Microvenus

Joe Davis

Biological objets d'art have been anticipated for at least a quarter century. In 1970 noted art historian Jack Burnham concluded his landmark book about contemporary sculpture *(Beyond Modern Sculpture)* with predictions for the future:

What then of sculpture in the twenty-first, and the last third of this century? Deep rooted drives lasting several millennia do not die easily. Carving or fabricating objects as sculpture will probably continue until A.D. 2000—but with less importance as an art form. . . . The stabilized dynamic system will become not only a symbol of life, but literally life in the artist's hands and the dominant medium of further aesthetic ventures. In retrospect, we may look upon the long tradition of figure sculpture and the brief interlude of formalism as an extended psychic dress rehearsal for the intelligent automata. . . . As the Cybernetic Art of this generation grows more intelligent and sensitive, the Greek obsession with "living" sculpture will take on an undreamed reality.[1]

Burnham recognized an academic, historical precedent for the creation of the artwork, *Microvenus*, a genetically engineered organism that is invisible to the human eye. *Microvenus* is undeniably connected to artistic traditions, but important inspiration also came from interdisciplinary notions about "universal" messages and the thought that certain biological materials may be useful in the experimental search for extraterrestrial intelligence. This paper first describes *Microvenus* and explains its generation and then explores some of its (her) implications for art.

Each *Microvenus* organism contains many copies of a special molecule designed by the artist and his colleagues. This artistic molecule is a short piece of synthetic DNA containing a coded visual icon that has been incorporated into a living strain of bacteria *(E. coli)*.[2] Ultimately, *Microvenus* is a work of art, a poetic image, yet the project to create it originated as a collaboration in both art and science. Now, like the particle/wave duality, neither explanation seems completely adequate.

The *Microvenus* project is a demonstration of the way in which extrabiological information can be written into DNA. To accomplish this, an intermediary language was created to convert generic data bases into biological form. This language, one of many possible such languages, was used to code a binary, graphic data base into the arrangement of atoms that comprise a small synthetic molecule of DNA.

The *Microvenus* data base describes a graphic icon that is identical with an ancient Germanic rune and other iconography originally used to represent *life* and the female *earth*. The icon consists of three linear elements *(fig. 1)* resembling the letter *y* with an upwardly extended vertical element. As I subsequently discuss, the icon can also be taken as a representation of the female human genitalia.

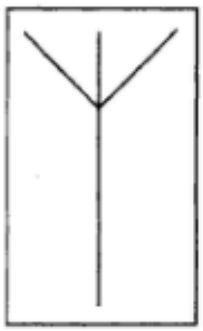


FIG. 1 *Microvenus* icon.

Microvenus was created by converting this graphic image into an easily understood sequence of DNA base pairs.[3] In 1974 Carl Sagan and Frank Drake confronted a similar problem of representing a graphic image in a radio transmission from Arecibo, Puerto Rico, to outer space *(figs. 2 and 3)* and their solution led to ours. The two-dimensional *Microvenus* graphic image was first translated into a five-by-seven bit-mapped *Microvenus*, consisting of the mathematical bits zero and one *(fig. 4)*. Thirty-five, the product of five and seven, is divisible only by those two prime numbers, meaning that the following one-dimensional (linear) thirty-five-bit binary sequence (created for insertion into DNA) can be converted back to only one two-dimensional figure (namely the five-by-seven or seven-by-five *Microvenus*):

10101011100010000100001000010000100

DNA can also be thought of as a coded sequence of values. Scientific notation used to describe DNA is usually expressed as a varying set of alphabetical characters that correspond to the first letter of each of the four *nucleotide* bases in DNA: cytosine, thymine, adenine, and guanine. All biological information is coded into varying sequences

of only these four substances, abbreviated CTAG. In order to permanently contain the *Microvenus* icon in the DNA "memory" of a bacterium, it was necessary to translate the bit-mapped *Microvenus* into a sequence of bases that could be included in cellular DNA.

