METAFONT

A Course on METAFONT Programming

Donald E. Knuth
Stanford University

During the spring of 1984, four dozen brave students attended an unusual class at Stanford University, taught by two brave professors and by another reckless one. The subject of these lectures was type design in general and the use of the new METAFONT in particular. The course was necessarily improvisational, because METAFONT was still taking shape during the entire time; but I think it's fair to say that the lectures hung together quite well and that the experience was rewarding for all. Videotapes of these 27 class hours are available for rental to anybody who wants to share in the adventures we had. I believe that anyone who is interested in the subject and has the time and opportunity to see these tapes will learn lots of important things.

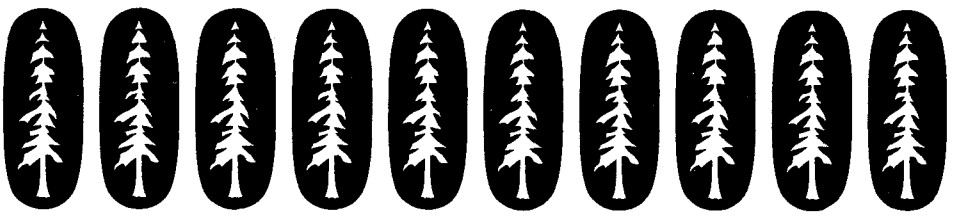
The main reason I can make this claim is that the two brave professors referred to above were Richard Southall and Charles Bigelow, who gave outstanding lectures in alternation with my own contributions. Southall's lectures covered the general subject of "Designing Typefaces," and he broke this down into five subtopics:

(1) Definitions — What is the difference between fonts and typefaces, between type design and calligraphy?
(2) Quality criteria — How can we objectively judge the success of text typefaces?
(3) Facets of the job — What does a type designer have to do?
(4) Methodology — How does traditional knowledge and practice teach us to tackle the problem of type design?
(5) 'Ideal' designs — Can anyone tell us what shapes the characters ought to be?

Bigelow lectured on the history of letterforms, from ancient times to the present. It was instructive to see how character shapes have changed as the technology has changed: Alphabet designs were originally created by a "ductal" process, i.e., by the movements of a writing tool; then printing types were produced by a "glyptal" process, i.e., by carving in metal; and nowadays most letterforms are produced by a digital or "pictal" process, i.e., by specifying patterns on a discrete raster. The work of master type designers of all eras was presented and critically evaluated, and Bigelow concluded by discussing the current state of the art in commercial digital typefaces and in designs for CRT displays. All of the lectures by Southall and Bigelow were lavishly illustrated, in most cases by unique slides from their personal collections.

My job was to relate this all to the new METAFONT. My luck held good throughout the quarter, as new pieces of the language would begin to work just about two days before I needed to discuss them in class. That gave me one day to get some programming experience before I was supposed to teach everybody else how to write good programs themselves. I lectured about (1) coordinates, (2) curves, (3) equations, (4) digitizing, (5) pens, (6) transformations, and (7) the syntax of METAFONT.

The students did several instructive homework problems. First there were two assignments done with cut paper, to illustrate the important differences between "what we see" and "what's there." Then came Homework #3, the first computer assignment, which was to write METAFONT code for Stanford's symbol, El Palo Alto (the tall tree); each student did just two of the branches, since it would have been too tedious to do all twelve of them, and I combined their solutions to obtain the following results:

