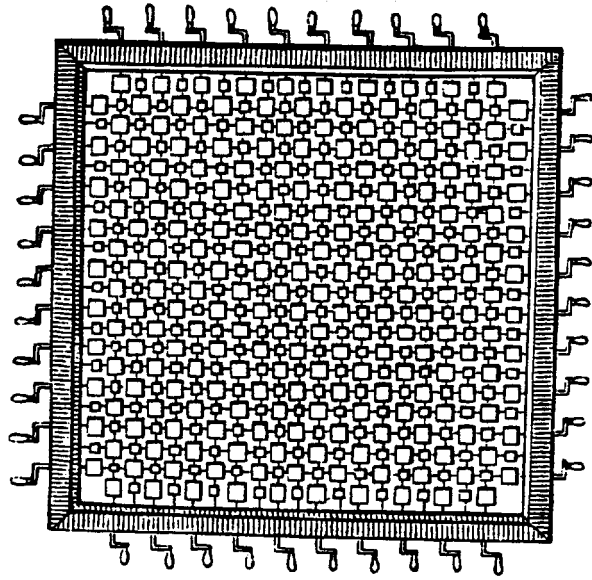
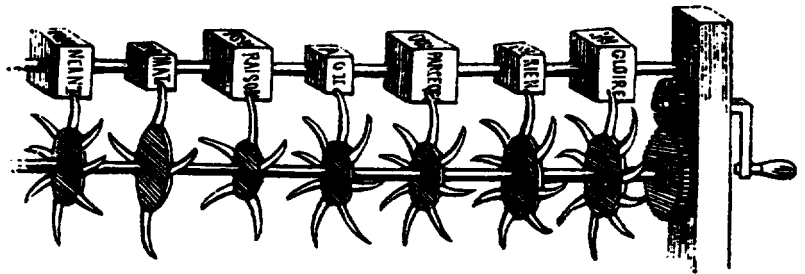


FIG. 5 A diagram for a *musikalisches Würfenspiel* (from Richard Kostelanetz, *John Cage* [New York: RK Editions, 1974], 101).

FIG. 6 The word machine from Jonathan Swift's *Gulliver's Travels* (illustration by Grandville, 1838).

extremely efficient) device for *ars combinatoria*. Separated entirely from these pursuits, Kabbalistic traditions and Lullism continued actively in various forms.

In the twentieth century, *ars combinatoria* can be found extensively in artistic production. The imagined *ars combinatoria* in Jorge Luis Borges's story "The Library of Babel" looks to past traditions as well as to the potential future of the form by artists, among whom Borges has been so influential. It describes a "universe" or "Library" that consists of "an indefinite and perhaps infinite" structure filled with volumes of text, each a unique and random permutation of the letters of the alphabet.<sup>22</sup> Borges clearly refers back to the *Sefer Yetzirah*, to the Kabbalah, and to the medieval notion of the world as a book. Because permutations of finite items, when repetition is allowed, provide infinite variations, Borges touches on the notion that exhaustive variations suggest a key to the mysteries of the infinite. (The mathematician Rudy Rucker explains that Borges's Library, however, is finite, though very large, because the number of pages and letters in the books are all the same. Only if the books could be of any possible finite length would the library be infinite.<sup>23</sup>)

There are many other examples of the combinatorial in twentieth-century art, especially in the 1960s when the idea of the computer had entered the public imagination. While the development of collage by the Dadaists in the early part of the century and appropriation by postmodern artists in the later half of the century could each be considered a kind of recombinant approach, they are not, strictly speaking, permutational. (One could make a case for the fact that they are *combinations*, i.e., elements that are taken from a larger set of preexisting elements and then combined with each other in a new way. The preexisting set, however, is the set of *everything*.) Real permutational systems of art making were employed by a number of artists who used conceptual, serial, or procedural strategies.

John Cage, over a lifetime of procedural work, made use of permutation, combination, and variation. Before discussing Cage, however, it is necessary to leave our chronology, go back thousands of years, and look at another ancient example of *ars combinatoria* that greatly influenced him, the *I Ching*.

