

April 1983

Report No. STAN-(X83-965

An Approach to Type Design and Text Composition in Indian Scripts

by

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**An Approach to
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In Indian Scripts**

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with a preface by

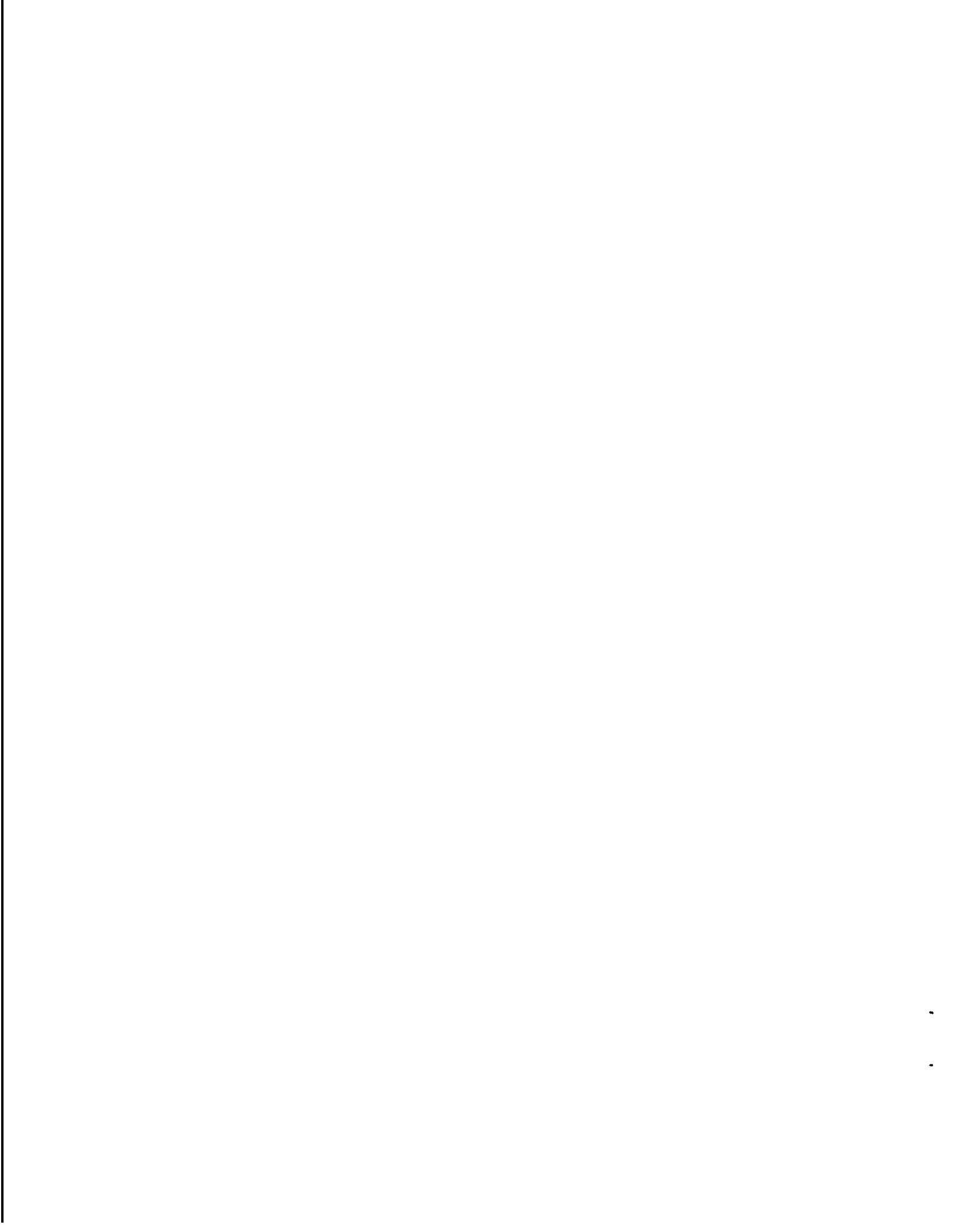
Donald E. Knuth

Research sponsored by

National Science Foundation IST -8201926
United Nations Development Program
Systems Development Foundation

COMPUTER SCIENCE DEPARTMENT
Stanford University



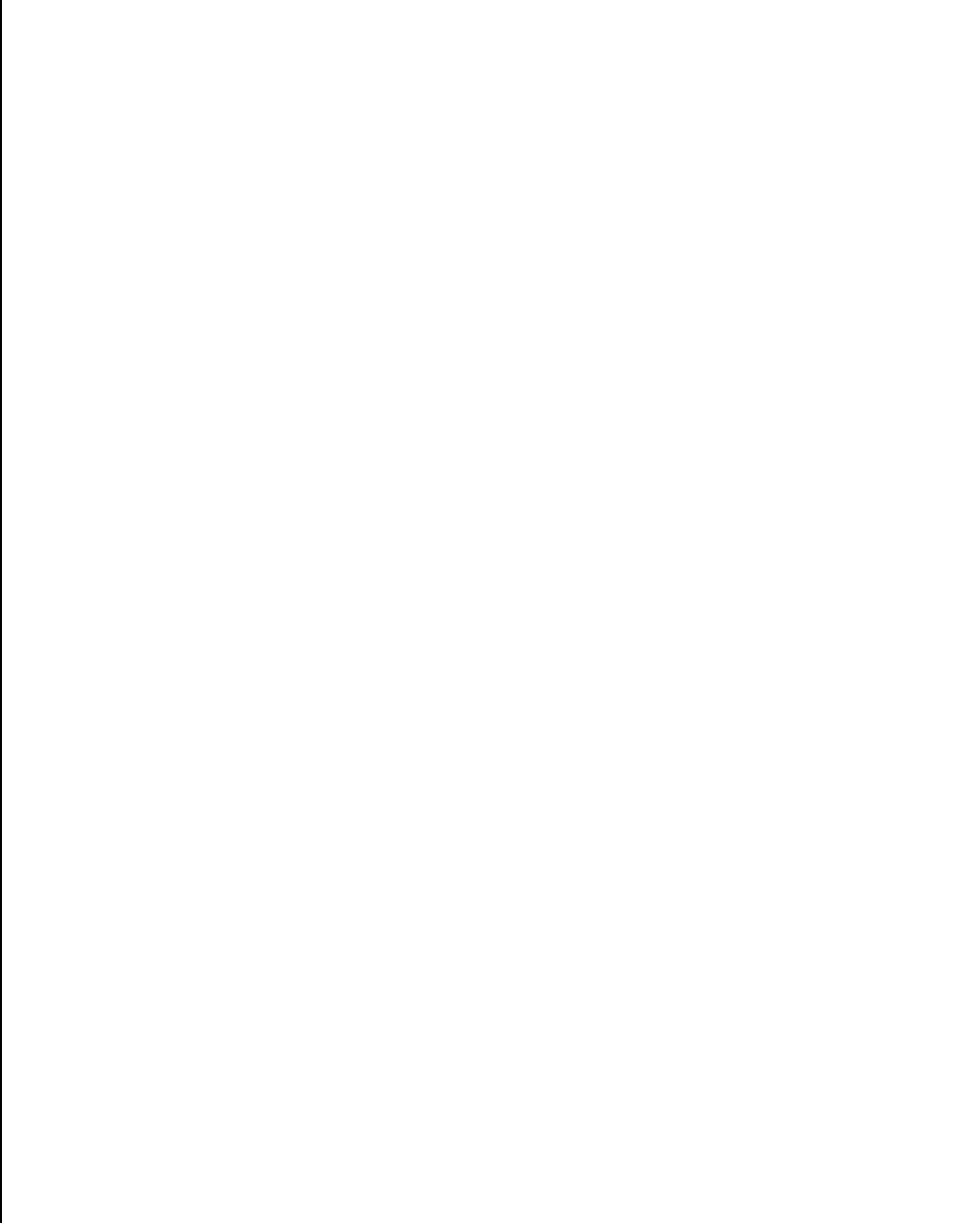


Preface

For the past several months, Stanford's digital typography project has had the good fortune to have been visited by Mr. P.K. Ghosh, who was awarded a fellowship by the United Nations Development Program. Mr. Ghosh was born in Calcutta in 1952, and after receiving an M.Tech degree from the University of Calcutta in 1978 he has been a scientific officer at the National Centre for Software Development and Computing Techniques, which is part of the **Tata** Institute of Fundamental Research in Bombay.

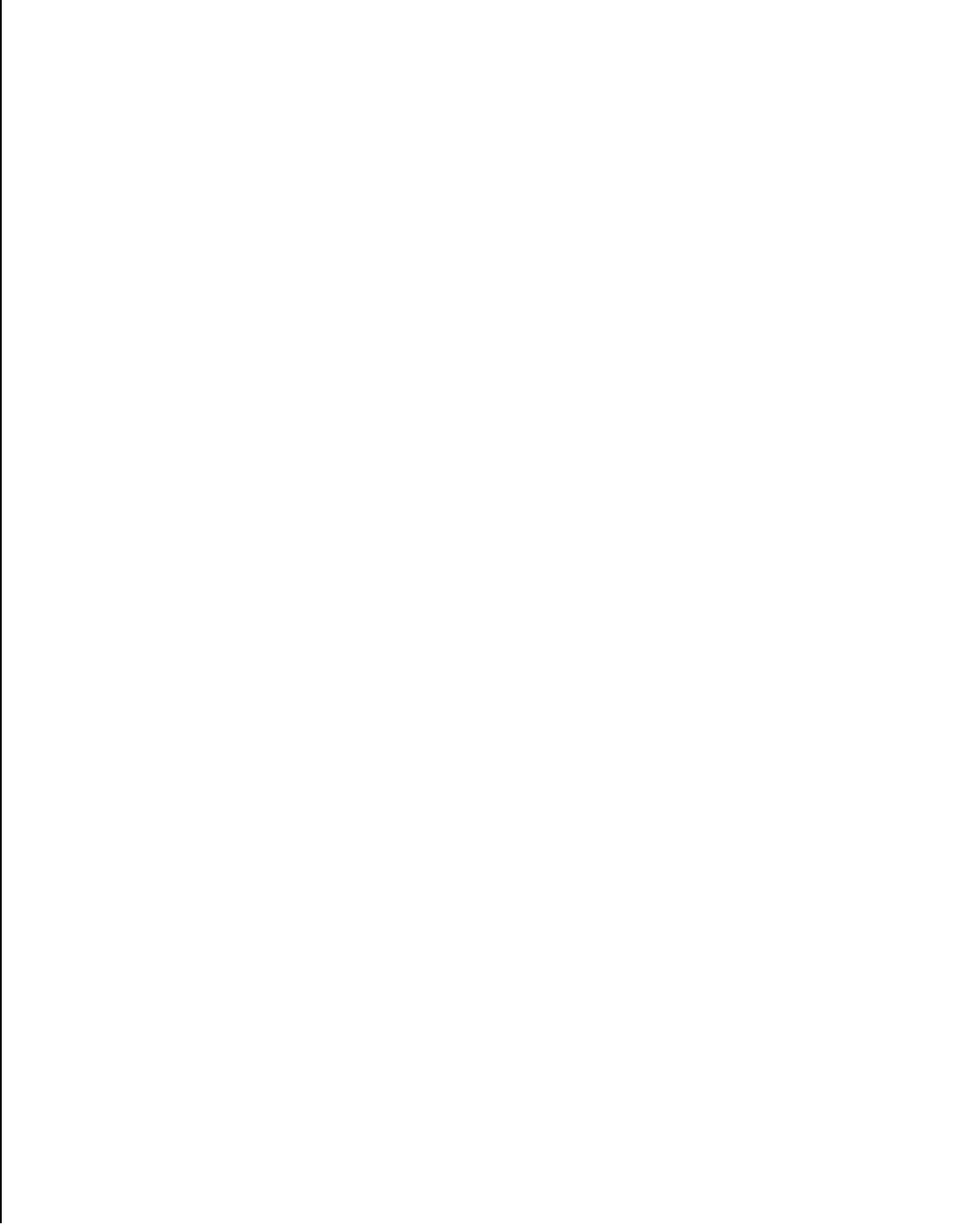
We are delighted to discover that the methods we had developed for English language typography have proved to be useful for the scripts of languages we had known little about. Mr. Ghosh has discovered, in fact, that two apparently different systems of writing have much in common; and he demonstrates in this report that the same computer tools can be used for both, in spite of their historical independence. This actually sheds new light on how the tools can be improved for use in English, so we have had a most productive two-way exchange. I sincerely hope that this pioneering work will facilitate the printing of all kinds of literature in India and elsewhere.

Donald E. Knuth
April, 1983



Acknowledgements

It is a very personal need for me to express my thanks for the support that I found wherever I turned. Above all I am extremely grateful to Prof. Donald E. Knuth without whose invaluable guidance, encouragement and support this work would never have been done. His pioneering work in digital typography has made it possible to extend this new technology to Indian scripts. Prof. R. Narasimhan served as my mentor at the National Centre for Software Development and Computing Techniques, T.I.F.R., India; I hope he has not counted the hours he spent in reading my long letters and writing back his indispensable suggestions in preparing this report. Dr. S.P. Mudur's earlier works and keen interest has helped me a lot. Almost all the members of the Digital Typography Project at Stanford listened to my ideas and offered suggestions for improvement. At the risk of committing many sins of omission I mention only Prof. Charles Bigelow, John Hobby, Scott Kim, David Siegel, Daniel Mills, Carol Twombly and Lynn Ruggles. I wish to thank Mr. Louis Rosenblum of the Graphic Art Research Foundation for his expert comments. I am particularly beholden to Mr. R.K. Joshi whose excellent drawings have enabled me to add the Appendix D of this report. It also remains to acknowledge with gratitude the help and cooperation of Ms. Phyllis Winkler in helping prepare this manuscript for typesetting.



About This Report

The knowledge of letters exerts a dual enchantment. When it uncovers the relationships between a series of arbitrary symbols and the sounds of speech, it fills us with joy. For others the visible expression of the letters, their graphical forms, their history and their development become fascinating. The advent of digital information technology has opened new vistas in the concept of letter forms. Unfortunately the graphics industry in India has remained almost unaffected by these technological advances, especially in the field of type design and text composition. This report strives to demonstrate how to use various tools and techniques, so that the new technology can cope with the plurality of Indian scripts. To start with all you need to know is the basic shapes of the letters of the Roman alphabet and the sounds they represent. With this slender thread of knowledge an enjoyable study of letter design and text composition in Indian scripts can begin.



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Unity Among Diversity¹

1.1 SCRIPTS IN VOGUE

India with an area as large as Europe without Russia and a vast population accounting for over one sixth of the human race, a country where so many different peoples from time immemorial have found a home, is, naturally enough, a land of many languages. There are sixteen(16) major languages and eleven(11) different scripts, a list of which is given below:

SCRIPTS	LANGUAGES
<i>(Northern Scripts- Nagari-family)</i>	
Devanagari	Sanskrit Hindi Marathi
Bengali	Bengali Assamese
Gujarathi	Gujarathi
Oriya	Oriya
Gurmukhi	Panjabi
<i>(Southern Scripts- Dravida-family)</i>	
Tamil	Tamil
Malayalam	Malayalam
Kannada	Kannada
Telugu	Telugu
<i>(Persian-Family)</i>	
Urdu	Urdu Kashmiri Sindhi
<i>(Roman)</i>	
Roman	English

Unlike the other scripts, Urdu and Roman (naturally) were not developed locally and had come down from Moslems and British rulers. Slighted extended Arabic (to include few extra consonants) can take care of Urdu script. Anyway, I will be concerned with the first nine major scripts in India.

1.2 THE ORIGIN

Although Nagari-family of scripts seem to be good deal different from Dravidian family, all those alphabets are ultimately descendent from the *Brahmi* script of ancient India (probably in the tenth century B.C. -derived either from the pre-*Aryan* script or from semitic system of writing). As its very name suggests the *Brahmi* script was invented for the preservation of *Brahma* or *Veda* (the oldest collection of hymns—the richest material in Hindu philosophy and religion). The religion and belief of the ancient Hindus required that the *Vedas* should be correctly pronounced; it could be done only through a teacher (or a *Brahamana*), who could recite the *Vedas* correctly, and not from a manuscript. Therefore the hand-written manuscripts were not at all popular and were used by the teacher for his own reference. Thus the scripts were changing from time to time, but there was a general uniformity of script up to a few centuries after Christ. Then local variations became accentuated in the different provinces. We have the Dravidian scripts or Southern scripts, an important development of which was the *Pallava* (c.500 A.D.), and this ultimately became Telugu, Kannada, Tamil and Malayalam. We have the Northern variations of *Brahmi*, successively the *Kushana* and the *Gupta-Brahmi*, the *Siddhamatrka* of the 7th century A.D. This last evolution of *Brahmi* in North India gave rise to three distinct groups during the closing centuries of the first millennium A.D., viz, the Panjabi (Gurumukhi), the Bengali-Assamese-Oriya, and Devanagari. The Gujarathi alphabet is but a cursive or broken form of Devanagari.

Let us come to some more close examinations. In spite of the difference in graphical forms, the sound system (i.e., phonetic system) is same for both Northern and Southern scripts. The Devanagari alphabet reads

VOWELS:

a, ā, i, ī, u, ū, ṛi, ṛī, ḷi, ḷī, e, ai, 0, au, am̐, ah

CONSONANTS:

1st series	k, kh, g, gh, ṅ
2nd series	ch, chh, j, jh, ṇ
3rd series	ṭ, ṭh, ḍ, dh, ṇ(cerebral)
4th series	t, th, d, dh, n(dental)
5th series	p, ph, b, bh, In
6th series	y, r, l, v
7th series	ś(palatal), g(cerebral), s(dental), h

This sequence of sound is the same in south Indian languages; but they have added short varieties of e and o and peculiarly south-Indian varieties of r and l. The Tamil alphabet is incomplete. In the first five groups of consonants it provides only for the 1st and 5th letters in every series. The first letter of every series is to serve the purpose of the 2nd, 3rd and 4th letters of that series. Ch serves the purpose of ś(palatal) also. The other three alphabets are as perfect as in Devanagari.

Let me jot down the basic theme of this chapter, before I finish it. Computer typography and typesetting of all pan-Indian scripts can be done easily if any one of them is considered carefully. (The scripts of Ceylon, Burma, Cambodia, Nepal and Tibet also can be handled, since they got their various scripts from India). We shall consider Devanagari as our basis since this is the script used by largest number of people in India.

2.1 GLOSSARY OF THE TECHNICAL TERMS TO BE USED

It is customary to put the glossary at the end. However, I feel this chapter may be well-understood if the readers become familiar with a few terms that will be used frequently. This chapter contains the Devanagari character set (graphical forms) with a brief introduction to the Indian mode of spelling. People who have a basic knowledge of phonetics can omit this glossary portion.

Aspirant: The use of more wind and addition of the h-sound to a non-aspirant. (In Devanagari the second and fourth letters of all consonant series, as well as the 7th series, are aspirants).

Cerebral: Letters that are pronounced by touching the roof of the mouth with the tongue (as 't' in 'put').

Dental: Letters that are produced by touching the teeth by the tongue (as 'n' in 'now').

Diphthong: Two vowel sounds pronounced in a single syllable (as 'i' in 'find' or 'u' in 'utensils').

Guttural: Letters pronounced from the throat (as 'k' in 'king').

Labial: Letters pronounced by lips (as 'p' in 'pan').

Nasal: The letter in pronouncing which, the wind passes partly through the nose (as 'ng' in 'song').

Sibilant: The letters that give a hissing sound at the time of pronunciation (as 's' in 'school').

Sonant: The letters that have softer sounds (as 'l' in 'law').

Palatal: When the upper blade of the tongue contacts the frontal hard palate of the mouth, we get palatal sounds (as 'ch' in 'Chinese').

2.2 SCHEME OF PRONUNCIATION:

In order to follow the Indian mode of spelling, one should use the International Script followed by the phoneticians. But the International Script is too complex for non-technical readers, so I shall use the simpler conventional system. According to this scheme,

1. The long vowels are represented by bars (ā, ī, ū), whereas the short ones without bars. For example,

SHORT	LONG
a pot/pat/	ā /arm/
i sit	ī see/sī/
u put	ū too/tū/ etc.

2. A few special vowels are represented by dots at the bottom, like ṛ Krishna etc.
3. Cerebral consonants are represented by dots below, e.g., ṭ time ḍ daily etc.
4. A few letters are represented in some clumsy way and you might need some personal help from people who are familiar with Devanagari script and spelling.

NOTE: The names of the letters in my METAFONT files do not follow the above scheme. One obvious reason is that I cannot use accents within my program. The scheme I followed can be described briefly like this:

1. Long form of the vowels like ā, ū etc. are represented by repeating the letter twice, e.g., ā=aa etc.
2. The cerebral letters are expressed by using the roman letters twice, e.g., ṭ=tt etc.
3. A roman letter or combination of letters that alone sounds nearer to the sound of the Indian letter is used for naming. The best example is the letter 'c' which alone sounds like 'i' as in 'pit'.
4. In all other cases I follow the phonetic scheme.

2.3 DEVANAGARI ALPHABET SET

Phonetically the basic alphabet consists of stand-alone vowels and stand alone consonants like Roman script.

1. Stand-alone Vowels:

These are vowels as 'independant sound units'.

SHORT	LONG
अ a	आ a
इ i	ई i
उ u	ऊ ū
ऋ ṛ	ॠ ṝ
ॠ ṝ	ॡ ṝ̄

DIPHTHONGS

ए e	ऐ ai
ओ o	औ au

ANUSWARA and VISARGA

अं am̐	अः a ḥ
--------	--------

2. Consonants:

Consonants are not considered as independant sound units, and are assumed to contain the basic vowel sound 'a'. The consonants are divided into seven(7) series. These are phonological groupings.

