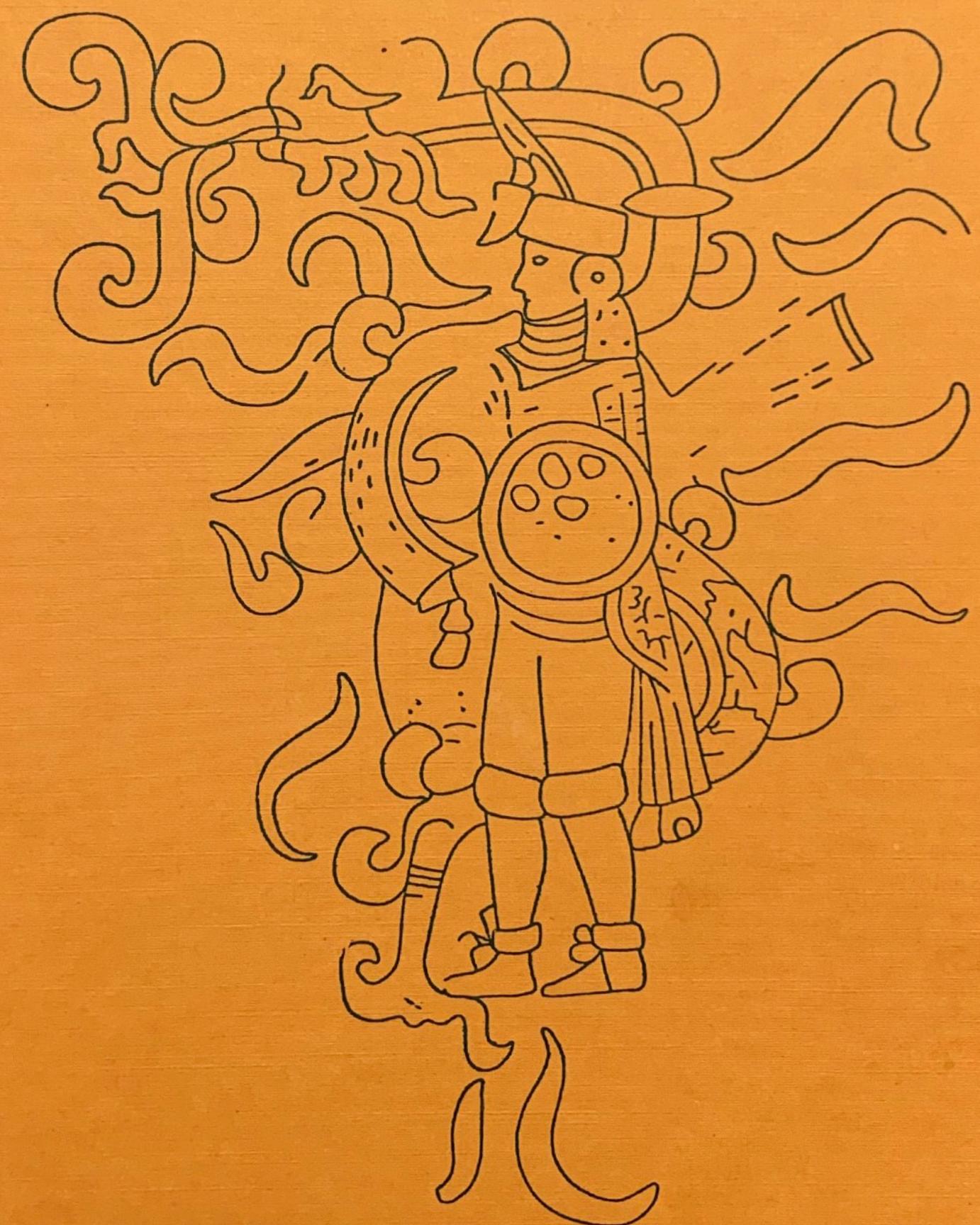




I. VISIBLE LANGUAGE

VISIBLE LANGUAGE

The research journal concerned with all that is involved in our being literate
Volume XVI Number 1 Winter 1982



Merald E. Wrolstad, Ph.D., Editor and Publisher
P.O. Box 1972 CMA, Cleveland, OH 44106

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The covers show details from Mesoamerican paintings on the Temple of the Jaguars at Chichen Itza with representations of a cloud serpent. They are believed to be the name glyphs of the Toltec rulers, Quetzalcoatl and Mixcoatl. See David Kelley's article beginning on page 39.

2 *Visible Language* XVI 1 1982

The Concept of a Meta-Font

Donald E. Knuth

A single drawing of a single letter reveals only a small part of what was in the designer's mind when that letter was drawn. But when precise instructions are given about how to make such a drawing, the intelligence of that letter can be captured in a way that permits us to obtain an infinite variety of related letters from the same specification. Instead of merely describing a single letter, such instructions explain how that letter would change its shape if other parameters of the design were changed. Thus an entire font of letters and other symbols can be specified so that each character adapts itself to varying conditions in an appropriate way. Initial experiments with a precise language for pen motions suggest strongly that the font designer of the future should not simply design isolated alphabets; the challenge will be to explain exactly how each design should adapt itself gracefully to a wide range of changes in the specification. This paper gives examples of a meta-font and explains the changeable parameters in its design.

Some of Aristotle's philosophical writings were called *Metaphysics*, because they came after his *Physics*, in the conventional arrangement of his works. By the twentieth century, most people had forgotten the original meaning of Greek prefixes, so that 'meta-' was assumed to add a transcendent character to whatever it qualified. We now have metapsychology (the study of how the mind relates to its containing body), metamathematics (the study of mathematical reasoning), and metalinguistics (the study of how language relates to culture); a metamathematician proves metatheorems (theorems about theorems), and a computer scientist often works with metalanguages (languages for describing languages). Newly coined words beginning with 'meta-' generally reflect our contemporary inclination to view things from outside, at

3 Knuth / Concept of a Meta-Font

Visible Language, XVI 1 (Winter 1982), 3-27.
Author's address: Department of Computer Science, Stanford University, Stanford CA 94305.
0022-2224/82/0001-0003\$02.00/0 © 1982 Visible Language, Box 1972 CMA, Cleveland OH 44106.

VISIBLE LANGUAGE Volume XVI Number 4 Autumn 1982



Editor's note

Visible Language has a long history of special interest in computer-assisted design of letterforms. A few months after the first issue appeared in January 1967 I walked across the street from my office to the Department of Computer Science at Case Western Reserve University to see if I could arouse any interest in research on the design of typefaces. Graduate student Paul Vargo was indeed interested and under the direction of his faculty advisor, Harry Mergler, produced as his doctoral dissertation the first computer system for parametric letter design. The results were published in this journal (then *The Journal of Typographic Research*) the following year. It was an introductory study and handicapped by equipment limitations of the mid-1960s. In essence, it was an idea whose time had not yet come.

Fourteen years later — in early 1981 — I walked across the street again to meet and talk with Donald Knuth about Meta-Font. By coincidence, Knuth is an alumnus of Case Western Reserve University but was graduated years before Paul Vargo and unaware of his research. I suggested to Knuth that when he was ready to present his ideas to the graphic design audience, he should use the pages of *Visible Language*. He agreed, and "The Concept of a Meta-Font" was published earlier this year.

It occurred to the editors that it might be valuable to follow-up publication with a survey of those most knowledgeable and most experienced in type font generation, asking for reactions and ideas on the meta-font concept and/or on computer-assisted letter design in general.

The article/response by Douglas R. Hofstadter which begins on the opposite page is followed by letters from type designers, graphic designers, and others in the graphic arts field — with a final response from Donald Knuth. The editors thank all of the respondents for their thoughtful replies. The lack of consensus at this stage of developing the meta-font concept is most heartening!

A few copies of the issues containing Knuth's article (Winter 1982) and the Mergler/Vargo article (Autumn 1968) are still available. To order, see the previous page.

M.E.W.

Metafont, Metamathematics, and Metaphysics

Comments on Donald Knuth's Article
"The Concept of a Meta-Font"

Douglas R. Hofstadter

It is argued that readers are likely to carry away from Donald Knuth's article "The Concept of a Meta-Font" a falsely optimistic view of the extent to which the design of typefaces and letterforms can be mechanized through an approach depending on describing letterforms by specifying the settings of a large number of parameters. Through a comparison to mathematical logic, it is argued that no such set of parameters can capture the essence of any semantic category. Some different ways of thinking about the problem of the "spirit" residing behind any letterform are suggested, connecting to current research issues in the field of artificial intelligence.

The "Mathematization of Categories" and Metamathematics

Donald Knuth has spent the past several years working on a system allowing him to control many aspects of the design of his forthcoming books — from the typesetting and layout down to the very shapes of the letters! Never has an author had anything remotely like this power to control the final appearance of his or her work. Knuth's TEX typesetting system has become well-known and available in many countries around the world. By contrast, his Metafont system for designing families of typefaces has not become as well known or as available.

In his article "The Concept of a Meta-font" [Knuth 82], Knuth sets forth for the first time the underlying philosophy of Metafont, as well as some of its products. Not only is the concept exciting and clearly well executed, but in my opinion the article is charmingly written as well. However, despite my overall enthusiasm for Knuth's idea and article, there are some points in it that I feel might be taken wrongly by many readers, and since they are points that touch close to my deepest interests in artificial intelligence and esthetic theory, I felt compelled to make some comments to clarify certain important issues raised by "The Concept of a Meta-font".

Although his article is primarily about letterforms, not philosophy, Knuth holds out in it a philosophically tantalizing prospect for us: that with the arrival of computers, we can now approach the vision of a unification of all typefaces. This can be broken down into two ideas: (1) that underneath all "A"s there is just one grand, ultimate abstraction

visible
language

Volume XVII Number 4 Autumn 1983

The quarterly concerned with all that is involved in our being literate

Is Roman Type an Open-Ended System? A Response to Douglas Hofstadter

I believe that Douglas Hofstadter (1982) is unfair in his critique of Donald Knuth's "metafont" article (Knuth 1982). I do not dispute Hofstadter's view that the production of new examples of semantic categories such as "chair" or "waltz" is often a creative act, in a sense which implies that the extension of such categories is not recursively enumerable. This is a point of view which I have often (e.g., Sampson 1979, ch. 3) been at pains to argue myself. (It seems unhelpful to invoke Gödel's theorem in this connexion; the issue is not primarily a mathematical one, and Wittgenstein's analysis of the word *game* in the *Philosophical Investigations* [Wittgenstein 1953, §66ff.] is surely a clearer and more persuasive statement of the case than any discussion in terms of formal logic. But that is by the way.) Even if we accept the existence of many non-enumerable categories, though, we must surely accept that there are also many categories which are rigorously enumerable; for instance the class of *colours* has infinitely many members (because wavelength, saturation, and so on, are continuous variables), but all those members are located within a logical space which has fixed boundaries that depend on the physiology of human vision and the properties of light—no one will ever be able to create a new range of colours different in kind from the ones we know already. Human life involves both open-ended categories and closed categories, and in many cases it is very hard to say whether a given intuitively-familiar category is open-ended or closed. Is the category "sentence of the English language" closed or open-ended? Academic linguists have different views on the question. Hofstadter writes as if Knuth assumes an obviously open-ended category to be closed; but I cannot see that Hofstadter has demonstrated this.