The strategy used to code the *Microvenus* icon compares the respective sizes, or molecular weights, of the bases to obtain an incremental reference. Cytosine is the smallest base, thymine is the next largest, then adenine, and finally guanine, so that

C = 1, T = 2, A = 3, G = 4

In order to compress the binary digits of the bit-mapped *Microvenus* into fewer genetic integers, the four bases were assigned *phase-change* values rather than incremental, *numerical* values; each base is used to indicate how many times each binary bit (e.g., zero or one) is to be repeated before changing to the other binary bit (e.g., one or zero), a technique used in many forms of computer-compression technology. This can be represented as:

C = X, T = XX, A = XXX, G = XXXX

The first five digits of the *Microvenus* binary code are 10101. Using the phase-change coding method, corresponding genetic characters would be CCCCC, because each binary digit occurs only once before switching to the other digit. The next part of the bit-mapped *Microvenus* reads 0111000 so again, the first digit, 0, translates to the genetic C (0 occurs just once before switching to 1). Then 1 occurs three times so these three binary digits can be represented by a single genetic A. The next change in the binary map is another triplet, 000, so again, a single A is used in the corresponding genetic sequence. The binary sequences 11 and 00 are signified by the genetic T; and G signifies either 1111 or 0000. Coded in this way, the thirty-five-digit *Microvenus* binary map translates to only eighteen DNA bases:

CCCCCCAACGCGCGCGCT

These can then be decoded into one of two binary codes:

10101011100010000100001000010000100

or

01010100011101111011110111101111011,

depending on which digit is chosen to start the decoding sequence. Transformation of either sequence into the correct five-by-seven prime-number grid will yield the *Venus* icon, and in this case, because the *Venus* icon is bilaterally symmetrical, more than one of several possible five-by-seven grids will assemble into the intended bit map.

The decoding clue CTTAAAGGGG has been added to the beginning of the *Microvenus* DNA sequence to imply C = X, T = XX, A = XXX, and G = XXXX. The combined *Microvenus* code thus reads:

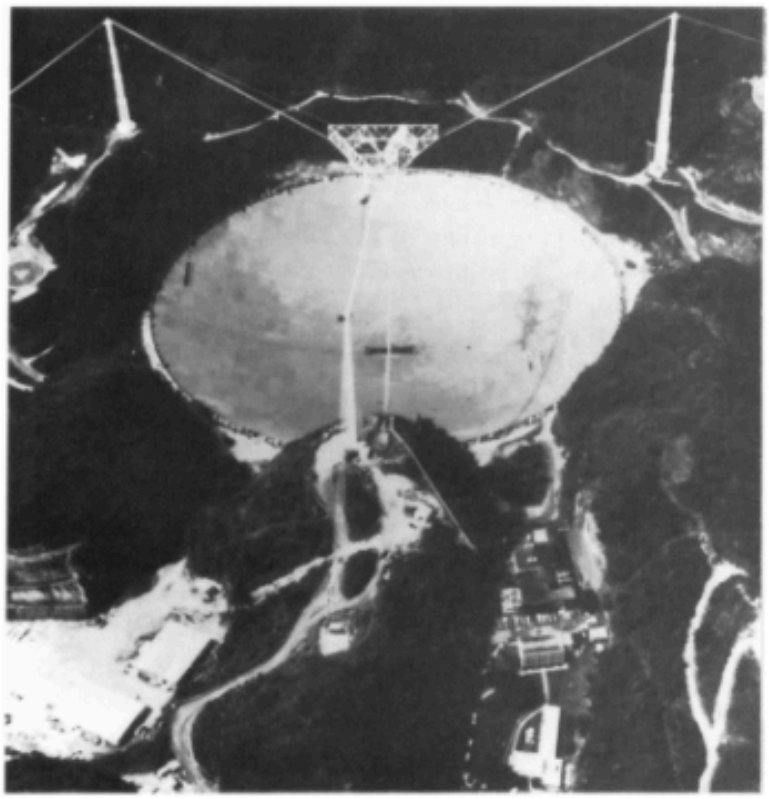


FIG. 2 Arecibo, Puerto Rico. The one-thousand-foot diameter radio/radar antenna enables scientists to study solar system objects with radar as far out as the planet Saturn. Sagan and Drake sent their message from this radar transmitter. Courtesy NASA.

FIG. 3 Sagan and Drake message, from Joe Davis's notebook.