1st series	Guttural	क ka	ख kha	ग ga	घ gha	ङ nga
2nd series	Palatal	च ch	छ chha	ज ja	झ jha	ञ nya
3rd series	Cerebral	ट ta	ठ ṭha	ड ḍa	ढ ḍha	ण ṇa

4th series	Dental	त ta	थ tha	द da	ध dha	न na
5th series	Labial	प pa	फ pha	ब ba	भ bha	म ma
6th series	Sonants	य ya	र ra	ल la	व va	
7th series	Sibilants	श sha	ष ṣha	स sa	ह ha	

Indian scripts are SYLLABIC in character. Each distinct graphical unit is called *akshara* which represents a unique phonetic syllable. (It should be mentioned that the Indian scripts are not syllabic in the same way as Chinese on the one hand and the cuneiform on the other). The *akshara* could be lone vowel or a consonant, as listed earlier. Moreover the *akshara* can be a combination of a consonant and a vowel, or two or more consonants, i.e., consonantal conjuncts and a vowel. That is why there are more graphical units in a script than the basic alphabet set containing only vowels and consonants. All the *aksharas* are composed out of the graphical forms from the basic alphabet. The composition rule is fairly simple and will be discussed elsewhere. I present here the graphical forms that are MOST essential to obtain reasonably good and acceptable print quality output.

3. Vowel Markers or *Matras*:

When vowels modify consonants and conjuncts to produce 'syllables', they are represented by special signs called vowel markers or *matras*.

<i>Matra</i>	Example	<i>Matra</i>	Example
┌ a	क ka	┌ ā	का kā
┆ i	कि ki	┆ ī	की kī
◡ u	कु ku	◡ ū	कू kū
◡ ṛ	कृ kṛ	◡ ṝ	कृ̄ kṝ
◡ e	के ke	◡ ai	कै kai
┆ o	को ko	┆ au	कौ kau
◡ am	कं kam	◡ aḥ	कः kaḥ

4. Half Consonants:

We have already stated that each of the thirty three consonantal symbols represent the consonantal sound in combination with the short a-matra. That is why you find the graphical symbol (ळ) with almost all the consonants, which is the graphical representation for a-matra. To render conjunct consonants, i.e., consonant+consonant+...+vowel, one needs the consonant sound without the vowel a; that can be achieved by using a special mark (*halant*) preceded by the consonantal symbol. The *halant* mark acts as an operator and swallows the a- *matra* part. The consonant is said to become "half". For example,

गृ = ळ (half ga);

ga + *halant*

In a few cases half consonants can take a completely new graphical form. Those cases are shown below.

क (half ka) फ (half pha)

ॠ ॡ ॢ ॣ (half ra) [unfortunately r has four half forms]

ह्र (half ha)

5. Conjunct Consonants:

These are two or more half consonants followed by a vowel marker or *matra*, e.g.,

क्लब = क + ल + ऩ + ब = क्लब

conjunct consonant

Traditionally most of the conjunct consonants are given completely separate graphical forms, i.e., क्ल should be written as क्ल, but nowadays they are represented simply by writing the constituent half forms of the consonants side by side, or the consonants followed by *halant* marks. However, some of the conjunct consonants are very popular in their distinctly separate graphical forms. They are listed below.

अ + ३ + गृ = अ३गृ (aum)

क् + ष = क्ष (ksha)

ज् + य = ज्ञ (jnya)

त् + र = त्र (tra)

द् + य = द्य (dya)

श् + र = श्र (shra)

6. Other Symbols:

Although each script has its own numerals, Western style numerals are widely accepted in all Indian scripts. Punctuation marks except the pause sign are also the same. The operator marker *halant* symbol is included within the symbol set.

| pause mark

halant mark

7. Special symbols for extended Devanagari

A few sounds of non-Sanskrit languages were not provided for in the traditional forms of Devanagari. For this reason, the Central Hindi Directorate, Government of India (Publication No.3/67, New Delhi, 1967) proposed 'Extended Devanagari' which can function as India's link-script for transliteration into all Indian scripts. They are known as diacritical marks and six such symbols are there.

˘ ˙ ˚ ˛ ˜ ˝

8. Some Problems

There appears to be a good deal of confusion among the researchers about the exact character set of Devanagari script. It sounds strange, but quite reasonable when we understand the fact that Devanagari has been tried to use as a link-script for a country having a variety of scripts, even roman and persian.

This is not a proper place to deal with those controversial issues, but I 'would like to point out a few problems relevant for type design and text composition in Devanagari.

1. Some of the letters are so much similar to the others in shape that there remains a finite chance of confusion between भ (bha) and म (ma); घ (gha) and ध(dha); and ख (kha) and रव (rava). There is a recommendation that the graphical shapes of भ, घ and ख should be slightly modified to remove such confusion.
2. Many letters have two established forms that are quite different from each other. For example, श and श्च . In the matter of joining two consonantal characters more than one style are in vogue. For example, 'kka' is written both as क्क and क्क. Even some of the words are written in two different ways. For example, अंतर and अन्तर.
3. The lower dot to signify five Arabic sounds has been rejected by some as superfluous while others stick to it. Some printers represent another Arabic sound 'ain' by giving a dot under अ.
4. One of the illogical features of the script is the system of the application of vowel markers to the consonants. The natural place of the *matras* is after the consonants, but in Devanagari only a few *matras* are put after the consonants. Among the rest some are marked over the consonants, some under them and there is one *matra* 'i' (ि) whose mark is given before the consonants. The mechanical writing (for example, composition by Linotype machines) has some features different from those of the traditional writing. For example, ँ or ञ *matras* are not put under the characters because a different matrix is used for any *matra* and it can come only before or after a character.

3.1 THE PROLOGUE

Emil Ruder's important book on typography (*Typography, 1981*) states very clearly that,

“ The written character is and remains the basis of every typographical activity. It is not a creation of our century. The written character goes far back in time, spanning the vast distance from early hieroglyphics to the abstract written symbols of today and involving many contradictions. The typographer must be familiar with the evolution and recognize its problems so that he can do justice to the task of the future.”

I would, however, like to assure the reader that I am not going to introduce a section on Indian palaeography, although I know it would be one of the most fascinating and instructive studies. My basic aim is to present, in brief, the materials and techniques of writing of ancient India. This enables the reader

1. to understand more the basic shape and rhythm of the Devanagari script;
2. to realize why South Indian group of scripts differ from Northern groups; and
3. to get an idea of the type of strokes involved in designing the letters of various Indian scripts.

3.2 THE STORY

'Every script contains the spirit of its age' (*Type Sign Symbols*, A. Frutiger, 1980). The effect of the technical bearings of the writing tool, primarily the pen and material of writing, on letter forms is in evidence and recognized everywhere. The stiff and sluggish clay employed by the ancient Assyrians was the primary reason for the cuneiform or wedged-shaped symbols; the use of the waxed surface of tablets by the Greeks and Romans compelled a broken and disconnected style of writing; the frail papyrus made a light touch and slender characters necessary. But when smooth and hard-surfaced vellum was introduced, firm, clear letters with marked contrasts of fine and thick strokes became the fashion. This is the transformation history of Roman script in short.

Printing began as an aid to the art of the scribes, not as an independent art. The earlier printers, in their anxiety to compete successfully with manuscript books, adopted the existing written letter forms and did not question their entire suitability as shapes for reproduction into metal types. Nor did either printer or founder, for many years until printing had been recognized for its own sake, make any attempt to seek or create letter forms better adapted to type reproduction than the written characters.

As the typefaces were based on the written letter forms of the scribes, it is very important to note that still the type designer has tried to capture as much of this written form as possible. A simple example (from Roman typefaces, since the readers are supposed to be familiar with them, and since these typefaces have passed through innumerable number of changes over the centuries) may reveal the fact.

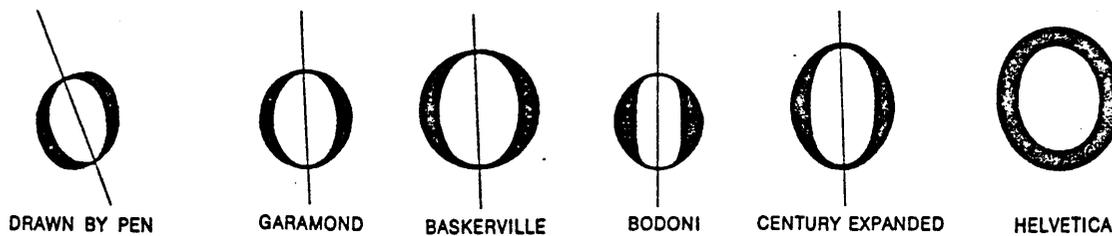


FIGURE 3.1

In Fig.3.1 the letter O has been drawn with a broad pen. This creates a thick stroke in the upper right and lower left, and a thin stroke in the upper left and lower right. This distribution of weight creates a diagonal stress through the thinnest part of the letter form.' It was this characteristic that the early typefaces tried to imitate. This is seen quite clearly in Garamond (Old style, 1617). As type evolved and the designer was no longer influenced by handwriting, the stress became more vertical (Baskerville-- transitional, 1757) and, later, totally vertical with Bodoni (Modern, 1788). In the Century Expanded (Egyptian, 1894) there is a return to a slight diagonal stress, and in the Helvetica (Contemporary, 1957) there is no noticeable change of stress at all.

In India, unlike the classical history of evolution of Roman typography, there is practically only one typeface in each script, and that also follows the early written

forms as far as possible. Practically no work has been done on Indian typography as yet, and the earliest typefaces are being used all over the country without any considerable modifications. The reasons for this gloomy picture (I am not going to discuss the country's socio-economic effect on typography, although this is the most important factor) is mainly because of the following reasons:

1. In Europe printing from movable types was introduced in the middle of the fifteenth century. (A copy of a letter of Indulgence now preserved at The Hague has the date of November 15, 1554. This is the first authentic date we have on any printed document.) Printing in India began in the late eighteenth century and it took quite sometime to become popular in regional languages.
2. The main bottleneck is the large number of complex graphical forms in each script.
3. Another problem has been that there are so many regional scripts. The Roman is the only script used uniformly throughout India.
4. In the eighth century, Emperor Charlemagne compelled the employing of skilled copyists and printing came at a time when the illuminated manuscript had reached its greatest period of perfection, and fifteen centuries of artistic traditions furnished beautiful models for the printers use. In India, by contrast much more stress was given on correct pronunciation of texts, and it was emphasised that the text should be memorised. The use of written texts for teaching or reciting was not regarded as honorable. Because of this, Indian printers had limited number of models for their use.

The history of the art of writing in India, like the history of ancient India in general, however, is quite exciting and interested readers may refer to the writings of D. Diringer, G. Grierson, G. Bühler, G.H. Ojha, R.B. Pandey, S.K. Chatterjee and S. Saran for detailed study.

3.3 WRITING MATERIALS AND THEIR EFFECTS ON INDIAN SCRIPTS

Ever since man made first scratch on the wall of a cave he has impressed by the performance of his art. The mother script *Brahmi* was widely used in engraving imperial proclamations on rocks and pillars by King Ashoka in the third century B.C. and later by his successors. *Brahmi* at that time showed many characteristics of semitic scripts- simplicity of strokes is one of such qualities. For example,

Phonetic Value	<i>Brahmi</i>
a	𑀅
b	𑀆 e t c .

The strokes contain mostly straight lines, with a very little curved portion here and there.

NORTH

Gradually paper like birch-bark (known in Sanskrit as *Bhurjapatra*) came to be in vogue as writing material (the earliest mention of birch-bark is found in the accounts of the Greek writer Q.Curtius (*Historiale Alexandri Magni*, Q.R. Curtius, 1908) who writes that at the time of Alexander's invasion of India the Indians wrote on bark; the earliest extant manuscript on bark belongs to the second or third century after Christ). The Himalayan regions produced this material in abundance and originally it was used in the north-western part of India and later on it travelled to other parts of the country; though in the south it never did become popular. The black ink that was most common was made of some pulverised charcoal mixed with water, gum, sugar or some other sticky substance. *Bhurjaputra* was very smooth for writing, and a flat hollow pen (shown in Fig. 3.2) was frequently in use.

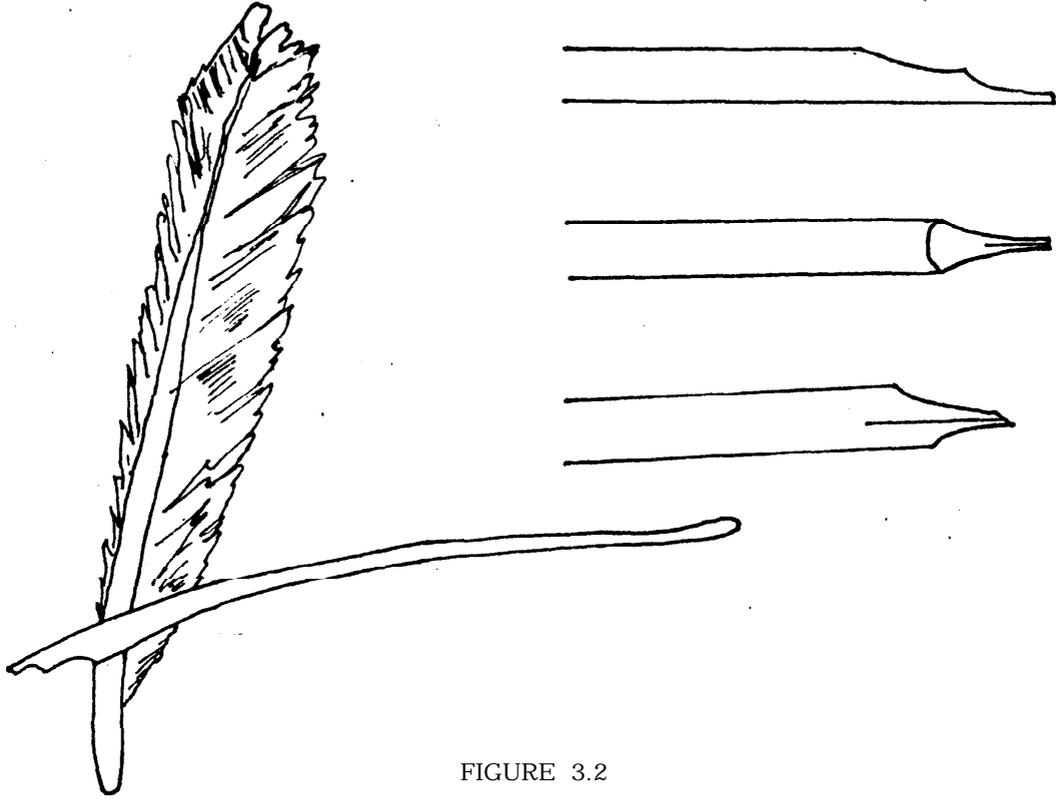


FIGURE 3.2

The calligraphy of the pen with its preference for curves followed the same rules in north Indian scripts as in western scripts, contrasting up-strokes with down-strokes and straight lines with curves. The first letter 'a' of all the north Indian languages is shown in Fig.3.3, which clearly illustrates the fact.

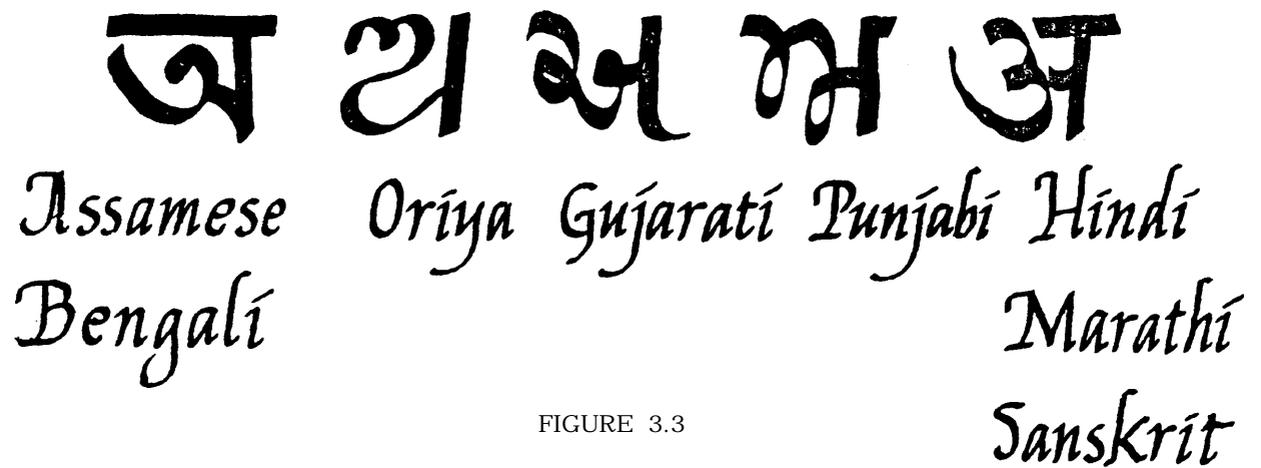


FIGURE 3.3

A few more characteristics of the Northern group of scripts should be mentioned.

1. Gujarathi script is more or less a direct adaptation of Devanagari **without head lines**. For example,

	Devanagari	Gujarathi
na	न	ન
ma	म	મ

The top horizontal head line or bar appeared as a practical matter, for alignment.

2. The chief difference between Nagari and Bengali (and Assamese) is that while in the former chiefly horizontal and vertical lines are used with a few rounded loops, in the latter, chiefly wedge-shaped or tapering downward lines are used with a few triangular loops. For example,

	Devanagari	Bengali/Assamese
na	न	ন
ma	म	ম
ka	क	ক

3. The Oriya script differs from Bengali in having an upward curve instead of head lines. This is because the Oriyas tried to write their letters on palm-leaves with stylus or pointed iron spokes, the leaves used to be torn, and so, instead of straight head lines, they used rounded ones. These eventually became more prominent than the letter themselves. For example,

	Bengali	Oriya
Ka	ক	କ

SOUTH

Another writing material that was very common in ancient India was palm-leaves (or *Tada-patra*) (the earliest manuscript belongs to second century A.D.). Palm was originally indigenous to southern India, where it was preferred to birch-bark because palm-leaves are so abundant in the south. Ink was introduced in the south rather late. The letters were scratched on the palm-leaves with a sharp, dry stylus. The manuscripts were made legible by dusting it with black powder, which remained in the crevices and made the writing visible.

For this reason the south Indian scripts are much rounder and more connected than those of north (since the leaf would be torn with horizontal lines). The formation of the stroke is absolutely fibre like (Fig.3.4).



FIGURE 3.4

The strokes are uniform so they can be obtained by using a circular pen. For example, the first letter 'a' of the southern scripts is shown in Fig.3.5.

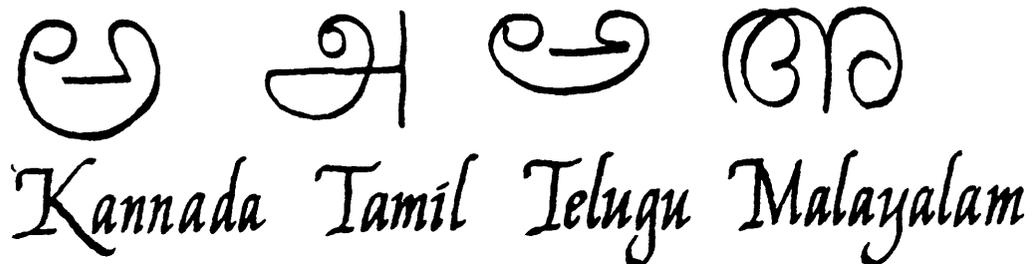


FIGURE 3.5

SIDDHAM Script

I feel my discussion on Indian scripts would be incomplete if I forget to mention the *Siddham* script. (The interested readers should consult R.H. van Gulik's book named *Siddham* for more information).

The study of the Sanskrit language never flourished in either China or Japan, while the Indian script- in a variety of *Brahmi* called *Siddham*— played an important role in far Eastern Buddhism ever since the introduction of this script into China in the eighth century A.D.

The calligraphic aspect of *Siddham* script can be described in a sentence like this: This is one of the four scripts in the world of such intrinsic artistic value as to deserve a place in the realm of fine art.

A few *Siddham* letters are shown in Fig.3.6.



FIGURE 3.6

3.4 EARLY PRINTING IN DEVANAGARI

Printing with movable metal types was introduced to India as a result of European penetration in the country. The first printing-press in India was set up by Portuguese Jesuits at Goa in the year 1556. The local speech of Goa was Konkani- a variety of Marathi. All the early Konkani works from Goa were printed with roman types.

In 1576-7 a blacksmith João Gonalves prepared just fifty Konkani letters and matrices (most probably in Devanagari script), but died the next year without completing the font.

The earliest printed specimens of Devanagari are in books produced in Europe. The oldest among them is the wood-cut signature of a ship's captain from Diu (island of Gujarath) on a bill of sale of goods to John Saris, General of East India Company's Eighth Voyage. This was reproduced in Samuel Purcha's *Purchas his pilgrimes* (4th edition) printed at London in 1625.

In the 1740s movable Devanagari types were cast in Rome at the Congregatio de Propaganda Fide press, on the orders of Pope Urban VIII. The letters were designed by Indian converts studying in Rome. These are the earliest known movable Devanagari types successfully cast in either India or Europe. These types were first used to print Indian words in Antonio Giorgi's *Alphabetum tibetanum* in 1759 and the expanded version in 1762, recasting some missing types. In 1771, the *Alphabeturn brammanicum*, an extensive treatise on Devanagari syllabary was issued from the press. Giambattista Bodoni's *Manuale tipografico* (2nd edition, vol 2, Parma, 1818) included a specimen of *Bracmanico* types clearly modelled on the Congregatio's Devanagari font.