The *I Ching*, or *Book of Changes*, is a method of divination based on a binary system and chance operations.

This mechanical oracle was developed over hundreds of years during the first millennium B.C. Based on a philosophy that considers the importance of chance and perpetual change, the mechanism works in this way: first, one asks a specific question: then, either by tossing three coins or by dividing and counting yarrow stalks in a much more complicated procedure, one arrives at numeric data that represent, finally, one of only two polarities. This is represented as either an unbroken line (yang force) or a broken line (yin force). Repeating this procedure six times results in two trigrams of three lines each that are then united to form a hexagram, a stack of six unbroken and/or broken lines. The variations of unbroken or broken lines in a structure of six positions are  $2^6$ , or 64, possible arrangements (fig. 7). An added complexity of possibilities is the fact that each unbroken or broken line is either unchanging or changing to its polar opposite depending on the numeric value of its coin toss or yarrow-stalk counting. If one or more lines is changing, a second hexagram is formed, representing how the questioner's situation will change. The interpretive texts for the hexagrams give guidance to the questioner in the form of symbolic situations.<sup>24</sup>

Though the *I Ching* was little known in the West before the nineteenth century, a diagram of a particular sequence of the hexagrams developed in the Sung period was sent by a Jesuit missionary to Leibniz, who had been developing a binary system of mathematics, the system on which computer language is based. Apparently, Leibniz was amazed and thrilled to see it because it validated his conviction that there were spiritual truths to be found in mathematical forms.<sup>25</sup> We can get a glimpse of this link between numbers and spirituality in Chinese thought by looking at the *Tao T'e Ching* by Lao T'se: "Tao gave birth to the one, the one gave birth to the two, the two gave birth to the three, and the three gave birth to all things."<sup>26</sup>

John Cage relied on the *I Ching* as a systematic basis to determine several aspects in a number of his works. So many of Cage's works were permutational (as well as having a variety of other procedural foundations) that it would be impossible to describe them all here. But two abiding principles in his work apply. The first is that he often used chance and/or indeterminacy for the positioning of elements in his pieces. (Indeterminacy refers to events that might be out of the artist's control but not chance-derived, like the choices left to the performers.) The second is that, in many of his works, no two performances would be alike, though they might include all of the same material. This was usually because they were devised so that the parts would fall together differently every time. In those situations, this might be because he and the artists he collaborated with (such as the choreographer Merce Cunningham) worked independently and only saw the synergistic results at the end of the process. Or, more pertinent to this discus-

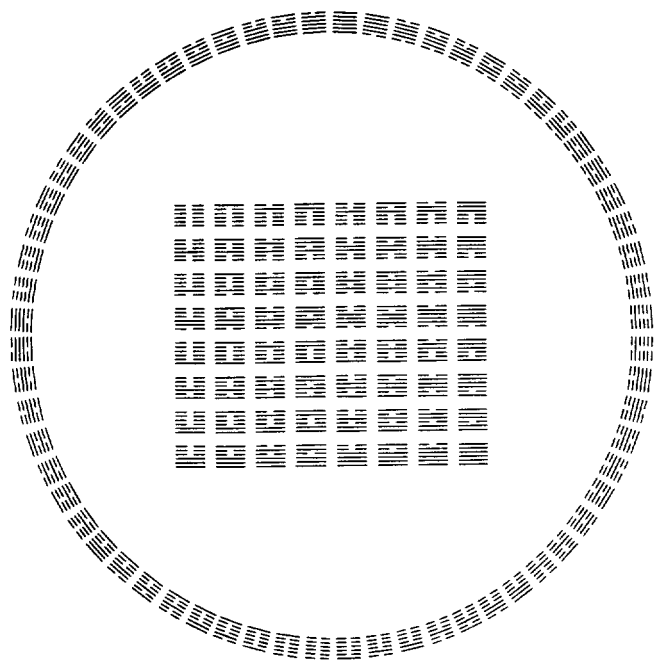


FIG. 7 Two sequences of the 64 hexagrams of the *I Ching* (from Helmut Wilhelm and Richard Wilhelm, *Understanding the I Ching* [Princeton, N.J.: Princeton University Press, 1960]).