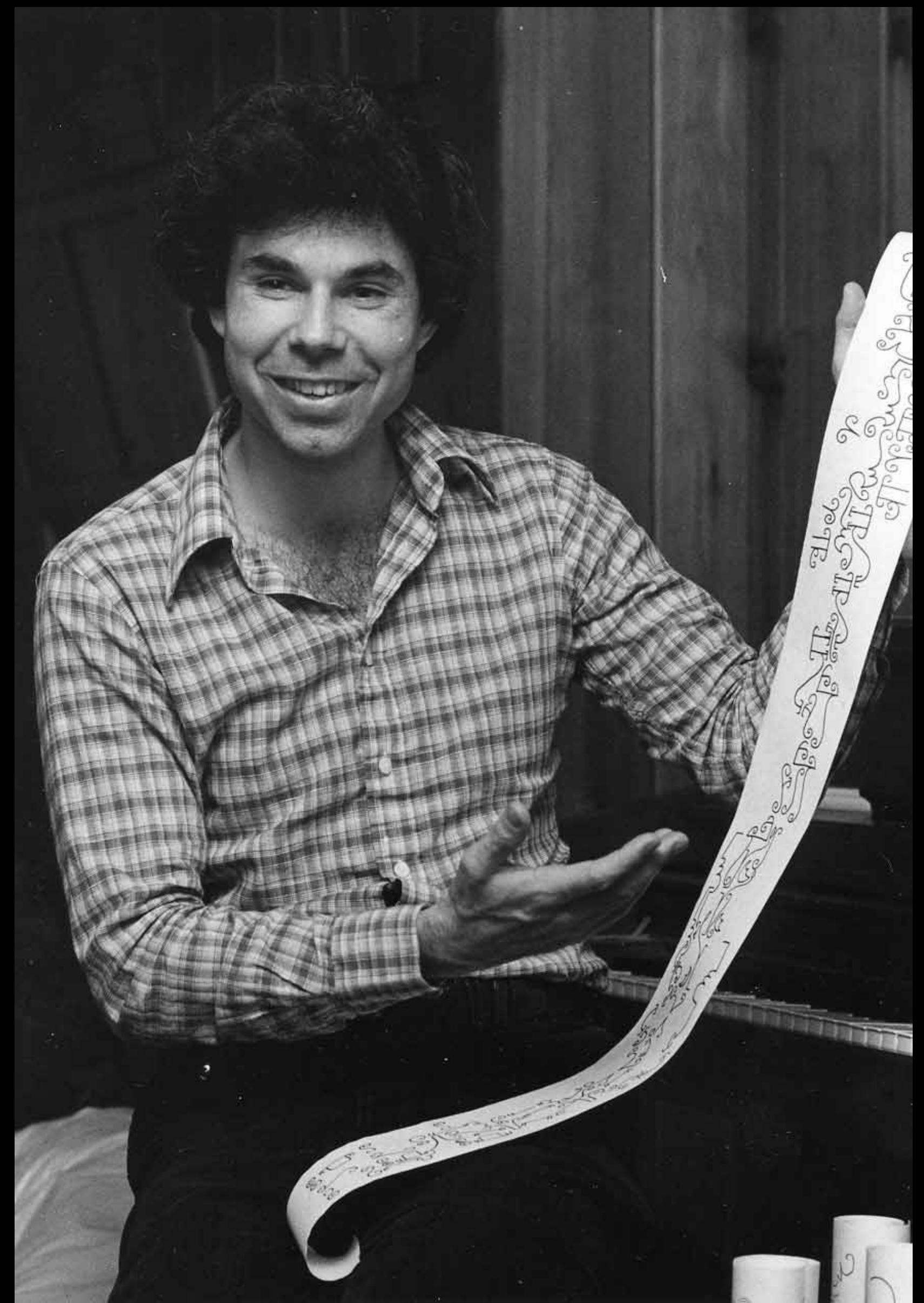
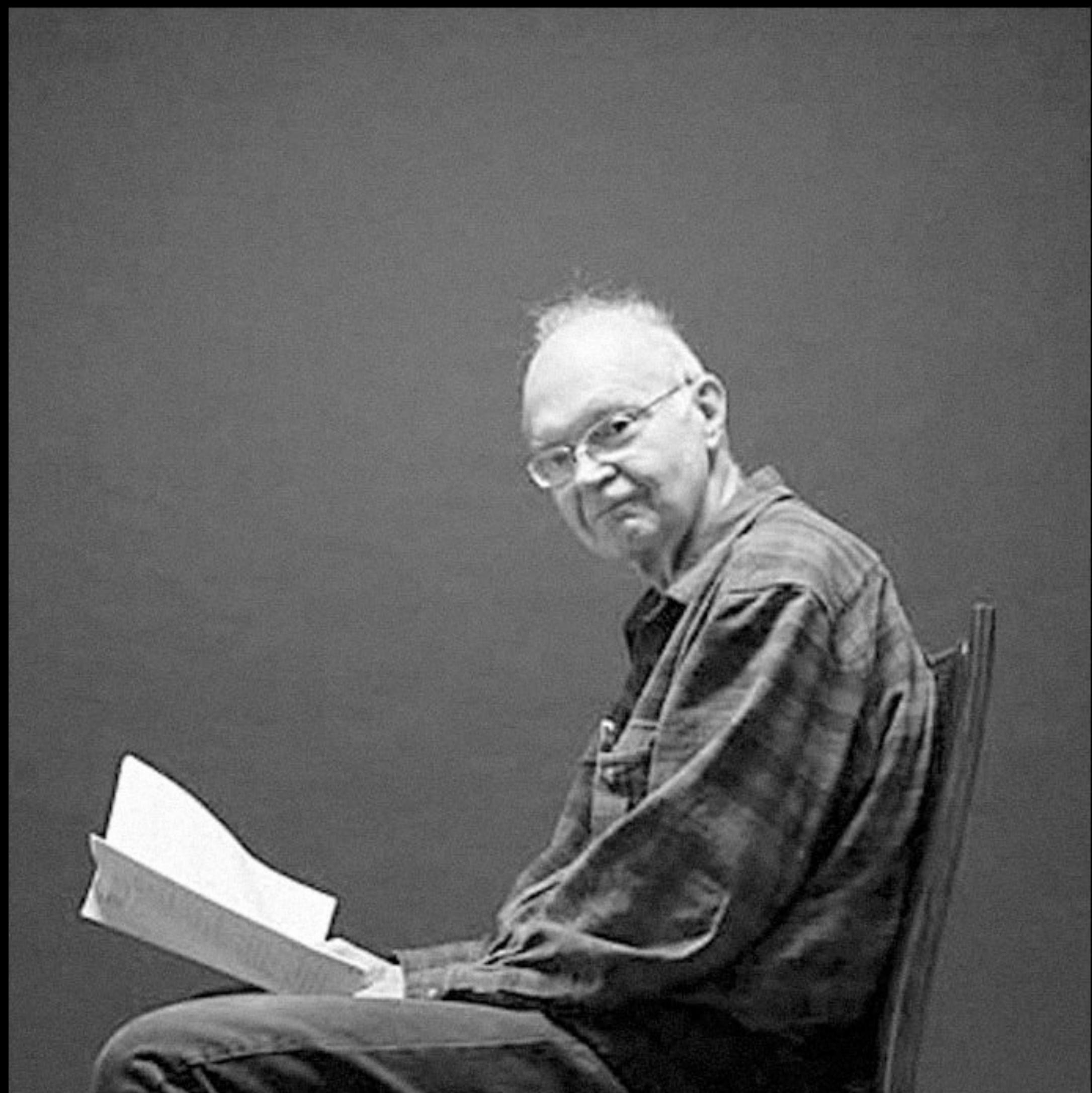
The kernel of Hofstadter's critique relates to Knuth's throwaway remark about a hypothetical font that is "one fourth of the way between Baskerville and Helvetica." According to Hofstadter, Knuth's belief that this concept sense commits Knuth to the idea that one could in principle define a "meta-a finite set of typographical variables which generates all actual Roman-al fonts (in the sense that any such font would correspond to some particular choice of value for each variable) and none that is not a Roman font." Hofstadter suggests the implausibility of this claim by illustrating a very dive of upper-case A's (his Figure 1).