In 1789, the Chronicle Press, Calcutta, issued volume one of *The new Asiatick miscellancy* containing Sanskrit and Dakkhini-Urdu verses printed with Devanagari types locally cast. This is the earliest known use of movable Devanagari types in India. The same press issued *Ulfaz udwiyeh*, a medical dictionary with 600 Hindustani names printed in the same Devanagari types in 1793. The London typefounder Joseph Jackson prepared a Devanagari font for William Kirkpatrick. In 1799, a small part of Kirkpatrick's work *New hindvi grammar* was printed in Calcutta using Jackson's font. Peter Spalding at the East India Company's Calcutta mint also cast Devanagari types for printing the Hindi translations of government regulations from 1793 onwards. In June 1796, these types were also used in an official notice in the *Calcutta Gazette*—the first appearance of Devanagari in a newspaper.

The Serampore Baptist mission press in Bengal (near Calcutta) under Carey, Marshman and Ward dominated the early 19th century's printing in India. In its type-foundry in 1803 Panchanan Karmakar, a Bengali blacksmith (who earlier cut a Bengali font) with Charles Wilkins produced a Devanagari font first used in 1805 to print *St. Matthew* in Marathi and Carey's Marathi grammar. During the years 1800 to 1838, of 212,000 Biblical volumes issued from Serampore, nearly 65,000 of these were printed in Devanagari. In 1818 Serampore published a Hindi monthly *Digadarshna*—the first 'all-Devanagari' periodical. The other notable Devanagari presses at that time were the Hindoostanee Press, Calcutta(1802–), Babu Ram's Sanskrit Press, Calcutta(1807–) and the Baptist Mission Press, Calcutta(1818–).

After Calcutta, Bombay became the center of Devanagari printing in India. In the year 1805, the *Bhagavadgita* was block-printed in Miraj. This was done on copper plates by a smith trained at Nana Fadnavis' craft school at Poona. In 1816 American Congregationalists set up a press in Bombay under Horatio Bardwell with Devanagari types from Calcutta. The Bombay Native Education Society had many school books printed in Devanagari such as the *Panchopakhyana* at the Courier Press in 1822 with types of Wilkins' design imported from England. Elijah Webster and Thomas Graham successfully substituted half-letters for conjuncts and reduced the size of Devanagari types while also improving the letters' shape. This was done in the American Mission Press' own type-foundry (set up in 1836). Ganapat Kṛsnaji and Javji Dadaji, once apprenticed to Graham, also contributed greatly to Devanagari typography.

From 1820s printing by lithography became popular in India. Excellent lithographic stones found locally made it economical and it reproduced the scribal hand easier for the majority to read than letterpress. The lithographic presses worthy to mention were, the Greenway family's press at Kanpur(1830–), the Bombay Government Lithographic Press(1824–) and George Jervis's Press at Poona(1830–).

Devanagari printing developed in England in the early 19th century because the East India Company sought to print oriental works locally rather than import them from India, especially for its training college at Haileybury(1806–). Moreover, the rise of indology in continental Europe led to the casting of excellent Devanagari fonts in Germany and France. Among them, Figgin's, Bodoni's, Delafond's and Vibert's design are worth mentioned.

This is not a place to discuss in detail of the history of printing art in Devanagari and the readers may refer to the works of the individuals I have mentioned. Anyway for the curious readers I am adding an example page (Fig.3.7) from C.R. Lanman's *A Sanskrit Reader* printed at Harvard University Press, Massachusetts in 1884.

श्मश्रुलोमनखानि वापयित्वोपकल्पयीरन्नवान्मणिकान्कुम्भा-
 नाचमनीयांश्च शमीसुमनोमालिनः शमीमयमिध्मं शमीम-
 य्यावरणी परिधींश्चानदुहं गोमयं चर्म च नवनीतमश्मानं च
 यावत्यो युवतयस्तावन्ति कुशपिञ्जूलानि ।४। अग्निवेलाया-
 5 मग्निं जनयेदिहैवायमितरो जातवेदा इत्यर्धर्चेन ।५। तं दीप-
 यमाना आसत आ शान्तरात्रादायुष्मतां कथाः कीर्तयन्तो
 माङ्गल्यानीतिहासपुराणानीत्याख्यापयमानाः ।६। उपरतेषु
 शस्त्रेषु संप्रविष्टेषु वा गृहं निवेशनं वा दक्षिणाद्वारपश्चात्प्रक्र-
 म्याविच्छिन्नमुदकधारां हरेत्तन्तुं तन्वन्नजसो भानुमन्विही-
 10 त्योत्तरस्मात् ।७। अथाग्निमुपसमाधाय पश्चादस्यानदुहं चर्मा-
 स्तीर्य प्राग्गीवमुत्तरलोम तस्मिन्नमात्यानारोहयेदा रोहता-
 युर्जरसं वृणाना इति ।८। इमं जीवेभ्यः परिधिं दधामीति
 परिधिं परिदध्यात् ।९। अन्तर्मृत्युं दधतां पर्वतैर्नित्युत्तरतो
 ऽश्मानमग्नेः कृत्वा परं मृत्यो अनु परेहि पन्थामिति चतसृभिः
 15 प्रत्यृचं हुत्वा यथाहान्यनुपूर्वं भवन्तीत्यमात्यानीक्षेत ।१०। युवत-
 यः पृथक्पाणिभ्यां दर्भतरुणकैर्नवनीतिनाङ्गुष्ठोपकनिष्ठिका-
 भ्यामक्षिणी आज्य पराच्यो विसृजेयुः ।११। इमा नारीरविधवाः
 सुपत्नीरित्यञ्जाना ईक्षेत ।१२। अश्मन्वती रीयते सं रभध्वमि-
 त्यश्मानं कर्ता प्रथमो ऽभिमृशेत् ।१३। अथापराजितायां दि-
 20 श्यवस्थायामिनानदुहेन गोमयेन चाविच्छिन्नया चोदकधार-
 यापो हि ष्टा मयोभुव इति तृचेन परीमे गामनेषतेति परि-
 क्रामत्सु जपेत् ।१४। पिङ्गलो ऽनङ्गान्परिणेष्यः स्यादित्युदाहरन्ति

FIGURE 3.7

This report is primarily intended for discussing a few issues of type design in Indian scripts, mainly Devanagari. For Indian scripts, however, the text composition problems cannot be separated from the problems of typeface design and this chapter may help the reader to comprehend the way they are inter-mingled.

4.1 BASIC FEATURES OF INDIAN LANGUAGES

1. Because of common origin, Sanskrit and all local languages possess identical structure with marginal variations.
2. Indian languages are phonetic. The phonetic accuracy of the languages compares well with that of the modern phonetic transcriptions.
3. The basic graphical unit is called *akshara* which represents a unique phonetic syllable.
4. Each script has quite a large *akshara* set, sometimes leading to eight hundred individual graphical forms.

5. The composition of a syllabic symbol from its component elements is not always linear in the Indian scripts. For Example,

क + ॊ = कु; क + ी = की.

consonant+matra

6. The syllabic symbols are arranged in linear succession and are read from the left to the right. For example,

कनु + थ् = कनुथ्

syllable Knu+th

7. Each script consists of seven phonetic classes of symbols, i.e., i) stand alone vowels; ii) full consonants; iii) vowel markers or *matras*; iv) a consonant and a *matra*; v) half consonants; vi) conjunct consonants; and vii) special symbols. In Chapter 2, I have discussed in some detail about different groups.

4.2 CONJUNCT CONSONANTS

I mentioned already that to generate a conjunct consonant, i.e., consonant+ consonant+ . . .+vowel combination, we need consonants without a-matra and that can be achieved by using a special symbol mark called *halant*. The rendering of conjunct consonants is a special problem for Indian syllabic writing.

Generally such combinations are related by ligatures- combination of the characteristic parts of the sign representing the syllable beginning with the preceding consonant, and of those of the sign representing the syllable beginning with the following consonant. Two, three or more consonant combinations could be represented in such a way. The parts of the symbols combined, which often underwent significant changes, could be arranged either horizontally (this representation is nowadays becoming popular for the ease of composition) or vertically. For example,

स्क ska प्र pra

Many such combinations actually became independent graphic entities which lost all connections with the component symbol and became invisible. Such ligatures are, in fact, graphic idioms.

क्ष ksha ज्ञ jnya श्र shra

4.3 PROBLEM OF TEXT COMPOSITION IN INDIAN SCRIPTS

The large number of distinct graphical symbols or *aksharas* in each script and their non-linear composition need a very large and cumbersome keyboard for inputting raw text. Moreover, direct coding of *aksharas* leads to at least 8-bit code (maybe 9-bit sometimes) and there are many advantages in restricting the code size within 7-bit which is required for coding roman script. Hence three major design issues that need to be tackled in extending the computerized text composition technology to Indian scripts are:

1. The design of smaller and simpler keyboards and keying techniques.
2. The design of efficient internal codes for the characters of a script for information processing, storage and transmission.
3. The design of information-processing algorithm and *akshura* composition logic. The logic for *akshara* composition could be made as facile as the actual writing of the script.

4.4 A VIABLE SOLUTION

Let

- S: character set in an Indian script
- V: stand-alone vowel set in the script;
- C: consonant set;
- M: *matra* set;
- X: a consonant plus a *matra* set;
- H: half consonant set;
- h: *halant* sign;
- 0: other special symbol set;
- Y: conjunct consonant set.

Therefore,

$$S=(V, C, M, H, h, 0, X, Y).$$

As far as graphical representation is concerned the eight members of S are disjoint, but from phonological point of view only V, C, h and 0 are basic set- the remaining four sound sets are the product sets of them.

What I would like to infer from this discussion is this:

Any *akshara* or syllable can be considered as a molecule with its consonantal and vowel radicals as atoms. Thus the elements of V, C, h and 0 are the phonological atoms and phonetically all *aksharas* are composed out of the elements from the basic phonetic atom set A.

$$A=(V, C, h, 0).$$

There is a dispute between the phoneticians in India over the issue of choosing a phonetic atom set. Some people consider the half consonant set H to be the primary consonantal sound set, instead of the full consonant set. They argue that a half consonant, when combines with the vowel sound 'a', forms a full consonant. Therefore,

$$A=(V, H, h, 0).$$

However, the basic idea remains the same and we are provided with a viable solution of the problems as mentioned before. Let me explain this in some more detail.

4.5 ASSIGN CODES TO INDIAN SCRIPTS

Instead of direct coding of the *akshurus*, we shall assign codes to the phonological atoms. The effective number of elements in the vowel set V are thirteen (13), since \bar{r} , \bar{l} , \bar{I} are no longer in use. There are thirty three (33) consonants, plus a *halant* symbol (1) and seven (7) other symbols including the pause sign. Moreover, there is a requirement of a BREAK function key which prevents some of the usual operations to be performed. For example, a consonant followed by the *halant* sign usually generates the half-form of the consonant, but the BREAK function is used if there arises a need to generate both the consonant and the *halant* sign- and not the half form, i.e.,

$$\text{क} + \text{्} = \text{क्}$$
$$\text{क} + \text{BREAK} + \text{्} = \text{क्}$$

Thus we have fifty five (55) distinct elements to be coded and this number is fairly small. We may safely adopt a 7-bit coding scheme for Indian scripts even after retaining all the control characters, numerals, punctuation marks and special characters of ASCII code. The stop sign(.) may be replaced by Indian pause symbol I . The fifty two roman letters, dollar sign and ampersand can be substituted by the rest fifty four elements. The lexical ordering of the phonological atoms has to be maintained before assigning the codes to them. A **Phonetic Atom Code Chart** thus formed is shown in Fig.4.1 .

This *phonetic atom coding scheme* far outweighs the *graphical coding scheme*. For example,

1. Since all Indian languages have same phonetic structure, a coding scheme based phonetically can serve all Indian scripts identically. There is a tremendous lot to gain by this. It would ease many of the future problems of information-processing in Indian scripts- primarily transliterations.
2. The 7-bit ASCII-like code enables all computer equipments produced for the English languages to be made use of with the changes at the software level only.

**Universal Phonetic Atom Code Chart
for Information Interchange**

	0	1	2	3	4	5	6	7
'000	NUL	SOH	STX	ETX	EOT	ENQ	ACK	BEL
'010	BS	HT	LF	VT	FF	CR	SO	S1
'020	DLE	DC1	DC2	DC3	DC4	NAK	SYN	ETB
'030	CAN	EM	SUB	ESC	FS	GS	RS	u s
'040	SP	!	*	#	~	%	अं	'
'050	()	*	+	,	-		/
'060	0	1	2	3	4	5	6	7
'070	8	9	:	;	<	=	>	?
'100	0	अः	'	-	.	,	5	अ
'110	क	ख	ग	घ	ङ	च	छ	ज
'120	झ	ञ	ट	ठ	ड	ढ	ण	त
'130	थ	द	ध	[\		.	-
'140		न	प	फ	ब	भ	म	य
'150	र	ल	व	श	ष	स	ह	आ
'160	इ	ई	उ	ऊ	ऋ	ए	ऐ	ओ
'170	औ	<अ>	BREAK	{		}	~	DEL

The total number of individual graphic symbols in any Indian language is too large, basic ones reaching to two hundred fifty or so. Direct coding of such syllables or *Aksharas* will lead to a large code. There are many advantages in restricting the code size (in bits) required to represent Indian languages to that required for coding English. The standard code for English is the ASCII, a 7-bit code. Indian languages should also be coded in 7-bit sequences.

We have adopted a solution of assigning codes to the "Phonological Atoms" and not to Graphical Forms. All Indian languages are phonetic. A coding scheme based on phonetic characteristics can serve all Indian scripts identically. Moreover, it would ease many of the future problems of information-processing in Indian scripts.

FIGURE 4.1

4.6 DESIGN OF KEYBOARD

The idea of phonetic atoms provides us with the unique facility of using QWERTY keyboard for text inputting in Indian scripts by merely changing the key top symbols. The phonetic atom set in any script is the minimal set, using which any piece of text of the script can be 'phonetically' keyed into the system. The usual 44 QWERTY keys, which provide an 88 character set by shift operation, are more than sufficient for this purpose.

It is better to mention that the keyboards used by the printer contain additional characters, symbols, points and function keys in different shift conditions for a variety of typesetting applications, although the QWERTY arrangement provides the basic layout for the alphabetic keys. In my discussion of keyboard design, however, I am not going to consider those additional keys.

The general considerations for designing the keyboard are:

1. **UNIVERSALITY:** The same keyboard can be used in both mechanical impact typewriter as well as electronic input keyboard.
2. **HAND LOADS:** The key arrangement of the typewriter should be for the convenience of the typist. (The English QWERTY layout doesn't serve this basic purpose). This claims that the major percentage of typing should be done on the home key row. Moreover, the loads should be properly balanced on fingers and on both hands. A proper frequency count of the characters is necessary for this purpose.

Over and above those, the phonetic keyboard layout for Indian scripts needs:

3. key assignment of the necessary phonetic atoms;
4. inclusion of additional graphical forms, depending on their frequency of occurrence and the availability of free key position on the keyboard;
5. proper grouping of letters, so that the letters of same phonetic group are located in close proximity for easier memorization.

A keyboard design by the author is provided in Fig.4.2 as a model.

Minimal-Sign Keyboard (44 Keys)

BREAK	'	()	%	.	-	+	=	ञ	*	'
BS	7	5	3	1	9	0	2	4	6	8	१
!	८	/	॰	:	क्ष	ज्ञ	छ	झ	ॠ	श्र	
?	,		प	र	ल	व	च	ज	ी	/	
भ	फ	य	ब	ख	घ	ह	श	ष	ॡ	ॢ	
म	त	न	क	ग	।	अ	स	,	.		
॰	ए	थ	ध	ठ	ढ	ण	ऋ	ॠ	ॡ	ॢ	
;	इ	उ	द	ट	ड	ॡ	ॢ	ॣ	।	॥	
SPACE BAR											

NOTE: The keyboard design is based loosely on the idea of Dvorak Keyboard. (The 'qwerty' arrangement throws too much work on the left hand and does not distribute the most used characters evenly over the fingers. In 1932 Lt.-Cmdr. August Dvorak and William L. Dealey patented a keyboard to give a character loading distributed for optimum fingering with 70 percent usage on the 'home' keys). All the diacritical marks for extended Devanagari and all most all the necessary punctuation marks are included in the present design. The frequently used conjunct characters are also added. Please note the arrangements of the numerals and punctuation marks in the layout.

FIGURE 4.2

An important point to be noted here is that because of the way keyboard design has taken place, there is no one-to-one correspondence between keys and the internal codes. This happens primarily for the following reasons:

1. Frequently occurring additional forms, as mentioned above, are included for efficient input of text. These additional forms are 'phonetic molecules' and internally will be represented by a sequence of two or more phonetic atom codes. For example,

$$\begin{aligned} \text{क्ष} &= \text{क} + \text{्} + \text{ष} \\ &= 110, 171, 154. \end{aligned}$$

2. It would be possible to input some *akshara* by a single key-stroke as well as a combination of key strokes from the minimal set and both should result in the same internal representation.

However, a simple software module for 'key code to phonetic atom code translation' solves the problem.

4.7 ALGORITHM FOR AKSHARA COMPOSITION

The basic philosophy behind our *akshara* composition logic is this: A sequence of phonetic codes represents a syllable here. Therefore, to generate a complex or fused graphical form, one has to input, in sequence, its consonantal and vowel **atoms**. The corresponding code (or codes) emitted by each key stroke is stored in the computer memory. From this sequence of phonetic codes a computer program then decides what the corresponding print code (or codes) should be (it is to be mentioned that each and every distinct graphical form has been given a unique print code for its proper identification) for the graphical form and passes it on to the output machine for its actual representation.

From the programming point of view, each phonetic atom has its own tree structure which connects the atom codes and the print codes of the *aksharas*. The main procedure is to walk through that tree, compare the code sequence stored in the memory with that of the tree and arrive at the correct print code (or codes).

Example: Fig.4.3 shows the tree diagram of the phonetic atom क (phonetic atom code:110).

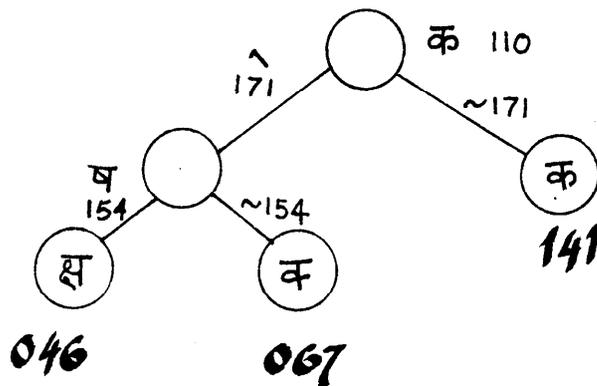


FIGURE 4.3

It follows clearly from the diagram that the phonetic atom code sequence 110, 171, 154 would produce a print code 046 (for the *akshara* क्ष), whereas if the code 110 is not followed by 171, the print code 141 for the *akshara* क will be generated.

PRINT CODES OF THE CHARACTERS:

There is no need to give special attention to choose the print codes of the characters, since they are supposed to be used only locally. Any Indian script contains more than 128 characters including special symbols, numerals and punctuation marks. There are many ways of handling the print code assignment problem. I am presenting here two simplest ways.

1. A 8-bit (or 9-bit, if there is more than 256 characters) code could be assigned to each character, if the text composition program can take care of that. For example, \TeX is one such package.
2. Most of the existing programs for typesetting English text handles only up to 7-bit codes, but allow the user to use at least four fonts at a time. It is, therefore, wise to sub-divide the character set into a number of convenient subsets, where each subset contains less than 128 characters. Each subset can then be considered as a separate font, and a 7-bit print code may be assigned to the characters of each subdivision. One such **Print Code Chart** is shown in Fig.4.4, where the numerals and punctuation marks are kept as a separate font.

Print Code Chart for Devanagari Characters

	0	1	2	3	4	5	6	7
'000		ॠ	ॡ	ॢ	ॣ	।	॥	०
'010	०						ॠ	ॡ
'020	ॢ	ॣ	।	॥	०	ॠ	ॡ	ॢ
'030	ॣ	।	॥		०		ॠ	
'040					ॠ	ॡ	ॢ	
'050							ॠ	
'060	ॠ	ॡ	ॢ	ॣ	।	॥	०	ॠ
'070	ॡ	ॢ	ॣ	।	॥	०		
'100		ॠ		ॢ	ॣ	।	॥	०
'110	ॠ	ॡ					ॠ	ॡ
'120	ॡ	ॢ	ॣ	।	॥	०		ॠ
'130	ॢ		ॣ					
'140		ॠ	ॡ	ॢ	ॣ	।	॥	०
'150	ॠ	ॡ	ॢ	ॣ	।	॥	०	ॠ
'160	ॡ	ॢ	ॣ	।	॥	०	ॠ	ॡ
'170	ॢ	ॣ	।					

Any Indian script contains more than 128 different graphical forms including the punctuation marks, special symbols and numerals. Therefore, one expects at least a 8-bit print code for the characters. Unfortunately the current version of METAFONT does not allow any 8-bit code. That is why the above print code chart is a 7-bit code chart and may create confusion. Please note that the numerals and punctuation marks are not shown there. Moreover, in this *Simplified Devanagari* the special diacritical marks are not included. A separate font containing the numerals etc serves the purpose of complete typesetting in Devanagari.

FIGURE 4.4

HYPHENATION:

The hyphenation rules for Indian scripts are trivial since each *akshara* represents a unique phonetic syllable.

A FEW PROBLEMS:

A few illogical features of the Indian scripts make the *Akshara Composition Logic* a bit difficult. Some of the immediate problems that arise are the following.

1. In Devanagari all the *matras* except one are written after the consonants and that is quite logical from phonetic viewpoint. The discrepancy is for *matra-i* (ि) which is written before the consonants. Moreover, this feature is not uniform in all other languages— more than one preceding *matras* are there in Bengali, Tamil and Malayalam.
2. The graphical symbol *reph* (े) is one of the four forms of half *ra*. In Devanagari the stand-alone vowel long-i (ई) graphically resembles the vowel short-i (इ) plus *reph* (े), which is phonetically illogical. The same phonetic problem exists for o- (ऌ) and au-*matra* (औ) that can be graphically formed from ā-*matra* (ा) and e- (ए) or ai-*matra* (ऐ).

