Handbook of Research on Computational Arts and Creative Informatics

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Chapter V
Randomness, Chance, & Art

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ABSTRACT

Randomness is a slippery term that conveys different meanings in different disciplines. In mathematics, an individual number is random when there is an equal chance for it to be any number from a set of possible values. In computer science the term becomes more relative and numbers have varying degrees of pseudo-randomness. Information theory equates randomness with unpredictability and, at odds with other definitions, concludes that a higher level of randomness indicates a greater concentration of information; a message's probable denseness of information is highest when the message is partially surprising and partially expected.There is no fixed definition for what randomness means in art, but analogies can be drawn to how the term is used in other fields. For example, information theory's definition might suggest that artworks have the greatest impact when using a mixture of pattern and unpredictability.

INTRODUCTION

Randomness, if it exists at all, is a fragile state. This fragility isn't intuitive to us; our day-to-day lives seem filled with disorder and unconnected events. The precarious nature of perfect order is more easily understood. We know that the nature of the universe is for things to break down, clutter, and fall apart. We have scientific laws (the law of entropy) and folk laws (Murphy's law) to explain why order cannot be maintained for long. With that in mind, perhaps it is more understandable that order's opposite—randomness—is similarly rare. Just as it is the nature of the universe for things to fall apart, it is also the nature of the universe for a cause to exist for every effect and for that effect to be determinable (at non-quantum levels[1]). But a truly random event has no relation to its trigger; the effect should not be deducible from the cause.

Look again at the very first sentence of this introduction and note the caveat of *if it exists at all*. The existence of randomness and the ability of humans to observe it is an ongoing debate. Knuth (1981) said, "People who think about this topic almost invariably get into philosophical discussions about what the word 'random' means. In a sense, there is no such thing as a random number; for example, is 2 a random number?" (p. 2). The goal of the chapter is to give a deeper understanding of randomness, how it is generated in computer science, and how it can be used in art.

BACKGROUND

Random is often used colloquially to indicate arbitrariness or things unrelated: random acts of violence, random thoughts, random encounters. A number of fields such as computer science, statistics, and informational theory have more rigorous definitions of randomness. But each of these fields uses the term in a way that is slightly at odds with the others.

As a starting point, let's establish what randomness means to a mathematician and, using that, build a working definition for what randomness might mean to an artist. In mathematics, an individual number is random when there is an equal chance for it to be any number from a set of possible values. When describing a sequence of numbers as random, we mean each number is statistically independent of the others; that the numbers in the series have no effect or relation to the others (Haahr, 2008). A random number or sequence is characterized as containing no meaningful information; if a number conveys some data (such as the result of a formula, a person's phone number, or the number of times the letter 'q' appears in this chapter[2]), then it is not random.

This trait of non-significance can be borrowed and used as a key characteristic of randomness in art. If an element in an artwork contains some meaningful information about the world around us, then the element isn't truly random. Consider this recipe by Tristan Tzara (one of Dada's founders) for writing poetry:

To Make A Dadist Poem
Take a newspaper.
Take some scissors.
Choose from this paper an article the length you want to make your poem.
Cut out the article.
Next carefully cut out each of the words that make up this article and put them all in a bag.
Shake gently.
Next take out each cutting one after the other.
Copy conscientiously in the order in which they left the bag.
The poem will resemble you.
And there you are--an infinitely original author of charming sensibility, even though unappreciated by the vulgar herd. (Brotchie, 1991, p. 36)

Would the resulting poem be random? Several aspects of this poetry generation process do seem analogous to our description of a random numerical sequence. However, the poem's recipe (or *algorithm*) is not rigorously random by mathematical standards. To improve the randomness of the process, we'd first want to remove any duplicate words so that common words (such as "the") wouldn't have a greater frequency in the poem. Second, we'd want to make sure that the slips of paper have identical sizes (otherwise, the larger slips would tend to float to the top upon being shaken and would bias our results). Finally, we'd need to question our basic ability to sufficiently randomize the slips of paper by shaking a bag. Several early attempts to generate random numbers (for use in scientific simulations) used slips of paper in bowls and bags, but were not able to generate sufficient randomness (Hayes, 2001).[3]

It isn't necessarily important to resolve the aforementioned issues for a work of art. Statistically rigorous randomness may be crucial (though elusive) in computer science and mathematics, but it is usually more than is required for stochastic artworks. In fact, giving common words a greater probability may even be desired. Even if we did wish to adjust the poetry-generating algorithm so that each word had a precisely equal chance of being drawn, we still wouldn't have a truly random poem. The source material of the article would largely determine the poem's content—a sports article would have an unusually large number of sports related words, a computer science article would be filled with computer jargon, and so on. The resulting poem would be unpredictable, yet through its vocabulary it would convey information.

The conveyance of meaning is an important distinction for the art-focused terminology proposed in this chapter: *random* refers to an unpredictability that communicates no information, whereas *chance* implies a basis in the real world, unpredictable yet meaningful. *Stochastic* describes randomness and chance either collectively or non-specifically. A painting in which colors were selected by rolling dice would have a random palette. A painting in which colors were selected based on the color of passing cars would have a chance-based palette. Both palettes could be described as stochastic.

CHANCE VS. RANDOM

The distinction between chance and randomness in art is a convenient taxonomy, but not every stochastic work cleanly fits into one category or the other. A painting's color choices being based on the movement of a ball in a sports game might convey some sense of the game or may simply seem arbitrary and better described as random, despite being determined by real-world events.

Tim Hawkinson's *Emoter* (2002) uses light sensors on a television screen to drive the facial expressions on a motorized photograph of the artist's face. If we were to categorize *Emoter*, we might describe it as chance-based—the sculpture's movements are triggered by whatever happens to be on television at a given moment. However, we might consider a fundamental characteristic of chance-based artwork to be the viewer having insight into the details of the cause and effect relationship. Viewers of *Emoter* are able to deduce that the television screen's image determines the photograph's movement, but an understanding of what specific television image traits result in which specific motion remains elusive. The impression is one of random motion, even though the movement is *deterministic*; presumably if the television were playing a video repeatedly, each replay would result in the same facial performance.

What may classify *Emoter* as a chance-based, rather than random, artwork is how crucial the relationship between the television screen and the facial expressions is to the work's concept. The connection suggests that emotional reactions to television shows are as artificial as the medium itself. The ever-changing, yet repetitive nature of the eerie face evokes the ever-changing, yet repetitive nature of television shows.