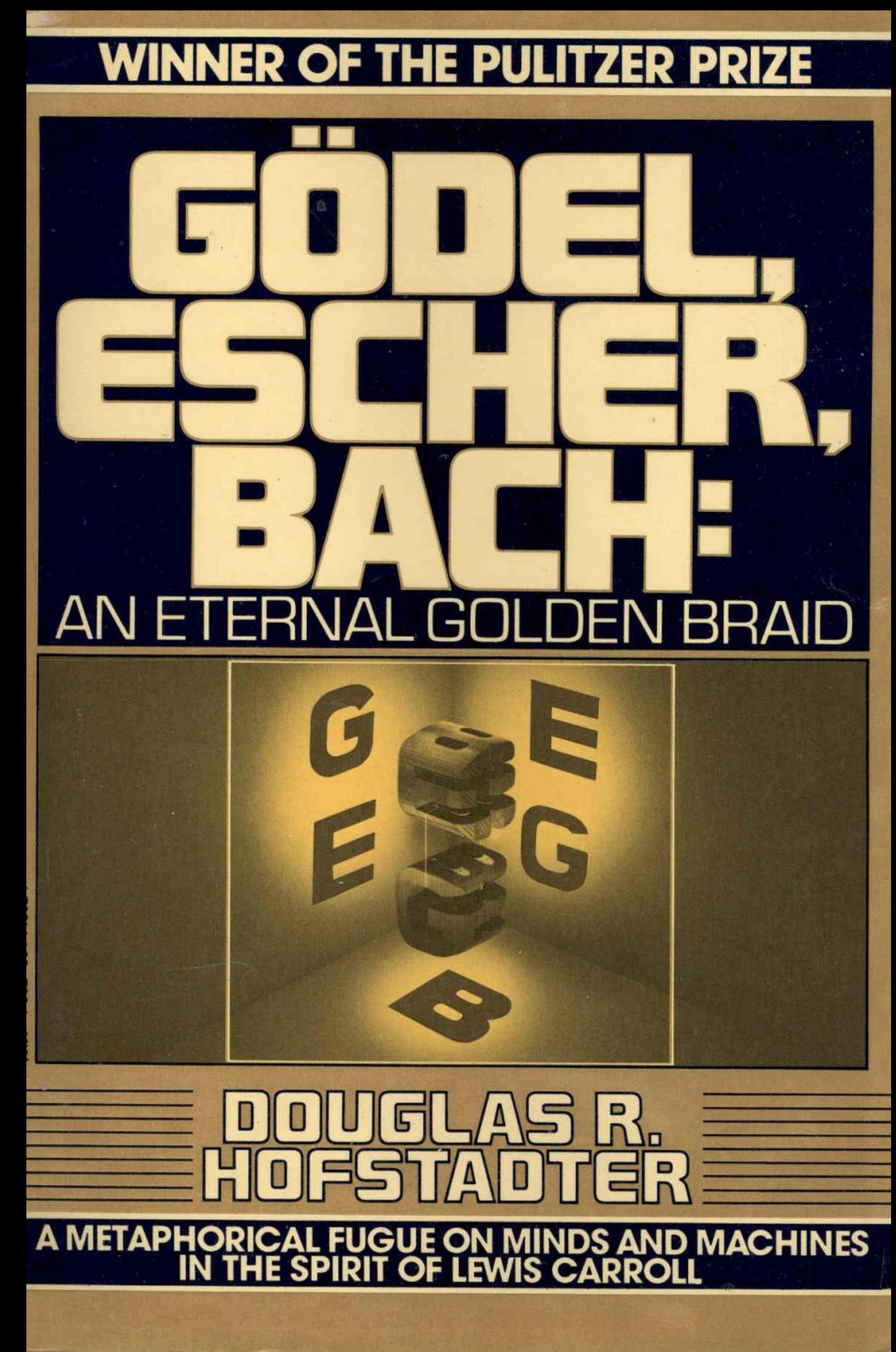
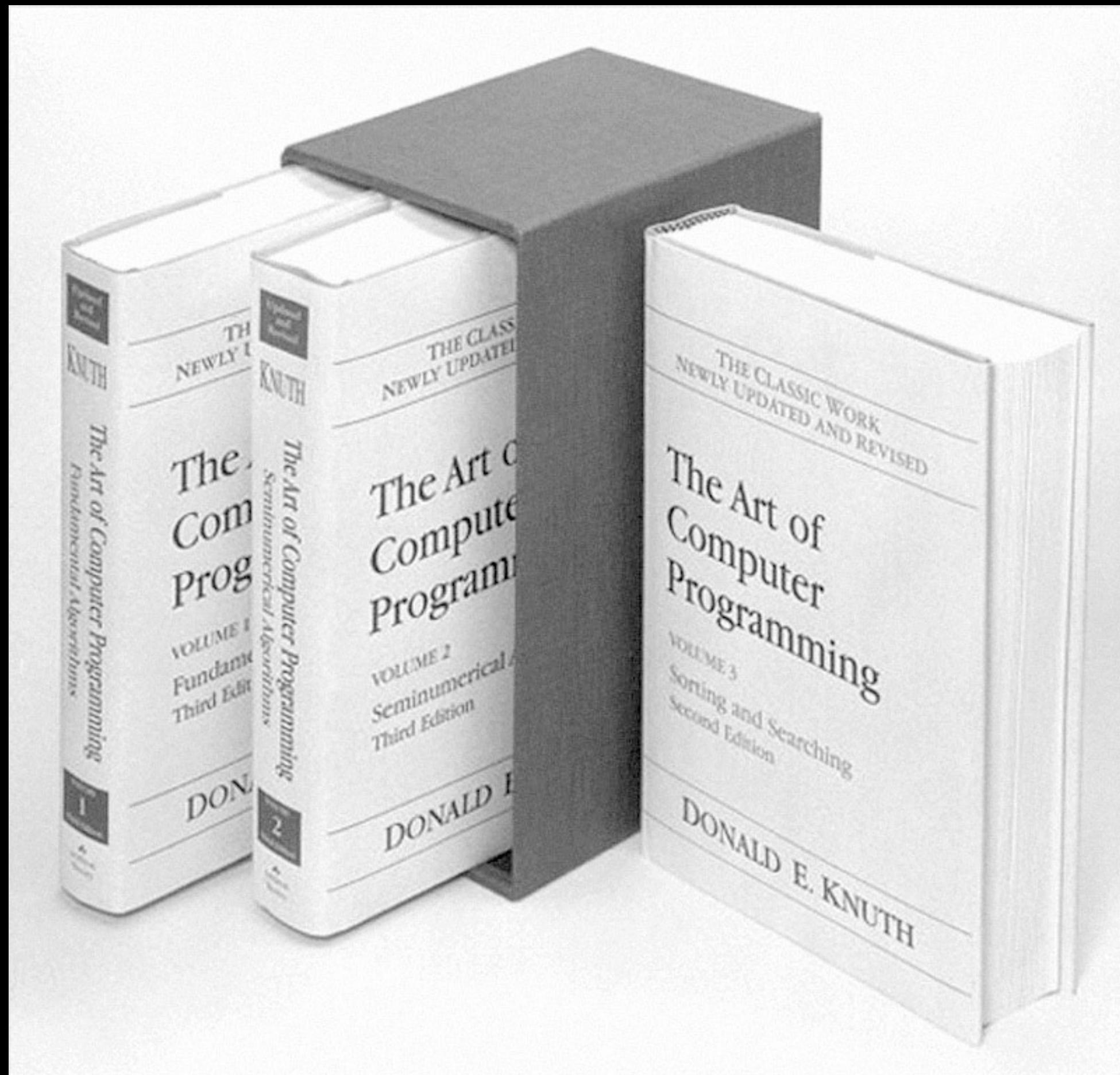
But, although Knuth's remark was so throwaway, in the context of what he says elsewhere in his article, it seems unreasonable of Hofstadter to lay so much stress on it, it would seem to me, as a reason for regarding Knuth's article as indefensible as Hofstadter makes it.

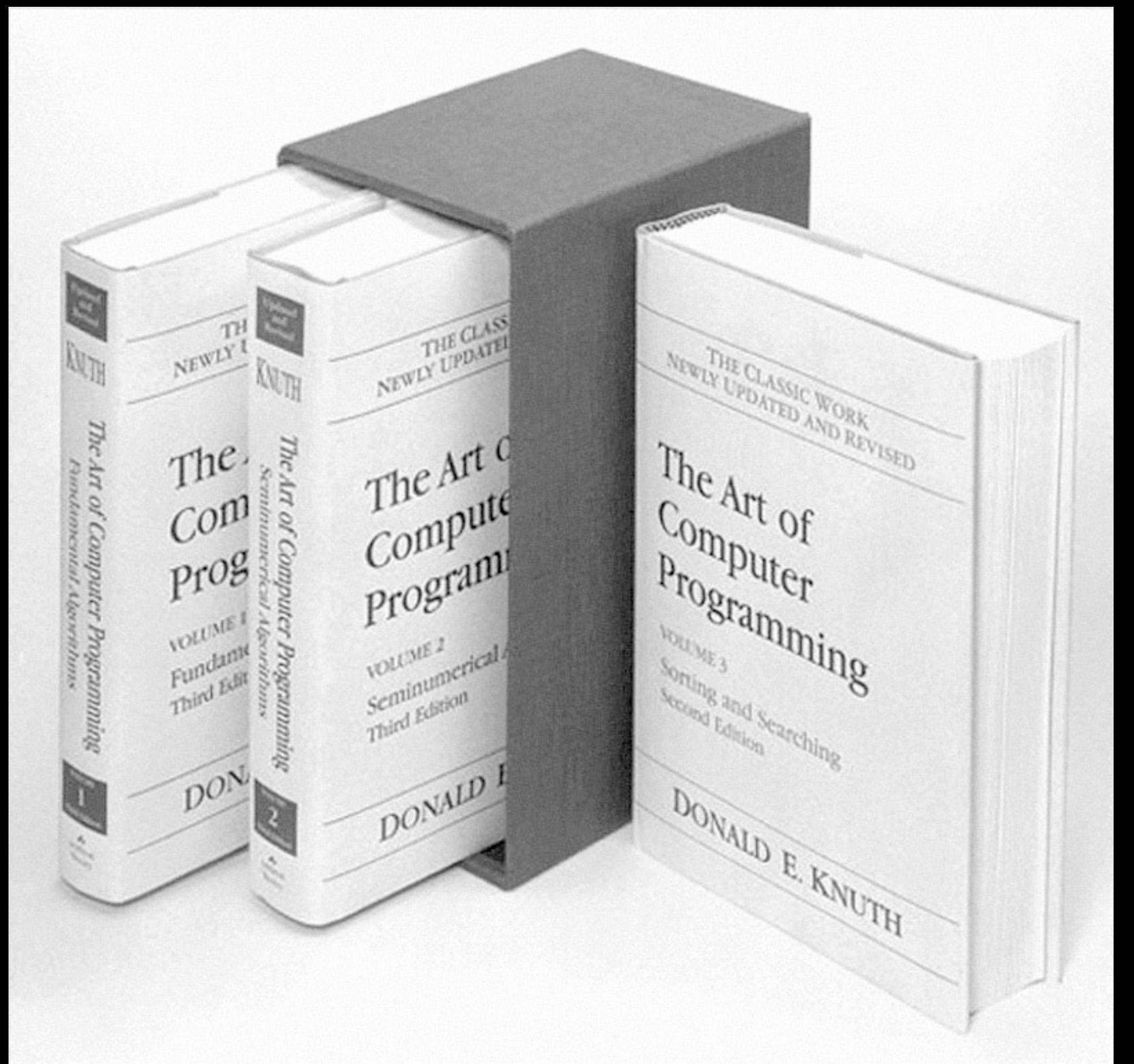
both book faces, rather than faces designed exclusively for display. On the other hand, the 56 As of Hofstadter's Figure 1 are all drawn from display faces. (Old English, E2 in Figure 1, has not been used as a book face for several centuries, and arguably is as distinct from the Roman alphabet in the normal sense as the Greek alphabet is—we do not classify it as a separate alphabet because we use it to write our own language.) It is much less obvious that the class of book faces is open-ended than that the class of display faces is.