There are some more. However, the solutions can be provided by adding an 'exception handler module' with the main routine.

5.1 LETTERING DESIGN

Following the discipline of letters cut in stone came the freedom of written letters which was followed by the firmer discipline of letters cast in a rigid system of metal types. Photocomposition allows more freedom where light and lenses can play a lot of tricks and deceptions. Now with the advent of digital typography we are again back to the infinite freedom of letterforms. Many critics often raise their voice against this new freedom. They find that lettering today is a confusing variety of styles, with standards of design and practice crumbling while eccentricity flourishes. Typography has a rich traditions and a correspondingly solid and extensive foundation of rules and requirements, for execution and appearance of the work. On the other hand, there are others who consider this foundation all too solid, its rules and doctrinal philosophy restrict the evolution of letterforms which are linked to new tools and technology. The tremendous speed and continuing reductions in cost of digital typesetting compared to analog typography 'may rival in significance the Renaissance shift from script to print.' At this transitional period it is really hard to find out unambiguous principles of construction of letters. However, I can recall Frutiger in this occasion who states,

“The replacement of mechanical by electronic methods, of relief type by the focussing screen and the photographic emulsion, does not make any basic difference to the fact that type represents and will remain above all a human problem.”

For the last few years I have been studying Devanagari typefaces designed at different times using different tools and techniques. We are in touch with thousands of contemporary roman type faces and quite a number of roman type fonts designed on the basis of past styles. I strongly feel that there are a few basic design considerations, some basic principles and pre-requisites, which are totally independent of material and technology; they do not differ whether it is a roman lettering design or any Indian script. In this section I would like to note down those basic principles which I followed to design my Devanagari fonts NCS D. I claim no fresh discoveries, but only careful editing of ideas of different typographers of different periods of history, which helped me in my lettering design- directly or indirectly. (Most of the time I have set examples from roman scripts, since almost all the readers are expected to be familiar with that).

5.2 A FEW PRE-REQUISITES

1. An awareness of historical developments:

The design of letters by no means implies the creation of entirely new shapes, for no one would recognize them. We re-use and adapt the forms we know, occasionally adding fresh and original variations. It is, therefore, essential to be aware of the historical development for a real understanding of letter-forms. "Tradition itself, however, is merely the ladder by which we climb, the working hypothesis that saves us from despair because it is all we have to go on. If we obey tradition, even though our efforts at first are crude and archaic, our work will rest upon a firm foundation" (*Typologia*, F.W. Goudy, 1940). Frutiger did an excellent experiment to find out the basic pattern of each letter for the best legibility. He selected a few classic type-faces and superimposed their screened-forms which resulted in a diagram as follows.(Fig.5.1)

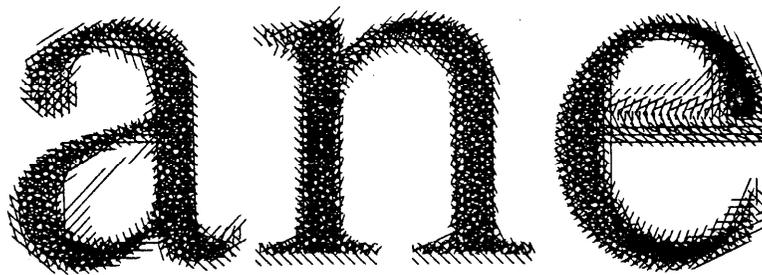


FIGURE 5.1

He concluded that the dark areas (or the silhouettes) covering all the figures form a kind of basic skeleton which have engraved themselves in the subconscious of the reader as a kind of elemental form.

2. A knowledge of tools, techniques and purpose of lettering

Design may either organic or inorganic. Organic design expresses the relation between the letter and its use or between the letter and the forms and

methods of combination of the material in which it is executed. In designing a typeface of any kind, first thought must be given to find out what is its function. A typeface intended for book covers or title pages should be different from a typeface used for printing a large amount of text.



(a)



(b)

FIGURE 5.2

In Fig.5.2a the letters with no historical associations, obeying no formal rules certainly express the driving force and individual quality of certain kind of jazz music, whereas the old fashioned feeling of a word is expressed by using letterforms which is no longer in every day use.(Fig.5.2b)

The second point of consideration in design is the tools and techniques: For example, in photomechanical typesetter machines an interior angle of a very sharply drawn part of a letter is quickly faded, whereas a step-like image results from digital typesetters. (Fig.5.3)

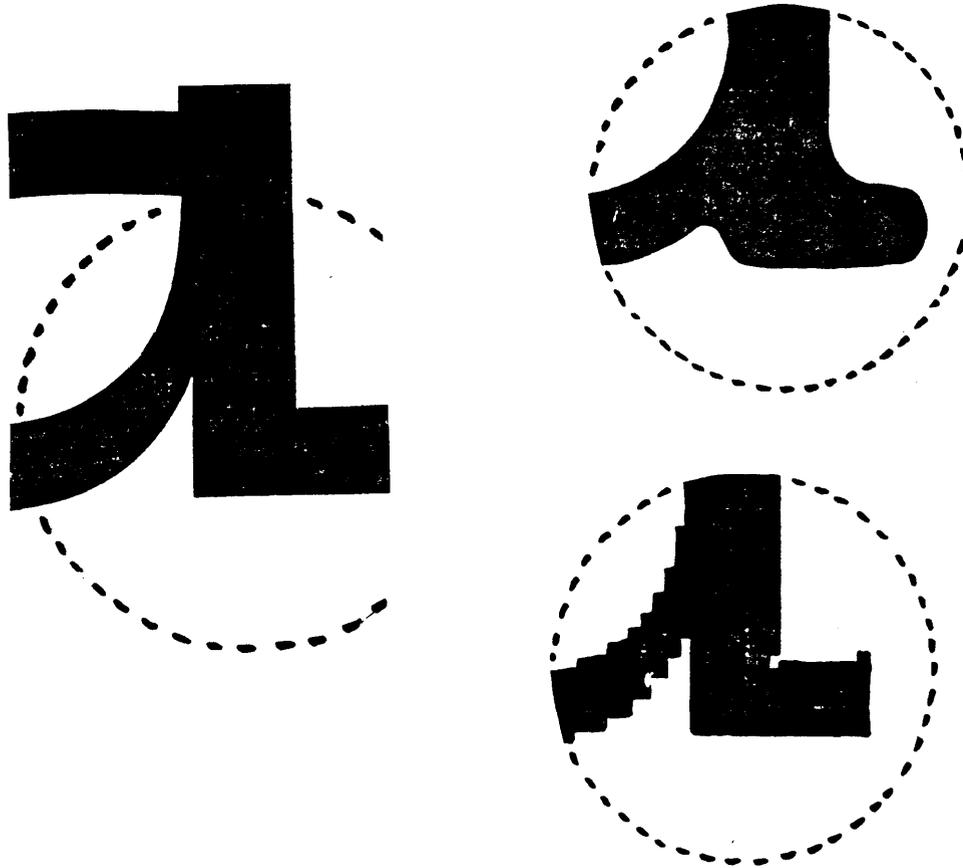


FIGURE 5.3

From the very beginning the type-designer must take into account of the special conditions for the new techniques.

Inorganic, or pure design expresses the relation between shapes, their proper arrangements and so on which will be discussed in the next section.

3. Understanding the difference between written letters and built-up letters

All letters in use today may be classified into two groups.

a) *Written letters or letters drawn directly with the tool (i.e., pen or brush) —*

In this class we find letters whose style and quality of line are dependent largely on the kind of the tool used. For example (Fig.5.4),

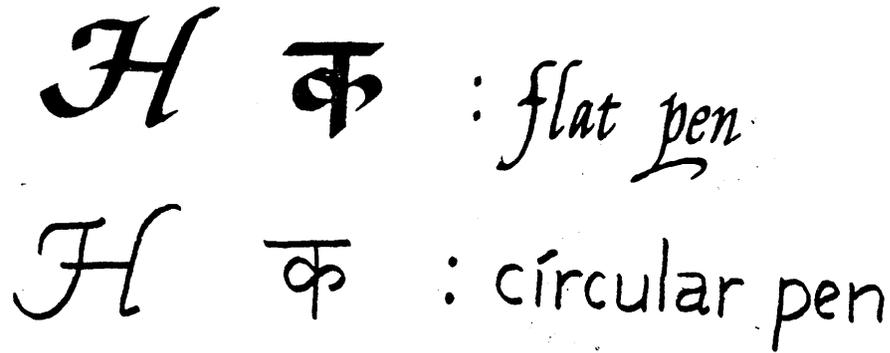


FIGURE 5.4

b) *Built-up letters or letters outlined and filled in —*

Built-up letters are dependent not on the tools so much as upon the taste and knowledge of the craftsman. In these letters, the designer has the all the liberty he chooses in the placing of the thicks and thins. For an amateur, it is better to practise the pen-made letters first- not the built-up forms. However, the type designers today go for built-up letters where corrections and retouching is not discoverable and better appearance may be achieved.

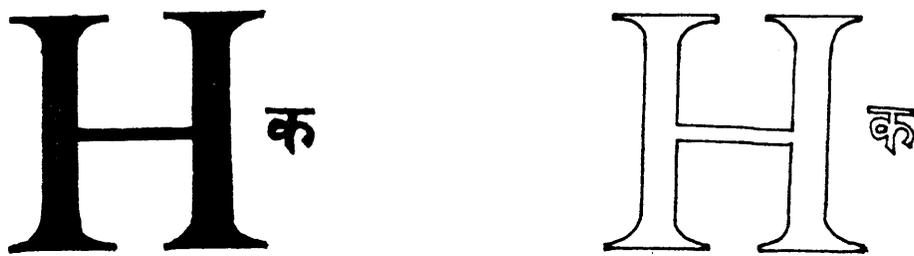


FIGURE 5.5

4. Proper grouping of letters

Disregarding all calculations, geometrical or otherwise, the designer has before him the problem of proper grouping of letters. This grouping is essential for type design to understand the similarities and dissimilarities of different letters in an alphabet. Depending on requirements, there may be different type of groupings. For example,

a) *Grouping to determine the respective heights of letters in a roman font*

group I: letters with no ascending or descending parts:

a, c, e, m, n, o, r, s, x etc.

group II: letters with ascending parts:

b, d, f, h, k, l etc.

group III: letters with descending parts:

g, p, q, y etc.

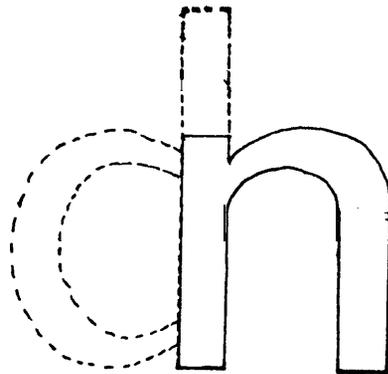


FIGURE 5.6

b) *Grouping for proper spacing of letters or for segmentation*

group I: letters to be made entirely of straight lines:

A, E, F, H, I, K, L, M, N, T, V, W, X, Y, Z etc.

group II: curved lines/combinations of curved and straight lines:

B, C, D, G, J, O, P, Q, R, S, U etc.

c) *Another grouping for spacing*

group I: open letters, or letters which let in light:

C, D, G, O, Q etc.

group II: letters which darken or tend to close:
B, H, R, K, E, M, W etc.

d) *Grouping according to widths of letters*

group I: letters about as wide as they are tall:
C, D, G, O, Q etc.

group II: letters $\frac{4}{5}$ width of the height:
A, H, N, U, V, Y, Z etc.

group II: narrow letters:
B, E, F, J, P, L, R etc.

Even we can think of *phonetic groupings* of letters for some particular application.

Although it is quite easy to sub-divide the letters of Devanagari characters into a number of convenient groups according to requirements, I would like to show one example. I have discussed on the groupings depending on the widths and heights of the letters in Sec.5 of this chapter.

a) *Grouping of letters having similar curve segments*

group I: letters with arc segment and vertical bar:
क ख व व

group II: letters with a two kink curve and vertical bar:
घ छ ध

group III: letters with fork:
प ण फ ष

group IV: open letters:
ट ठ द ह

5. Awareness of some geometrical, optical and organic aspects

Our visual perception and our aesthetic sense are superior to geometric constructions. The typeface which looks 'right' to the eye, a human organ, can not be constructed from totally geometrical considerations. For example, the eye tends to magnify all horizontal lines and to diminish vertical ones. A few optical illusions in this context may be mentioned which are important for type design.

1. To the eye, the geometric square looks greater in width than in height. An optical square must therefore be slightly increased in height.

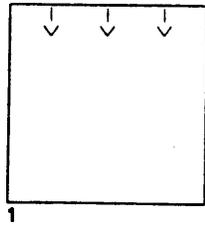


FIGURE 5.7

2. The horizontal divisions, which are central, appear to be lower. The top halves appear larger or wider than the bottom halves. Therefore, for optical balance the horizontal division should be raised to the optical center line above the actual center line.

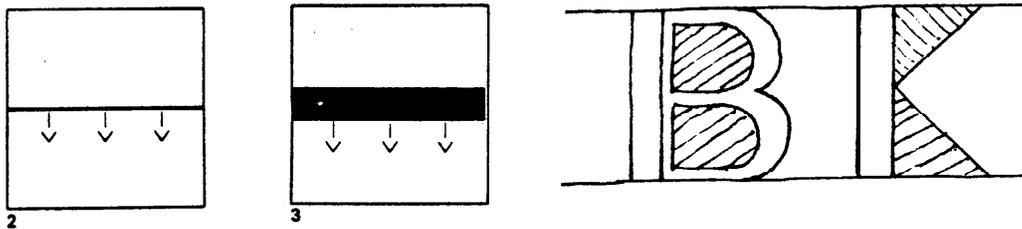


FIGURE 5.8

3. The thick horizontal bar looks fatter than a bar of equal thickness placed vertically.

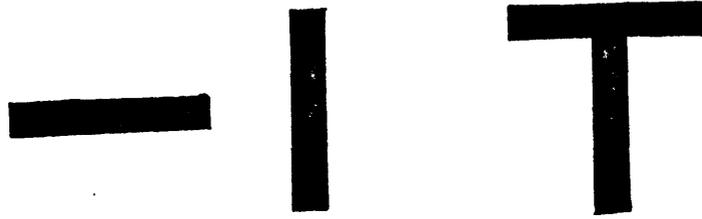


FIGURE 5.9

4. A square appears to be wider than the triangle and the circle although their widths happen to be the same. This is due to the area of the circle is 0.7854 of a square unit and that of triangle is $1/2$ a square unit.



FIGURE 5.10

5. At the junction of straight and curved strokes, and of two curved strokes, an excess of weight is apparent. A progressive reduction in the radii of the outer curves as they meet the junction will cure this visual effect.



FIGURE 5.11

A few other geometrical considerations are necessary for proper design of letter forms. For example, the letter forms for road-making are made narrow (Fig.5.12) which give the driver from a approaching car the illusion that he is reading normal letters.

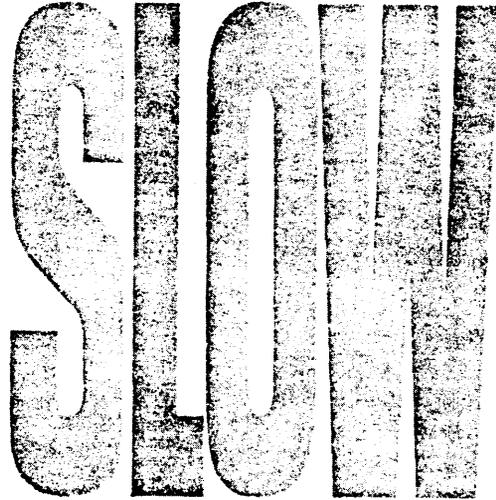


FIGURE 5.12

For more informations in this subject the interested reader may consult the books by Michael Harvey, Emil Ruder, Nicolete Gray and Hermann Degering.

6. Comprehension of the form and counter-form

The unprinted area in a letter (or word) is not an undefinable vacuum but an essential element of what is printed. The counter or interior 'white' also shares in the form of a letter, and the type designer must constantly balance form and counter-form when drawing. The various effects obtained by the combination of letters are determined by the interplay of the white of the counter and the white of the set width. Letter spacing provides the typographer with the means of reducing the effect of counters. (Fig.5.13)

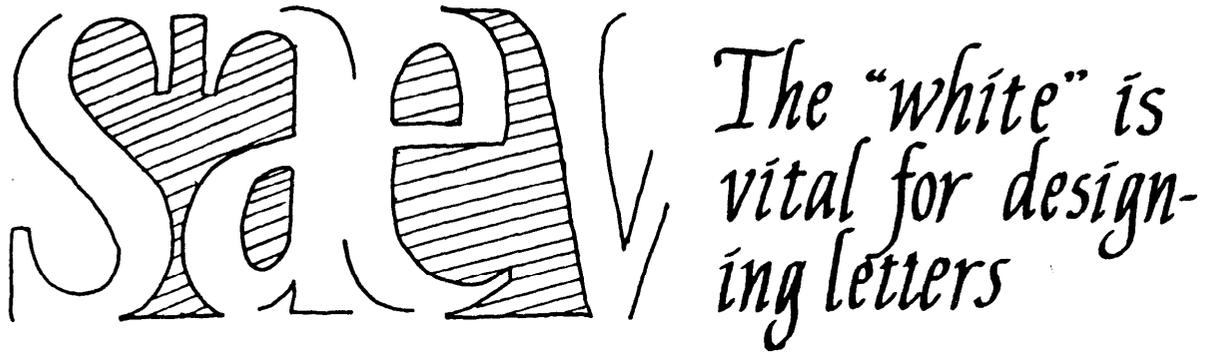


FIGURE 5.13

5.3 QUALITIES OF GOOD LETTERING

The first general virtue of lettering is *readability*, the second, *fitness* for a given use. *Fitness* is a general term which is comprised of two qualities- *beauty* and *character*.

Let us analyse these three qualities into some more detail.

a) READABILITY

1. *Simplicity*- Books are printed in order to be read- not to be seen. In this context Stanley Morison has said it best: "The good type-designer therefore realises that, for a new fount to be successful, it has to be so good that only very few recognize its novelty. If readers do not notice the consummate reticence and rare discipline of a new type, it is probably a good letter". A type should be so simple to make the printing invisible.
2. *Distinctiveness*- In an alphabet each letter is different in graphical form from the other. The distinguishing characteristics of each letter should be strongly marked.
3. *Proportion*- By the term 'proportion' we mean, no part of a letter should be over exaggerated or dwarfed. Letters are used in combination to form words and sentences, and no one of them should stand out from its fellows or draw attention to itself. This point may require experiment to determine the limits of variety permissible without sacrificing beauty of form and proper spacing between letters.

b) BEAUTY

4. *Beauty of form*— The basic form of a letter should be beautiful. If the form is fundamentally wrong, no added ornament by way of disguise can rectify it. Each letter should look like a living individual- not a mere collection of parts.
5. *Beauty of uniformity*- The ancient craftsmen who cut the historic inscriptions in stones, it seems, were more concerned for a harmony of their letters than with mere details of execution. By assimilating corresponding parts- 'bodies', 'limbs', 'heads' etc.- the designer should achieve the 'family likeness' of the different letters, so that they go well together.

6. *Beauty of arrangement*- The most beautifully designed letters may be spoiled if they are not well arranged or spaced. In lettering two elements are alternated to form the series: one of these elements is the letters themselves, often called 'black'; the other is the spaces between the letters or 'white'. Without an equal distribution of the white, the general fitness or the unity is lost, the letter won't appear to belong to each other as part of a complete design and legibility will suffer.

c] CHARACTER

7. *Personality*— Although the fundamental shapes of letters are now fixed, yet the designer is free. Goudy in his book *The Alphabet and Elements of Lettering* presented six drawings of a Lombardic capital 'A' to illustrate this point. There is enough scope to show the characteristics that distinguish one designer's hand from another's. Let the artist get at the underlying form and cautiously work out his own variations. 'Mere copies involve loss of vitality- every real work of art, even the humblest, is inimitable'.

5.4 DESIGN OF NCSD

NCSD which stands for Novice *Calligrapher's Simple Devanagari*, is a font family designed by P. K. Ghosh at the Department of Computer Science, Stanford University, during the period July-October, 1982, using \TeX and METAFONT system of D. E. Knuth. The general design principles that were followed at the time of designing NCSD have been discussed in the previous part of this chapter. Yet there are a few more points to be added, because Indian scripts are quite different from roman types. For example, the text composition in Indian scripts is non-linear and each script contains a large number of distinct graphical forms compared to only fifty two letter forms in roman. Roman type marches along a base line, while Indian scripts hang from an upper line. There are lot of other differences also. Moreover, a completely new design tool has been used to design the typeface.

1. The design model

The NCSD type is not in any sense a copy of any early font- it is original. However, the idea of the font description came from an archaic Jain Nagari script in a late-15th-century manuscript of the *Kalpasutra*. The question naturally arises why the author choose an old manuscript as model rather than a contemporary type font. This is mainly for the following reasons.

- a] The new ideas and printing techniques at different ages trimmed, filed, and one might even say 'ground down' the original calligraphic forms of the roman scripts, while so far the Indian letters have been copied by the type-founders and matrix-makers in accordance with the original pen strokes. The tradition which has embalmed and preserved the thoughts and experiments of generations of scribes must be superior to the efforts of a beginner in the craft, and even though our efforts at first may be crude and archaic, our work will rest upon a firm foundation.
- b] Many lettering artists have the opinion that no pencil-outlined forms, later filled in with ink can give so vivid a quality of life, variety and harmony as those written directly and spontaneously with a pen or brush. The METAFONT system provides the artist to define a pen of his own and the path which the pen travels in producing a letter. A calligraphic approach which was adopted is best suited for such a system, as well as for designing Indian scripts.