Sabrina Raaf's[4] *Translator II: Grower* (2004-2005) is another work that is activated by chance

Figure 1.

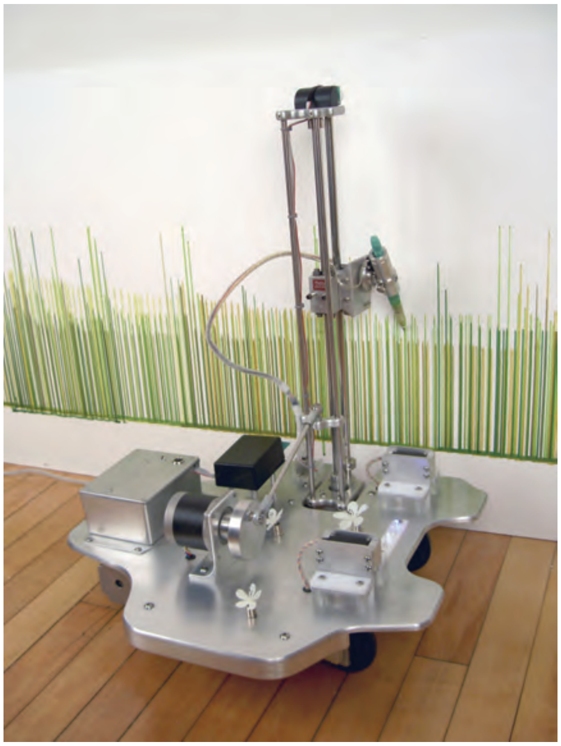


Image used with permission of Sabrina Raaf factors. The artwork consists of a small robot that slowly works its way around a room, hugging the walls. A sensor near the ceiling detects the room's level of carbon dioxide and transmits the information to the robot. Every few seconds the robot draws a vertical green line on the wall—the higher the level of carbon dioxide, the taller the line. The lines become both a representation of grass and a bar graph tracking the carbon dioxide level (and consequently the presence of people) over time. The act of observing the artwork provides the chance stimulus that drives the art generation.

HOW RANDOM?

In the early and mid-1960s several researchers independently came to the conclusion that when looking at the randomness of a set of numbers, it makes little difference whether or not they were generated by a random process. What is more important than how the numbers were generated is how random the numbers appear to be (Chaitin, 1975). For example, using coin tosses to generate a series of ones and zeros (ones representing heads and zeros representing tails), the series 1010101010101010 is just as likely a result as the series 1011101001010111.[5] However, if we define "randomness" as the absence of a pattern, then the second set of numbers is random and the first set is not. Of course the first example's pattern is coincidental and one additional coin toss could have broken the pattern. But if we simply look at numbers in front of us and disregard our knowledge of how they were created, we would conclude that one is random and the other isn't.[6]

This data-centric approach views randomness in terms of complexity and lack of pattern. In 1965, while an undergraduate at The City College of New York, Gregory Chaitin proposed this definition and suggested that the randomness of a finite series of numbers could be measured based on the size of the smallest computer program that can generate the series[7]. If we wanted to write a program to output 1010101010101010, the smallest set of instructions would be "print '10' eight times." For 1011101001010111, there is probably no algorithm shorter than "print 1011101001010111." Since the examples are relatively short series, there isn't a great difference in the size of the instructions needed to generate them. However, we could easily create a much larger series of numbers that follow the first example's pattern: "print '10' one thousand times." Now we have an instruction set that is 29 characters long that generates a number that is 2,000 characters long. We can establish that this series of 2,000 characters is not very random because the smallest possible program that can generate the series is so much smaller in size than the result. A very random number would require (as our 1011101001010111 example did) a program that is very close in size to the data it generates.[8] In essence, there are no shortcuts generating a random number because a random number has no patterns.[9]

Defining randomness in terms of the data's complexity was undoubtedly crucially influenced by computer science and the impossibility of having computers algorithmically generate true random numbers. Impossible because the very fact computers generate the "random" numbers using formulas means that the numbers have a pattern. Computer-generated "random" numbers are referred to as *pseudorandom* in acknowledgement of their algorithmic origin. Early in the history of computers it became apparent that not all *pseudorandom number generators* (PRNG) are of equal quality and, consequently, the numeric sequences they generate have varying degrees of randomness—some sequences are more random than others. This equating of "level of complexity" with "level of randomness" is in contrast with the idea that randomness is an absolute state; that something is either random or not.

The compressibility of data is affected by the data's level of randomness. Most electronic files (such as graphics, text, video, and sound) can be compressed; algorithmically processed into a file of smaller size. Generally speaking, the less varied the data, the greater the compression. To use an analogy, consider the text "See Jane run. Run Jane run. Run run run." This can be summed up as "Check out Jane running." That's a compression of 42.5%. We were able to do that by removing the repetitions and patterns. However, this is a "lossy" compression; the compressed text maintains the meaning of the original, but cannot be restored to the original verbatim. We could do a lossless compression of the data: "1=run:See Jane 1. 1 Jane 1. 1 1 1." Using this lossless compression we were able to reduce the size by 15% (lossless methods provide less compression than lossy methods).

A file of highly random data, however, cannot be compressed in a lossless manner—a compression algorithm cannot find any patterns to squeeze. This is not to say that programmers don't regularly claim to have created an algorithm that will compress random data—they do in a manner reminiscent of cranks claiming to have invented a perpetual motion machine. However, none of these claims prove to be valid.[10]

Assert(Random == Information)

In *Chaos Bound* (1990), Hayles explores a proposition[11] that a communication's level of randomness is an indicator of the amount of information it contains. Surprisingly, the greater a communication's randomness, the more information it is likely to contain. This is more understandable when we consider our data compression example from before. The "Dick and Jane" stories are highly repetitive and even a first grader might wish for something more complex and varied. Increasing the denseness of information results in a greater level of textual complexity, a lower compressibility, and (by Chaitin's definition) greater randomness.

We can increase the randomness/denseness of a communication (and consequently its components' informational probability) by compressing it. An example of such compression is removing the vowels from text: "t wld gt vry ld vry qckly f ths ntr chptr hd n vwls." The compression results in an increase of informational content for each character in the message; the same amount of information is communicated in fewer characters. One cost of this denser information is an increase in decompression time; reading the information will take more time than reading an uncompressed version.