sion, because elements in his own work were "scored" to have ever changing positions, usually dependent on chance operations and indeterminacy at the moment of performance. Toward the end of his life, Cage used the computer more often as a tool to continue and expand on the complex systems he had developed throughout his career. Though he began as a composer, Cage eventually did not confine himself to one medium or discipline. He composed music, wrote texts, made theater pieces, made visual work, and, more often than not, used two or more disciplines in a single work.

Early on, Cage wrote music that recombined a given number of elements. To make *Williams Mix* in 1952, he painstakingly hand-spliced digital sound tapes, cutting them into tiny pieces and reassembling them according to a structure that was determined by chance operations (fig. 8). *Williams Mix* lived as eight separate mono tracks that were played simultaneously, presenting the possibility that the tracks would fall together differently every time it was played. Cage stressed that a recorded version was, then, not definitive.<sup>27</sup> In 1969 he worked with Lejaren Hiller to make *HPSCHD*, a piece for fifty-one computer-generated sound tapes and seven solo harpsichord parts. The composers used Mozart's dice game structure for the solos and filled the blank measures with various elements, the choices made, appropriately, by the roll of dice. They also used a computer program that approximated the *I Ching*'s chance operations to assemble other solos and the fifty-one sound tapes. Much of the variety in live versions of *HPSCHD*

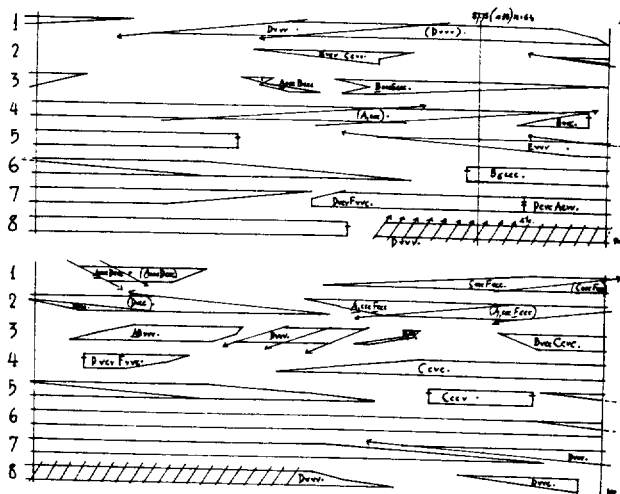


FIG. 8 John Cage, diagram of magnetic-tape splicing for part of *Williams Mix*, 1952 (from Richard Kostelanetz, *John Cage* [New York: RK Editions, 1974], 110).

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depended on a wide latitude given the performers to make their own choices from a large amount of material.<sup>28</sup> For a recording of the work, another element of indeterminacy was thrown into the mix: the listener is presented with a computer-generated set of instructions, showing how the knobs of the stereo system should be turned to change channels and volume for specific sections. Hiller notes, "It's the first instance that I know of where the home listener's hi-fi set is integral to the composition."<sup>29</sup>

Throughout his life, Cage wrote texts and gave readings that were developed by chance operations on found texts or recycled bits of his previous writings. For two earlier works, *Mureau* and *Muoyce*, he took material from Thoreau and Joyce respectively and reconfigured them into entirely new texts. In 1988, asked to give the six Norton Lectures at Harvard, he created a complex work titled *I-VI* using several computer programs and massive amounts of found material. Using IC, a computer program by Andrew Culver that simulates *I Ching* procedure, and Mesolist, another program by Jim Rosenberg that follows rules to place the text in a mesostic form (like an acrostic, but with a center backbone of capital letters that form words when read downward), Cage combined texts from Wittgenstein, Thoreau, Emerson, McLuhan, newspapers, his own writings, and more. At Memorial Hall, Cage read the texts to hypnotic effect. He explained in the introduction to the book of *I-VI*, "I gave up making choices. In their place, I put the asking of questions. The answers come from the mechanism, not the wisdom, of the *I Ching*. . . . Something strikingly like this occurs for each person when he is conceived. The DNA RNA."<sup>30</sup>