2. A few experiments

The design of Ω CSD was considered as a research project and a few novel experiments were performed for better understanding of the design issues.

- a] Each letter was considered as a 2-D picture composed of a few basic *pen-strokes*. Some of the constituent strokes, such as *horizontal top bar* or *vertical bar* are common for almost all characters. A careful *stroke analysis method* proves that there are a few more stroke elements that are frequently used. All the basic pen strokes were generated separately and conceptually they were grouped and pasted together to form a letter. This method of *Stroke Analysis and Synthesis* is adopted with an idea that a context-free grammar may be evolved in future for *Syntactic Letter Form Generation*.
- b] Conjunct characters can be formed by using the *halant* sign after full consonants or directly typing the complex/half character if it is available on the keyboard. A BREAK key has been provided if one wants to print specifically the *halant* sign after full consonant (*see* the words *Knuth* or *Scott* in the sample pages). Actually the ligature list in the Ω CSD metafont program contains almost the full *forest* information of half, full and conjunct characters of Devanagari script.
- c] The type composition in Indian scripts are nonlinear and it is taken care of automatically by the present system. For example, you don't have to be worried how the vowel-markers like *u-matras/ai-matra* appear at the bottom/top of the previous character. Type your text linearly from a Roman Keyboard and you will get your text printed with all sorts of complex nonlinear composition (sometimes it might be three level or more, but it does not matter).

3. Metafont programs for Ω CSD font family

- a] *Variable parameters*: One of the most important issues in metafont-description of a letter is the choice and use of parameters- the parameters that are assigned different values for generating different fonts from a single description. The parameters chosen for Ω CSD fonts can be subdivided into three sets-- i) Global parameters that affect all the members (i.e., the letters) of a font; ii) Semi-global parameters that change only the members of some particular group of letters. iii) Local parameters

that are concerned with some particular letters. A careful optimality has been maintained in choosing the type and number of parameters. They are not too many/too complex so that other designers become perplexed to use them in future. At the same time they are sufficient enough to produce at least thirty different fonts that are reasonably good. Moreover they are conceptually simple enough to comprehend.

- b) *Basic grid for the letters:* A 3-tier grid was chosen for each letter which is shown in the following figure.(Fig.5.14)

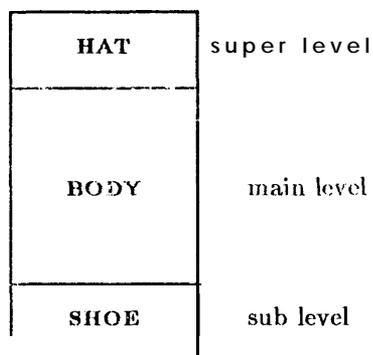


FIGURE 5.14

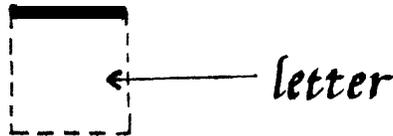
The width of the grid and the heights of super, main and sublevels were kept as independent global parameters. For most of the normal fonts the main body was a square grid, although the letters are not of the same widths or heights. For example, the letters like अ, ऋ, क, etc., are wider characters, whereas इ, र, etc., are narrower. The letters like द, ह, etc., are longer than the other letters. The height of the hat and the shoe were kept equal and they are nearly half of the main body height. However, for some of the fonts like *funny font* or *elongated font*, some of the above relations do not hold true.

- c) *Pens used:* Two types of METAFONT pens were used. The characters were drawn by an almost flat pen held at an angle of -50 degree with the horizontal axis. This is achieved by using 'special pen' or *spen* of METAFONT system. In practice this pen is elliptical in shape and flat pen simulation was obtained by keeping the value of the minor axis of the ellipse much smaller than the major axis. A wide variety of pens can be simulated at ease by varying the axes-values and the pen-inclination. Another pen is 'vertical pen' or *vpen* used for drawing the top horizontal

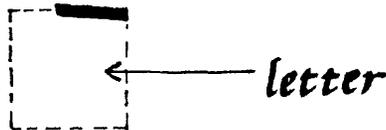
bar. However, this vpen can be replaced by *spen* if the designer would like to use the same pen all through out his work.

d] *Spacing between letters*: It should be mentioned specifically that the spacing between the letters is defined in terms of variable parameters. The type designer has enough scope to play with those parameters and set them differently for different fonts.

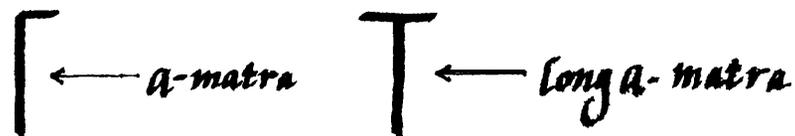
e] *A few basic graphical primitives*: The most common graphical primitives in Devanagari script is the *top horizontal bar*. Each *akshara* in the script hangs from this head line, which was evolved practically for aligning purposes. The width of the top bar is equal to the width of the *akshara*. Therefore, it looks like this:



However, for a few letters the top bar is shorter than the letter-width. This mainly happens for those letters whose limbs protrudes over the head line. For example, see the letters अ, ए, etc. In these cases, the top bar looks as follows:



Another common graphical symbol is short a-matra. Most of the consonantal symbols have this matra at their extreme right. One should not confuse this graphical symbol with that of the long a-matra.



f] *Generation of half consonants*: I have already mentioned in a previous chapter that the consonants that have short a-matra sign at their right side can be easily transformed to their half forms by chopping the a-matra part. In Ω CSD-programs, a rectangular eraser was used for this purpose to rub out the the a-matra. For example,



One can, however, adopt the *method of synthesis*, i.e., originally generating the half forms and afterwards pasting the *a-matra* in the right for producing the full consonants.

Some of the consonants like क, फ, ह, etc. have completely new graphical patterns for half forms. Some others have no separate half forms and represented by the full forms followed by the *halant* sign.

g) *Same strokes with different techniques*: The same stroke has been generated at different times using different tools of the METAFONT system. This may enable the designers in future to better understand the ease and problem in generating different kind of strokes as well as the basic structure of each type of stroke in some more detail.

h) *Devanagari script and the problem of digitization at low resolution*: The graphical forms of the *aksharas* have too many curve portions which cause great problems when they are digitized at medium or low resolution. Due to jaggedness, the letters start losing their finer details and smoothness in a quicker rate than roman letters. In fact, type face below 15 point size looks ugly when produced by the low resolution printers like Dover or Canon.

i) *The sample pages*: METAFONT allows the designer to generate different fonts by changing the values of the variable parameters of the programs.

Three fonts of NCSD family are available on the Xerox Dover printer (resolution: 384 dots per inch) at the Department of Computer Science, Stanford University. NCSD10 is a 20 point face; NCSDSL is also a 20 point type, but slanted and slightly bolder than NCSD10. NCSDBB is a 30 point bold Devanagari face.

Imagen's Canon printer (resolution: 240 dots per inch) provides thirty different experimental fonts, some of which are shown here.

The sample page *THE COLLECTION* and a few other pages contain a few lines of a poem by Vidyapati, one of the most popular poet of India in the 14th century A.D. and who is still popular in some parts of India. The choice of Vidyapati is for the following reasons:

1. His poems have the fragrance of the old tradition of India and can express most effectively the fundamental frequency of NCSD fonts.

2. Vidyapati is read throughout four different language areas, namely those of Hindi, Bengali, Assamese and Maithili.
3. His poems have multi-dimensional flavors, like hymns dedicated to God, lyrics dealing with *Vaisnava* themes, songs for festive occasion as well as erotic poems.

The fonts were chosen for *THE COLLECTION* page in such a way to produce the effect of a hand-written manuscript.

j| Print code chart: The Dover printer samples provide a code chart of Devanagari characters. I should mention specifically that it is the *Print Code chart*- and not the *Phonetic Atom Code Chart*. The Devanagari character set shown in the sample pages is not the *Extended set*. At present METAFONT provides only 128 characters per font. Many vacant places are kept which could accommodate extra characters in the font in future if necessary. The punctuation marks and other common symbols are obtained from roman fonts.

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Appendix A
The Dissection Room

Almost all the typographers have described (directly/indirectly) how they made letters from simple brush/pen strokes. For built-letters also similar parts of different letters are compared carefully when we observe the fact that the letters h, n, m etc or v, w, y are grouped together at the time of drawing. In fact, there exists a *Pattern Primitive Set* for each alphabet. All the letters are composed from the elements of the PPS.

In Appendix A, I have shown the graphic primitives I used to construct the Devanagari letters. There were two basic considerations behind this selection: the primitive elements should be conceptually simple enough for concatenation; the total number of elements should be as small as possible.

This stroke analysis method is, however, subjective and is left to the designer of the future for more exploration.

				
1	2	3	4	5
				
6	7	8	9	10
				
11	12	13	14	15
				
16	17	18	19	20

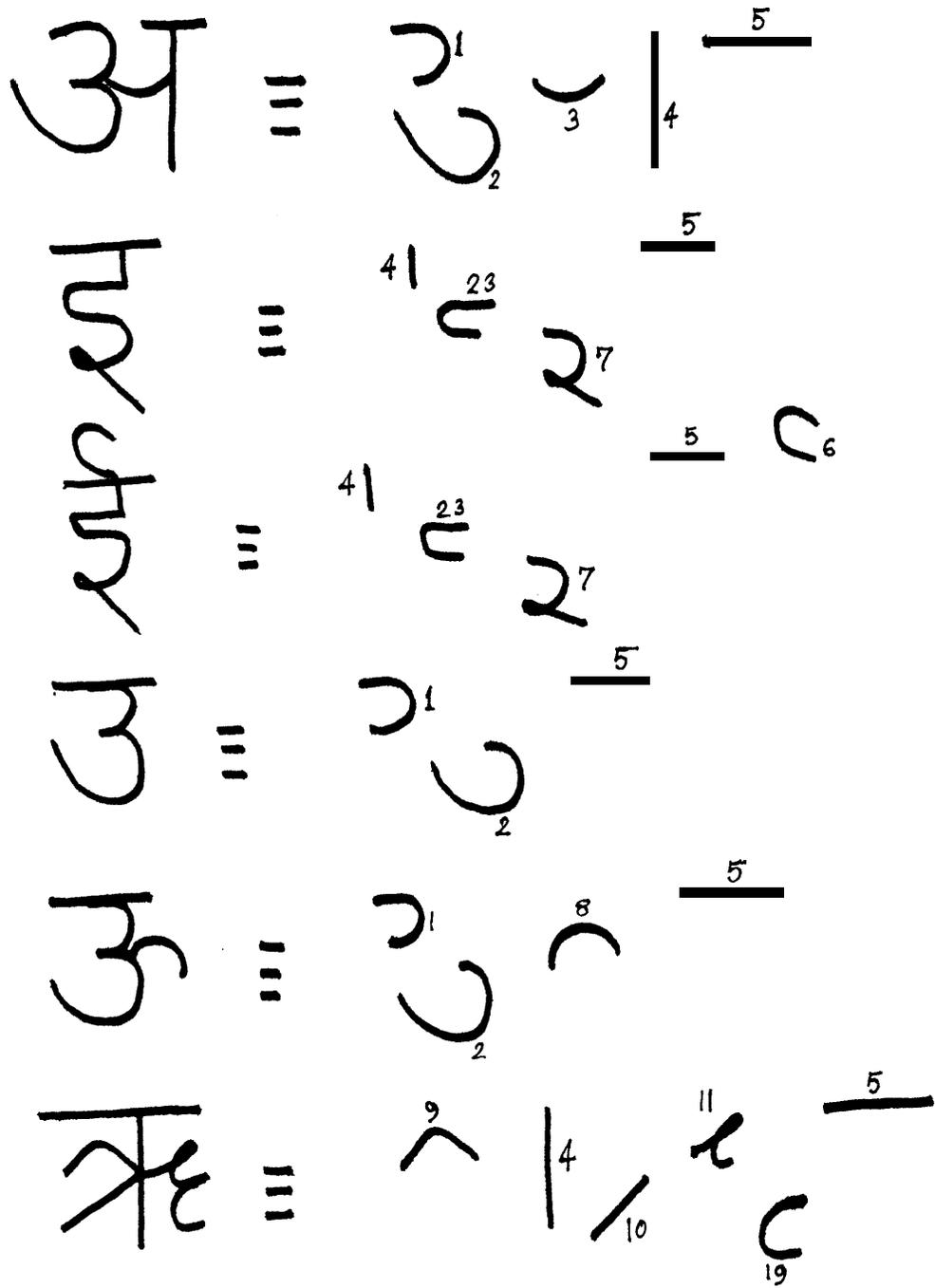
Pattern Primitive Set

Appendix A

 21	 22	 23	 24	 25
 26	 27	 28	 29	 30
 31	 32	 33	 34	 35
 36	 37	 38		

Pattern Primitive Set

Appendix A



Appendix A

ऐ ≡ 4 | 12 13 5 14

अं ≡ 1 2 3 4 5 15

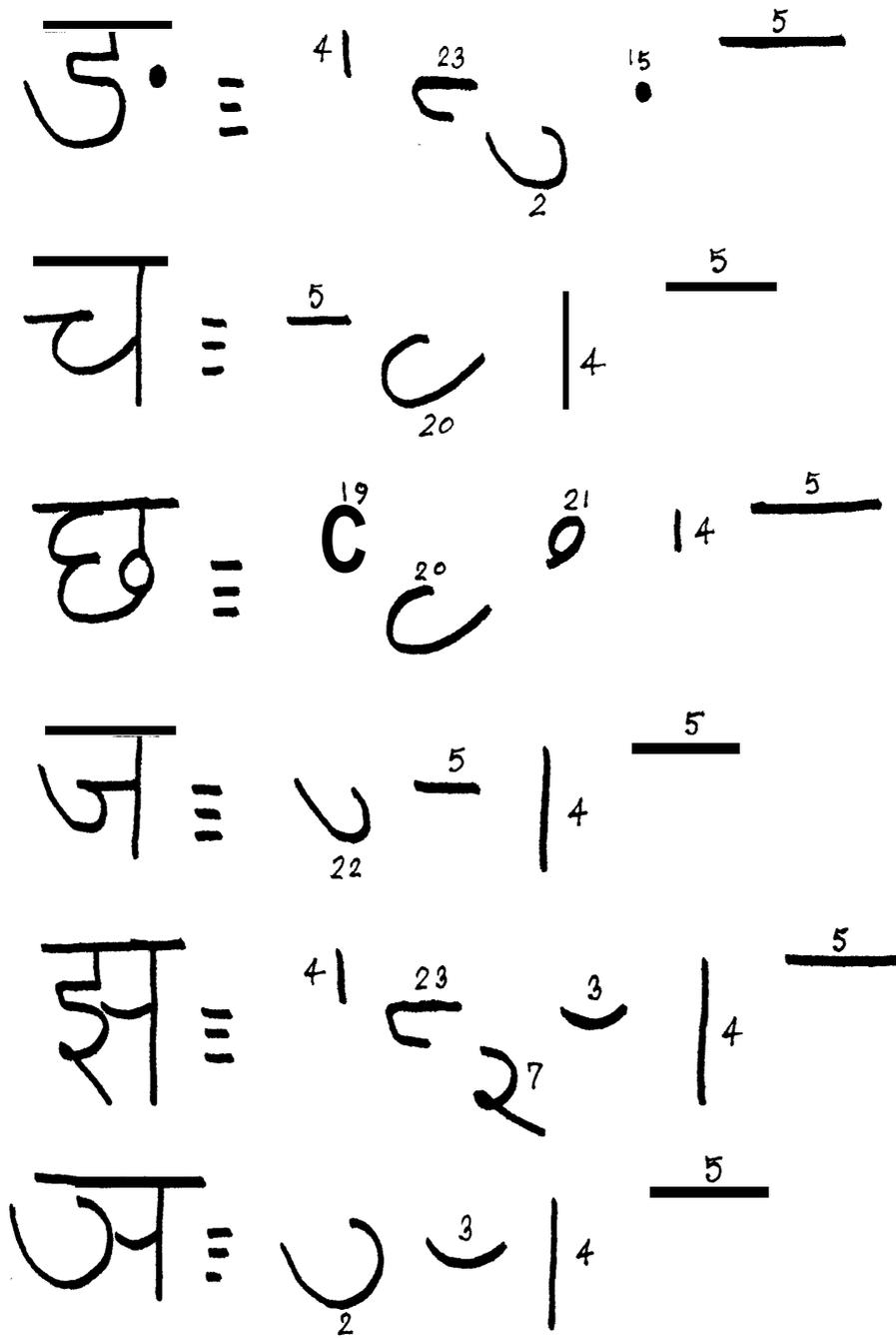
क ≡ 4 | 16 8 5

ख ≡ 17 18 16 4 5

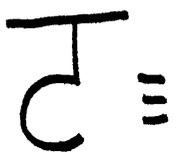
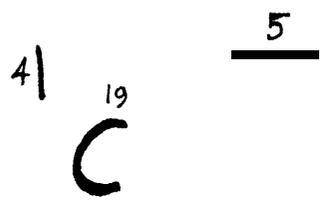
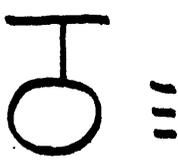
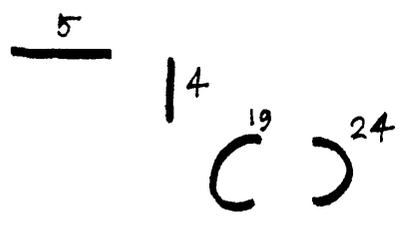
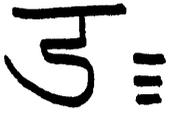
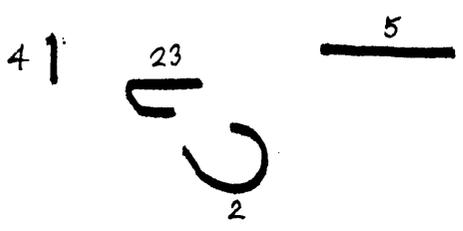
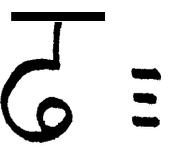
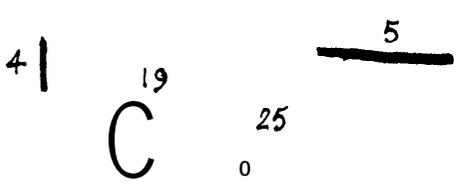
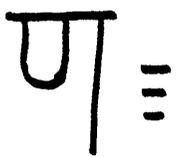
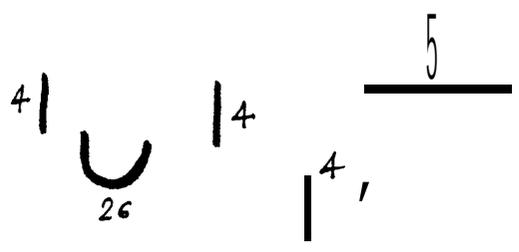
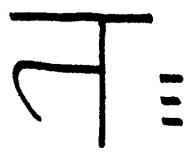
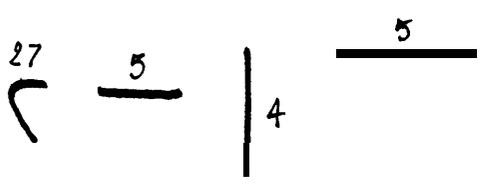
ग ≡ 4 | 30 5 4