CTTAAAGGGGCCCCCCAACGCGCGCGCT

In a double-stranded DNA molecule, each base pairs with its complementary base to form the doublets that comprise the rungs of the DNA ladder. The two strands of DNA molecules are distinguished on this basis as primary and complementary strands. Both a primary and a complementary strand are ultimately needed to form double-stranded DNA. The sequence of bases in the *Microvenus* complementary strand is:

5'-AGCGCGCGCGTTGGGGGGCCCCTTTAAG-3'

The *Microvenus* molecule is thus a double-stranded DNA with twenty-eight base-pairs, eighteen of them encoding the binary picture raster and the remaining ten containing decoding information:

Primary Strand
5'-CTTAAAGGGGCCCCCCAACGCGCGCGCT-3'
| | | | | | | | | | | | | | | | | | | | | | | | | | | | |
3'-GAATTTCCCCGGGGGGTTGCGCGCGCGA-5'
Complementary Strand

Once the DNA representing the *Microvenus* was chemically synthesized and converted into a form that can be inserted into a cell, the next step was to introduce this DNA into a kind of biological "shipping carton" that scientists usually refer to as a "vector."[4] A vector in this sense is typically a viruslike entity that is not able to "live" autonomously but that can be absorbed through cell membranes and thus enter and reproduce inside living cells. The DNA of many different kinds of vectors is now routinely disassembled in the laboratory, combined with "foreign" DNA, and then reassembled as chimeric molecules that can be "piggybacked" into cells along with genetic machinery that, with remarkable specificity, is designed to do just that.

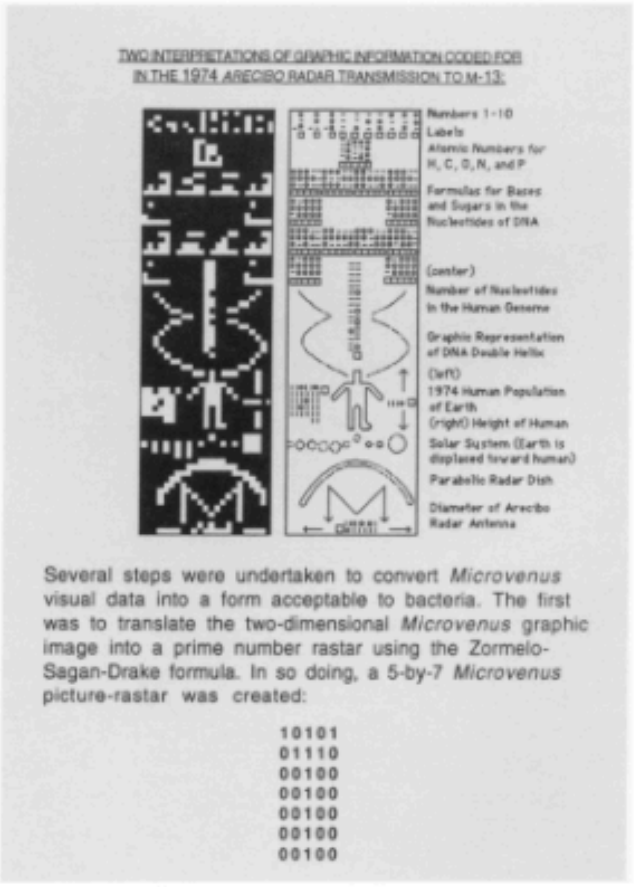
One particularly useful vector is a plasmid. Plasmids are circular pieces of DNA that propogate within a bacteria independent of the host-bacterium's genome but using the host's genetic machinery. When bacteria reproduce, they pass along to progeny any plasmids they happen to contain. Plasmids depend on reproducing bacterial hosts and do not kill cells.

Plasmids have been created with built-in recognition sites for many different enzymes, including so called restriction enzymes used to cut the ordinarily circular plasmid DNA molecules at very specific points. Each of these points is like a file drawer. The genetic engineer can use an enzyme to open up a particular file in order to insert a new piece of DNA there. Other enzymes are used to close the file (repair the circular plasmid), but the first enzyme can always be used to reopen the file at exactly the same place. Once inserted, a single chimeric plasmid will replicate many copies of itself in a given bacteria cell. Plasmids pUC 19 and pSK M13+ were used to vector *Microvenus* into bacterial hosts.

The techniques used to clone the *Microvenus* plasmid were essentially the same as those used in the 1970s by Stanley N. Cohen, Annie C. Y. Chang, Herbert W. Boyer, and Robert B. Helling to create some of the first recombinant organisms. Restriction enzymes were used to cleave plasmids. Other enzymes (ligase and polymerase) were used to attach *Microvenus* DNA to plasmid DNA and to "glue" the recombinant plasmids back together again.