In 1987 Cage made *Europerras 1 & 2* for the Frankfurt Opera. Every element of the work was combinatorial. He took two hundred years of European operas and used fragments of them, chosen through computer-generated

chance operations. Orchestral musicians could begin their parts anytime within a bracketed period that was shown on a digital display, while the singers chose any arias they preferred. Timing, stage movements, the appearance and removal of scenic flats with cropped images, and lighting were also chance-generated; empty areas of the stage were sometimes illuminated, whereas performers might or might not be lit. Cage took lines from pocket guides to opera plots and computer-mixed them into hilarious melodramatic plots that were then inserted into the playbills; members of the audience got different versions of these plots, none of which referred to events onstage. Though the piece seems to be a conglomeration of parts, it formed a whole. Elsewhere Cage talked about "the togetherness of differences,"<sup>31</sup> as though this work of reconfiguring was a truly synergistic project (fig. 9).

Finally, the museum exhibition *Rolywholyover A Circus* was conceived and planned by Cage, though it was presented in several cities posthumously. One of the rooms of the exhibition held artworks on loan from museums all over the world. A computer program specified time brackets within which these artworks were to be moved during viewing hours, and where they were to be placed. Visitors saw a gallery in constant motion; by the time the installers finished one set of reconfigurations, they could begin on a new one, freshly generated by the computer. The juxtapositions were often surprising, changing the way one read each particular work; and the usually static gallery setting was transformed into a lively performance, like all of Cage's work, in a continual process of generating something else.

Many other artists who used procedures in their work often used permutation as one such approach. The Fluxus artist Emmett Williams wrote permutational poems, some as early as the 1950s. Later, permutational procedures entered many of his performative works. In one titled *Four Directional Song of Doubt for Five Voices*, each of the five performers is given a square score for one word of the piece: *you, just, never, quite, know*. Choosing what path to take through the gridded score by any method they prefer, the performers say their words when they reach a black dot, moving through all one hundred squares to the beat of a metronome. Williams says, "There must be a google or two of possible variations."<sup>32</sup>

Similar strategies entered the visual arts. In 1967 Robert Morris made a sculpture titled *Permutation*. Morris said that he came up with the idea when he found that some of his works were too large to fit through doorways. *Permutation* is made of a number of minimal modular forms of fiberglass that can be reconfigured in space in a variety of ways. Morris said: "The situation sort of presented itself to me that I might make a series of forms that would have no definite shapes, but rather a set of possible shapes."<sup>33</sup>

To make *Axiom of Exhaustion* in 1971, Mel Bochner

wrote consecutive numbers on eight tapes laid in a grid on the floor (fig. 10). He exhausted all possibilities of both direction and orientation in the process of making the work (as well as in the reading of the piece) by combining the four possible directions that the numbers are oriented with the four possible directions in which numbers travel. For example, one row of numbers might run from east to west while facing south, and so forth. Within each grid square, he placed a symbolic fraction, using the letters A–D, representing the directions of the tapes that bound the square. Bochner says, “it is the ‘exhaustion’ of the complete set of permutations of directions and orientation. . . . There may be nothing more, or less, to it than that.”<sup>34</sup> It is interesting to compare this work to the *Sefer Yetzirah*, which also exhausts direction (“a depth of beginning, a depth of end, a depth of good, a depth of evil, a depth of above, a depth of below, a depth of east, a depth of west, a depth of north, a depth of south”<sup>35</sup>), as well as to Lull’s Art, where letters represent divine attributes.