घ ≡ 19 20 4 5

Appendix A



Appendix A

Appendix A

शुं = ०²⁵ ७²⁸ २९ | 4 5

ह = 4 | १९ ११ 5

ध = १९ २० | 4 5

य = ३० 5 | 4 5

प = 4 | २६ 4 5

फ = 4 | २६ 4 १^४ 5

Appendix A

वः 4 5 16 C 18

मः 5 4 30 5 4 5

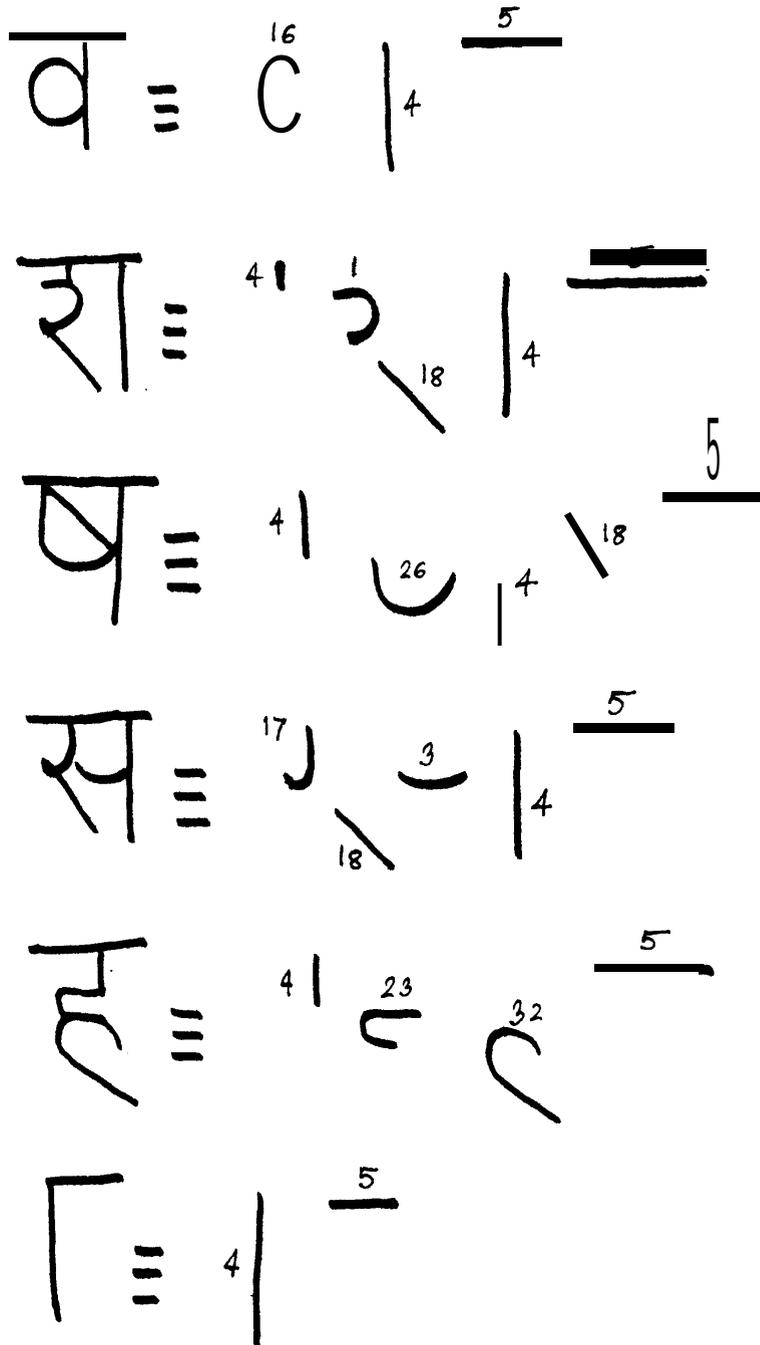
मः 4 30 5 4 5

यः 28 3 29 4 5

सः 17 5 3 18

अः 31 4 5

Appendix A



Appendix A

T ≡ 4 | 5

f ≡ 4 | 5 93

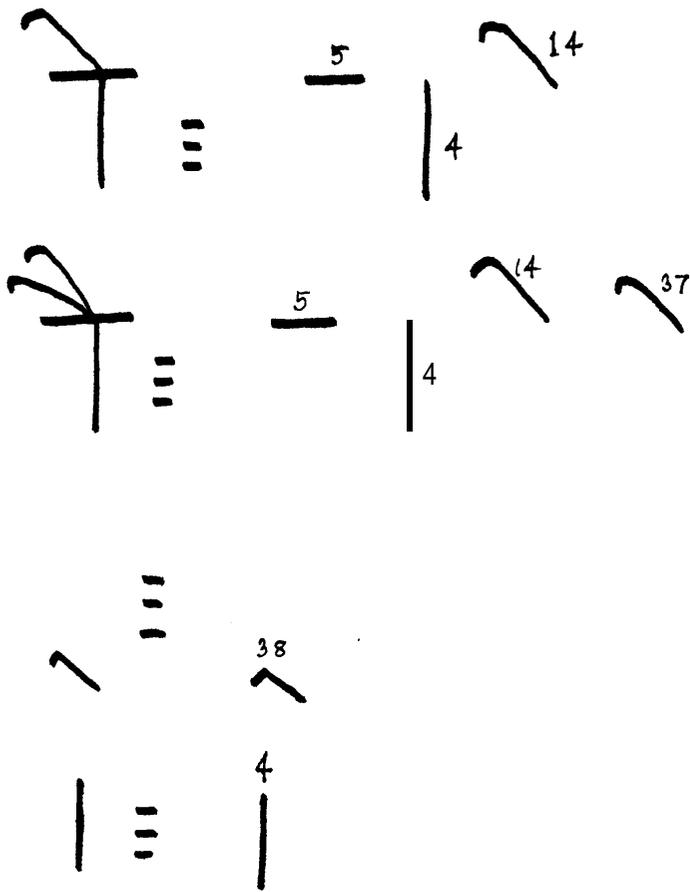
F ≡ 4 | 5 34

U ≡ U³⁵ / 2

u ≡ u³⁶

c ≡ c¹⁹

Appendix A



The Metafont Programs

The `METAFONT` programs for the `NCSD` font family are presented in Appendix B. These programs are simple enough to comprehend, but they do not express the full capabilities of `METAFONT` system. It is, therefore, advisable to go through the programs written by D.E. Knuth for his `Computer Modern Roman` fonts which show how to use the `METAFONT` techniques efficiently to design a family of typefaces.

Appendix B

1. NCSD FILES

```
%-----  
%  
%The whole NCSD files are divided into three separate files.  
%The GLOBAL file contains the global. parameters used.  
%The SUBRTN file contains a number of useful subroutines.  
%The DEVNAG file contains the programs of the Devanagari 'Letters.  
%  
%-----  
mode= ?;           %input appropriate mode  
modegrid=1;       %when modegrid is 1 it draws the basic grid.  
detail=1;         %detail=1 means, draw the arrows around the grid.  
input global;  
input subrtn;  
input devnag;  
%-----
```

Appendix B

2. GLOBAL.MF

```
%THIS FILE KEEPS GLOBAL DATA FOR ONE FONT
%
%-----
%      Data for Type size
%( unit,height,hat and shoe,width,exratio,slant )
%-----
u=10;
h=10u;
t=4.5u; d=t;
l=h;
sqrttwo=sqrt 2;
slant=0.00;
%
%-----
% Data for varying type font
%-----
bxr=4.0;           %begining of x position for the letters gha etc.
exr=4.5;           %ending of character by its a-matra
byr=10/6;          %begining of y position for letters like ta.
eyr=10/3;          %ending pt of y for letters like gha.
bxrm=5.0;          %bxrm, exrm for matras
exrm=4.5;
%
%-----
%      Data for Pen size
%-----
w0=1;              %vpen width
w1=1.6u;           %vpen height
%Setting for s-pen
ang=-50;
mjaxis=(1000/686)*w1;
mnavis=0.6u;
%
vpenwd w0;
%-----
```

Appendix B

3. SUBRTN.MF

S/This file was written for Indian script (Devanagari) Generation.

%Start your file with "INPUT SUBRTN" and you will get

%a host of useful subroutines for free.

ptsize=10;

%-----Preamble (same as basic.mf for cmr) -----

proof = 0; %symbolic names of modes

Iowres = 1;

crs = 2;

dover = 3;

canon = 4;

minvr 0; %allow sharp turns without correction

minvs 0;

maxvr 999999 ;

maxvs 999999 ;

designsize psize; f/ignore error messages you get with old MF!

fxerox=1.03; %Xeroxing enlarges by this factor (approximately)

fivemm=5*384/25.4/4; %this many pixels makes 5mm of proofmode output on Dover

if mode<0: %negative modes assume that 'mag' is set

mmode=-mode; new mode; mode=mmode;

else: mag=1; fi;

magnification mag;

if mode=0: %for initial. design of characters

proofmode; drawdisplay; titletrace;

pixels*20/36=fxerox.fxerox.fivemm;

%matches a drawing that has been xeroxed three times

blacker=0; overcorr=1;

else: if mode=1: %XGP, Versatec, Varian, etc.

fntmode; tfxmode; no modtrace;

magnification (3.6/200/.013837)mag;

pixels=3.6mag; blacker=.6; overcorr=.4;

else: if mode=2: %Alphatype

crsmode; tfxmode; titletrace; no modtrace;

pixels=73.7973; blacker=4; overcorr=1;

Appendix B

```
else: if mode=3: %Dover
ocmode; tfmmode; dotwdmode; no modtrace;
overcorr=.6;
pixels=384*.013837*mag; blacker=0.75;
else: if mode=4: %Canon
chrmode; tfxmode; no modtrace;
pixels=240*.013837*mag;
blacker=.2; overcorr=.4;
else: if mode=5: %Zapf
titletrace; proofmode; no points;
pixels*20/36=fivemm; blacker=0;overcorr=1;
else: if mode=6: %Hornet
fntmode; tfxmode; no modtrace;
magnification(3.6/300/.013837)mag;
pixels=3.6mag; blacker=.6; overcorr=.4;
else: if mode=7: %Proofmode, but without display;
proofmode; no drawdisplay; titletrace;
pixels*20/36=fxerox.fxerox.fivemm;
%matches a drawing that has been xeroxed three times
blacker=0; overcorr=1;
else: if mode=8: %Proofmode, but without grid;
proofmode; drawdisplay; titletrace;
pixels*20/36=fxerox.fxerox.fivemm;
%matches a drawing that has been xeroxed three times
blacker=0; overcorr=1;
else: input mode;
fi; fi; fi; fi; fi; fi; fi; fi; fi; fi;
fontfacebyte 254-2*ptsize;
hresolution pixels; vresolution pixels.
```

Appendix B

```
%-----Initialization-----  
%-----  
subroutine charbegin  
(var charno, %seven-bit character code  
var charw, var charlw, var charrw, %middle(pt), left, right(pxl) width  
var charph, var charpd): %height, depth (point)  
%.....  
new r;  
no eqtrace; no calltrace; no drawdisplay; %no tracing in this subroutine  
charcode charno;  
charic 0;  
charht charph;  
chardp charpd;  
charwd charw+charlw/pixels+charrw/pixels; %width in points  
chardw round(charw*pixels+charrw+charlw); %in pixels  
incx charlw; %in pixels  
r = charw;  
if modegrid=1: call basicgrid; fi;
```

Appendix B

```
%-----Grids-----
subroutine basicgrid:
no drawdisplay; no proofmode; no drawtrace; no plottrace;
x1=x3=x5=x7=0;
x2=x4=x6=x8=1;
y5=y6=-d;
y1=y2=0;
y3=y4=h;
y7=y8=h+t;
cpen; 2 draw 5..6;
draw 1..2;
draw 3..4;
draw 7..8;
%
draw 5..7;
draw 6..8;
%
x9=x10=x1+0.25(x2-x1);
x11=x12=x9+0.25(x2-x1);
x13=x14=x11+0.25(x2-x1);
y9=y11=y13=y5;
y10=y12=y14=y8;
y15=y16=y1+0.25(y3-y1);
y17=y18=y15+0.25(y3-y1);
y19=y20=y17+0.25(y3-y1);
x15=x17=x19=x1;
x16=x18=x20=x2;
cpen; 1 draw 9..10;
draw 11..12;
draw 13..14;
draw 15..16;
draw 17..18;
draw 19..20;
%
```

Appendix B

```
if detail=1:
call arrow(stx,h+t,0.9,0.9,90);
call arrow(endx,h+t,1.2,1.2,90);
call arrow(1,sty,0.8,0.8,0);
call arrow(1,endy,1.2,1.2,0);
fi;
fi.
%----- subroutine arrow -----
subroutine arrow
(var posx,
var posy,
var sx, var sy ,
var rot):
% ----- - -----
no calltrace; no eqtrace; no drawdisplay;
new nax; new nbx; new ncx;new ndx;
new nay; new nby; new ncy;new ndy;
new cs; new sn;
cs=cosd(rot); sn=sind(rot);
nax=ax.cs-ay.sn;nay=ax.sn+ay.cs;
nbx=bx.cs-by.sn;nby=bx.sn+by.cs;
ncx=cx.cs-cy.sn; ncy=cx.sn+cy.cs;
ndx=dx.cs-dy.sn; ndy=dx.sn+dy.cs;
x1=nax.sx+posx; y1=nay.sy+posy;
x2=nbx.sx+posx; y2=nby.sy+posy;
x3=ncx.sx+posx; y3=ncy.sy+posy;
x4=ndx.sx+posx; y4=ndy.sy+posy;
cpen; 1 draw 1..2;
draw 1. .3;
draw 1. .4;
fi.
```

Appendix B

```
%-----Pens ( same as BASIC.MF for cmr )-----T-----Y-----
%-----T-----Y-----
%
S/This routine computes the parameters necessary to make an
% spen (elliptical pen) of given dimensions and angle of inclination.
%For instance, ellipticalpen(3,2,30) describes an ellipse with
f/major axis of length 3, minor axis of length 1.5, tilted
%30 degrees counterclockwise.
%
%The equation for the nonrotated ellipse is  $aa.x.x + cc.y.y = 1$ .
%
#Unfortunately this routine cannot create the spen itself,
%since Metafont does not allow pens to be passed across
%subroutine boundaries. Instead, the calling program
%must, immediately after calling ellipticalpen, say
%spen(ellipsa,ellipsb,ellipsc,0,0,0,0)
%
subroutine ellipticalpen(var diameter, var ratio, var angle):
new radius,sindangle,cosdangle,aa,cc,ellipsa,ellipsb,ellipsc;
radius = .5diameter;
sindangle = sind(angle);
cosdangle = cosd(angle);
aa = 1/( radius      radius      );
cc = 1/((radius/ratio)(radius/ratio));
ellipsa = aa.cosdangle.cosdangle + cc.sindangle.sindangle;
ellipsb = 2(aa-cc)(sindangle.cosdangle);
ellipsc = aa.sindangle.sindangle + cc.cosdangle.cosdangle;
fi.
```

Appendix B

```
%-----a-matra (one of the basic graphical units)-----
%-----
%This routine draws one of most common graphical units of
%all Indian scripts. This contains a very small top bar and
%the vertical bar; one has to provide character width and
%character height as variable parameters.
%-----
subroutine Amatra
  (var charw,
  var charph):
%
  call smalltopbar(charw, charph);
  call vertical.bar(charw, charph);
  fi.
%----- subroutine small top bar -----
subroutine smalltopbar
  (var charw,
  var charph):
%
%Drawing of the top bar
x2=charw; x1=round(charw-charw/exr-w1/2);
y1=y2=charph;
vpen; w1 draw 1..2;
fi.
%----- subroutine vertical. bar -----
subroutine verticalbar
  (var charw,
  var charph):
%
S/Drawing the vertical bar
%
x1=x2=round(charw-charw/exr);
y1=charph; y2=0;
call ellipticalpen(mjaxis, mnaxis, ang);
spen(ellipsa, ellipsb, ellipsc, 0, 0, 0, 0);
draw 1..2;
fi.
```

Appendix B

```
%----- subroutine rest top bar -----
subroutine resttopbar
  (var char-w,
  var charph):
%
%Drawing of the top bar(rest of A-matra)
x1=0; x2=round(charw-charw/exr);
y1=y2=charph;
vpen; w1 draw 1..2;
fi.
%----- Top and Vertical. bar -----
%
%This routine is another common and basic graphical unit. This is
%supposed to draw the full top bar and the vertical bar; the
%supplied variables are character width and character height.
%-----
subroutine topvertibar
  (var charw,
  var charph):
%
call fulltopbar(charw,charph);
call verticalbar(charw,charph);
fi.
%----- subroutine full top bar -----
subroutine fulltopbar
  (var charw,
  var charph):
%
%Drawing of top bar
x1=0; x2=charw;
y1=y2=charph;
vpen; w1 draw 1..2;
fi.
```

Appendix B

```
%----- Few subroutines for matras -----
%----- subroutine vertibar for matras -----
%This is used for drawing the vertical bar for e,a-matras
%etc. If the topsw is 0 it gives only the vertical. bar
%without small top bar. It is different from amatra in the
%small top bar.
% -----
subroutine verticalbarm
(index i, %specifies position
var charw, var charph, %width, ht of 'letters
var topsw):
%
%Drawing of vertibar
x3=xi; y3=yi;
x4=x3; y4=yi-charph;
call ellipticalpen(mjaxis,mnaxis,ang);
spen(ellipsa,ellipsb,ellipsc,0,0,0,0);
draw 3..4;
%Drawing of small top bar if topsw=1
if topsw=1:
x1=xi-charw/bxrm; y1=yi;
x2=xi+charw/exrm; y2=yi;
vpen; w1 draw 1..2;
fi;
fi.
```

Appendix B

```
%----- Subroutine aem -----
S/This subroutine is drawing the ae-matra. This is used
%for drawing ae-matra, ai-matra etc.
%-----
subroutine aem
(index i, %specify starting position
var ln, %width of ae-matra
var ht): %height of ae-matra
%
xl=xi; yl=yi+w1;
x2=xi-0.90*ln; y2=yi+ht;
call ellipticalpen(mjaxis,mnaxis,ang);
spen(ellipsa,ellipsb,ellipsc,0,0,0,0);
draw 1 { -50,50 } ..2 { -50,-50 } ;
fi.
%-----
%----- Eraser for Generating Half Consonants -----
%This is a rectangular eraser to erase the A-matra portion
%of the full consonants. This is how I would 'like to produce
S/half consonants from full letters.
%-----
subroutine eraseamatra:
new erht; erht=w0;
new erwd; erwd=round(l/exr+0.58w1);
hpenht erht;
x50=l-0.5(l/exr+0.52w1); y50=h+0.508w1;
x51=x50; y51=-0.508w1;
hpen#;erwd draw 50..51;
fi.
```

Appendix B

```
%----- Subroutine dot -----
%This subroutine actually draws a rectangle, not a dot.
%This type of dot is used for drawing aum-matra, ah-matra,
%dot in nga etc.
% -----
subroutine dot
(index i): %specify starting position
%
x101=xi; y101=yi;
x102=xi+mjaxis*cosd(-ang); y102=yi+mjaxis*cosd(-ang);
call ellipticalpen(mjaxis,mnaxis,ang);
spen(ellipsa,ellipsb,ellipsc,0,0,0,0);
draw 101..102;
fi.
%----- Subroutine reph -----
%Reph is one form of the 'letter half-ra. This has been
%made a subroutine because this graphical form is used
%in other places like vowel long-e etc.
%-----
subroutine reph:
x1=l-l/exrm-w1/2; y1=h+w1/2;
x2=l-l/exrm-0.20l; y2=h+w1+0.45t;
x3=l-l/exrm-0.15l; y3=h+w1+0.70t;
x4=l-l/exrm+0.15l; y4=h+w1/2+0.60t;
call ellipticalpen(mjaxis,mnaxis,ang);
spen(ellipsa,ellipsb,ellipsc,0,0,0,0);
draw 1 { -50,50 } ..2 { 0,1 } ..3..4 { 50,-50 } ;
fi.
```

Appendix B

```
%----- Set of subroutines for quarter circles -----  
%  
% Three subroutines are given here to draw 1) quarter of a circle  
% 2) half circle and 3) full circle;  
%  
%-----  
subroutine qcirc  
  (index i,  
  index j,  
  index k):  
  xj=1/sqrttwo[xi,xk]; yj=1/sqrttwo[yk,yi];  
  call ellipticalpen(mjaxis,mnaxis,ang);  
  spen(ellipsa,ellipsb,ellipsc,0,0,0,0);  
  draw i { xk-xi,0 } ..j { xk-xi,yk-yi } ..k { 0,yk-yi };  
  fi.  
%-----  
subroutine hcirc(index viii,index i,index ii,index iii,index iv):  
  xiv=xviii; yii=1/2[yiv,yviii];  
  call qcirc(viii,i,ii); call qcirc(iv,iii,ii);  
  fi.  
%-----  
subroutine circle(index i,index ii,index iii,index iv,  
  index v,index vi,index vii,index viii):  
  xiv=xviii=1/2[xvi,xii]; yii=yvi=1/2[yiv,yviii];  
  call qcirc(viii,i,ii); call qcirc(iv,iii,ii);  
  call qcirc(iv,v,vi); call qcirc(viii,vii,vi);  
  fi.
```

Appendix B

4. DEVNAG.MF (a few selected routines)

```
%-----DEVANAGARI LETTERS-----  
%This file contains character set for DEVANAGARI  
%alphabet. This file, preceded by global.mf and  
%subrtn.mf enables u to generate a pixel file for  
%Devanagariscript. But do not forget to specify  
%"mode" iniatially, if u don't want shouting from  
%the system.  
%-----
```

Appendix B

```

" THE LETTER A ";
%
new sft; sft=0.171;

call charbegin('A,1.17p1,1sp,rsph,0);
%
% Drawing of the left top hook

x1=0+sft; y1=h/byr+0.25h;
x2=1/bxr+0.051+sft; y2=h;
x3=1-1/exr-0.301+sft; y3=h/byr+0.18h;
x4=1/bxr-0.101+sft; y4=h/byr-0.02h;

call ellipticalpen(mjaxis,mnaxis,ang);
spen(ellipsa,ellipsb,ellipsc,0,0,0,0);

draw 1{50,50}..2{1,0}..3{0,-1}..4{-1,0};

% Drawing of bottom hook

x5=1/bxr+sft; y5=h/byr-0.02h;
x6=1-1/exr-0.251+sft; y6=h/eyr;
x7=1/bxr+sft; y7=h/eyr-0.25h;
x8=-0.121+sft; y8=h/byr-0.20h;
x9=0+sft; y9=h/eyr-0.10h;

draw 5{1,0}..6{0,-1}..7{-1,0}..9..8;

% Drawing the notch

x10=1-1/exr+sft; y10=h/byr;
x11=1-1/exr-0.151+sft; y11=h/byr-0.15h;
x12=1/bxr+0.101+sft; y12=h/byr;

draw 10{0,-1}..11{-1,0}..12{0,1};

% Drawing the vertical bar

x17=1-1/exr+sft; y17=h;
x18=x17; y18=0;

draw 17..18;

% Drawing of a very small triangle on the top bar

x13=1+sft; y13=h;
x14=1-2*1/exr-0.061+sft; y14=h;

vpen; w1 draw 14..13;

x15=x14-0.061; y15=y14;
x16=x14+0.051; y16=y14;

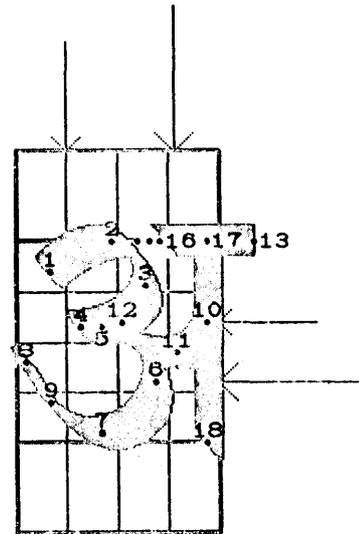
new mjaxis,mnaxis;
mjaxis=w1/sind(50); mnaxis=1u;

call ellipticalpen(mjaxis,mnaxis,ang);
spen(ellipsa,ellipsb,ellipsc,0,0,0,0) #;

draw 15..16;

fi.