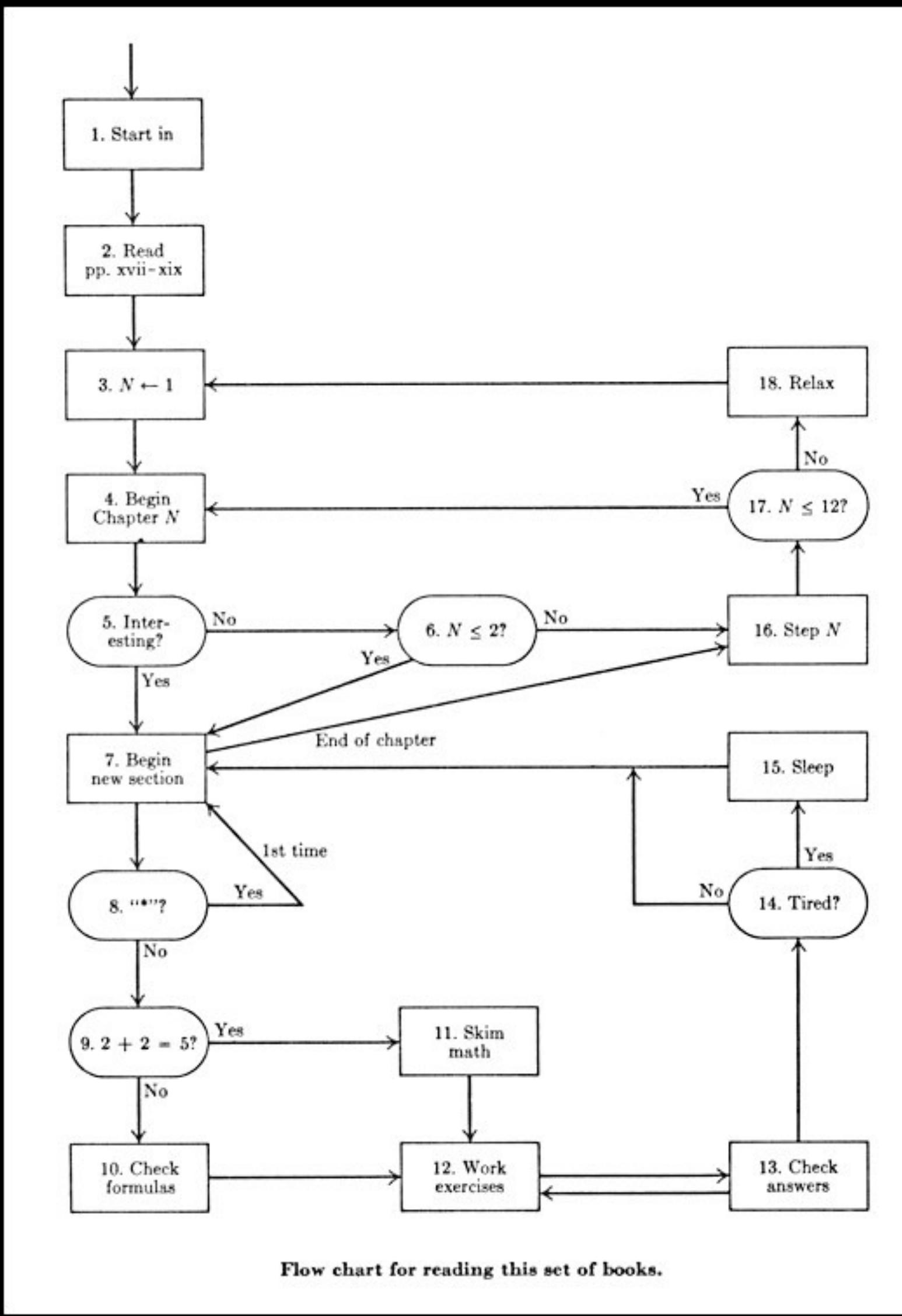
In the design of a display face the aim of instantiating the various Roman letters is often subordinate to the aim of creating a particular visual effect. Sometimes the designer goes so far to achieve the second aim that he fails to achieve the first. When a concept is open-ended, there will often be room for doubt about whether a given marginal instance falls within its extension or not (that is why, in the law, we have the institution of "test cases" as a mechanism for reaching society-wide agreement about whether given actions fall inside or outside the open-ended category of "illegal acts"). Hofstadter says that a metafont would need to generate all the letter-shapes in his Figure 1; but I believe that some of them are not in fact examples of the letter A. I would make that claim for D5, which is one of the variants offered for A in Cathedral; for E8, which I have not succeeded in identifying; and, less confidently, for C4 (Block Up) and A8 (Stop). Just as, being a native speaker of English, I judge that the poet E.E. Cummings's line *Anyone lived in a little how town* is not an English sentence (whatever other virtues it may have), so, as a "native reader" of the Roman alphabet, I judge that the shape D5 is not a letter A. An inscription in letters all of which were as distorted as D5 could not be read by an otherwise competent reader, unless he learned the distorted letters as one can learn the Greek or Hebrew alphabet. (Most of the other letter-shapes in Cathedral are relatively standard, so in practice D5 would be understood from context.)

The problem of designing a metafont to generate all and only the possible Roman letters might not have to cope with everything in Hofstadter's Figure 1, even if it is intended display as well as book faces. Still, I guess that the range of letters generated would in fact be broader than needed even if pathological items like D5 and E8 were excluded. But if we take the range of letters asked to book faces (which are the only ones mentioned by Knuth), the open-endedness of the range really does become questionable. In his note to page 323 (Knuth 1982, n. 323) denies that this restriction affects his metafont, saying that "more complex characters . . . [o]ne simply has to look at a finer level of detail, and all the same old issues reappear." Do they? The only argument Knuth gives for this is the difficulty of "parametrizing" the contrast between the dots of Baskerville i, j and the square dots in Helvetica, and the contrast between the forms of Q in the two faces. But Hofstadter concedes that it is not "impossible" to imagine that these problems could be solved. Furthermore, it seems to me that there are a number of such points, where two faces differ with respect to the shape of an individual letter in a way that appears not to be









482 *Digital Typography*

first time. That experience changed my life. Already on February 8 I began to talk to colleagues about the possibilities of using such machines to typeset my own books.

My diary of 1977 says nothing more about typographic matters until March 30; on that day, however, the die was cast.

30 Mar: Galley proofs for vol. 2 finally arrive, they look awful... I decide I have to solve the problem myself. *typographically*
Seder supper at church, is a bright spot in dull week.

I had to devote the month of April to finishing the other projects I had started. But by the beginning of May I had decided to create a program called 'TEX', and I was gearing up to embark on a new adventure.

2 May: Section 7.1 finished tonight at 1:00 a.m. — Hurray!

3 May: To San Jose with Jill, looking at church records from towns near Heidelberg, figuring out old German handwriting

BULLETIN (New Series) OF THE
AMERICAN MATHEMATICAL SOCIETY
Volume 1, Number 2, March 1979

MATHEMATICAL TYPOGRAPHY

BY DONALD E. KNUTH

Dedicated to George Pólya on his 90th birthday

ABSTRACT. Mathematics books and journals do not look as beautiful as they used to. It is not that their mathematical content is unsatisfactory, rather that the old and well-developed traditions of typesetting have become too expensive. Fortunately, it now appears that mathematics itself can be used to solve this problem.

A first step in the solution is to devise a method for unambiguously specifying mathematical manuscripts in such a way that they can easily be manipulated by machines. Such languages, when properly designed, can be learned quickly by authors and their typists, yet manuscripts in this form will lead directly to high quality plates for the printer with little or no human intervention.

A second step in the solution makes use of classical mathematics to design the shapes of the letters and symbols themselves. It is possible to give a rigorous definition of the exact shape of the letter "a", for example, in such a way that infinitely many styles (bold, extended, sans-serif, italic, etc.) are obtained from a single definition by changing only a few parameters. When the same is done for the other letters and symbols, we obtain a mathematical definition of type fonts, a definition that can be used on all machines both now and in the future. The main significance of this approach is that new symbols can readily be added in such a way that they are automatically consistent with the old ones.

Of course it is necessary that the mathematically-defined letters be beautiful according to traditional notions of aesthetics. Given a sequence of points in the plane, what is the most pleasing curve that connects them? This question leads to interesting mathematics, and one solution based on a novel family of spline curves has produced excellent fonts of type in the author's preliminary experiments. We may conclude that a mathematical approach to the design of alphabets does not eliminate the artists who have been doing the job for so many years; on the contrary, it gives them an exciting new medium to work with.

I will be speaking today about work in progress, instead of completed research; this was not my original intention when I chose the subject of this lecture, but the fact is I couldn't get my computer programs working in time. Fortunately it is just as well that I don't have a finished product to describe to you today, because research in mathematics is generally much more interesting while you're doing it than after it's all done. I will try therefore to convey

Josiah Willard Gibbs Lecture, given under the auspices of the American Mathematical Society, January 4, 1978; received by the editors February 10, 1978.

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TEx

An Example Document

Leslie Lamport

January 21, 1994

This is an example input file. Comparing it with the output it generates can show you how to produce a simple document of your own.

1 Ordinary Text

The ends of words and sentences are marked by spaces. It doesn't matter how many spaces you type; one is as good as 100. The end of a line counts as a space.

One or more blank lines denote the end of a paragraph.

Since any number of consecutive spaces are treated like a single one, the formatting of the input file makes no difference to L^AT_EX, but it makes a difference to you. When you use L^AT_EX, making your input file as easy to read as possible will be a great help as you write your document and when you change it. This sample file shows how you can add comments to your own input file.

Because printing is different from typewriting, there are a number of things that you have to do differently when preparing an input file than if you were just typing the document directly. Quotation marks like "this" have to be handled specially, as do quotes within quotes: "this' is what I just wrote, not 'that'".

Footnotes¹ pose no problem.

L^AT_EX is good at typesetting mathematical formulas like $x - 3y + z = 7$ or $a_1 > x^{2n} + y^{2n} > x'$ or $(A, B) = \sum_i a_i b_i$. The spaces you type in a formula are ignored. Remember that a letter like x is a formula when it denotes a mathematical symbol, and it should be typed as one.

Mathematical formulas may also be displayed. A displayed formula is one-line long; multiline formulas require special formatting instructions.

$$(\Gamma, \psi') = x'' + y^2 + z_i^n$$

Don't start a paragraph with a displayed equation, nor make one a paragraph by itself.

Dashes come in three sizes: an intra-word dash, a medium dash for number ranges like 1-2, and a punctuation dash—like this.

¹This is an example of a footnote.

```
% This is a sample LaTeX input file. (Version of 12 August 2004.)  
%  
% A '%' character causes TeX to ignore all remaining text on the line,  
% and is used for comments like this one.  
  
\documentclass{article}          % Specifies the document class  
  
\title{An Example Document}      % The preamble begins here.  
\author{Leslie Lamport}           % Declares the document's title.  
\date{January 21, 1994}           % Declares the author's name.  
                                  % Deleting this command produces today's date.  
  
\newcommand{\ip}[2]{(#1, #2)}      % Defines \ip{arg1}{arg2} to mean  
                                  % (arg1, arg2).  
  
%\newcommand{\ip}[2]{\langle #1 | #2\rangle}    % This is an alternative definition of  
                                              % \ip that is commented out.  
  
\begin{document}                  % End of preamble and beginning of text.  
  
\maketitle                      % Produces the title.  
  
This is an example input file. Comparing it with  
the output it generates can show you how to  
produce a simple document of your own.  
  
\section{Ordinary Text}          % Produces section heading. Lower-level  
                                  % sections are begun with similar  
                                  % \subsection and \subsubsection commands.  
  
The ends of words and sentences are marked  
by spaces. It doesn't matter how many  
spaces you type; one is as good as 100. The  
end of a line counts as a space.  
  
One or more blank lines denote the end  
of a paragraph.  
  
Since any number of consecutive spaces are treated  
like a single one, the formatting of the input  
file makes no difference to  
  \LaTeX,                                     % The \LaTeX command generates the LaTeX logo.  
but it makes a difference to you. When you use  
\LaTeX, making your input file as easy to read  
as possible will be a great help as you write  
your document and when you change it. This sample  
file shows how you can add comments to your own input  
file.  
  
Because printing is different from typewriting,  
there are a number of things that you have to do  
differently when preparing an input file than if  
you were just typing the document directly.  
Quotation marks like  
  ``this''  
have to be handled specially, as do quotes within  
quotes:  
  ``\,``this''                                % \, separates the double and single quote.  
                                              % is what I just  
                                              % wrote, not `that'\,''.  
                                              %
```