Other artists to explore permutation in their work at that time include, of course, Sol LeWitt, whose wall drawings and sculpture permute elements of form extensively; Allan Kaprow, who used variations on a given number of elements in performance work; the choreographer Deborah Hay, who used specific movements as permutable elements in works such as *20 Permutations of 2 Sets of 3 Equal Parts in a Linear Pattern*; and the filmmaker Hollis Frampton, who often systematically reconfigured and repeated a limited set of images through editing.

In 1961 the writer Raymond Queneau published an unusual book titled *Cent mille milliards de poèmes*, or *100,000,000,000,000 de poèmes*, designed by Massin (fig. 11).<sup>36</sup> A rhyming sonnet is printed on each page of the book. The separate lines of each page are cut horizontally, one from the other, so that they can be peeled back in any combination, revealing new sonnets with new meanings. There are, of course, 100,000,000,000,000 possible sonnets. Queneau was part of a group called Oulipo, or *Ouvroir de littérature potentielle*, which he founded in 1960 with François Le Lionnais; and which included Harry Matthews, George Perec, and Jacques Roubaud. Oulipo was a workshop whose members explored the use of procedural constraints on generative systems for the production of texts.<sup>37</sup> Many other members of Oulipo made permutational poems.

There are several on-line versions of *Cent mille milliards de poèmes*; some of them randomly permute the lines of the poem each time the sites are visited.<sup>38</sup> Queneau’s book seems to stand as a prototype for many contemporary artists who use the computer as a text-generating device or as a means to make hypertextual work.

Several contemporary poets have constructed poems by taking a source text or an original text and rearranging



FIG. 9 John Cage, *Europemas 1 & 2*, 1988, Pepsico Summerfare Production. Courtesy of The John Cage Trust.

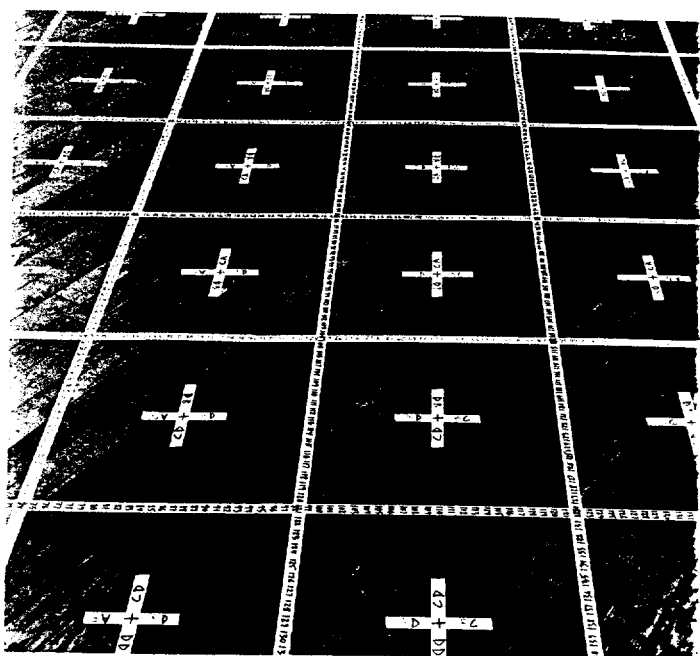


FIG. 10 Mel Bochner, *Axiom of Exhaustion*, 1971, markers on tape on floor, 194 x 194 inches. Installation at Sonnabend Gallery, New York. Photo courtesy Sonnabend.

the words according to a particular procedure. These include Jackson Mac Low, Joan Retallack, Ron Silliman, Eugen Gomringer, and Louis Zukofsky. Poetry is an arena where this activity has moved easily to the computer. Alison Knowles used a computer in 1968 to make a simple incantatory poem titled “A house of dust.”<sup>39</sup> Mac Low and the French group A.L.A.M.O., which grew out of Oulipo, have also used the computer to generate permutational poetry. The poet Charles O. Hartman has made a number of sophisticated text-generating programs, making the fine distinction between text generators that begin with a vocabulary but no source text and then invent new text according to rules, and text generators that start with a source text and permute or combine elements from that text to create new ones.<sup>40</sup>