```



Appendix B

```

" THE LETTER long-E ";
%
call charbegin('D,p1,1sp-1/bxr,rsp,ph,0);
%
% Drawing of the top bar

    x15=1; y15=h;
    x2=1/bxr; y2=y15;

vpen; wl draw 2..15;

% Drawing of the inverted L portion on top

    x1=1-1/exr; y1=h;
    x3=x1; y3=h/byr+0.17h;
    x4=1/bxr+0.181; y4=y3;

call ellipticalpen(mjaxis,mnaxis,ang);
spen(ellipsa,ellipsb,ellipsc,0,0,0,0);

    draw 1..3..4;

% Drawing of the round part on left

    x5=1/bxr+0.081; y5=h/byr;
    x6=x4; y6=h/byr-0.15h;

    draw 4{-1,0}..5{0,-1}..6{1,0};

% Drawing of the horizontal line

    x7=1-1/exr; y7=y6;

    draw 6..7;

% Drawing of the third bottom portion

    x8=1-1/exr+0.051; y8=h/eyr;
    x9=1/bxr+0.201; y9=h/eyr-0.20h;

    draw 7{1,0}..8{0,-1}..9{-1,0};

% Drawing of the bottom most portion

    x10=1/bxr+0.101; y10=h/eyr-0.17h;
    x11=1/bxr+0.181; y11=h/eyr-0.05h;
    x12=1-1/exr+0.051; y12=-0.50d-0.05h;

new angm;
angm=-(90+ang);
call ellipticalpen(mjaxis,mnaxis,angm);
spen(ellipsa,ellipsb,ellipsc,0,0,0,0);

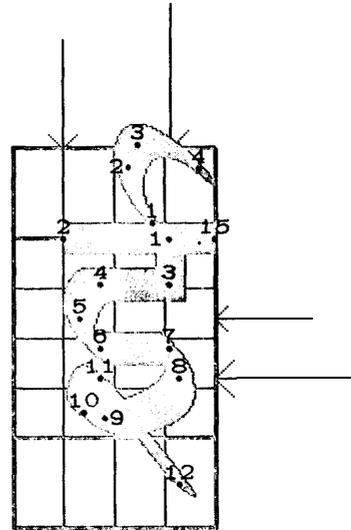
    draw 9{-1,0}..10{0,1}..11{1,0}..12;

% Drawing of top hook part. This portion is additional than letter E

    call reph;

fi.

```



Appendix B

```

" THE LETTER long-U ";
%
call charbegin('F,p1,1sp,rsph,0);
call fulltopbar(1,h);
%
new shift;
shift=l/bxr-0.151;
% Drawing of the left top hook

    x1=0+shift; y1=h/byr+0.25h;
    x2=l/bxr+0.011+shift; y2=h;
    x3=l-l/exr-0.301+shift; y3=h/byr+0.15h;
    x4=l/bxr-0.101+shift; y4=h/byr-0.03h;
    x10=l/bxr-0.151+shift; y10=y4;

call ellipticalpen(mjaxis,mnaxis,ang);
spen(ellipsa,ellipsb,ellipsc,0,0,0,0);

    draw (1..2){1,0}..3{0,-1}..4{-1,0}..10;

% Drawing of bottom hook

    x5=l/bxr+shift; y5=h/byr-0.02h;
    x6=l-l/exr-0.251+shift; y6=h/eyr;
    x7=l/bxr+shift; y7=h/eyr-0.25h;
    x8=-0.051+shift; y8=h/eyr+0.05h;
    x9=-0.021+shift; y9=h/eyr;

    draw 5{1,0}..6{0,-1}..7{-1,0}..9..8;

% Drawing of the right most hook (addition to UU from U)

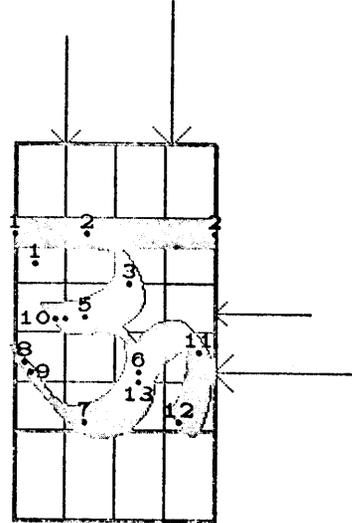
    x11=l-l/exr+0.151; y11=h/eyr+0.10h;
    x12=l-l/exr+0.051; y12=h/eyr-0.25h;
    x13=x6; y13=y6-0.05h;

new mjaxism; mjaxism=w1*1000/800;
call ellipticalpen(mjaxism,mnaxis,ang);
spen(ellipsa,ellipsb,ellipsc,0,0,0,0);

    draw 13{0,1}..11{0,-1}..12{-1,0};

fi.

```



Appendix B

```

" THE LETTER RRI ";
%
call charbegin('G,1.3pl+0.5w1/pixels,1sp,rsp,ph,0);
call topvertibar(1,h);
%
% Drawing of the left part

      x1=l/bxr-0.181;   y1=h/byr+0.05h;
      x2=l/bxr+0.151;   y2=h/byr+0.20h;
      x3=1-l/exr;       y3=h/byr+0.05h;

call ellipticalpen(mj axis, mmaxis, ang);
spen(ellipsa,ellipsb,ellipsc,0,0,0,0);

      draw 1{50,50}..2{1,0}..3;

% Drawing of the left bottom part

      x4=1/bxr-0.151;   y4=h/eyr-0.05h;
      x5=x3;           y5=h/byr-0.10h;

      draw 4..5;

% Drawing the right top loop

      x6=x3;   y6=h/byr-0.05h;
      x7=1+0.201;   y7=h/byr+0.05h;
      x8=1+0.151;   y8=h/byr+0.12h;
      x9=1+0.281;   y9=h/byr-0.27h;

      draw 6{1,0}..7{0,1}..8{-1,0}..9{50,-50};

% Drawing of the bottom hook on right

      x10=1-l/exr+0.221;   y10=h/eyr-0.15h;
      x11=x9;   y11=0;

      draw 9{-1,0}..10{0,-1}..11{1,0};

% Drawing of the rest of top bar on right half

      x12=1;   y12=h;
      x13=1.31;   y13=y12;

vpen; wl   draw 12..13;

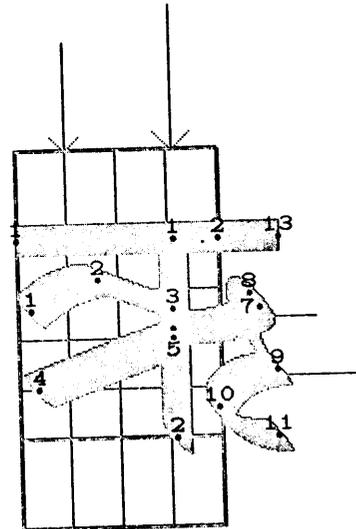
% To extend the top bar a little

      x14=1;   y14=h;
      x15=1.31+0.5w1;   y15=y14;

      draw 14..15;

fi.

```



Appendix B

```

"THE LETTER AI ";
%
call charbegin('I,p1,1sp,rsph,0);
call fulltopbar(1,h);
%
% Drawing of the left part

x1=1/bxr; y1=h;
x2=x1; y2=h/byr-0.35h;
x3=1-1/exr; y3=-0.40d;

call ellipticalpen(mjaxis,mnaxis,ang);
spen(ellipsa,ellipsb,ellipsc,0,0,0,0);

draw 1..2..3;

% Drawing the small circular part at bottom

x4=1-1/exr+0.11l; y4=-0.65d;
x5=1-1/exr; y5=-0.85d;

draw (2..)3..4..5{-1,0};

% Drawing of the right half

x6=1-1/exr; y6=h;
x7=x6; y7=h/byr-0.28h;
x8=1-1/exr-0.20l; y8=y2;

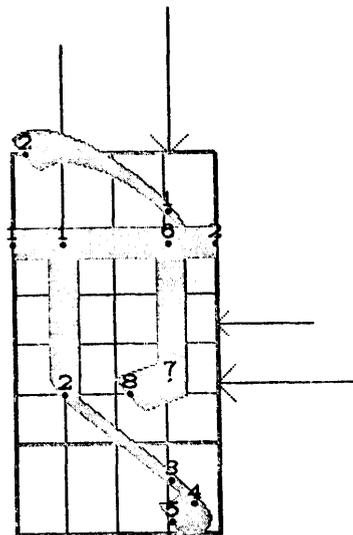
draw 6..7..8;

% Drawing of ae-matra (this part is only additional than AE)

new ln; ln=1-1/exrm;

x9=1-1/exrm; y9=h;
call aem(9,ln,t);
fi.

```



Appendix B

```

" THE LETTER KA" ;
%
call charbegin('a,1.15pl,1sp,rsph,0);
%
new sft;   sft=0.015l;

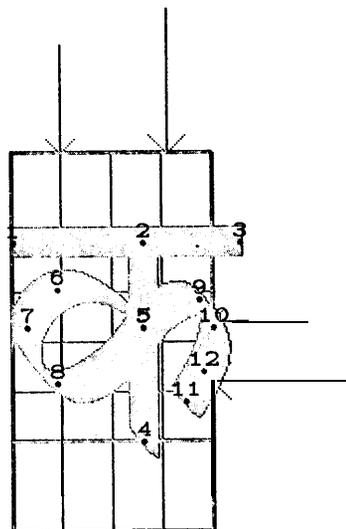
% drawing top & mid bar
x1=0+sft; y1=h;
x3=1.15l;  x2=4/7(x3-x1)+sft;
y1=y2=y3;
x4=x2; y4=0;
vpen; w1 draw 1..3;
call ellipticalpen(mjaxis,mnaxis,ang);
spen(ellipsa,ellipsb,ellipsc,0,0,0,0);
      draw 2..4;

%
% drawing the left loop
x5=x4; y5=round(h/byr-0.03h);
x6=round(l/bxr-0.03l)+sft; y6=round(h/byr+0.16h);
x7=x1+0.05l+sft; y7=y5;
x8=x6; y8=round(h/eyr-0.01h);
      draw 5{-70,100}..6..7..8..5{70,100};

%
% drawing of the right hook
x9=0.93l+sft; y9=y6-0.5u;
x10=l+sft; y10=y7;
x11=0.86l+sft; y11=round(h/eyr-0.1h);
x12=0.95l+sft; y12=round(h/eyr+0.05h);
      draw 5{70,100}..9{82,-35}..10..12..11;

fi.

```



Appendix B

```

" THE LETTER KHA ";
%
call charbegin('b,p1,lsp,rsp,ph,0);
call amatra(1,h);
call resttopbar(1,h);
%
call ellipticalpen(mjaxis,mnaxis,ang);
spen(ellipsa,ellipsb,ellipsc,0,0,0,0);

%Drawing the hook at the left of a-matra

x11=round(1-1/exr); y11=h/byr+0.01h;
x12=x11; y12=h/eyr+0.15h;
x13=1-1/exr-0.331; y13=1/2[y12,y11]-0.10h;

draw 11{0,1}..13{0,-1}..12{0,1};

new sft; sft=-0.121;

% Drawing of the top curved portion

x1=1/bxr+0.051+sft; y1=h;
x2=1/bxr+0.121+sft; y2=h/byr+0.01h;
x3=1/bxr-0.031+sft; y3=h/byr-0.15h;

draw 1{10,-50}..2{0,-1}..3{-1,0};

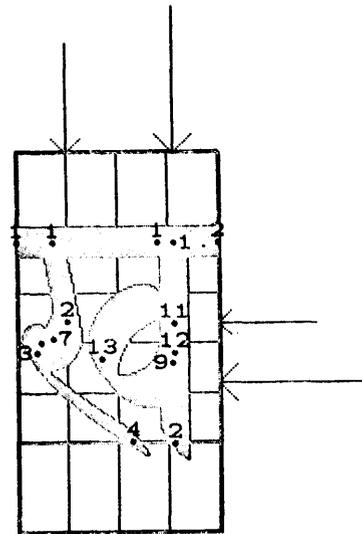
% Drawing of the bottom line

x4=1-1/exr-0.081+sft; y4=h/eyr-0.28h;
x7=1/bxr+0.051+sft; y7=h/byr-0.08h;
x8=1/bxr-0.011+sft; y8=h/byr-0.10h;
x9=1-1/exr; y9=h/eyr+0.10h;

draw 7{-1,0}..8..3..4{50,-30};

fi.

```



Appendix B

```

" THE LETTER NGA ";
%
call charbegin('e,p1,lsp,rsp,ph,0);
call fulltopbar(l,h);
%
% Drawing the top reflected-L shape:

x1=1/2; y1=h;
x2=x1; y2=h/byr+0.15h;
x3=1/bxr-0.031; y3=y2;

call ellipticalpen(mjaxis,mnaxis,ang);
spen(ellipsa,ellipsb,ellipsc,0,0,0,0);

draw 1..2..3;

% Drawing of the left hook

x4=1/bxr+0.171; y4=h/byr-0.10h;

draw 2..3..4{1,0};

% Drawing of the bottom portion

x5=1-l/exr-0.171; y5=h/eyr-0.01h;
x6=1-l/exr-0.401; y6=h/eyr-0.25h;
x7=0.081; y7=h/eyr;
x8=1-l/exr-0.221; y8=y4-0.02h;

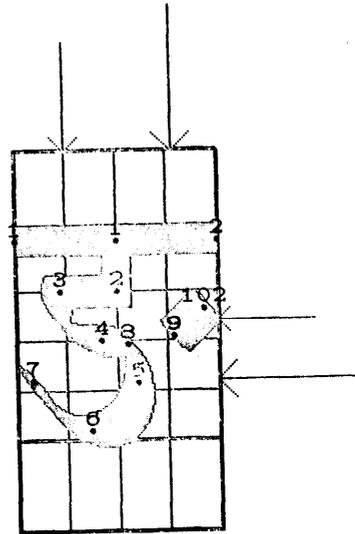
draw 4{1,0}..8..5{0,-1}..6{-1,0}..7{-30,50};

% Drawing of the circular spot

x9=1-l/exr+0.011; y9=h/byr-0.08h;

call dot(9);
f;

```



Appendix B

```

" THE LETTER CHHA ";
%
call charbegin('g,p1,lsp,rsp,ph,0);
call fulltopbar(1,h);
%
% Drawing of the top hook

x1=1/bxr+0.051; y1=h;
x2=1/bxr-0.151; y2=h/bye+0.07h;
x3=1/bxr+0.171; y3=h/bye+0.04h;

call ellipticalpen(mjaxis,mnaxis,ang);
spen(ellipsa,ellipsb,ellipsc,0,0,0,0);

draw 1{-24,-10}..2{10,-400}..3{20,10};

% Drawing of the bottom hook

x4=x2; y4=h/eye-0.08h;
x5=1-1/exr+0.131; y5=h/eye+0.14h;

draw 3{-20,-10}..4{30,-100}..5{0,1};

% Drawing of the circular part

x6=1-1/exr+0.051; y6=h/bye+0.08h;
x7=1-1/exr-0.181; y7=y5-0.11h;

draw 5{0,1}..6{-1,0}..7{0,-1}..5{0,1};

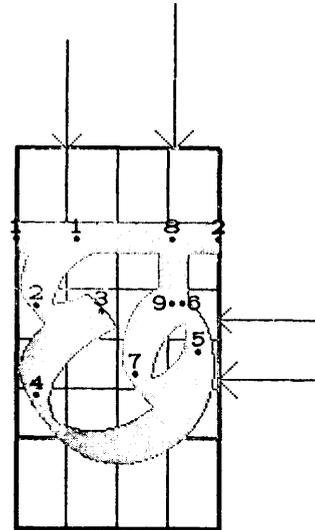
% Drawing of the vertical small bar

x8=1-1/exr; y8=h;
x9=x8; y9=y6;

draw 8..9;

fi.

```



Appendix B

```

" THE LETTER DDHA ";
%
call charbegin('n,p1,lsp,rsp,ph,0);
call fulltopbar(1,h);
%
% Drawing of the bottom hook

x1=1-l/exr; y1=h/byr+0.05h;
x2=1/bxr-0.15l; y2=h/eyr+0.03h;
x3=x1+0.03l; y3=h/eyr-0.17h;

call ellipticalpen(mjaxis,mnaxis,ang);
spen(ellipsa,ellipsb,ellipsc,0,0,0,0);

draw 1{-1,0}..2{0,-1}..3{40,60};

% Drawing of the small horizontal bar

x4=x1; y4=h;

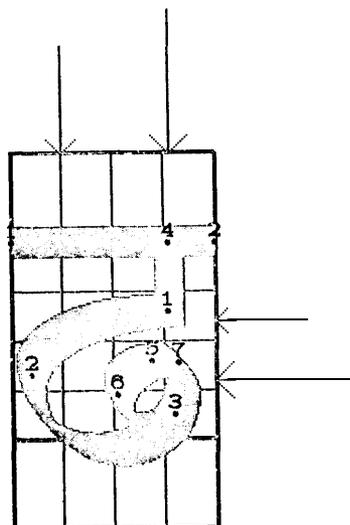
draw 4..1;

% Drawing of the bottom circle

x5=x1-0.08l; y5=h/eyr+0.10h;
x6=x1-0.25l; y6=h/eyr-0.07h;
x7=x1+0.05l; y7=h/eyr+0.09h;

draw 3{40,90}..7{-50,80}..5..6..3{40,90};
fi.

```



```

" THE LETTER murdha-NA ";
%
call charbegin('o,p1,lsp,rsp,ph,0);
call resttopbar(1,h);
Call amatra(1,h);
%
% Drawing of the two vertical lines

x1=x2=1/bxr-0.10l; x3=x4=1-l/exr-0.30l;
y1=y3=h; y2=y4=h/byr-0.10h;

call ellipticalpen(mjaxis,mnaxis,ang);
spen(ellipsa,ellipsb,ellipsc,0,0,0,0);

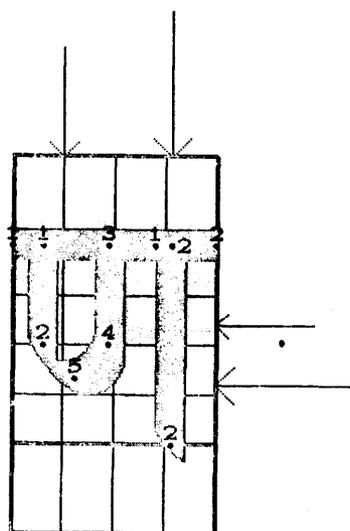
draw 1..2;
draw 3..4;

% Drawing of the circular arc

x5=x2+1/2(x4-x2); y5=y2-1/2(x4-x2);

draw 2{0,-1}..5{1,0}..4{0,1};
fi.

```



Appendix B

```

" THE LETTER THA ";
%
call charbegin('q,pl,isp,rsph,0);
call amatra(1,h);

% Drawing the top half circular hook

x1=1/bxr-0.031; y1=h;
x2=1/bxr+0.171; y2=h/byr+0.10h;
x3=1/bxr; y3=h/byr-0.15h;
x4=1/bxr-0.171; y4=h/byr-0.10h;

call ellipticalpen(mjaxis,mnaxis,ang);
spen(ellipsa,ellipsb,ellipsc,0,0,0);

draw 1{1,0}..2{0,-1}..3{-1,0}..4{0,1};

% Drawing of the bottom hook

x5=1/bxr+0.131; y5=h/eyr-0.05h;
x6=1-1/exr; y6=h/eyr+0.15h;

draw 4{0,-1}..5{1,0}..6{0,1};

% Drawing of the small circle on top

new radius:
x7=x1-0.151; y7=y1-0.23h;
x8=1/bxr+0.151; y8=h-0.20h;

draw 1{-1,0}..7{0,-1}..8{50,50};
% call circle(8,9,10,11,12,7,13,1);

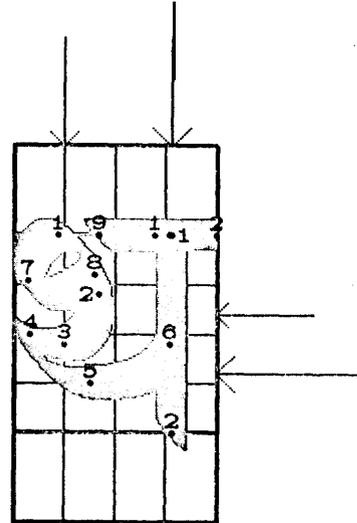
% Drawing of the small top bar

x9=x1+0.231; y9=h;
x10=1-1/exr; y10=y9;

draw 9..10;

fi.

```



Appendix B

```

" THE LETTER DHA ";
%
call charbegin('s,p1,lsp,rsp,ph,0);
%
% Drawing of the top hook

x1=1/bxr+0.051; y1=h;
x2=1/bxr-0.151; y2=h/byr+0.07h;
x3=1/bxr+0.301; y3=h/byr+0.10h;

call ellipticalpen(mjaxis,mnaxis,ang);
spen(ellipsa,ellipsb,ellipsc,0,0,0,0);

draw 1{-1,0}..2{10,-400}..3{20,10};

% Drawing of the bottom hook

x4=x2; y4=h/eyr-0.03h;
x5=1-1/exr; y5=h/eyr+0.027h;

draw 3{-20,-10}..4{0,-1}..5{20,22};

% Drawing of the small top bar

x6=1-1/exr-0.301; y6=h;
x7=1; y7=y6;
x8=1-1/exr; y8=h;

draw 6..7;

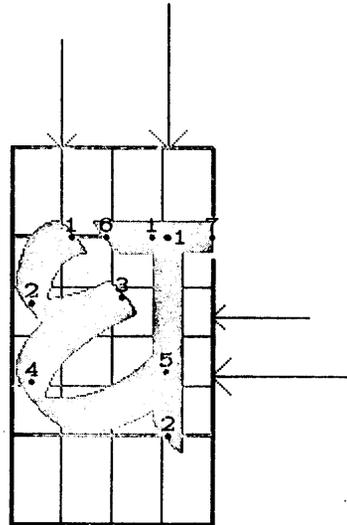
% To make the right half of small top bar vertical

new rwd; rwd=1/exr+0.5 sqrt(w1*w1+mjaxis*mjaxis);
new rht; rht=round(w1+0.05h);
rpenht rht;

rpen#; rwd draw 8;

call amatra(1,h);
fi.