Does an increase of randomness always indicate a probable increase of information? If so, "xjblw9 fjmksdpgk kdo vnaie pxs fr" likely contains more information than "There is nothing like a dream to create the future.[12]" To avoid this kind of absurdity, the information theorists who developed the concept of information probability further surmised that every communication contains a mixture of information and noise (i.e., meaningless or garbled data). As a message's randomness/complexity increases, the probability that its components are informational increases. However, once a message reaches a halfway point in terms of randomness/complexity, the probability of information decreases and the probability of noise increases. So a message that contains very little complexity ("aaaaaaaaaaaaaaaaaaaaaaaaaaa") and a message of extreme complexity ("WgAx;. UJ,B2Lf.WSI2;8FzRGeX") both have low probabilities of containing information.

These theories lead to the conclusion that a communication is likely to have the greatest concentration of information when the message is partially surprising and partially expected (Hayles, 1990). Likewise, artwork utilizing stochasticism is likely to have the greatest impact when the result is a mixture of pattern and unpredictability. That mixture is largely determined by how much control is maintained by the artist.

Control & Generative Art

Stochastic methods are often used as a way of relinquishing control. The Dadaists did so to emphasize the absurd. The Surrealists gave up conscious control as a way of tapping into the subconscious. Artists creating *generative art* give up control to stochastic processes to simulate the complexity of nature or the spark of creativity.

Generative art is art that was created according to an algorithm. Dadaist poems created using Tzara's directions (from earlier in this chapter) are generative artworks. Golan Levin (Zanni, 2004) argues that interactive and generative artworks are about "creating an *illusion of control*: the sense that the 'artist' has relinquished authorship to the user, or to some clever algorithm. In fact, this is a myth." In many cases Levin is correct—the truly defining characteristic of most generative artworks are the elements over which the artist maintains control.

It would seem that the percentage of decisions that are determined by stochastic data would directly correspond to the level of control abdicated by the artist, but this isn't the case. More significant than the number of random choices, is the breadth of variety that is manifested by those decisions. How the artist frames randomness can greatly throttle or expand an artwork's unpredictability.

For example, Jared Tarbell's *Node Garden* (2004)[13] uses a very large number of random choices every time it generates an image. However, those choices do not add up to works that look significantly different.

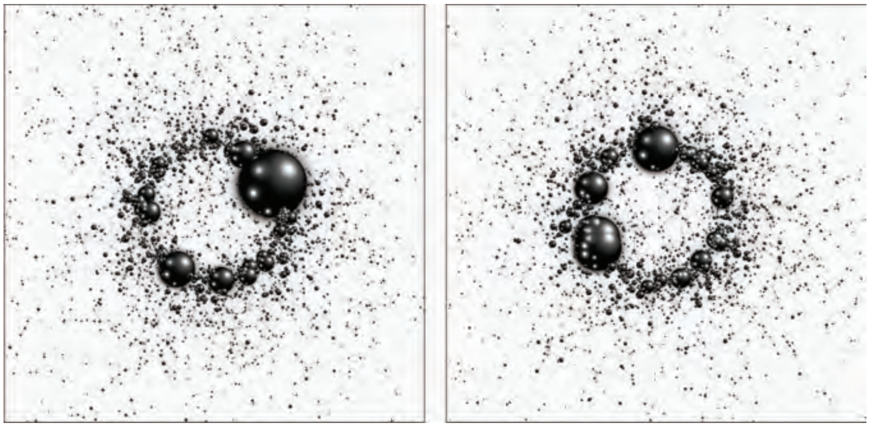
If the goal of generative art is the creation of a series of distinct artworks, then *Node Garden* would have to be considered ineffective. However, evaluating *Node Garden* using that criterion would be judging it against aims it did not have.

For generative artworks like *Node Garden,* randomness is a collaborator who does the grunt work—in *Node Garden*'s case, randomness takes care of the tedious work of placing all the picture's elements. As long as the artist's vision is maintained, the particulars of the execution do not matter too much. This is the approach Sol LeWitt took for his wall drawings. For those drawings, LeWitt limited his involvement to providing written directions for executing the drawings. The physical act of creating the artworks was relegated to teams of workers, whom LeWitt called draftsmen. In recognition of the collaborative aspect of the art, LeWitt always credited the draftsmen in the exhibition catalogs. One execution of LeWitt's drawing directions varies from another based upon the walls' dimensions, the workers' skill and care, and how freely the instructions[14] were interpreted.

Time-Based Art

When creating *Node Garden*, Tarbell's focus was developing an algorithm that gives a particular (and predictably) pleasing result, not an algo-

Figure 2.



Images used with permission of Jared Tarbell rithm whose output would continually surprise the viewer. Perhaps artworks like *Node Garden* are best thought of as a kind of performance. We wouldn't consider a particular performance of a play to be a unique work of art, even though it differs slightly from every other performance. Still, there is excitement and reward in seeing a live performance just as there can be real enjoyment in seeing *Node Garden* generate a new image in response to a computer mouse click.

A sense of time-based performance is present in many stochastic artworks, even those that are static and do not continually change. The heightened presence of time is due to its arrow being particularly straight in stochastic artworks. Part of relinquishing decisions to chance and randomness is that once the die is cast, the outcome is accepted without revision.

Erik Sommer[15] is a painter who uses mixtures of concrete and paint that peel off his canvases. Sommer regards the peeling as random and, unlike Jackson Pollock, does not "deny the accident" (Karmel, 1999, p. 22). Sommer does, however, rework the canvases until he is happy with the concrete's chance effect. A process that is random in the same way that repeatedly rolling a die until it comes up six is random.

By not fully committing to the chance outcome, Sommer's use of stochasticism is less constrained than Tarbell's. Sommer can comfortably allow a

Figure 3.

Erik J. Sommer, Taught, 2007, 48" x 48", mixed medium on canvas. Collection of the artist.

Figure 4.

Mailed Paintings, Karin Sander. Photo © D'Amelio Terras Gallery, New York.

greater range of unpredictability because he can revise outcomes that go too far astray. In some ways chance is a more marginal element in Sommer's art—perhaps an unnamed assistant rather than a full-fledged collaborator. While Sommer's approach does harness chance's potential for unexpected outcomes, it also mitigates the excitement of a live, unedited performance.