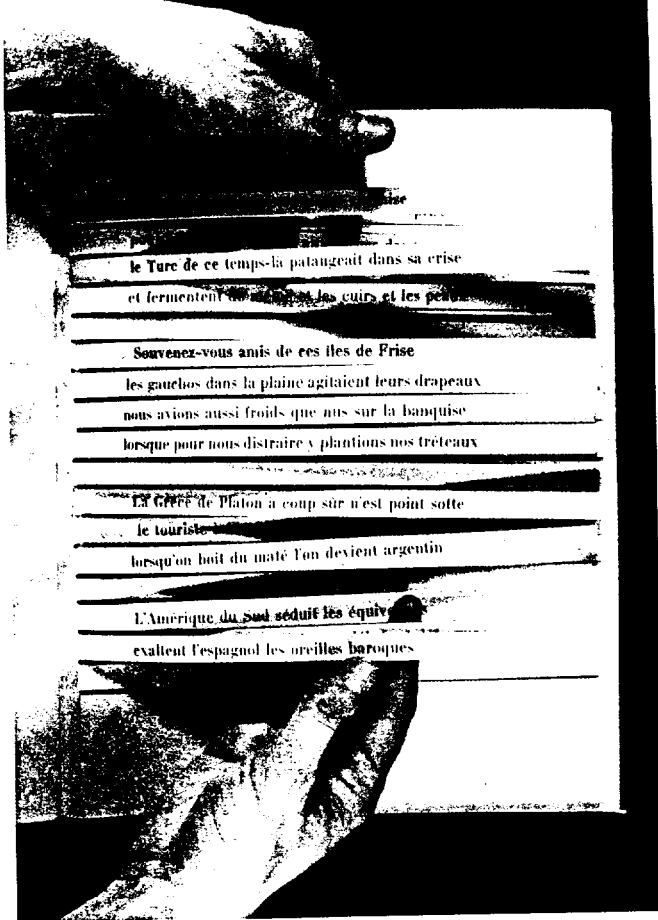


FIG. 11 Raymond Queneau, *Cent mille milliards de poèmes* (Paris: Éditions Gallimard, 1961).

The writers mentioned above, following the models of Oulipo and John Cage, have each written or used a program that exploits the computer's capacity to make random selections or to generate text according to certain rules. Other writers have gone in a different direction, exploring the possibilities of hypertextual fiction, poetry, and websites. Hartman discusses the difference between these two approaches by describing the former as a way of using the computer as a generative machine that collaborates with the writer to produce poetry and the latter as a new way of *presenting* poetry.<sup>41</sup> A different distinction could be made in a discussion of where the work of art resides, whether the artwork is the machine (i.e., the procedure or program) or the material that the machine generates. Writers who use hypertext and text generation together, such as Jim Rosenberg, Eduardo Kac, the French group L.A.I.R.E., and other "new media poets," focus on the visual potential of the computer's display, following in the tradition of concrete poetry, but adding the elements of time and motion in the reconfigurings of text on the screen. An aspect of this new poetry is the shift in importance it makes from the art "object" to the procedure that generates it.<sup>42</sup> In the same way, Ramon Llull's "Art" seems to reside more in his combinatorial wheels than in the individual "truths" they can generate.

Often, fans of hypertext will claim the aforementioned

early systems of thought, such as the *Sefer Yezirah*, Kabbalah, and Llull as their precursors. For example, the cover of the book *Hypermedia and Literary Studies* bears a beautiful Renaissance combinatorial diagram.<sup>43</sup> Some hypertext works, however, do not succeed as well as others within this tradition of "creative magic" because their interactivity consists merely of a reordering of discrete pages and paragraphs. The narrative or plot changes somewhat, but not qualitatively, since the overall meaning and style usually remain unchanged. This is also true of our interactions on the Web, which are simply page reorderings determined by the reader. In language, every utterance is a permutation of the letters of the alphabet, or of the speaker's vocabulary of words, inventing new meaning. When permuting letters or even entire words, one alters content semantically, not just syntactically as in most hyperfiction. So when the "chunks" of material are quite large, like paragraphs or pages, this semantic shift is not as striking. But conversely, when permuting with repetitions the 0s and 1s of binary code or the four tiny building blocks of DNA, the possibilities of generative variation are infinite.