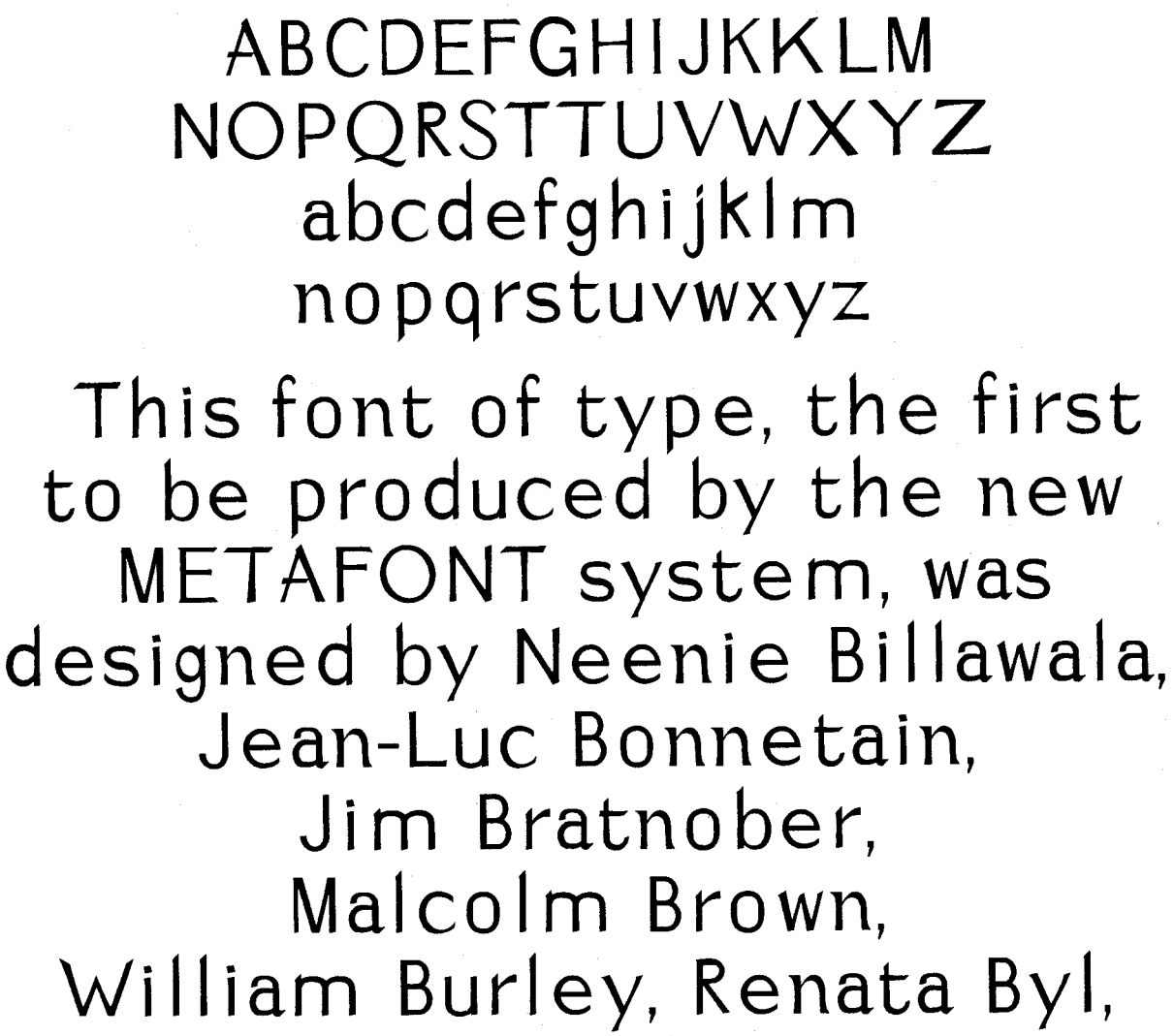


(Each of these trees is different, although many of the individual branches appear in several different trees because some of the branches were worked on more often than others.) The purpose of this exercise was to help the students get used to the ideas of coordinates and simple curves, as they became familiar with the computer system and its text editor. An organic shape like a tree is very forgiving.

The fourth homework assignment was much more interesting, and we called it "Font 1." The class created a new typeface with a sans-serif, calligraphic flavor; we had just enough people who had completed Homework #3 so that everybody could be assigned the task of creating one uppercase letter and one lowercase letter. I presented an uppercase 'U' and lowercase 'l' as examples that would help to set the style; but of course each student had a personal style that was reflected in the results, and there wasn't much unity in our final font. This fact was instructive in itself.

I had prepared two METAFONT macros to draw penlike strokes and arcs, and the students were required to draw everything with those two subroutines. This was a signification limitation, but it helped to focus everyone's attention by narrowing the possibilities. The students were also learning the concepts of meta-design at this time, because their programs were supposed to be written in terms of parameters so that three different fonts would be produced: normal, bold, and bold extended. This gave everyone a taste of METAFONT's algebraic capabilities, in which the computer plays a crucial rôle in the development of one's design.

The best way to describe the outcome of Homework #4 is to present the font that we made:



Pavel Curtis, Bruce Fleischer, Kanchi Gopinath, John Hershberger, Dikran Karagueuzian, Don Knuth, Ann Lasko-Harvill, Bruce Leban, Dan Mills, Arnie Olds, Stan Osborne, Kwang-Chun Park, Tuan Pham, Theresa-Marie Rhyne, Lynn Ruggles, Arthur Samuel, New Wave Dave, Alan Spragens, Nori Tokusue, Joey Tuttle, and Ed Williams.

(See also the examples of bold and bold extended at the close of this article.) As I said, we didn't expect Font 1 to have any unity, but I was pleased that many of the individual characters turned out to be quite beautiful even when the parameters were changed to values that the students had not tried.

The fifth and final homework assignment was more interesting yet. Everybody was to design a set of eight characters that could be used to typeset border designs. These characters were called NW, NM, NE, ME, SE, SM, SW, and MW in clockwise order starting at the upper left; here 'N' means North, 'E' means East, 'S' means South, 'W' means West, and 'M' means Middle. The height of each character was determined by the first component of its name, and the width was determined by the other component. Thus, for example, NW and NM were required to have the same height; SE and ME were required to have the same width. As a consequence, the four characters with M's in their names could be used as repeatable extension modules to make arbitrarily large rectangles together with the four corner characters. But there were no other ground rules besides these mild restrictions on height and width, and the students were urged to let their creative minds dream up the greatest borders that they could program in METAFONT.

It was especially exciting for me to see the completed border projects, because I was impressed by the originality of the designs and (especially) because I was glad to see that the new version of METAFONT was working even better than I had

dared to hope. We still need to wait awhile before we'll know how adequate METAFONT will be as a tool for letterform design, but already we can be sure that it's a super tool for borders! The results of this experiment appear below and elsewhere in the pages of this issue of *TUGboat*.

I should mention some of our experiences related to the "high tech" nature of a class like this. None of the computers accessible for classes at Stanford had a high-resolution screen with graphic capabilities, so we had ordered SUN workstations to fill the void. When those machines finally arrived—a week before the class was scheduled to begin—they were a new model for which new software needed to be written in order to put them into the campus network and connect them to various peripheral devices. The manufacturer balked at letting us see the source code of their software, but we needed it in order to get going. We also found that we couldn't use their version of UNIX anyway, because it allocated each file on our main disk to a specific workstation; that would have forced each student to log in at the same workstation each time! Furthermore their PASCAL compiler was unusable on a program as large as METAFONT.

So we decided to use a locally developed operating system called the V-System or V-Kernel, due to Profs. David Cheriton and Keith Lantz and their students. Fortunately one of those students, Per Bothner, was a member of the TEX project, and he had also written his own PASCAL compiler. Unfortunately, however, we couldn't use the V-System without connecting all of our SUNs to a more powerful machine like a VAX, and we didn't own one. To make matters worse, the building in which we had planned to put our SUNs was being renovated; we were originally scheduled to occupy it in January, but each month another problem had delayed the construction, and it was clear by the end of March that we wouldn't have any place to put the SUNs until May at the earliest!

Here again Prof. Cheriton saved the situation for us, because he had independently been making plans to set up a teaching lab with graphic workstations in another building. His workstations hadn't arrived yet, so we were able to loan part-time use of our SUNs in return for the use of his lab. Furthermore he had a new VAX that we could install next door.