Microvenus plasmids were cloned into several laboratory strains of *E. coli* (with molecular geneticist Dana Boyd) at Jon Beckwith's laboratory at Harvard Medical School in the spring of 1988 and again at Alexander Rich's Laboratory of Molecular Structure at MIT. *Sequencing* ("reading back") of *Microvenus* DNA was undertaken in summer of 1990 with Shuguang Zhang and Curtis Lockshin at MIT.

The *Microvenus* DNA now resides in a bacterium that is a delicate "living carriage" that cannot ordinarily withstand exposure to air and sunlight. In fact, it was chosen because it could be easily destroyed. But this fragility is deceptive. Most *Microvenus* bacteria *(E. coli)* would be quickly killed on exposure to a variety of typical natural environments, yet 100 percent fatality would be an extremely unlikely, if not impossible, event. Thus, unless it is purposefully destroyed, in its present form the *Microvenus* icon, together with the essential hereditary



Several steps were undertaken to convert *Microvenus* visual data into a form acceptable to bacteria. The first was to translate the two-dimensional *Microvenus* graphic image into a prime number rastar using the Zormelo-Sagan-Drake formula. In so doing, a 5-by-7 *Microvenus* picture-rastar was created:

10101
01110
00100
00100
00100
00100
00100

FIG. 4 Bit-mapped *Microvenus*, from Joe Davis's notebook.

information it is attached to, could potentially survive for a period that is considerably longer than the projected lifespan of humanity itself.[5]

The production of this living art form satisfies Burnham's prediction of twenty-five years ago, and it also embodies other notable features. These include an investigation of new techniques and media for extraterrestrial communication, efficiency and durability of information storage,[6] and an uncensored representation of human anatomy.

The *Microvenus* project originally emphasized biological and artistic solutions for problems associated with the search for extraterrestrial intelligence.[7] This topic pertains to many different fields in the arts and sciences. Investigators attempting to create messages for "intelligent" nonhumans are led to broad descriptions of various intrinsically human notions, including such ideal concepts as *intelligence, mathematics, art,* and *life* itself. Similarly, any artwork created for communication with extraterrestrial intelligence will almost certainly include concepts and issues not normally included in purely artistic treatments.

This has been an especially suitable context for *Microvenus* because an important objective has been to help inform the arts and humanities about the recent explosion in understanding of the molecular basis of all living things. The physical form of the *Microvenus* artwork and of the raw materials used and the formulas and operations used to carry out its assembly are fundamental to all living things. The same chemicals and series of reactions are employed by living cells to create (or re-create) themselves. An understanding of the former (the artwork) therefore implies, at least to some extent, an understanding of the latter (basic molecular operations of living things).

Traditional approaches to the problem of interstellar communications call for reliable transmitting media that can penetrate deep into interstellar space. With this in mind the qualities of familiar information storage systems compare poorly with the characteristics of such a natural biological data base as *Microvenus.* Although images cast in noble metals like gold are very durable on earth (but not necessarily in space), most sophisticated modern information storage media, such as optical disks, integrated circuit "chips," and magnetic tape, cannot permanently withstand exposure to heat, light, moisture, and oxidizing chemical activity encountered in normal terrestrial environments. DNA itself is actually a relatively stabile chemical, yet like conventional communications media, it will ultimately fall apart in "shirt-sleeve" environments because most terrestrial environments contain enzymes that will degrade DNA. Kept within a bacterial carrier however, especially in spore-forming bacteria, it might survive intact for an indefinite period of time. Because DNA is a *language* in the formal sense, containing coded instructions for the creation of many unrelated cellular materials, its biological function is analogous to conventional media for information handling and storage.