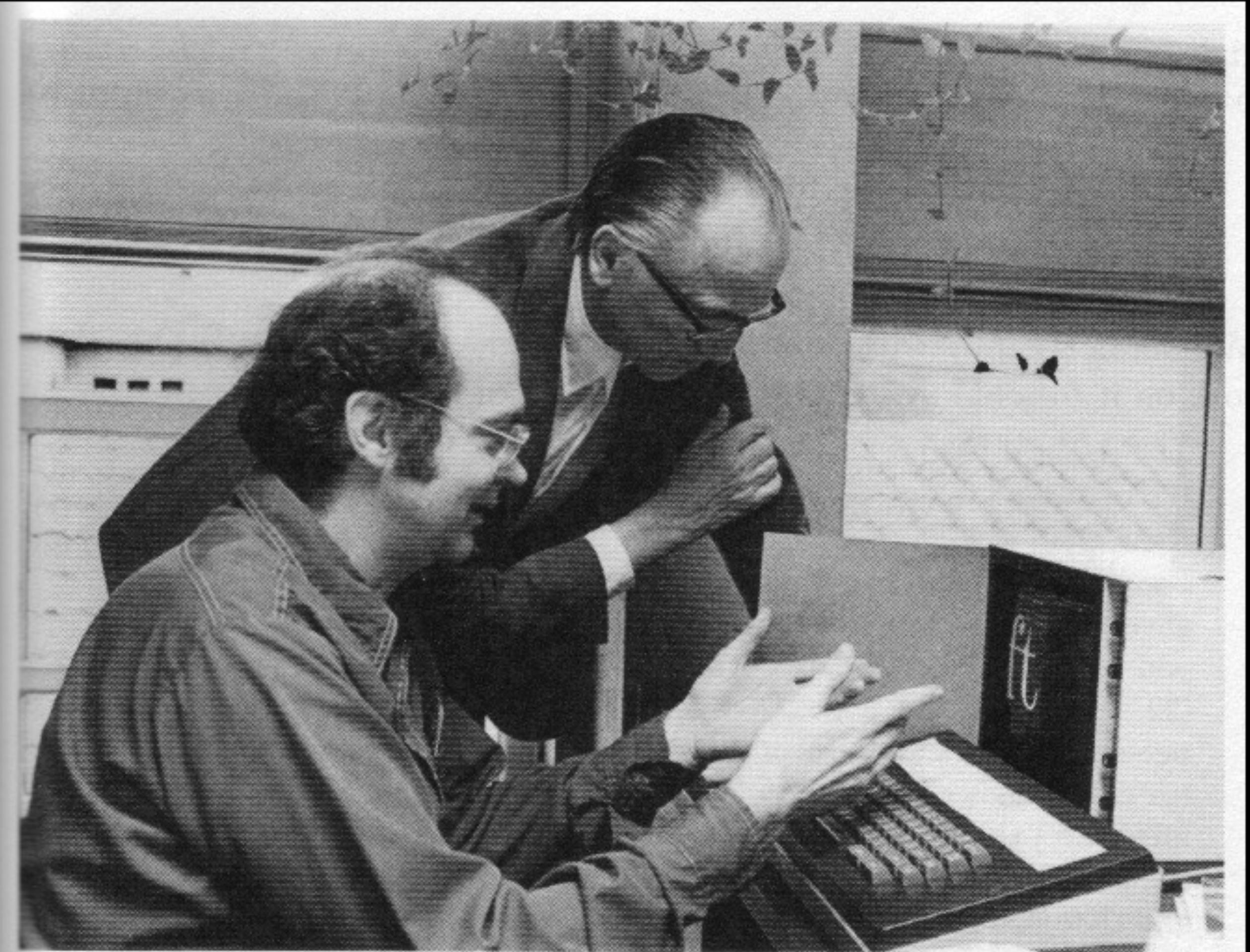
$$\left(1 - \frac{1}{9}\right) \cdots \left(1 - \frac{1}{n^2}\right) \left(1 - \frac{1}{(n+1)^2}\right) = \frac{n+2}{2n+x}$$

The calculation holds for $n = 2$ and for $n = k + 4$.
Therefor it holds for $n \geq 2$. Q.E.D.

If you have that

$$\prod_{n=2}^{\infty} \left(1 - \frac{1}{n^2}\right) = \frac{1}{2}$$

METAFONT

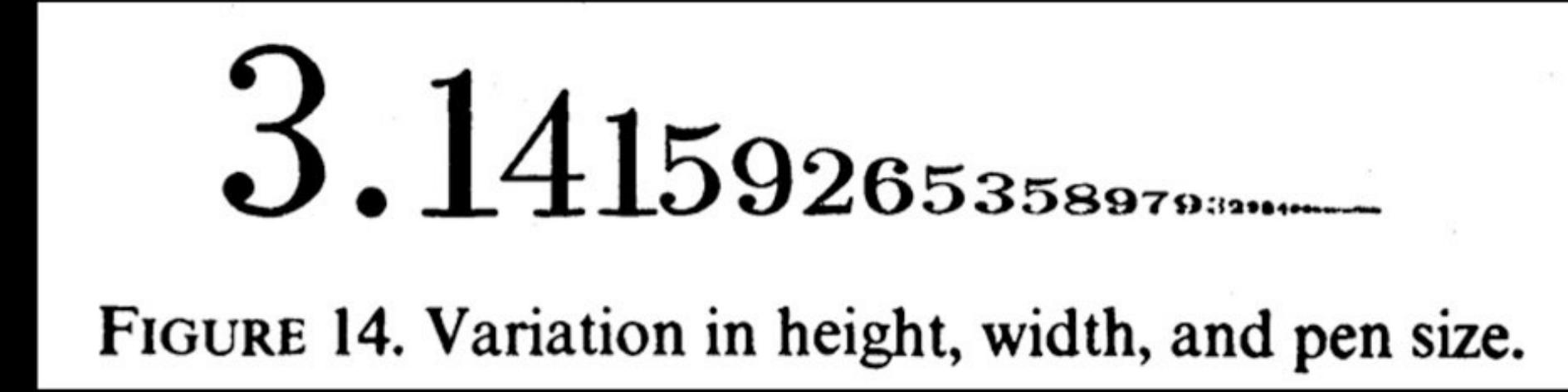


The first collaboration between DEK (seated) and HZ (standing), 14 February 1980. [Stanford News Service photo by Chuck Painter.]



0123456789

FIGURE 9. Digits 0 to 9 drawn by the prototype METAFONT programs.
(Further refinements to these characters will be made before the font has its final form.)



3.1415926535897932384626433832795028841971693993751058286095505118574427466143734343494412841972749258309029101573830351902799726614638915735940309533183011129012874713321691661804593518165873563053429721049338874498045133411473216070403

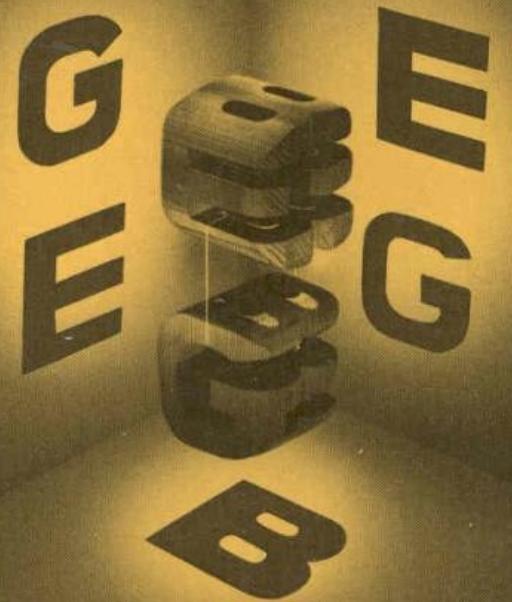
FIGURE 14. Variation in height, width, and pen size.

Computer
Modern

WINNER OF THE PULITZER PRIZE

GÖDEL, ESCHER, BACH:

AN ETERNAL GOLDEN BRAID



**DOUGLAS R.
HOFSTADTER**

**A METAPHORICAL FUGUE ON MINDS AND MACHINES
IN THE SPIRIT OF LEWIS CARROLL**



Ambrigram

Amnigrum



Ambrigram

Bach

f
ü
G
a

The image shows a handwritten musical score for 'Crab Canon' by J.S. Bach. The score consists of three staves of music, each with two treble clef staves. The first staff begins with a quarter note followed by a dotted half note. The second staff begins with a eighth note followed by a sixteenth note. The third staff begins with a quarter note followed by a dotted half note. The music is written in common time, with a key signature of one flat. The title 'CRAB CANON JSB' is written in capital letters above the first staff, and the words 'are noway back' are written below the third staff.

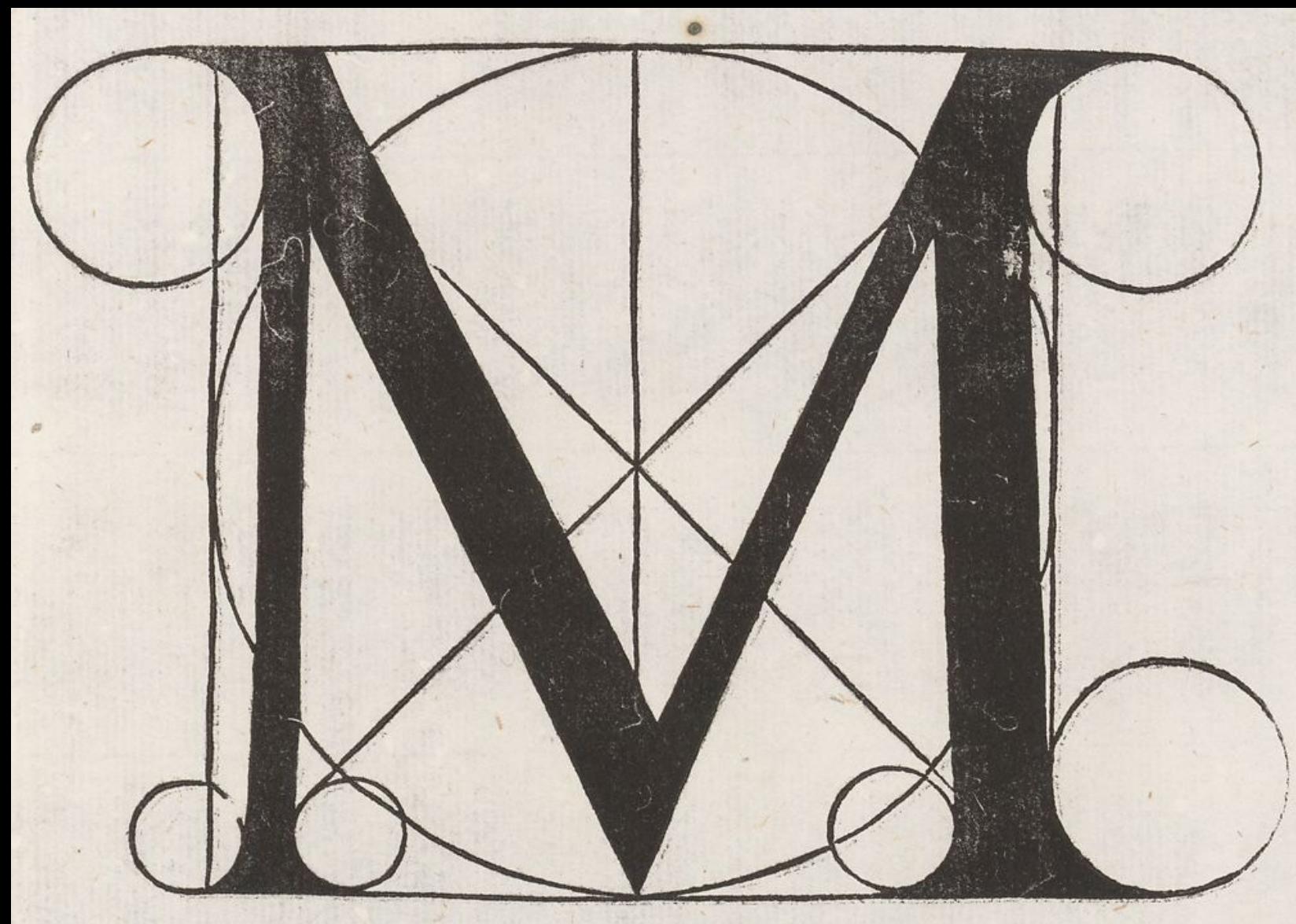
FIGURE 44. Crab Canon from the Musical Offering, by J. S. Bach. [Music printed by Donald Byrd's program "SMUT".]