In science, there are wonderful coincidences with the systems described here. Combinatorial systems are at the heart of our chemical and genetic makeup. The carbon atom is distinctive for its ability to combine with other carbon atoms as well as with many other elements in elaborately complex ways, forming long molecular strings. In fact most of our bodies are made up of just four elements, carbon, hydrogen, oxygen, and nitrogen. The scientist John Gribben writes, "the complexity of living molecules arises not from the fact that they contain a great variety of different kinds of atoms . . . but from the fact that these four kinds of atoms can be combined in large numbers in very many different ways."<sup>44</sup>

At the genetic level, we are also defined by a four-part code. The four nucleotides, or building blocks, of DNA are adenine, cytosine, guanine, and thymine (A, C, G, and T). Along the chromosomal double helix, these four are uniquely ordered and paired for each person, spelling out specific genetic information, depending on that order. A single chromosome of the forty-six each human carries in every cell may have as many as five billion nucleotide pairs. Everyone's genetic information is different, though spelled out only by variations of A, C, G, and T. Each parent passes on a unique set of only twenty-three chromosomes to each offspring. The two parent sets form a new combination of forty-six chromosomes with its own individual genetic code.

In mathematics, combinatorial systems overlap with set theory, and set theory opens many of the mystical themes about the nature of numbers and infinity. A set is a combination or grouping of things. George Cantor, who developed some of the fundamental principles of modern

set theory in the late 1800s, said, "A set is a Many which allows itself to be thought of as a One."<sup>45</sup> We combine or make variations from a given set of elements, creating new sets. Any number of real things, imaginary and intangible things, as well as other sets can be combined to create a new set, making the number of possible sets infinite. We can imagine an absolute set or a set of all sets, but that set is never attainable. Since a set cannot contain itself, a new set can always be made by adding the current set of all sets to all of the other sets, ad infinitum.

In cosmology, there are more coincidences with the mystical or generative aspects of our examples. According to the most currently accepted theory of creation, our universe started at the Big Bang. Some theorize that this universe was at first what scientists call "a singularity," defined either as one very dense "seed" or "point" smaller than a proton which contained all of the matter currently in the universe,<sup>46</sup> or "a state of zero size and infinite density."<sup>47</sup> These theories can be compared to mystical systems that define God as the One, the Absolute, and, at the same time, the Infinite.

There is also debate about whether our universe is open or closed, that is, infinite or finite. It is certainly expanding, and some cosmologists believe it may continue to do so forever, while others believe that at some point it may begin to fall back on itself. This brings up the theme of the exhaustion of permutational possibilities. At the end of the 1952 science fiction story by Arthur C. Clarke cited in the epigraph to this article, "The Nine Billion Names of God," the universe ends at the moment that the Tibetan monks, using the computer, print out the very last permutation of these nine billion names. The dual notions of permuting a closed system to exhaustion versus making variations on a set of things to infinity are closely linked with mystical speculations. The number of permutations of the Hebrew alphabet is very large but finite and exhaustible; Abulafia permuted to ecstatic exhaustion; Raymond Queneau devised a system that was exhausted at the precise number of 100,000,000,000,000; and the computer can theoretically make variations on the 1s and 0s of binary code to infinity. Here, the only thing that can be said with certainty on this subject is that once one starts to explore the permutational realm, the examples, coincidences, and possibilities seem endless and inexhaustible. ■

#### Notes

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7. *Ibid.*, 113–25.
8. *Ibid.*, 190.
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17. ([http://berlin.icf.de/~inscape/llullus/llull\\_dos.html](http://berlin.icf.de/~inscape/llullus/llull_dos.html)).
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