Once inside the bacteria into which it can be introduced, DNA can be robust. Bacteria have been shown to survive extreme pressures and temperatures. By 1975 both NASA and the Soviets had demonstrated that many species of bacteria could readily survive direct exposure to the vacuum of space.[8] Further, if bacterial DNA molecules are accidentally damaged due to injury or ionizing radiation, built-in capabilities can self-correct, a feature generally lacking in physical-storage media or in other cellular components. As Arthur Kornberg wrote:

Cellular repair of damage to a macromolecule is known only for DNA. In no other instance is the integrity of a single molecule so vital to the survival of the cell. Since a bacterial gene has a fifty percent chance of remaining unaltered even after having been duplicated one hundred million times, it is not surprising to find that the cell has a variety of devices for protecting the integrity of DNA and repairing the lesions introduced into it.[9]

Another important feature of biological data storage is that it is self-copying. Astronomical numbers of individual bacteria (and/or bacterial spores) can be safely and inexpensively produced by fermentation of one or more "parent" cells in an appropriate medium (nutrient broth). Because their production is safe and cheap, bacteria can conveniently be sent to numerous possible destinations.

The graphic *"Venus"* icon drafted for the *Microvenus* project was inspired by some of the oldest messages Homo sapiens have left for themselves (i.e., ten- to fifty-thousand-year-old "Venus figurines") and partly by episodes of censorship that are now historically associated with "scientific" attempts to create messages for extraterrestrial intelligence.[10] Ironically, the human body is more comprehensively represented in ancient stone and terra-cotta *"Venus"* objects than in scientifically prepared messages that were rocketed into space.

Certain features of human surface anatomy were intentionally omitted from message plaques and records now moving away from the solar system with NASA's *Pioneer (fig. 5)* and *Voyager* probes. Drawings of two nude human figures accompanied various other notation lofted into space with *Pioneer* instrument packages. The figures are fashionably "groomed" and so, according to the Western "taste," completely disregard the existence of facial and body hair and the female, but not the male, genitalia. In my personal communication with Drake, I learned that NASA later entirely prohibited representations of nude human figures (of both sexes) on circular message plaques launched with the *Voyager* probes.

The two *Voyagers* carried additional visual (video) information coded into part of the content of audio records that were sent along as part of the message. In this highly

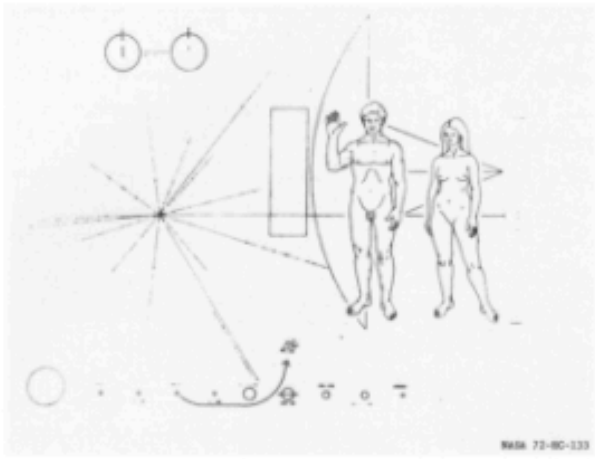


FIG. 5 Pioneer F Plaque, destined to be the first man-made object to escape from the solar system into interstellar space. The plaque is designed to communicate with intelligent inhabitants of another solar system. Courtesy NASA.

coded form, textbook illustrations of the human anatomy were originally included in the *Voyager* message package. Unfortunately, these images were also deleted (censored) before launch. It seems that an important part of the messages humans have created for extraterrestrial intelligence has described the facts of human intolerance, an entirely appropriate though possibly inadvertent description of human beings. The *Microvenus* was created because the graphic it depicts was omitted from previous messages (the female genitalia) and because this omission is generally not recognized in contemporary accounts of so-called CETI (Communications with Extraterrestrial Intelligence) experiments.

Any message to extraterrestrial intelligence is about Homo sapiens. Whoever discovers and interprets such a message correctly will need similar abilities to read and write language, a scientific attitude toward nature, and sight for visual messages. By sending messages to extraterrestrial intelligence, human beings are importantly engaged in a search for themselves. They must first reveal themselves to themselves before they can reveal themselves to anyone else. This has not only been a central dilemma in the search for extraterrestrial intelligence, but it has also been an essential element of art, history, psychology, and classical philosophy.

With horticulture and animal husbandry, human beings have historically transplanted "aesthetically pleasing" genes into the progeny of many different kinds of plants and animals and derived an improved *quality of life*. Collateral aesthetic and technical knowledge in genetics and reproductive biology is also reflected in various romantic concepts about beauty and nature that have been securely attached to the scientific discussion of living things. In his only recently published notebooks, we find that Charles Darwin speculated as to why a flower should seem pretty to us.[11] Perhaps Darwin realized that a complete description of any natural phenomenon must include many different points of view. These include composition of a body; the chemical activity and shapes of its individual molecules; its biological or mineral forms; its adaptations, habitats, and environments; and its social behavior.