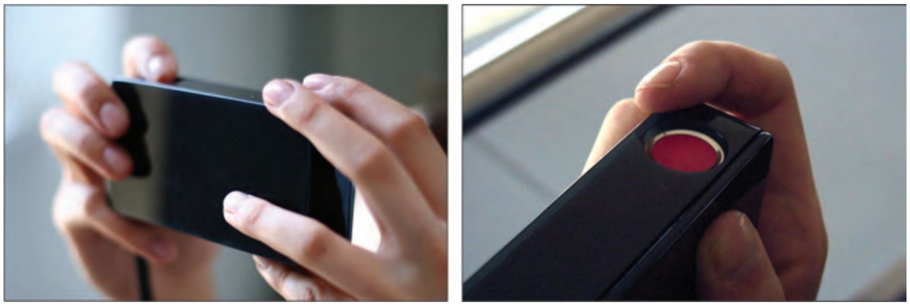
Andy Goldsworthy's *Sheep Paintings* (1997-1998) achieve a greater sense of performance. The *Sheep Paintings* were created by laying out canvases in sheep pastures. Each canvas was "painted" by the marks of mud, feces, and urine surrounding a cleaner area that was protected by the placement of a salt lick. Goldsworthy (2007) says, "Whilst each painting is a result of chance, the choice of place, time, canvas size, food source and container radically affect its final appearance. The making of these decisions gives me the opportunity to work the canvases, albeit at a distance" (p. 153). Goldsworthy also notes that the work taught him "the importance of knowing when not to touch" (p. 153). Goldsworthy retains the artistic decision of when to remove a canvas from the field. If he chose to, he could also make an editorial selection of which canvases to exhibit without compromising the project's concept.

In contrast, the absence of the artist's hand is central to Karin Sander's[16] *Mailed Paintings* (2007). The paintings are pre-stretched, store-bought canvases that Sander mails unwrapped from various international locations to the art gallery. As the canvases are scuffed, stickered, and banded, they become a diary of their journeys. The viewer is very aware of the works' passage in time and place. If Sander were to intervene and adjust the aesthetic of any of these works, they would be wholly compromised—it would be as if a singer's live performance was lip-synced to another vocalist's voice.

Sascha Pohflepp's[17] *Buttons* (2006) is another artwork with a strong connection to time. *Buttons* is a camera without optical parts. When the camera's button is pressed, the camera does not record an image, instead it records the time. It then wirelessly searches the Internet for photographs that were taken by someone else at the very moment of the button press. Pohflepp (2006) explains, "After a few minutes or hours, depending on how soon someone else shares their photo on the web, an image will appear on the [camera's] screen." The photos are selected using a chance connection—two people happening to press a camera button at the same moment. Regarding the selected photograph, Pohflepp says, "In a way, it belongs half to the person who had pressed the button and still remembers that moment. Because of that connection, the photos are never dismissed as random, no matter how enigmatic they may be."

DSCN slide show (2002) by Philippe Blanc also makes connections based on photograph uploads. Each time a photo is taken using a digital camera, the image is given a default name. For

Figure 5.



Images by Sascha Pohfleep. Used with permission.

example, the very first photo taken with a new Nikon™ camera is given the name DSCN001. Blanc created a program to search the Internet for photographs with the DSCN001 name. The result is a slide show of photographs connected by the shared experience of using a new camera for the first[18] time. Neither *Buttons* nor *DSCN slide show* generates new artwork. Instead the projects act as automated curators and select work based on a chance association.

Sometimes a work of art is completely deterministic yet is experienced by the viewer as being stochastic. This is the case for an on-going performance of John Cage's *Organ²/ASLSP* (1987), a musical composition in eight parts. *Organ²/ASLSP*'s sheet music comes with instructions that the performer should omit one of the parts, repeat one of the parts, and play the composition as slowly as possible[19]. The work's premiere lasted twenty-nine minutes. A performance that began on September 5, 2001 is intended to stretch out the music for 639 years (Wakin, 2006). The extended performance is located in a disused church in Halberstadt, Germany, the town where an organ with the first chromatic keyboard layout was built in 1361 (639 years prior to the originally planned start of the 639-year performance). The first twenty months of the performance were silent due to *Organ²/ASLSP* beginning with a rest. The first chord (two G sharps and a B in between) was struck on February 5, 2003 and lasted seventeen months. Small weights hold down the keys for the notes that are being played and the organ's pipes are changed to correspond.

Every note is predetermined, yet the audience has arbitrary musical experience. Whichever note happens to be playing is what the listener hears.

Control & Generative Music

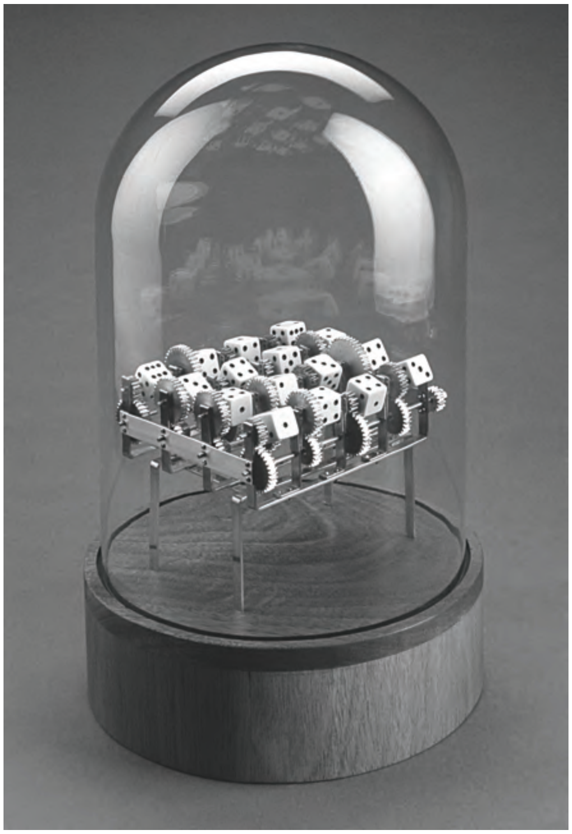
Musikalisches Würfelspielen (musical dice games) were popular in Europe during the late 18th and early 19th centuries. Using published rules and a randomizer (such as dice or tops) players selected pre-composed musical phrases to create random musical compositions. Several such games were spuriously published under Mozart's name[20]. One such fraud, dating from 1787, used two six-sided dice to determine sixteen minuet measures and one six-sided die to determine six trio measures. This calculates out to $11^{16} * 6^{16}$ (or 1.23^{29}) possible compositions, though to the listener many of these variations would sound excruciatingly similar.