The actual timetable went something like this: On March 24 I had finished coding a subset of METAFONT that I hoped would be enough to use in the class, but I hadn't started to debug it yet. On April 1, I obtained the first successful output of that program on a small test case, and METAFONT also displayed a character correctly for the first time on my screen. (This was on the SAIL computer, a one-of-a-kind 36-bit machine on which I have done all of the development of TEX and METAFONT.) The next day, April 2, I learned about the possibility of using Cheriton's lab for our course; the room was still without furniture, computers, and air-conditioning, but David Fuchs and other people pitched in to help get things moving there. On April 3, Per Bothner successfully transported METAFONT from SAIL to a SUN workstation using the V-System. And April 4 was the first day of class.

Pavel Curtis

The V-Kernel system had previously been used only by hackers, so there was no decent manual for novices; furthermore none of us except Per knew how to use it. Arthur Samuel came to the rescue and began to prepare an introductory manual. Meanwhile, we had special meetings with Stanford's TV network technicians, because there was no adequate way to run METAFONT from a classroom so as to display the results online to the audience. On April 6 I began to write GFtoDVI, a fairly long program that is needed to get proofsheets from METAFONT's output; I knew that it would take at least two weeks to complete that program. Lynn Ruggles had already made progress on another utility routine, GFtoQMS, which produces fonts suitable for a new printer that we had just received. (But that printer wasn't installed yet.)

Bigelow and Southall knew that it would be a miracle if the computers were all in place on time, so they were prepared to "vamp" until I was ready. I gave my first lecture on Friday, April 13, one day after Lynn had been able to typeset the first METAFONT-made character on our QMS. The students had had non-computer homework to do, as mentioned above, so we were able to make it seem natural that the first computer assignment was not distributed until April 27.

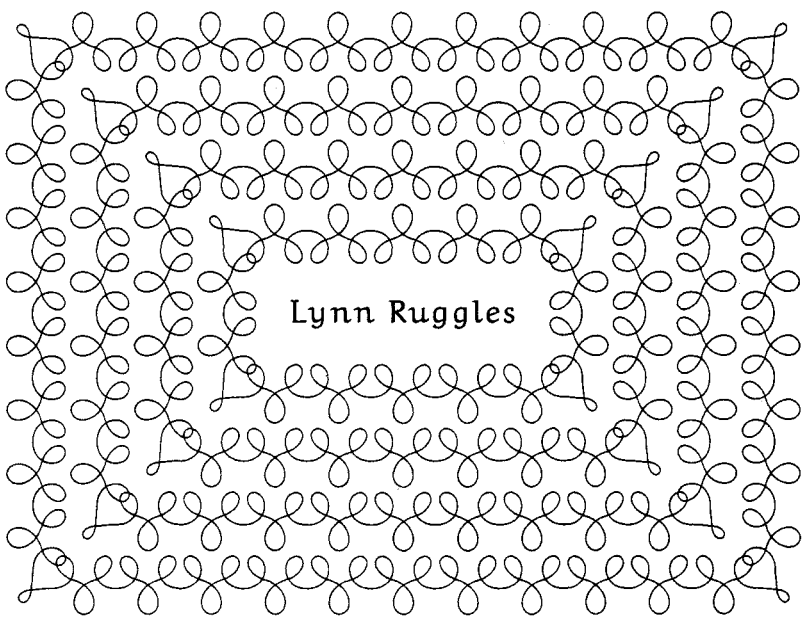
Well, the month of May was a long story, too—the computers broke down frequently because of inadequate air-conditioning, which took weeks to install—and there were plenty of software problems as I kept making new versions of METAFONT. But people were good natured and they tolerated the intolerable conditions; I rewarded them for this by cancelling a planned Homework #6. Teaching assistants Dan Mills and Dave Siegel did yeoman service to keep everything running as smoothly as possible throughout the nine weeks of the class.

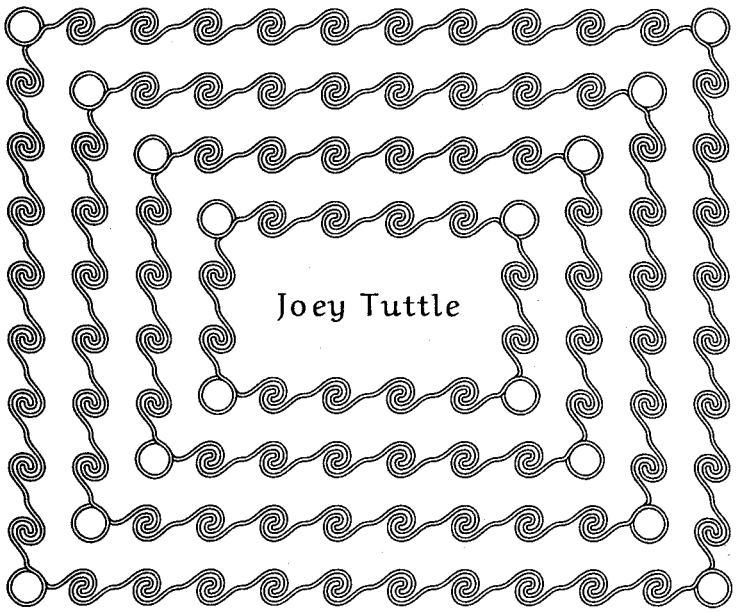
Finally the course came to a glorious finish as we took a field trip to San Francisco. We had a picnic on Font Boulevard, then toured the fascinating MacKenzie–Harris type foundry and the Bigelow & Holmes design studio. I can best convey the jubilation of that memorable day by showing a picture of the "italic" font that we all made just after lunch:

Jill Knuth

In every period there have been better or worse types employed in better or worse ways.
The better types employed in better ways
have been used by the educated printer
acquainted with standards and history,
directed by taste and a sense of the fitness of things,
and facing the industrial conditions of his time.
Such men have made of printing an art.
The poorer types and methods have been employed
by printers ignorant of standards
and caring alone for commercial success.
To these, printing has been simply a trade.
The typography of a nation has been good or bad,
as one or other of these classes had the supremacy.
**And today any intelligent printer can educate his taste,
so to choose types for his work and so to use them,
that he will help printing to be an art rather than a trade.**
There is not, as the sentimentalist would have us think,
a specially devilish spirit now abroad
that prevents good work from being done.
**The old times were not so very good,
nor was human nature then so different,
nor is the modern spirit particularly devilish.
But it was, and is, hard to hold to a principle.**
The principles of the men of those times
seem simple and glorious.
**We do not dare to believe that we, too,
can go and do likewise.**

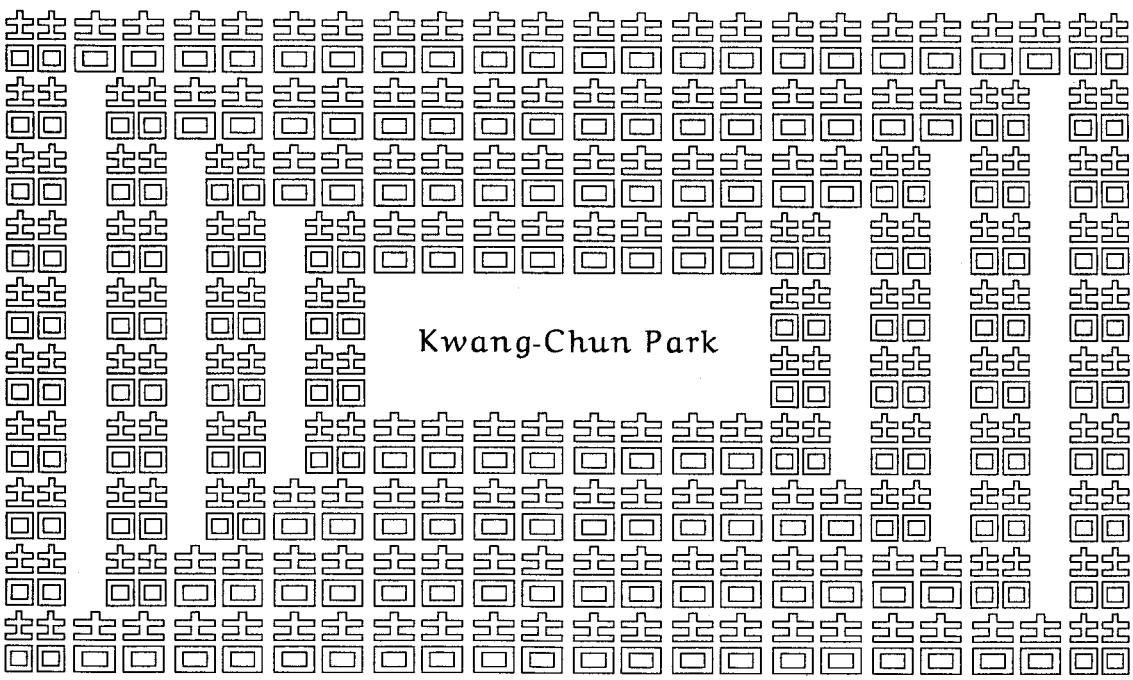
DANIEL BERKELEY UPDIKE

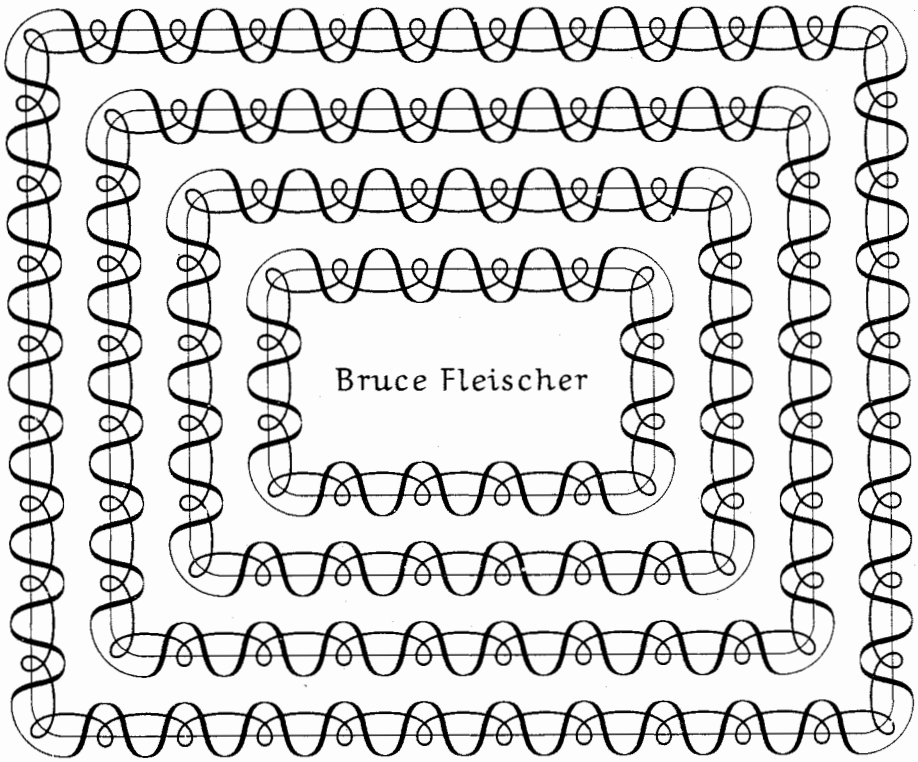




METAFONT

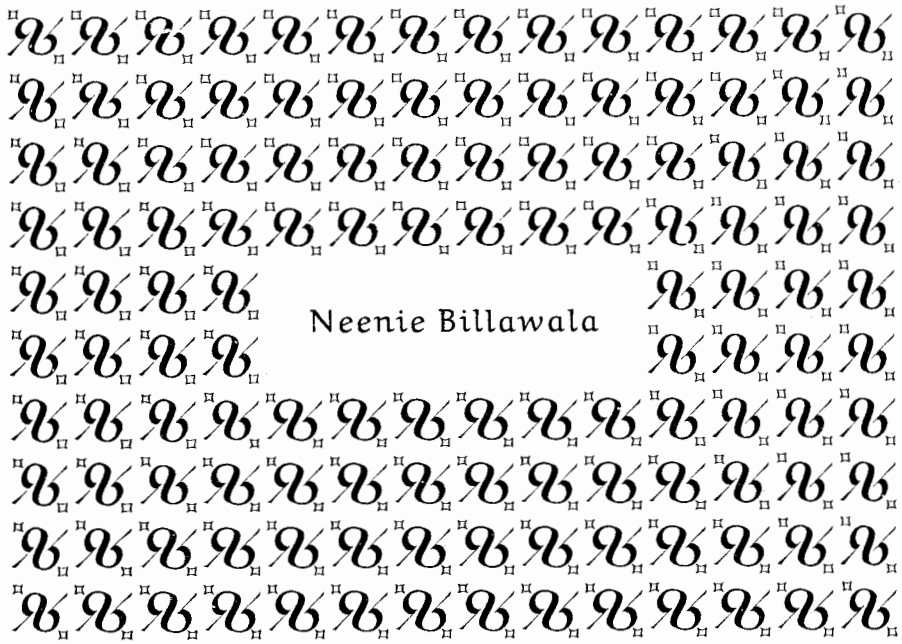
John Hershberger

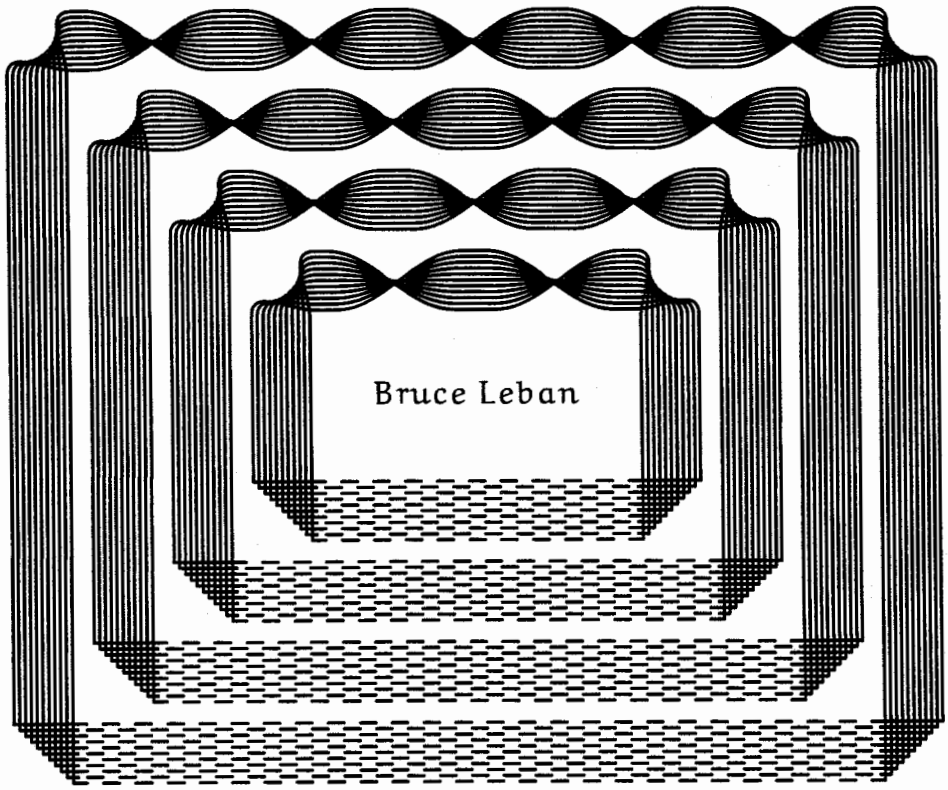


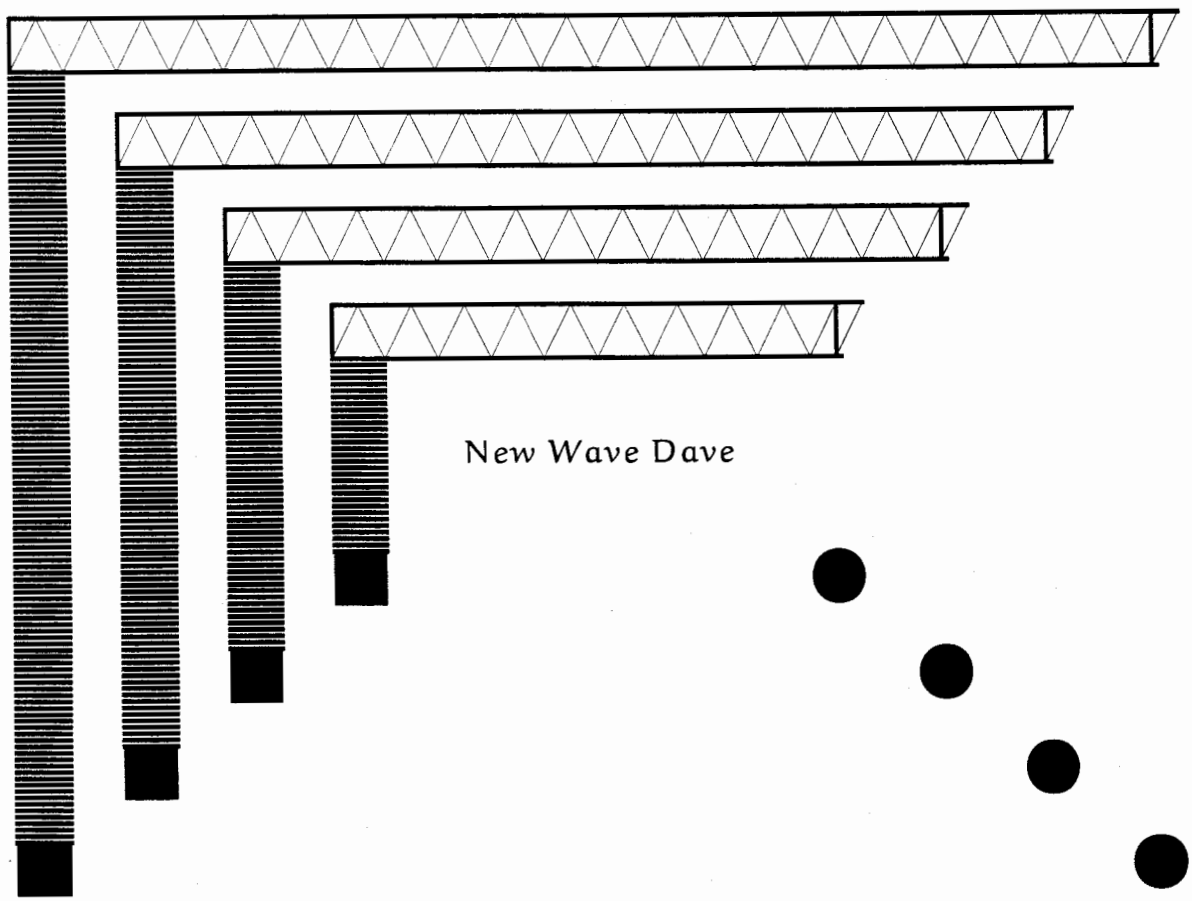


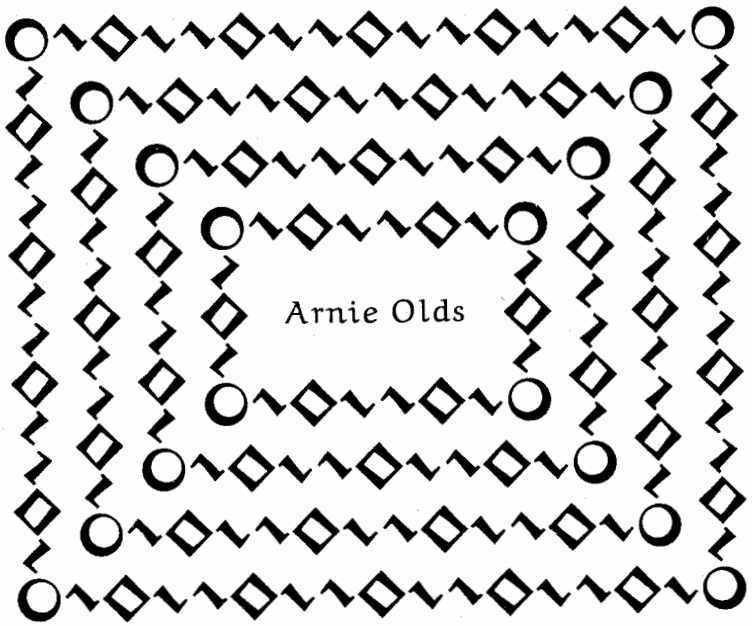
METAFONT

Nori Tokusue

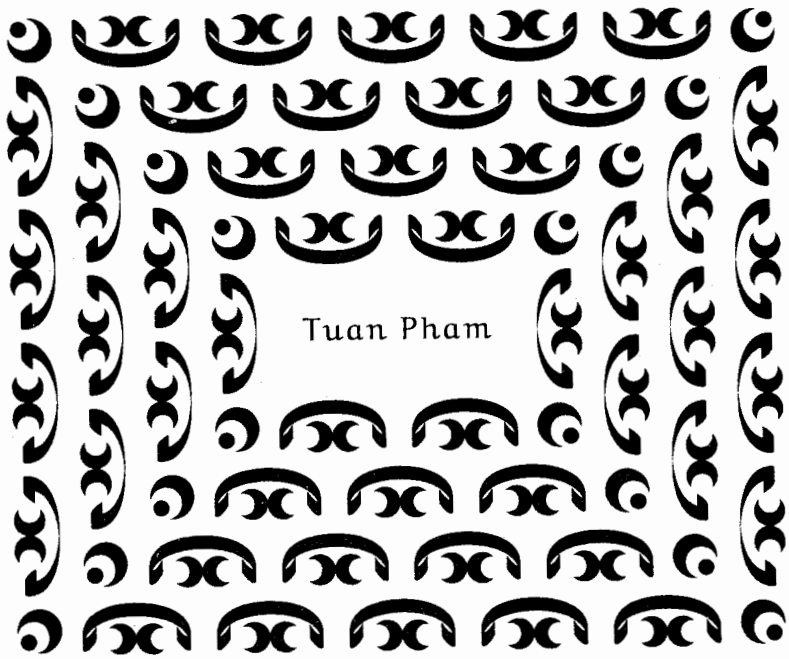



Bruce Leban


New Wave Dave