J = 74

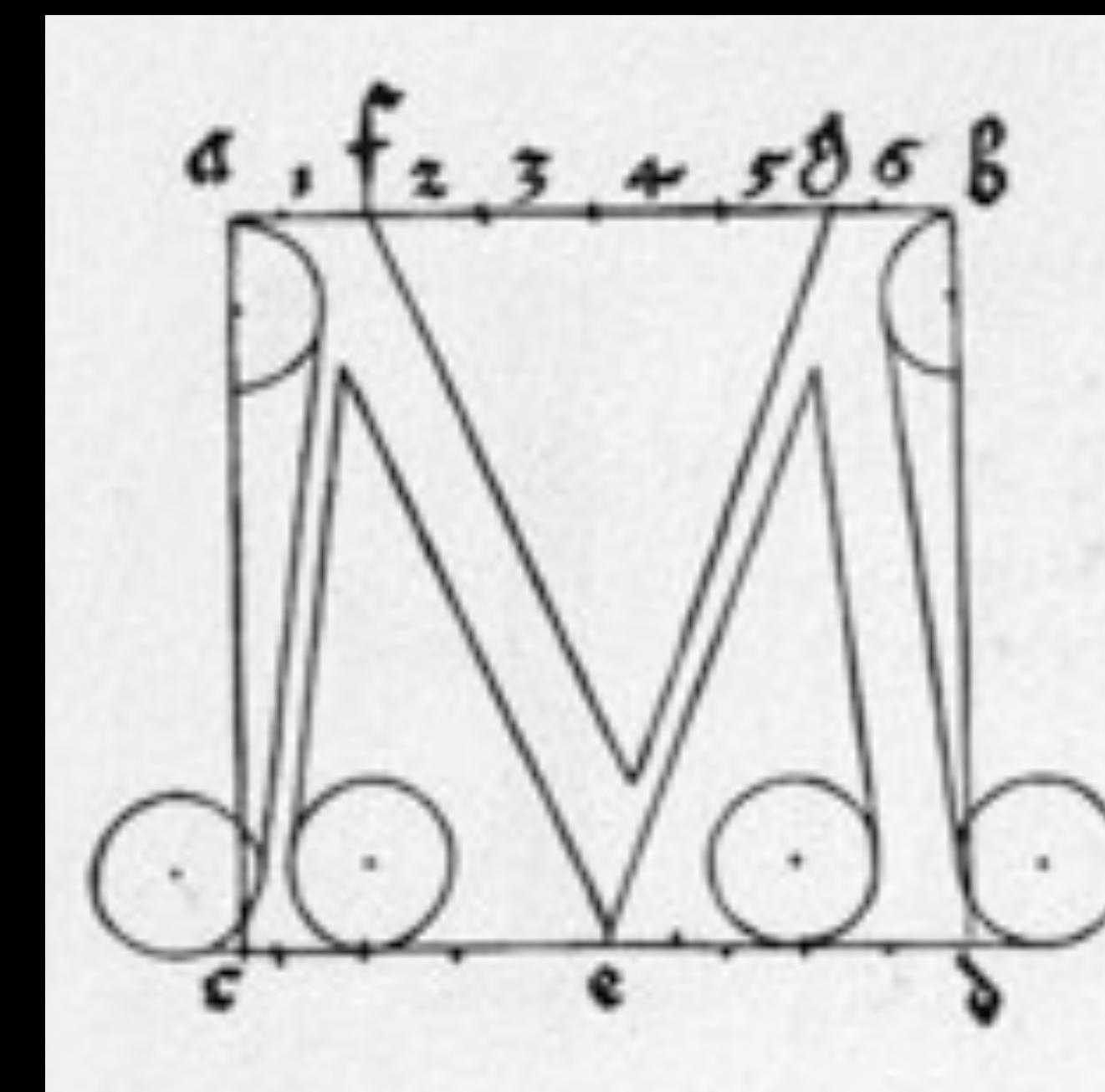
A musical score for a single melodic line. The key signature is one flat (B-flat), and the time signature is common time (indicated by 'C'). The tempo is marked 'J = 74'. The score consists of two staves. The first staff begins with a quarter note followed by a half note. The second staff begins with a half note. Both staves continue with a series of eighth notes and sixteenth-note patterns. Measure numbers 1 and 10 are indicated above the staves. Measure 1 ends with a fermata over the last note. Measure 10 ends with a fermata over the last note.

II. RATIONALIZING THE ALPHABET









SEGOND LIVRE. FEVIL.XXI.

tre vertus Cardinalles pour mōstrar q noz l̄es Atti certaie quadrature qui ḡst en l̄ogitude & altitude.

estre enties tes, requie de la haul eur facon, npas. Par ee perseue & deumēt e, certaine eux lignes xales y lo loing lune partiedra.

igure diui commāt la diuision, runelle de

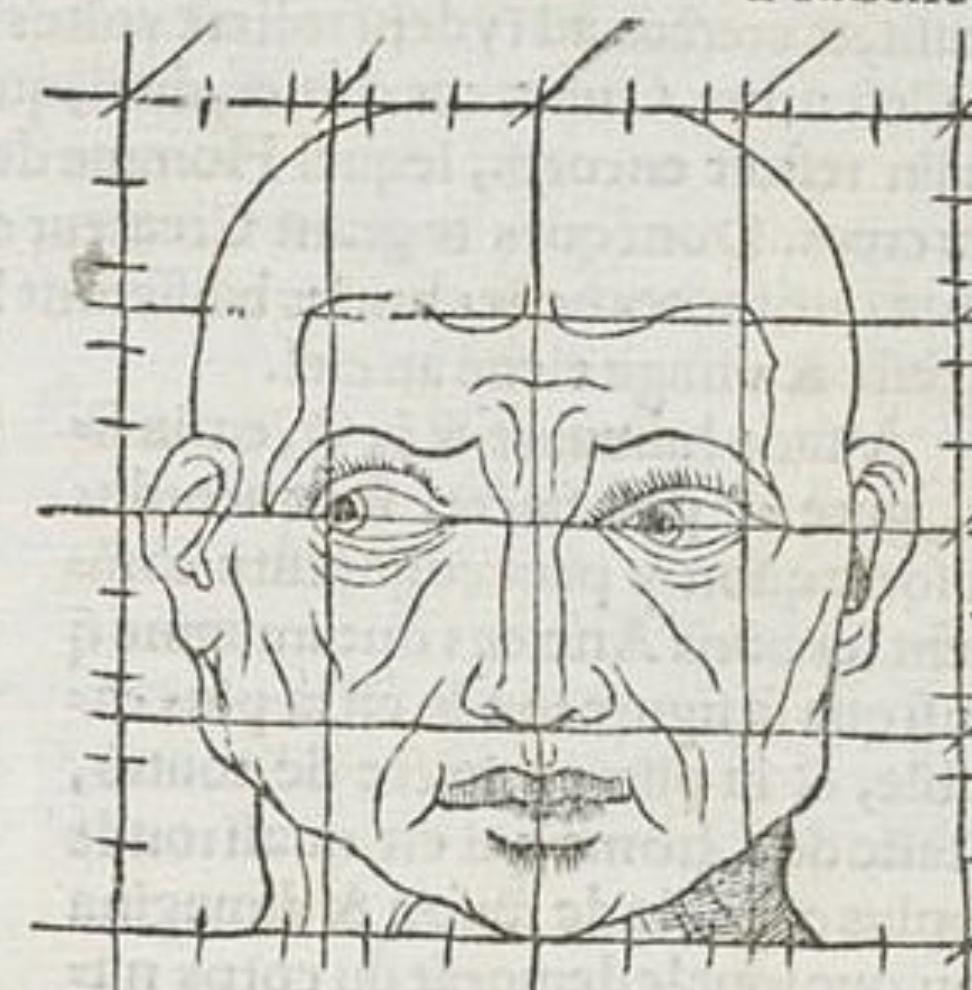
entrique &

Force.

ce que iay dict cy dessus, que toute lettre ayant bri is la dicte ligne ceutrique précisemēt, & nō ailleurs. deux yeulz, tout au lōg du nees, & dessus la bouche e proportionaire & triūphalle I: pour bailler tous

Justice.

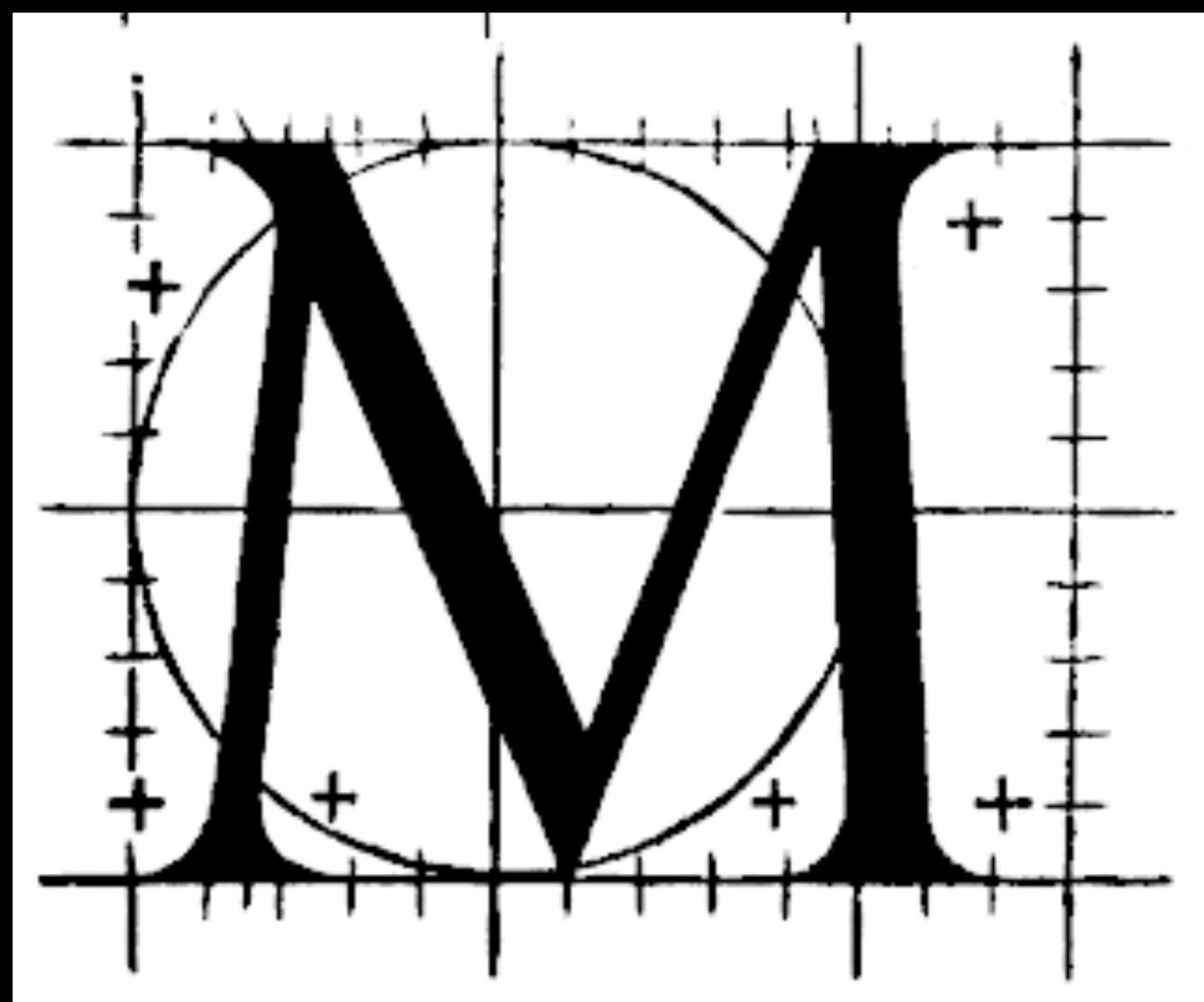
Prudence.