While the dice game has many possible variations, the musical phrases provided by the composer/game-designer maintain a high degree of control over the listener/player experience. In contrast John Cage typically relinquished much more control in his stochastic compositions. He viewed this as releasing himself "from what I had thought to be freedom, and which actually was only the accretion of habits and tastes" (Pritchett, 1988).

Beginning in the 1950s, Cage generated random music by tossing coins and using the *I Ching* fortune-telling process. Cage would start by randomly determining the broadest aspects of a composition (e.g., the key or time signature) and then proceed to the individual notes.[21] While Western music conventions may impose a general structure on these compositions, they are much more freeform than the Musikalisches Würfelspielen compositions. Cage's *Music of Changes* (1951), which was composed in this manner, does occasionally have the brief musical phrase that sounds conventional, but taken as a whole it is reminiscent of a cat walking on a keyboard. Comparing Musikalisches Würfelspielen and *Music of Changes* shows that the randomness of the input (which is the same for both) is only incidental to the resulting unpredictability. The greater factor is the process established by the artist.

Another Cage composition, *Imaginary Landscape No. 4* (1951) was composed in much the same way as *Music of Changes*. However, it introduced the added stochastic element of being written for twelve radio receivers instead of a piano. Each receiver has one performer to adjust volume and

Figure 6.



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another performer to adjust the frequency. *Music of Changes* incorporated a random composition technique, but does not change with each performance.[22] In contrast, *Imaginary Landscape No. 4* is tied to the time and locale of the concert so that each performance is entirely uniue.

Seeds & Pseudorandom Number Generators

Mandala #2 (2000), a sculpture by Marc Berghaus[23], consists of a grid of sixteen dice under a bell jar. Gears driven by a hidden motor turn the dice at different speeds. Berghaus (2007) explains, "Due to my use of unusual gear ratios (say, 1:1.7, rather than 1:2) in the gears that connect the drive shafts to the dice's axles, very few of the cycles line up again at once, and it becomes impossible to predict the patterns of all the tumbling dice, despite the fact that all actual randomness has been stripped from them" (p. 49).

The rotation of *Mandala #2*'s dice is completely deterministic, so it may seem a poor simulation of randomness. And perhaps it is. But it is a very good, real world representation of how computers generate random numbers.

As mentioned earlier, computers cannot create true random numbers and instead they use formulas to generate pseudorandom numbers. Pseudorandom numbers are important for everything from shuffling the deck of a solitaire game program to negotiating communication on a computer network[24].

When preparing to use a pseudorandom number generator, programmers start by giving it a "seed" value. This seed is an arbitrary number used by the PRNG's algorithm to generate the series of numbers[25]. Without this seed number, a PRNG would generate the same series of numbers each time it was restarted. In a way, "the pseudorandom generator does not actually generate any randomness; it stretches or dilutes whatever randomness is in the seed, spreading it out over a longer series of numbers like a drop of pigment mixed into a gallon of paint[26]" (Hayes, 2001, p. 302).

Given this characterization of the seed as the source of the PRNG's randomness, one may wonder how a seed's value is determined since computers innate lack of randomness was the issue in the first place. One approach is to use input from outside the computer (such as user input) to establish the seed. But by far, the most common technique for creating a seed value is to use the current time (which on UNIX computers is expressed in the number of seconds that have elapsed since January 1, 1970).

Neglecting to seed a PRNG results in it giving the same default series of numbers each time it is restarted[27]. Likewise, a particular seed value will always return the same series of numbers. Years ago the author of this chapter programmed

Sanctum, a two-person online game. Every time a new game was started, the network would pass the same number to both players' computers to use as a seed value. That way, every time a random number was used in the game (for example, to determine whether an arrow hit a monster), both players' computers would have identical outcomes. Very occasionally, an error in the program would cause one player's computer to use a random number where the other player's didn't, with the result that one computer would be a step ahead in the series of random numbers. Once that occurred, every following use of a random number would cause the game state on the two computers to diverge further apart. Eventually the two players would be seeing completely different game states (an occurrence reminiscent of the science fiction genre of "alternative histories" where a slight change in history—in this universe or a parallel one—results in a very changed present).

Hardware Random Number Generator

Given the limited randomness provided by PRNGs, one might think that real world randomizers such as dice would provide better results. In 1965 statistician Frederick Mosteller had a unique opportunity to test this when Willard H. Longcor walked into his office and offered to record the results of a few million die tosses (Peterson, 1998). Mosteller compared the results to what would be predicted by distribution theory and found that Longcor's throws matched very closely (and the few places where it diverged pointed to errors in the theory). Coin flipping has also been extensively tested. During World War II an English mathematician spent his time in a prisoner of war camp tossing a coin—he came up with 5,067 heads in ten thousand tosses (Peterson, 1998).

But these accurate results seem to be the exception. The best pseudorandom number generators can outperform (in terms of tests of randomness) some physical number generators (Hayes, 2001). Physical number generators' faults come from the same source as their virtue; the messiness of real world. That messiness can provide back doors for patterns to sneak in.

For example, British biometrician W. F. R. Weldon and his wife Florence spent a good deal of time rolling dice and recording the results to demonstrate the laws of probability. However, in 1900 the English mathematician Karl Pearson[28] analyzed the results of 26,306 of the Weldons' rolls and found that they broke the rules of probability—there were too many fives and sixes.

In 1977, Doyne Farmer fell in with a group of graduate students who were pioneering the field of chaos[29] at the University of Santa Cruz. Farmer was obsessed with using chaos theory to beat roulette[30] and spearheaded group forays into casinos with a computer hidden in a pair of shoes. While at a roulette table, information about the roulette tables spin, release of the ball, and so forth would be entered into the computer using toes. The computer would predict in which eighth of the wheel the ball was liable to stop and would transmit the results to a third shoe (worn by another member of the group) who would then place a bet. Apparently the system worked well enough for the group to make money (Kelly, 1995).