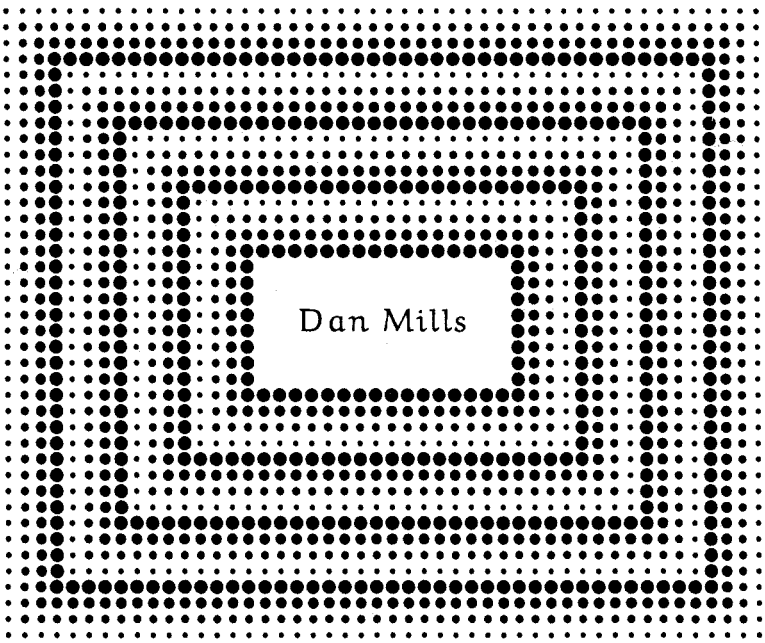


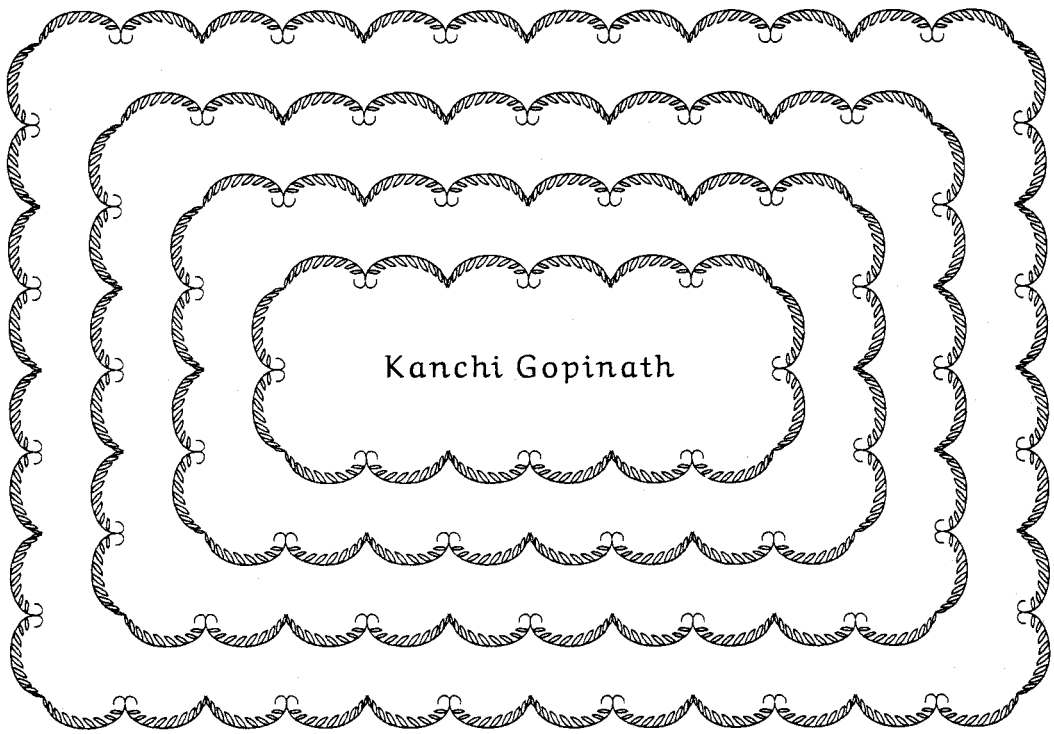
Arthur Samuel



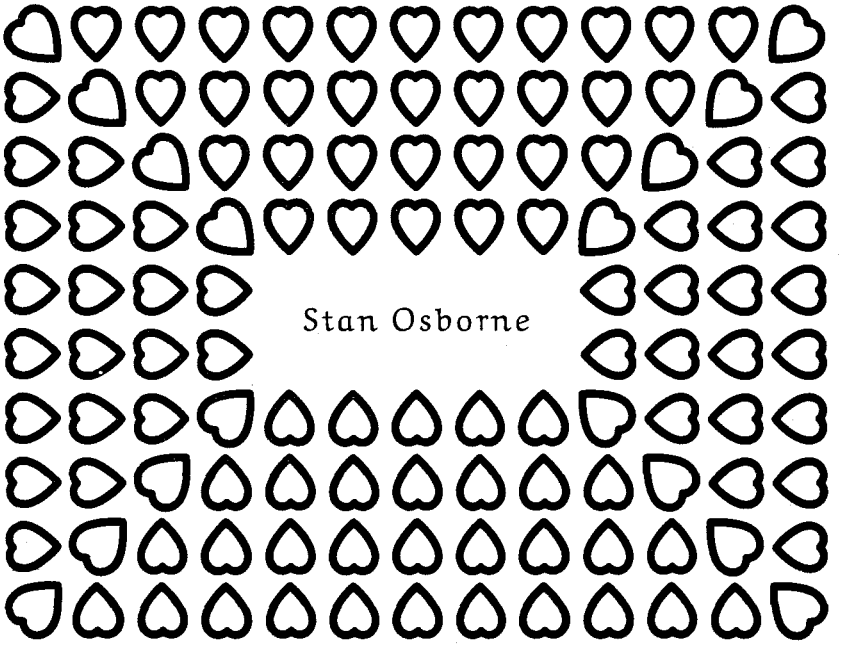
METAFONT

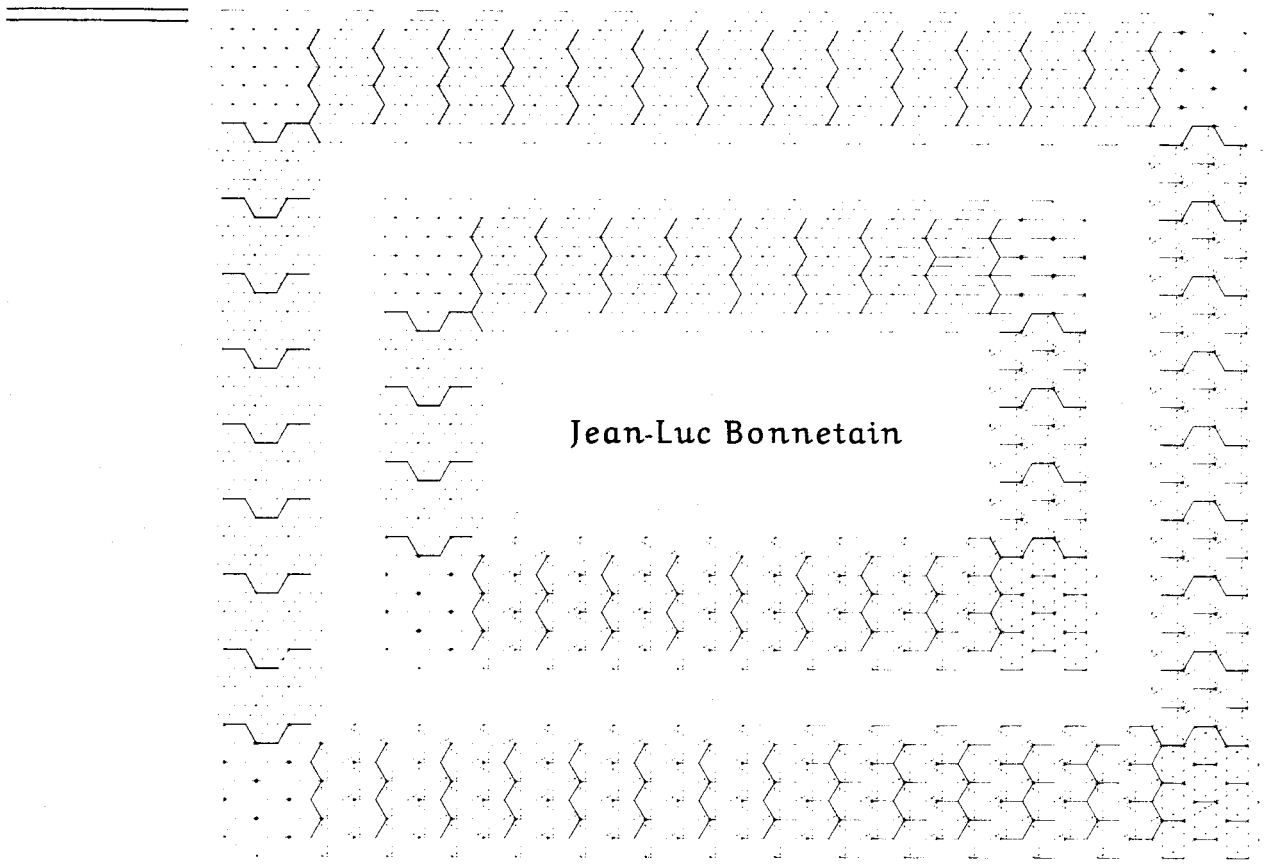
Jim Bratnober

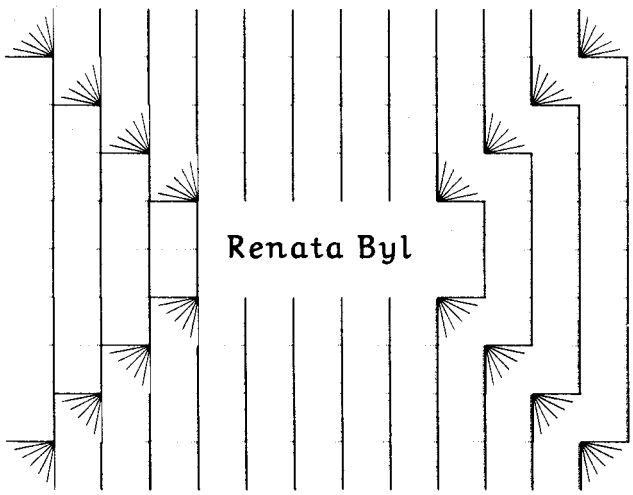


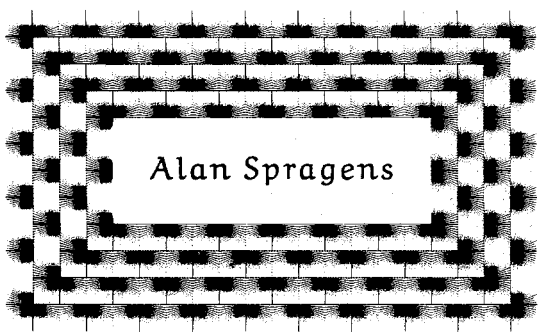


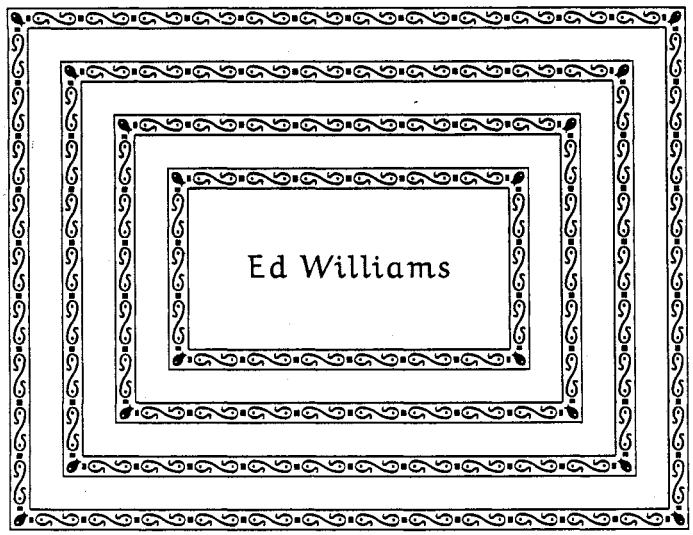
William Burley




Jean-Luc Bonnetain


Renata Byl


Alan Spragens



METAFONT

Malcolm Brown