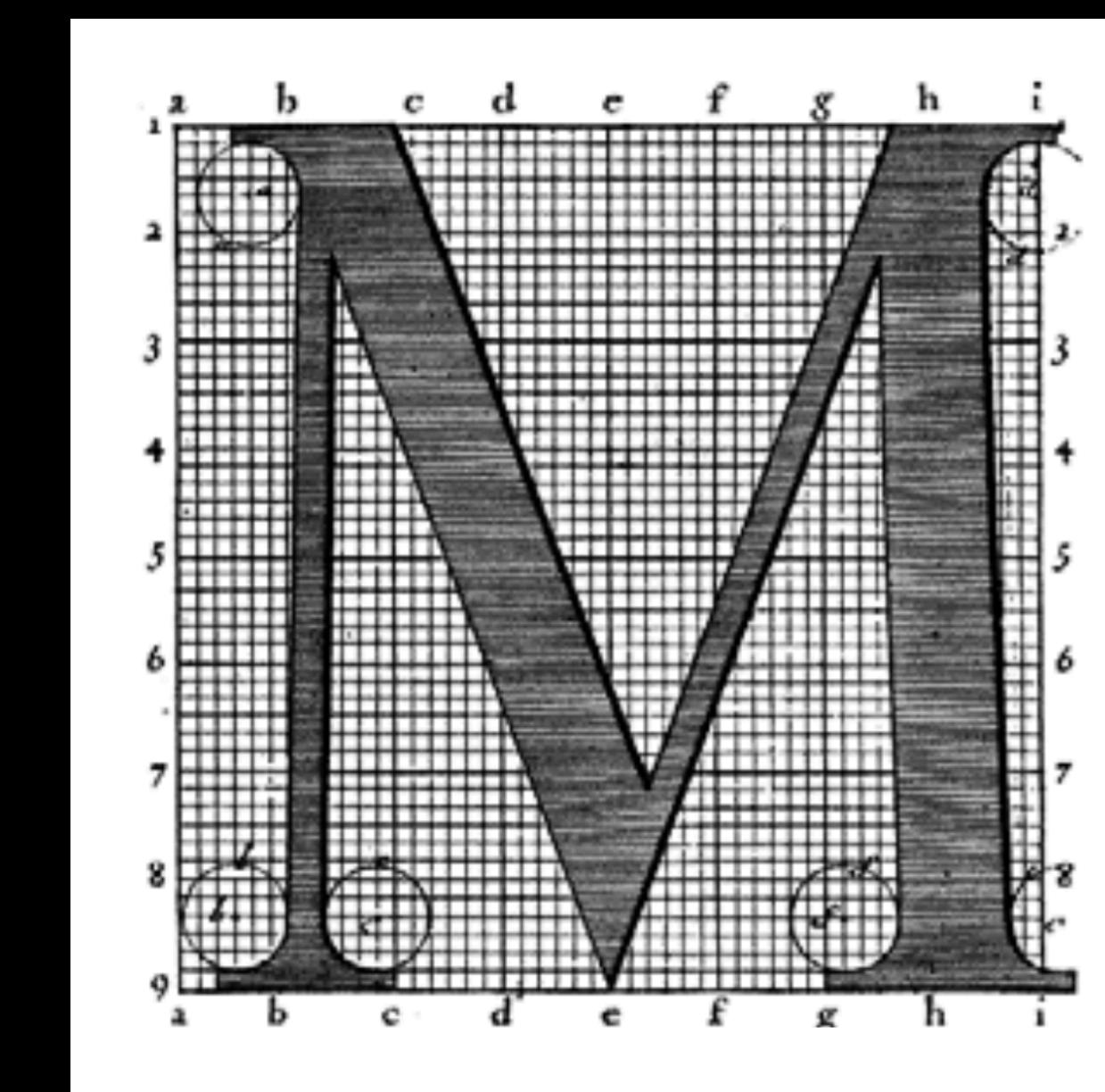
Atrempence.

Significa tion des quatre vert° car dinale, avec let tres Attis ques,

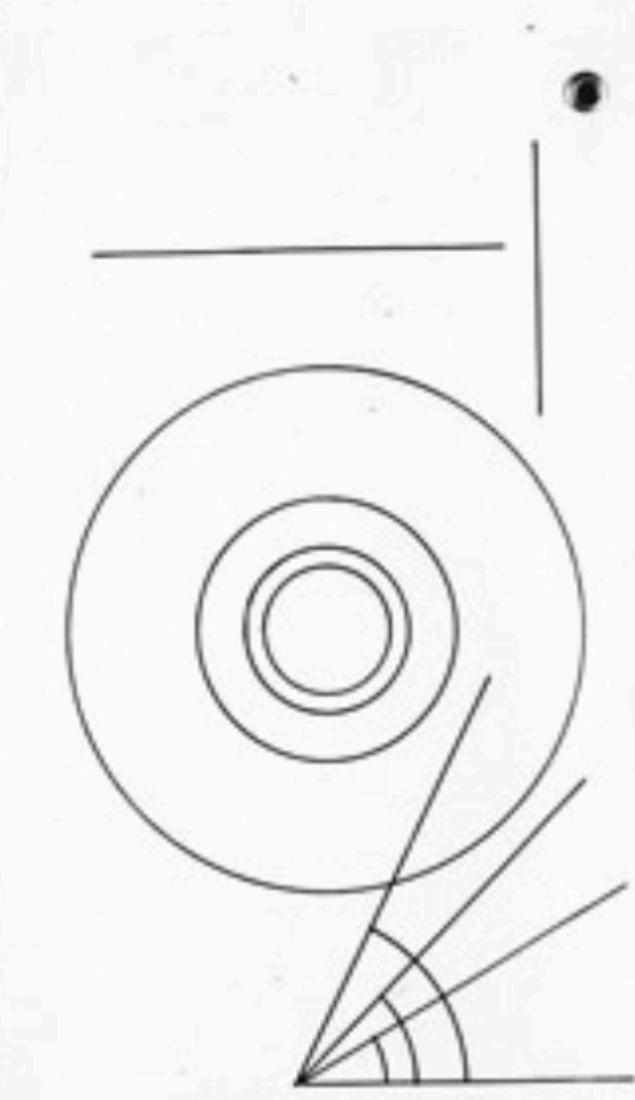
Notable regulier,







a b c d e f g h i j k l
m n p q r s t u v w
x y z a g dd



a b c d e f g h i j k l m n o p
q r s t u v w x y z
A B C D E F G H I J K L M N O
P Q R S T U V W X Y Z 1 2 3

B 123456
7 890 A C
D F G H I J L
E M N O P Q
R S T U V W
X Y Z A K W

THE



TIMES

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LONDON MONDAY OCTOBER 3 1932

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PRICE 2d

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overseas, and to foreign countries.

DEATHS (continued)

POPE.—On Sept. 28, 1932, Pope Pius XI, the head of the Roman Catholic Church, died at the age of 85 years. He was born in 1857 and had been Pope since 1922. He was succeeded by Pope Pius XII.

PLINT.—On Oct. 1, 1932, at Broadgate, Parkgate Avenue, Marylebone, London, C. S., 70 years old, the widow of the late Mr. W. H. Plint, a well-known architect, who died in 1928. She was buried at St. Paul's Church, and her funeral service was conducted by Rev. Canon G. H. D. Smith, Vicar of St. Paul's.

POTTER.—On Sept. 28, 1932, at St. George's Gardens, London, S.W. 1, Dorothy Wallace-Potter, 50 years old.

PERSONAL

THREE new members for our Committee under and over 30 years old have joined the Society.

WEDDING.—At the present time there are 100 members of the Society, and we are looking forward to the next year with great interest.

£5 NOTE GRATUITELY MAILED from the Society to those who have not yet received it.

HIGH LIFE and many other attractions.

FIFTY-YEAR'S MEETING.—An

EXHIBITION.—The Society has arranged a special exhibition of its members' work, which will be held at the Royal Academy, from Oct. 10 to Nov. 10, 1932.

CLUB ANNOUNCEMENTS
CHEPSTOW RACE CLUB.
WEDNESDAY & THURSDAY, OCTOBER 10 & 11.
Price 2d. 2 p.m. Last Race, 4.15 p.m.

Second Conference and Dance Day from 6.30 p.m. until 11 p.m.

PERSONAL

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BUSINESS OFFERS
100 YEARS OF EXHIBITIONS

THE 100th Anniversary of the Royal Academy of Arts, which will be held at the Royal Academy, from Oct. 10 to Nov. 10, 1932.