In 1955 the Rand Corporation published *A Million Random Digits with 100,000 Normal Deviates*, a 600-page book[31]. Rand used an electronic "roulette wheel" to generate the numbers. However, the machine proved to not be statistically random, despite repeated tinkering and modifications. Eventually Rand had to succumb to mixing and mathematically manipulating the numbers to have them pass statistical testing (Peterson, 1998 and Hayes, 2001). Rand's roulette table was in reality an electronic machine that generated a stream of bits (1's & 0's). In a twenty-five page introduction to the book, the method of number generation is outlined in order to assure the reader of the data's randomness. This introduction attributes the source of the bits to a "random frequency pulse source." Rand provided no further details, but the *Computer Handbook* (Huskey & Korn, eds., 1960) surmises that it was probably a Geiger counter and a low-grade radioactive material.

The same approach is taken by quite a few hardware random number generators—random number generators that don't use (or at least don't exclusively use) algorithmic methods for generating a number. John Walker's *HotBits* website[32] provides random numbers that are generated by measuring the nuclear decay of Cæsium-137. His method is to first detect the length of time between two electrons being given off by the radioactive material. A second set of electrons is timed and the two durations are compared. If there first set of decays has the shorter time interval a zero is generated, if it is longer then a one is generated. The resulting binary data is then converted to decimal numbers (e.g., 1001 would become a 9). This technique generates about 200 digits per second.

A less radioactive system is used at Random.org. The website provides random numbers generated using atmospheric noise (e.g., thunder). Yet another web-based random number provider is LavaRnd[33]. LavaRnd uses a web-cam with the lens covered. In the absence of light, the CCD chip on the video camera creates chaotic thermal "noise" which is put through a hash algorithm to remove unwanted, predictable patterns and is converted into random numbers. Atmospheric noise, video camera noise, and the fluid dynamics of LAVA LITE® lamps are all chaotic sources. A chaotic process is one in which minor variations in a process's initial conditions result in wildly different effects (i.e., the apocryphal "butterfly effect" where the flap of a butterfly's wing in a Brazil leads to a tornado in Texas). Chaotic systems often appear to be random even though their behaviors are entirely deterministic and based upon the initial conditions. So a random purist might argue that hardware random number generators using chaotic events are not truly random. This would leave just quantum event based (i.e., radioactive decay) random number generators as being truly random, however even that is in question. There is an ongoing debate as to whether even quantum events are truly random or simply chaotic. This is the kind of conundrum that led Knuth (1981)

Figure 7.

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to pragmatically accept that "being 'apparently random' is perhaps all that can be said about any random sequence anyway" (p. 3). Even if one accepts quantum events as random, the numbers the generate may not be due to patterns sneaking from biases or flaws in the detection tools.

Nina Katchadourian's[34] *Talking Popcorn* (2001) translates the sounds of popcorn popping into a glossolalic babble. The sculpture consists of a microphone housed in a movie house popcorn machine. A hidden computer interprets the popping as Morse code and provides simultaneous spoken translation through a computer-generated voice. *Talking Popcorn* determines the Morse code by measuring the silences between popcorn pops in very much the same manner that radioactive-based hardware random number generators compare the durations between Geiger counter clicks. *Talking Popcorn* equates the longer silences as Morse code dashes and shorter silences as dots. These silences are measured relative to the running average speed of the popping so that as it speeds up, the pops don't become interpreted as an indistinguishable series of Morse code dots. The adjustment of popping speed smoothes out the particular, bell-curved popping cadence of a batch of popcorn and normalizes it into raw randomness. *Talking Popcorn* removes the real-world characteristic of popcorn building to a crescendo and then dropping off to the last few reluctant pops. Where some artworks, such as Hawkinson's *Emoter*, might be editorially classified as random (because the cause and effects are opaque to the viewer) even though it is actually based on chance events, *Talking Popcorn* is truly random through and through. There is no carryover of meaningful information because the triggering data's patterns have been smoothed out in much the same manner as LavaRnd does with its thermal noise events and the Rand Corporation did with its "frequency pulse" data.

Talking Popcorn's generation of information is reminiscent of a story that Hayles describes in her introduction to *Chaos Bound*. The story[35], which comes from Stanislaw Lem's *The Cyberiad*, can be seen as a parable illustrating the relationship between chaos and information. In the tale, two constructors[36] are captured by a space pirate who pillages and hoards information. To gain their freedom, the constructors build a "Demon of the Second Kind"[37] for the pirate. The demon is designed to interpret the movement of stale air molecules as information. Whenever the motion of the molecules adds up to something intelligible, the Demon transcribes it onto paper tape using a tiny diamond-tipped pen. The pirate underestimates the amount of information contained within the chaotic motion, and he is soon buried in a mountain of paper filled with useless information: all the words that rhyme with spinach, why fan-tailed fleas won't eat moss, the sizes of bedroom slippers available on the continent of Cob, how Kipling would have written the beginning of *The Jungle Book 2*, et cetera.

Figure 8.

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The idea that we can be paralyzed by an overabundance of information seems even more relevant today (with the constant influx of information from the Internet, text messaging, emails, cel phones, and MP3 players) than when Lem wrote the story in 1967 or when Hayles discussed it in

1990 (a few years before the arrival of Mosaic, the first graphical web browser).

Unlike Lem's Demon of the Second Kind, Katchadourian's *Talking Popcorn* does not filter out the babble. In this regard, it is more like Borges's "The Library of Babel" which describes a universe composed of hexagonal, book-lined rooms. The narrator of the story posits that each book is unique and that every possible combination of text exists.[38] Since every possible book exists, the Library must contain the ultimate truth. There would also be many slight variations on the truth[39], and even more books filled with lies, and even more variations of those lies. But overwhelmingly the Library contains books of gibberish.

FUTURE TRENDS

The Internet provides a huge reservoir of data; a channel for receiving interactive stimulus; and a cheap and convenient platform for publishing art. These characteristics are attractive to artists exploring stochastic art, so the Internet is likely to continue to develop as an environment for random and chance-based art.

Physical computing—the use of microcontrollers and electromechanical devices—often uses chance and randomness (as seen in Raaf's *Translator II: Grower*). Recent innovations such as the Processing programming language and the Arduino microcontroller boards have made the electronics and programming required for physical computing much more approachable and popular. This trend is likely to continue. In the same way that creating a webpage has gone from a task for programmers to something pre-adolescents can do on social networking sites, we may see electronics development and the creation of electronics-based stochastic art become within reach of a more general public.

CONCLUSION

The motivations for using stochastic elements in art can range from a desire to free the creative process from conscious concerns to wanting to mirror the frenetic pace of our data-soaked lives. Both random and chance occurrences can be effectively used in art, but using chance may lead to richer, more interesting artworks because it brings an element of the world and a greater potential for resonance than the sterile isolation of true randomness.