Microvenus thus looks in two directions: outward to an unexplored cosmos and inward to the self and human nature. Aristotle called such understanding the principal of *recognition and reversal*.[12] Recognition (or *anagnorisis* in Aristotle's theory of tragedy) of a message for extraterrestrials implies a reversal to retransmit the signal to human beings. The tragedy of *recognition and reversal* is that the loneliness implied by the search is perpetuated by the futility of attempting to communicate with anything ultimately *other* (including, unfortunately, other human beings). Yet far from being a reason to refrain from creating and sending such messages, serious efforts to contact extraterrestrials will necessarily raise the questions of what we know and who we are and confirm the need to continue the search. ■

Notes

1. Jack Burnham, *Beyond Modern Sculpture: The Effects of Science and Technology on the Sculpture of This Century* (New York: Charles Braziller, 1970), 376.

2. *E. coli*, in many respects a typical bacterium, is normally a cylindrical object measuring about 2μm (2×10^{-4} cm) in length, and 1μm in diameter, with a wet weight of approximately 10^{-12} g and an approximate dry weight of 10^{-13} g.

3. In its most frequently occurring molecular conformation (B-DNA), the base stacking distance of the DNA molecule (the length of molecule occupied by one base, if single stranded, or two bases if double stranded) is about 3.4 angstroms (10^{-8} cm) and the molecular diameter is 20 angstroms.

4. J. Sambrook, E. F. Fritsch, and T. Maniatis, *Molecular Cloning: A Laboratory Manual*, 2d ed. (New York: Cold Spring Harbor, 1969).

5. G. Horneck, "Survival of Microorganisms in Space: A Review," *Advanced Space Research* 1 (1981): 39–48; P. R. Lorenz, "Survival of Microorganisms in Space," *Space Life Sciences* 1 (1968): 118–30; G. Horneck et al., "Microorganisms in the Space Environment," *Science* 225, no. 4,658 (July 13, 1984): 226–28.

6. G. Horneck et al., "Cell Inactivation, Repair and Mutation Induction in Bacteria after Heavy Ion Exposure: Results from Experiments at Accelerators and in Space," *Advanced Space Research* 9, no. 10 (1989): 105–16; and A. A. Imshenetsky, "Biological Effects of Extreme Environmental Conditions"; translated from *Biologicheskiye Effekty Ekstremal'ykh Usloviy Okrukhayushchey Sredy*, vol. 1, pt. 3 (Moscow: Academy of Sciences USSR, 1973).

7. Carl Sagan and Frank Drake, "The Search for Extraterrestrial Intelligence," *Scientific American* 232, no. 5 (May 1975): 80–89; Donald Goldsmith and Donald Owen, *The Search for Life in the Universe* (Menlo Park, Calif.: Benjamin/Cummings, 1980).

8. V. V. Antipov, "Biological Studies aboard the Spacecraft *Vostok* and *Voskhod*," in N. M. Siskyan, ed., *Problems of Space Biology*, vol. 6 (Moscow: Nauka Press, 1967), 67–83; A. C. Schuerger, B. L. Norman, J. A. Angelo, Jr., "Survival of Epiphytic Bacteria from Seed Stored on the Long Duration Exposure Facility (LDEF)," *LDEF 69 Months in Space: First Post-Retrieval Symposium Proceedings* (Washington, D.C.: NASA, 1991), 1,637–38; and A. A. Imshenetsky et al., *Life Sciences and Space Research* 14 (1975): 359.

9. Arthur Koenberg, *Replication* (San Francisco: W. H. Freeman, 1980).

10. Paul Watzlawick, *How Real Is Real? Confusion, Disinformation, Communication* (New York: Random House, 1976).

11. P. H. Barrett and P. J. Gautrey, eds., *Charles Darwin's Notebooks 1836–1844* (Cambridge: Cambridge University Press, 1987).

12. S. H. Butcher, *Aristotle's Theory of Poetics and Fine Art: With a Critical Text and Translation of the Poetics*, 4th ed. (London: MacMillan, 1911).

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