CLUB ANNOUNCEMENTS
CHEPSTOW RACE CLUB.
WEDNESDAY & THURSDAY, OCTOBER 10 & 11.
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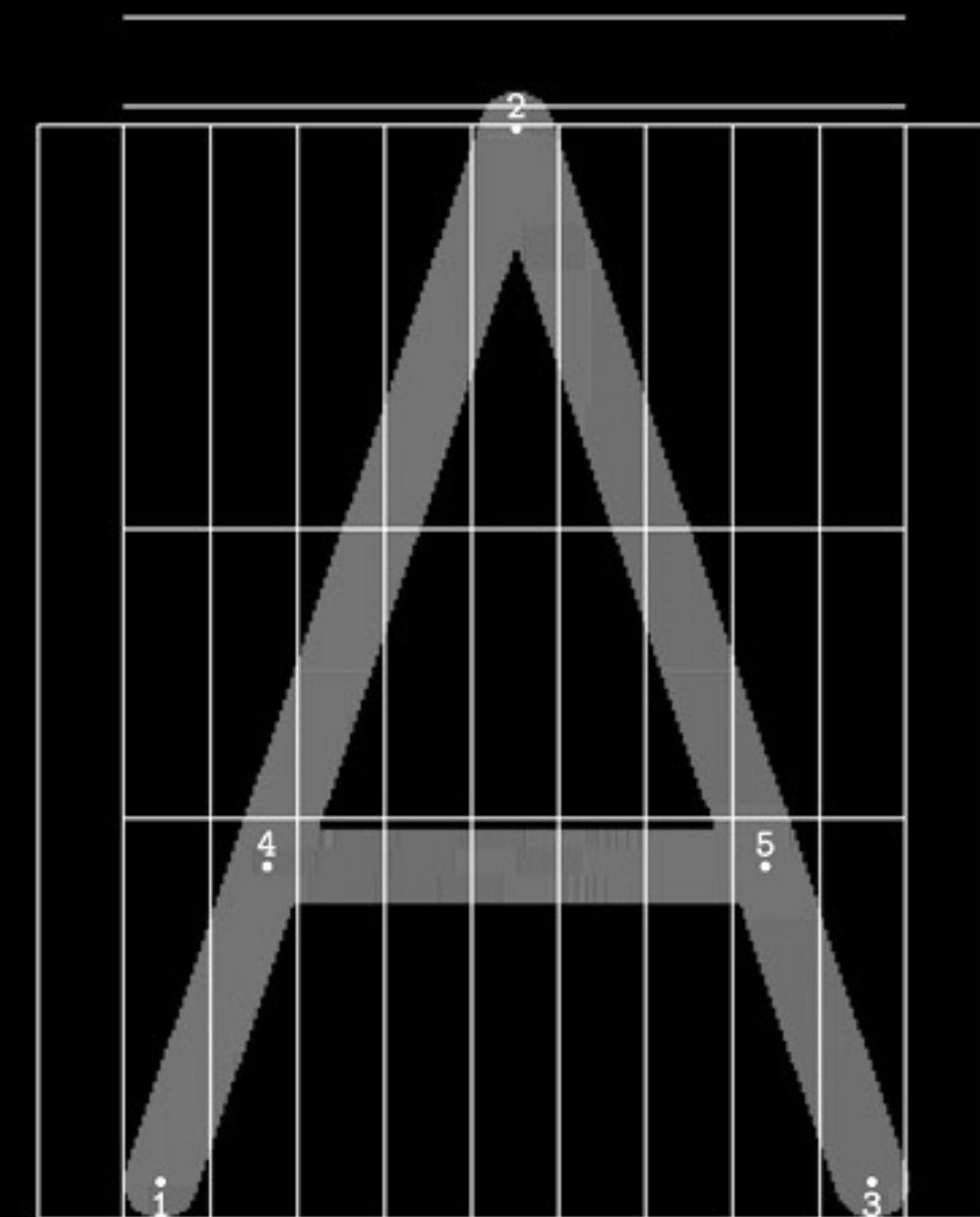
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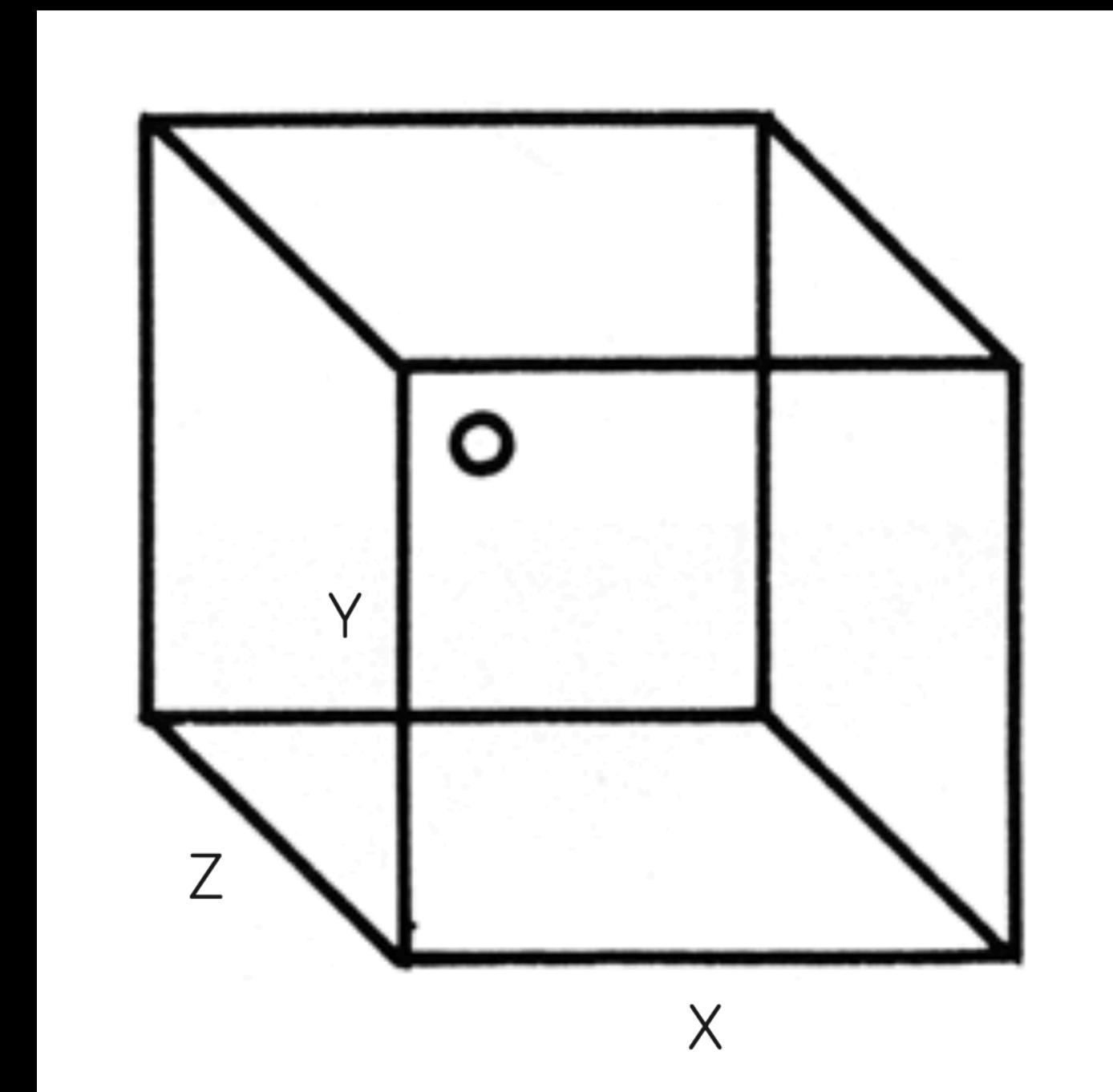
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Hello world

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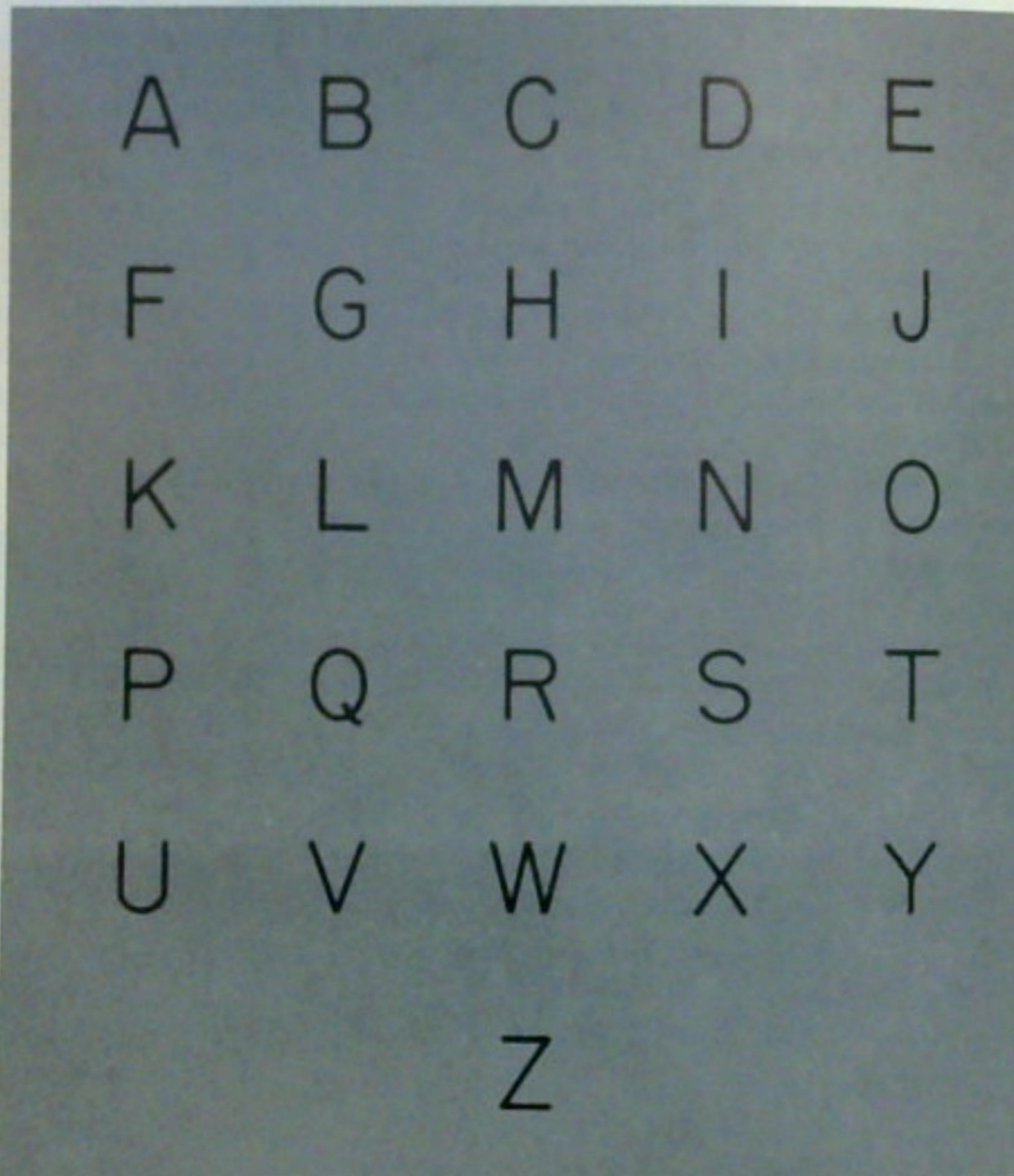
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The image consists of a 10x10 grid of small, white-outlined geometric shapes on a black background. The shapes are composed of straight lines and include various orientations of squares and triangles. The pattern repeats every two columns, creating a visual effect where some shapes appear to be rotated or offset relative to their neighbors. The overall design is minimalist and abstract.

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FIGURE 1.5



Every schoolboy knows that an ordinary sheet of paper has two sides. Sometimes he must write only on one side, or draw only on one side. In this section we shall study surfaces which have only one side, but first let us consider in some detail exactly what surfaces we are talking about.

A surface should be "two-dimensional". What about a sphere with a spine? What about two spheres joined at a point (Fig. 2.1b); are these surfaces? We shall study a special type of surface called a manifold. A manifold is a surface (i.e., a surface "all in one piece"). If a surface has a single point, the surface is topologically equivalent to a point. If for each point p of the surface, all points near to p form a set topologically equivalent to an open disk, then all points of the surface near to p is a neighborhood of p .

Neither of the surfaces shown in Fig. 2.1a is a manifold. In Fig. 2.1a the points on the spine do not have neighborhoods. In Fig. 2.1b the surface is not topologically equivalent to a disk because the point of tangency of the two spheres is not a neighborhood of itself.

A surface is *bounded* iff the entire surface can be contained in a ball. A torus is a bounded surface. A surface is *unbounded* iff it is not bounded. If we consider a particular piece of a surface, then the boundary of the surface is defined to be the curve which separates the interior from the exterior of the surface. For example, consider a circular disk. The boundary of the disk is the circle which separates the interior from the exterior. A boundary in a plane consists of two circles.