REFERENCES

Berghaus, M. (2007). Simulated Chance and Staggered Gear Ratios. *Leonardo Music Journal,* 17, 1-90.

Borges, J. L. (1998). *Collected Fictions*. New York, NY: Penguin Putnam, Inc.

Brotchie, A., & Gooding, M. (Ed.). (1991). *A Book of Surrealist Games*. Boston, MA: Shambhala Publications, Inc.

Bryan-Wilson, J. (2003). Sol LeWitt. In Molesworth, H. (Ed.), *Work Ethic* (pp. 158-159). University Park, PA: The Pennsylvania State University Press.

Chaitin, G.J. (1975). Randomness and mathematical proof. *Scientific American* 232(5), 47-52.

Goldsworthy, A. (2007). *Enclosure*. New York, NY: Abrams.

Haahr, M. (1998-2008). *Introduction to Randomness and Random Numbers*. Retrieved January 15, 2008, from http://random.org/randomness/

Hayes, B. (2001). Randomness as a Resource. *American Scientist, 89*(4), 300-304. Research Triangle Park, NC: Sigma Xi.

Hayles, N.K. (1990). *Chaos Bound: Orderly Disorder in Contemporary Literature and Science*. Ithaca, NY: Cornell University Press.

Hayles, N.K. (1994). Chance Operations: Cagean Paradox and Contemporary Science. In M. Perloff, & C. Junkerman, (Eds.), *John Cage: Composed in America* (pp. 226-241). Chicago, IL: University of Chicago Press.

Hermida, A. (2005). *Sony shows off new PlayStation 3*. Last updated May 17, 2005 on BBC News website, http://news.bbc.co.uk/2/hi/technology/4554025.stm

Huskey, P., & Korn, G. (Eds.). (1962). *Computer Handbook*. New York, NY: McGraw-Hill Book Co.

Karmel, P. (Ed.). (1999). *Jackson Pollock: Interviews, Articles, and Reviews*. New York, NY: The Museum of Modern Art.

Kelly, K. (1995). *Out of Control*. New York, NY: Perseus Books.

Kelvin, L. (William Thomson). (1901). Nineteenth century clouds over the dynamical theory of heat and light. *The London, Edinburgh and Dublin Philosophical Magazine and Journal of Science, Series 6, 2, 1–40.*

Ketner, J., Herbert, L., & Volk, G. (2002). *Roxy Paine: Second Nature*. Houston, TX: Contemporary Arts Museum, & Waltham, MA: The Rose Art Museum, Brandeis University.

Knuth, D. (1981). *The Art of Computer Programming, Volume 2: Seminumerical Algorithms (2nd Edition)*. Reading, MA: Addison-Wesley Publishing Company.

Lem, S. (1974). *The Cyberiad: Fables for the Cybernetic Age* (M. Kandel, Trans). New York, NY: Harcourt Brace Jovanovich.

Noguchi, H. (1990). Mozart - Musical Game in C K. 516f . *Mitteilungen der International Stiftung Mozarteum, 38*(1-4), pp. 89-101.

Peterson, I. (1998). *The Jungles of Randomness: A Mathematical Safari*. New York, NY: John Wiley & Sons.

Pincus, S., & Singer, B.H. (1996). Randomness and Degrees of Irregularity. In *Proceedings of the National Academy of Sciences of the United States of America*, *93*(5), 2083-2088. Washington, DC: National Academy of Sciences.

Pohflepp, S. (2006). Buttons. *Between Blinks & Buttons*. Retrieved February 22, 2008, from http://www.blinksandbuttons.net/buttons_en.html

Poundstone, W. (2005). *Fortune's Formula*. New York, NY: Hill and Wang.

Pritchett, J. (1988). *The use of chance techniques in the music of John Cage, 1950-1956*. Unpublished doctoral dissertation, New York University, New York.

Tippett, L.H.C. (1927). Random sampling numbers. *Tracts for Computers, 15*. London: Cambridge University Press.

Wakin, D. (2006, May 5). *An Organ Recital for the Very, Very Patient* [Electronic version]. *The New York Times*.

Zanni, C. (2004). Interview with Golan Levin. *CIAC Magazine,* 16 June 2004.

KEY TERMS

Algorithm: A set of well-defined instructions for completing a task.

Chance: In this chapter "chance" refers to unpredictable, but deterministic, events.

Chaotic: behaviors where minor changes in initial conditions can result in widely divergent results. Chaotic systems often appear random even though they are completely deterministic.

Deterministic: A situation where events are completely predictable based upon cause and effect.

Generative Art: Art that is created according to an algorithm. Generative art is typically intended to give the appearance of machine creativity.

Hardware Random Number Generator: A method for generating random numbers using a physical process, such as the nuclear decay of radioactive material. The generated numbers are often referred to as "true random" numbers in contrast with pseudorandom numbers generated by a pseudorandom number generator.

Pseudorandom Random Number: A number that was generated using an algorithmic process called a pseudorandom number generator (PRNG). Because the numbers are created deterministically they have the appearance of randomness, but are not truly random.

Quantum: Used in this chapter to refer to subatomic processes.

Random: used in this chapter to specifically refer to unpredictable events that are completely self-contained and communicate no information (in contrast to "chance").

Stochastic: having unpredictable characteristics. Used in this chapter to refer to both random and chance events.

ENDNOTES

[1] Later in this chapter we'll discuss random number generators that uses quantum events (i.e., the nuclear decay of radioactive materials).

[2] 52 times.

[3] Lord Kelvin (1901) tried generating random numbers by drawing cards and reported, "The best mixing we could make in the bowl seemed to be quite insufficient to secure equal chances for all the billets [cards]." L. H. C. Tippet (1927) had a similar problem when he tried drawing a thousand cards from a bag: "It was concluded that the mixing between each draw had not been sufficient, and there was a tendency for neighbouring draws to be alike." The 1969 U.S. military draft lottery was flawed due to a strong reverse-correlation between the order in which the slips were put into the mixing bin (by calendar date) and the order in which they were drawn (Wetzel, 1998). In plainer English, potential draftees who were born later in the calendar year were placed into the mixing bin last and had a significantly higher chance of being selected for the draft.

[4] www.raaf.org

[5] Both series have a 1 in 65,536 (i.e., 2^{16}) chance of occurring.

[6] The idea that randomness comes from a number's method of generation rather than an inherent characteristic is what Knuth was driving at in his previously quoted statement: "In a sense, there is no such thing as a random number; for example, is 2 a random number?" (Knuth, 1981)

[7] A. N. Kolmogorov of the Academy of Science of the U.S.S.R. independently proposed a similar idea at about the same time as Chaitin. Unbeknownst to Chatin and Kolmogorov, Ray J. Solomonoff of the Zator Company made a similar proposal in 1960 as a method for measuring the simplicity of scientific theories. (Chaitin, 1975)

[8] The program we're describing is not a general-purpose number generator, but rather a program that is capable of generating a specific series of numbers. This is not the same as saying that the file size of a *pseudorandom number generator* (PRNG) is an indicator of its quality. It's also important

to realize that never generating a number that contains a pattern (e.g., 101010) is not a virtue in a PRNG. Coincidental patterns are commonplace and a PRNG that filtered out such patterns would be weaker than one that allows them.

[9] Chaitin's theory is related to earlier research on ciphers that was done by Claude Shannon, a pioneering information theorist who we'll reference several times in this chapter. Ciphers are algorithms that use an arbitrary piece of information (called a key) to encrypt data. Shannon determined that it is impossible to decrypt a cipher without the key if the key is truly random and is the same length (or longer) as the data that was encrypted (Hayes, 2001).

[10] Mark Nelson and Mark Goldman have issued separate challenges (with $100 and $5,000 prize monies) on the comp.compression newsgroup to anyone who achieves such compression. To date, no one has been able to legitimately claim the money, though programmer Patrick Craig attempted to take advantage of a loophole in Goldman's challenge.

[11] The idea originated in an article by Claude Shannon and was interpreted and expanded upon in a commentary by Warren Weaver. See *The Mathematic Theory of Communication* by Shannon and Weaver (1949).

[12] Victor Hugo, *Les Miserables*, 1862

[13] www.complexification.net

[14] Bryan-Wilson (2003) cites LeWitt giving directions such as "The lines should be made a close together as possible. They do not have to be regular but would differ with each person who does them." (p. 158)

[15] www.erikjsommer.com

[16] www.karinsander.de

[17] www.pohflepp.com

[18] Or 1,000th time since the default naming repeats after 999 photos.

[19] Hence the *ASLSP* in the title: "As SLow aS Possible."

[20] Mozart does appear to have created an unpublished dice game that used the letters of a friend's name to generate the composition (Noguchi, 1990).

[21] Once such a system of rules is established, it doesn't matter who executes them, human artist or machine. Cage eventually made extensive use of generative software, including a coin-tossing program, written by his assistant Andrew Culver. A list of programs used by Cage can be seen at www.anarchic-harmony.org/People/Culver/CagePrograms.html.

[22] Cage might argue that every musical performance is a unique work. This is the concept of his *4'33"*, a work in which the musicians play no notes, so the aural experience consists of the ambient noises of the audience coughing, et cetera.

[23] www.marcberghaus.com

[24] When two nodes on a network are attempting to send data simultaneously we don't want them to act like two cars trying to enter an intersection at the same time only to stop simultaneously, then try to enter the intersection at the same time again. To avoid such a scenario, the Ethernet protocol has both nodes pick a random number to determine how long to wait before trying to send data again. (Hayes, 2001)

[25] A series of random numbers created by a pseudorandom number generator will begin repeating within 2^n-1 results where n is the bit size of the seed number). A Sony PS3 console runs at 218 gigaFLOPS—i.e, 218 billion floating-point operations per second (Hermida, 2005). Assuming a 32-bit seed value and 100 floating-point operations for each generated pseudorandom number, a PS3 could run through the entire series of random numbers associated with a particular seed in 1.97 seconds. A 32-bit number has

4,294,967,295 possible seeds values (again, 2^n-1 results where n is the bit size), so it would take 268 years for a single PS3 to go through every possible series of random numbers.

[26] This idea of the PRNG's randomness stemming from the seed was expressed in the 1980s by Manuel Blum.

[27] A casino player once noticed that this was the case for a keno game. Each time the keno machine was powered off and back on, the number draw sequence repeated. The player won $600,000 as a result (Peterson, 1998).

[28] At about the same time he analyzed the Weldons' data, Pearson did twenty-four thousand coin tosses himself and came up 12,012 heads (Peterson, 1998)

[29] Chaos theory is more formally known as nonlinear dynamics. Later in this chapter we'll compare chaos and randomness.

[30] Claude Shannon (whose information theories are discussed earlier in the chapter), along with fellow Bell Labs researcher John L. Kelly, jr. and M.I.T. mathematician Ed Thorp, made a fortune in the early 1960s by successfully applying game theory to roulette and blackjack in Las Vegas. (Poundstone, 2005)

[31] The book had recently become available as a reprint. It can also be downloaded for free at www.rand.org/pubs/monograph_reports/MR1418/index.html.

[32] www.fourmilab.ch/hotbits

[33] www.lavarnd.org. Landon Curt Noll, one of the minds behind LavaRnd, was also part of the team that created the lavarand (LavaRnd and lavarand are not the same, despite their confusingly similar names). Lavarand was a Silicon Graphics project in the 1990s. It involved using captured images of LAVA LITE® lamps to generate random, 140-byte seed values for feeding PRNGs.

[34] www.ninakatchadourian.com

[35] The short story has the burdensome title of "The Sixth Sally, or How Trurl and Klapaucius Created a Demon of the Second Kind to Defeat the Pirate Pugg."

[36] Constructors are magician-like sentient robots who can construct a contraptions (often artificially intelligent) for almost any purpose. *The Cyberiad* has the universe alternating between being populated by biological and robotic beings—each of whom eventually succumbs to tackling the challenge of creating the other (only to be overthrown by their creation).

[37] The first kind of demon is Maxwell's Demon, a creature described in a thought experiment that challenges the Second Law of Thermodynamics (also known as the Law of Entropy).

[38] It is further detailed that every book has 410 pages, each page has forty lines, and each line approximately eighty black characters. There are twenty-five "orthogonal symbols" consisting of a space, period, comma, and twenty-two letters. That calculates out to $25^{1,312,000}$ possible books (or, as the scientific calculator on my Macintosh puts it, "Infinity").

[39] There would be 1,312,000 books that vary by one character and $1.72*10^{12}$ books that vary by two characters.