```



Appendix B

```

" THE LETTER PHA " ;
%
call charbegin('v,p1,1sp,rsp,ph,0);
%
% drawing top & mid bar
x1=0; y1=h;
x3=1; x2=4/7(x3-x1);
y1=y2=y3;
x4=x2; y4=0;
vpen; wl draw 1..3;
call ellipticalpen(mj axis, mmaxis, ang);
spen(ellipsa, ellipsb, ellipsc, 0, 0, 0, 0);
draw 2..4;
%
% Drawing of the small vertical bar at right side

x5=1/bxr-0.171; y5=h;
x6=x5; y6=h/byr;

draw 5..6;

% Drawing the bottom arc

x7=1/bxr+0.101; y7=h/eyr+0.10h;
x8=x2; y8=h/byr-0.10h;

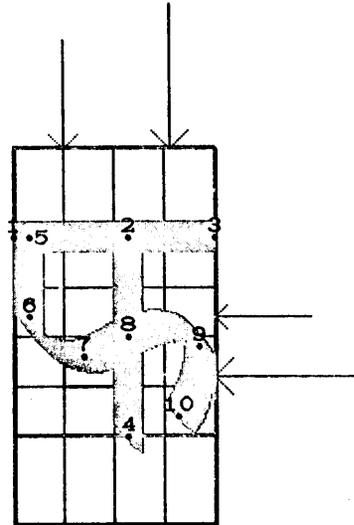
draw 6{0,-1}..7..8{50,30};

% Drawing of the right most hook

x9=1-1/exr+0.151; y9=h/eyr+0.15h;
x10=1-1/exr+0.051; y10=h/eyr-0.20h;

draw 8{50,30}..9{0,-1}..10{-50,-50};
fi.

```



Appendix B

```

" THE LETTER BHA ";
%
call charbegin('x,p1,1sp,rsp,ph,0);
call amatra(1,h);
%
% drawing of left part

x1=1/bxr-0.171; y1=h;
x2=1/bxr-0.051; y2=h/eyr-0.10h;
x3=1/bxr-0.171; y3=h/eyr+0.12h;
x4=1-1/exr; y4=y3;

call ellipticalpen(mjaxis,mnaxis,ang);
spen(ellipsa,ellipsb,ellipsc,0,0,0,0);

draw 1{1,0}..2{-25,-50}..3..4;

% Drawing the top very small bar

x5=0; y5=y1;
x6=1/bxr-0.151; y6=y1;

vpen; w1 draw 5..6;

% To draw the top small bar

x7=1-2*1/exr-0.051; y7=h;
x8=1-1/exr; y8=y7;

vpen; w1 draw 7..8;

% To make one side triangular

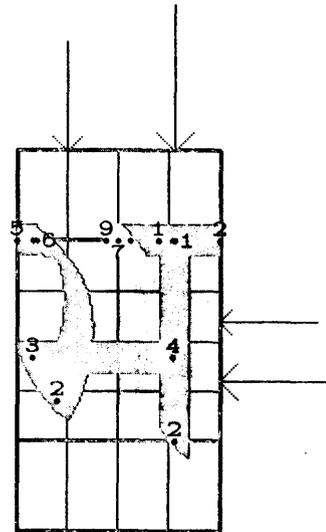
x9=x7-0.061; y9=y7;
x10=x7+0.061; y10=y7;

call ellipticalpen(mjaxis,u,ang);
spen(ellipsa,ellipsb,ellipsc,0,0,0,0)#;

draw 9. .10;

fi.

```



Appendix B

```

" THE LETTER SHA ";
%
call charbegin('3,p1,1sp,rsph,0);
call resttopbar(1,h);
call amatra(1,h);
%
% Drawing of the left side hook

x1=1/bxr-0.181; y1=h/byr+0.15h;
x2=1/bxr+0.251; y2=h/byr+0.05h;
x3=1/bxr-0.091; y3=h/eyr+0.05h;

call ellipticalpen(mjaxis,mnaxis,ang);
spen(ellipsa,ellipsb,ellipsc,0,0,0,0);

draw 1{50,25}..2{0,-1}..3{-1,0};

% Drawing of the bottom slant line

x4=1/bxr-0.051; y4=h/eyr+0.15h;
x5=1/bxr-0.081; y5=h/eyr+0.11h;
x6=1-1/exr-0.221; y6=0;
x7=1/bxr-0.081; y7=y3;

new angm: angm=-(90+ang);
call ellipticalpen(mjaxis,mnaxis,angm);
spen(ellipsa,ellipsb,ellipsc,0,0,0,0);

draw 7..5{-50,50}..4..6;

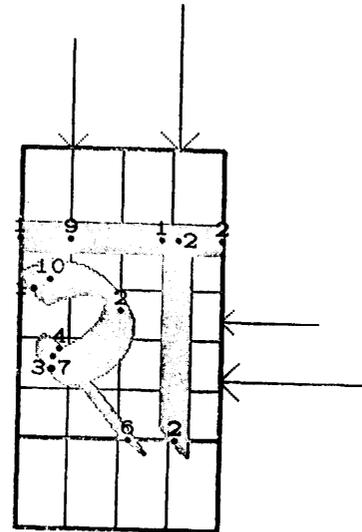
% Drawing of the very small verti-bar at the top

x9=1/bxr; y9=h;
x10=x9-0.101; y10=y1+0.05h;

vpen; wl draw 9..10;

fi.

```



Appendix B

```

" THE LETTER SA ";
%
call charbegin('5,p1,1sp,rsph,0);
call restopbar(1,h);
call amatra(1,h);

% Drawing of the top curved portion

x1=1/bxr; y1=h;
x2=1/bxr; y2=h/byr;
x3=1/bxr-0.101; y3=h/byr-0.18h;

call ellipticalpen(mjaxis,mnaxis,ang);
spen(ellipsa,ellipsb,ellipsc,0,0,0,0);

draw 1..2{0,-1}..3{-1,0};

% Drawing of the bottom line

x4=1-1/exr-0.321; y4=0;
x7=1/bxr-0.011; y7=h/byr+0.01h;
x8=1/bxr-0.121; y8=h/byr-0.05h;

new angm; angm=-(90+ang);
call ellipticalpen(mjaxis,mnaxis,angm);
spen(ellipsa,ellipsb,ellipsc,0,0,0,0);

draw (3..)7..8..3(..7);
draw 3..4;

% Drawing of the notch left of amatra

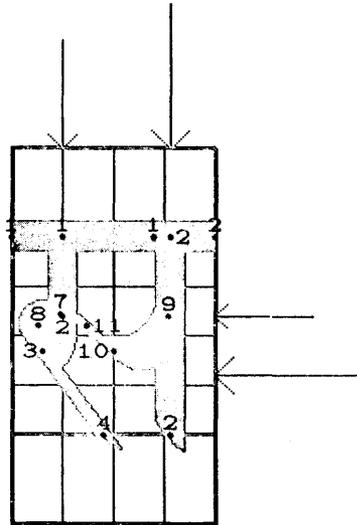
x9=1-1/exr; y9=h/byr;
x10=1-1/exr-0.271; y10=h/byr-0.18h;
x11=1/bxr+0.121; y11=h/byr-0.05h;

call ellipticalpen(mjaxis,mnaxis,ang);
spen(ellipsa,ellipsb,ellipsc,0,0,0,0);

draw 9{0,-1}..10..11{-50,50};

fi.

```



Appendix B

```

" THE LETTER HA ";
%
call charbegin('6,p1,1sp,rsp,ph,0);
call fulltopbar(1,h);
%
% To draw the top hook

x1=1-1/exr; y1=h;
x2=x1; y2=h/byr+0.15h;
x3=1/bxr; y3=y2;
x4=1/bxr-0.151; y4=h/byr+0.02h;
x5=1/bxr-0.051; y5=h/byr-0.15h;

call ellipticalpen(mjaxis,mnaxis,ang);
spen(ellipsa,ellipsb,ellipsc,0,0,0,0);

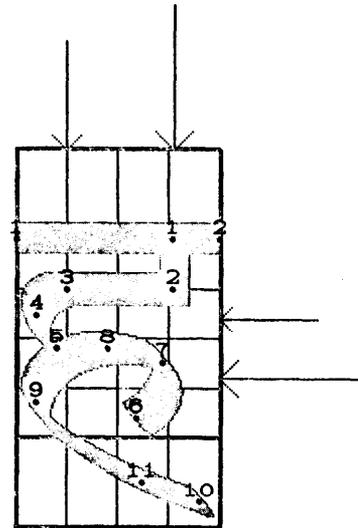
draw 1..2..3;
draw 3{-1,0}..4{0,-1}..5{1,0};

% Drawing of the bottom hook

x6=1-1/exr-0.181; y6=h/eyr-0.20h;
x7=1-1/exr-0.051; y7=h/eyr+0.08h;
x8=1/bxr+0.201; y8=h/byr-0.15h;
x9=x4; y9=h/eyr-0.12h;
x10=1-0.101; y10=-0.70d;
x11=1-1/exr-0.151; y11=-0.47d;

draw 6{50,25}..7..8{-1,0}..9{0,-1}..11..10;
fi.

```



Appendix B

```

" THE AI-matra ";
%
call charbegin('V,p1,-1.0,ph,0);

% Drawing of top ae-matra portion

      x3=1-1/exrm-0.021;  y3=h+0.50w1;

new ln,ht;
ln=0.601;ht=t-0.50w1;
call aem(3,ln,ht);

% Drawing the bottom ae-matra part

      x4=1-1/exrm;  y4=h+w1;
      x5=0.151;  y5=h+0.5t;

call ellipticalpen(0.75*mjaxis,mnaxis,ang);
spen(ellipsa,ellipsb,ellipsc,0,0,0,0);

      draw 4{-50,25}..5{-50,-25};

fi.

" THE AU-matra ";
%
call charbegin('X,p1,lsp-1+1/bxrm+1/exrm,rsph,0);

% Drawing of top ae-matra portion

      x3=1-1/exrm-0.021;  y3=h+0.50w1;

new ln,ht;
ln=0.601;ht=t-0.50w1;
call aem(3,ln,ht);

% Drawing the bottom ae-matra part

      x4=1-1/exrm;  y4=h+w1;
      x5=0.151;  y5=h+0.5t;

call ellipticalpen(0.75*mjaxis,mnaxis,ang);
spen(ellipsa,ellipsb,ellipsc,0,0,0,0);

      draw 4{-50,25}..5{-50,-25};

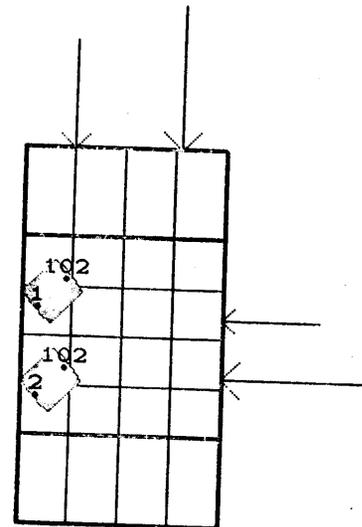
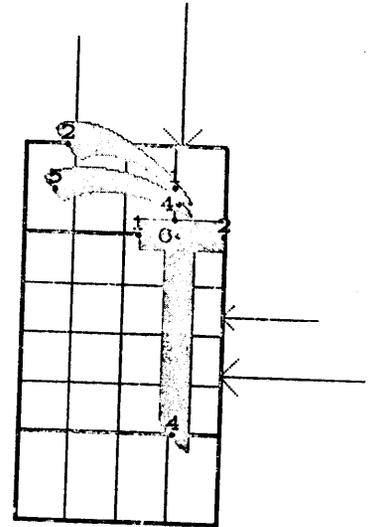
% To draw the vertical bar

      x6=x4;  y6=h;

call verticalbarm(6,1,h,1);
fi.

" THE AH-matra ";
%
call charbegin('Z,w1/pixels,lsp,rsph,0);
%
      x1=w1/2;  y1=h/byr+0.05h;
call dot(1);
      x2=x1;  y2=h/eyr-0.10h;
call dot(2);
fi.

```



Appendix B

```

" THE LETTER half GHA ";
%
call charbegin('003,p1-p1/exr-0.55w1/pixels,1sp,rsph,0);
call restopbar(1,h);
call amatra(1,h);
%
% Drawing of the top hook

x1=1/bxr+0.051; y1=h;
x2=1/bxr-0.151; y2=h/byr+0.07h;
x3=1/bxr+0.301; y3=h/byr+0.10h;

call ellipticalpen(mjaxis,mnaxis,ang);
spon(ellipsa,ellipsb,ellipsc,0.0,0.0);

draw 1{-24,-10}..2{10,-400}..3{20,10};

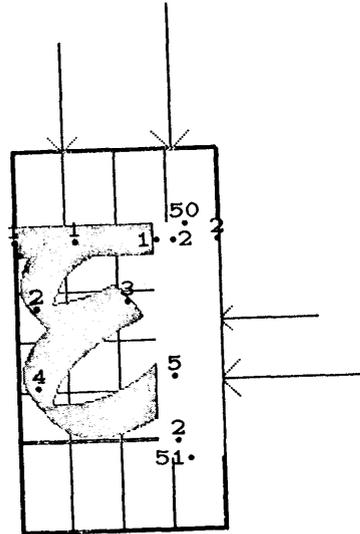
% Drawing of the bottom hook

x4=x2; y4=h/eyr-0.03h;
x5=1-1/exr; y5=h/eyr+0.027h;

draw 3{-20,-10}..4{0,-1}..5{20,22};

call eraseamatra;
fi.

```



Appendix B

```
" THE SYLLABLE KSHHA ";
%
call charbegin('046,p1,1sp,rsph,0);
call amatra(1,h);
```

```
% Drawing the Top loop
```

```
x1=1-1/exr; y1=h/byr+0.10h;
x2=1/2; y2=h/byr-0.10h;
x3=1/bxr-0.171; y3=h/byr+0.20h;
x4=1/bxr-0.051; y4=h;
x5=1/bxr+0.131; y5=h/byr+0.15h;
```

```
call ellipticalpen(mjaxis,mnaxis,ang);
spen(ellipsa,ellipsb,ellipsc,0,0,0,0);
```

```
draw 1{0,-1}..2{-1,0}..3{0,1}..4{1,0}..5{0,-1}
```

```
% Drawing of the bottom portion
```

```
x6=x3; y6=h/eyr;
x7=1/bxr+0.101; y7=h/eyr-0.30h;
x8=x7+0.081; y8=h/eyr-0.21h;
x9=x7+0.021; y9=h/eyr-0.18h;
x10=x7-0.051; y10=h/eyr-0.25h;
x11=1-1/exr-0.231; y11=-0.5d;
```

```
draw 5{0,-1}..6{0,-1}..7{1,0}..8{0,1}..9{-1,0}..10{0,-1}..11{50,-45};
```

```
% Drawing of the top triangular portion
```

```
x12=1-1/exr-0.301; y12=h;
x13=1-1/exr; y13=h;
```

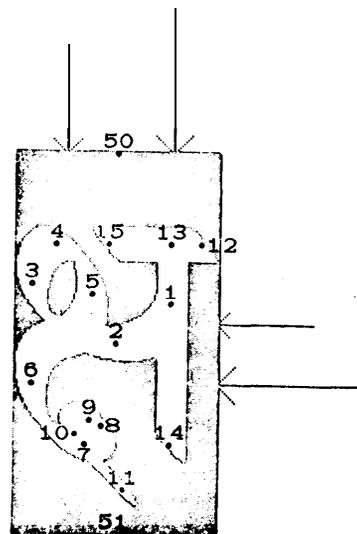
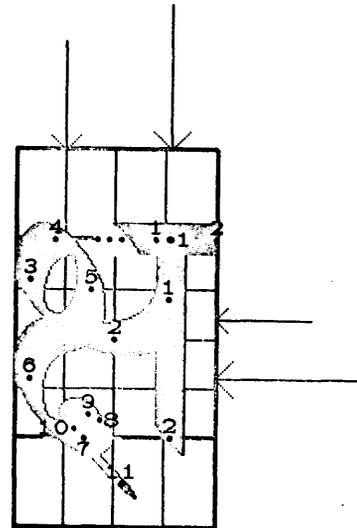
```
vpen; wl draw 12..13;
```

```
x14=x12-0.061; y14=y15=y12;
x15=x12+0.061;
```

```
call ellipticalpen(mjaxis,mnaxis,ang);
spen(ellipsa,ellipsb,ellipsc,0,0,0,0)#;
```

```
draw 14..15;
```

```
fi.
```



Appendix B

```
" THE SYLLABLE GNA ";
%
call charbegin('036,p1,1sp,rsph,0);
call topvertibar(1,h);
```

```
% Drawing the horizontal bar
```

```
x1=1-1/exr; y1=h/byr+0.08h;
x2=1/bxr-0.151; y2=y1;
```

```
call ellipticalpen(mjaxis,mnaxis,ang);
spen(ellipsa,ellipsb,ellipsc,0,0,0,0);
```

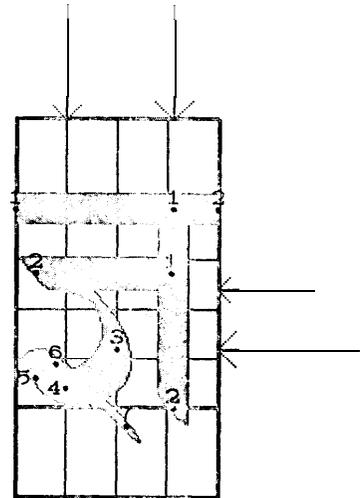
```
draw 1..2;
```

```
% Drawing the lower half
```

```
x3=1/bxr+0.251; y3=h/eyr;
x4=1/bxr; y4=h/eyr-0.20h;
x5=1/bxr-0.151; y5=h/eyr-0.15h;
x6=1/bxr-0.051; y6=h/eyr-0.08h;
x7=1/bxr+0.301; y7=-0.20d;
```

```
draw 2{1,0}..3{0,-1}..4{-1,0}..5{0,1}..6{1,0}..7{50,-50};
```

```
fi.
```



```
" THE SYLLABLE SHRA ";
```

```
%
call charbegin('044,p1,1sp,rsph,0);
call amatra(1,h);
```

```
% Drawing of the left loop part
```

```
x1=1/bxr-0.171; y1=h/byr-0.15h;
x2=1/bxr+0.151; y2=h/byr+0.23h;
x3=1/bxr; y3=h;
x4=1/bxr-0.121; y4=h/byr+0.15h;
x5=1-1/exr; y5=h/eyr+0.10h;
```

```
call ellipticalpen(mjaxis,mnaxis,ang);
spen(ellipsa,ellipsb,ellipsc,0,0,0,0);
```

```
draw 1{50,50}..2{0,1}..3{-1,0}..4{0,-1}..5{50,-30};
```

```
% Drawing of the bottom half ra part
```

```
x6=1/bxr+w1/2; y6=w1/2;
```

```
draw 5..6;
```

```
% To draw the top small bar
```

```
x7=1-2*1/exr-0.101; y7=h;
x8=1-1/exr; y8=y7;
```

```
vpen; w1 draw 7..8;
```

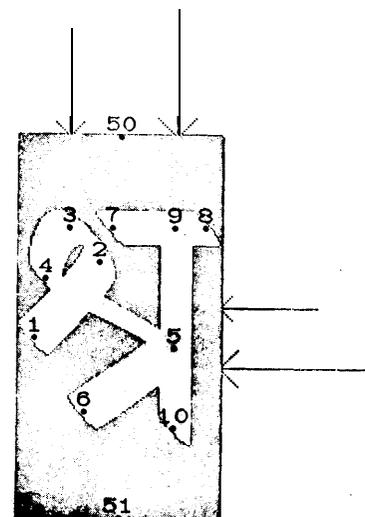
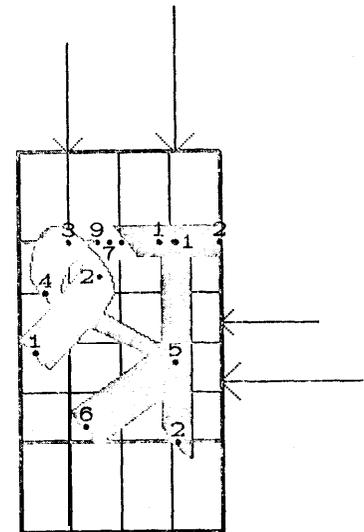
```
% To make one side triangular
```

```
x9=x7-0.061; y9=y7;
x10=x7+0.061; y10=y7;
```

```
call ellipticalpen(mjaxis,u,ang);
spen(ellipsa,ellipsb,ellipsc,0,0,0,0)#;
```

```
draw 9..10;
```

```
fi.
```



Appendix B

```

" THE SYLLABLE DYA ";
%
call charbegin('045,1.1p1,1sp,rsph,0);
%
% Drawing of the left vertical line

      x1=1/bxr+0.251; y1=h;
      x2=x1; y2=h/byr+0.15h;

call ellipticalpen(mj axis, mnaixs, ang);
spen(ellipsa,ellipsb,ellipsc,0,0,0,0);

      draw 1..2;

% Drawing of the topmost hook

      x3=1/bxr-0.171; y3=h/byr-0.00h;
      x4=1/bxr+0.201; y4=h/byr-0.20h;

      draw 2{-1,0}..3{0,-1}..4{1,0};

% Drawing of the bottom hook

      x5=1/bxr-0.121; y5=h/eyr-0.10h;
      x6=1/bxr+0.131; y6=w1/2;
      x7=1-1/exr+0.101; y7=h/eyr+0.20h;

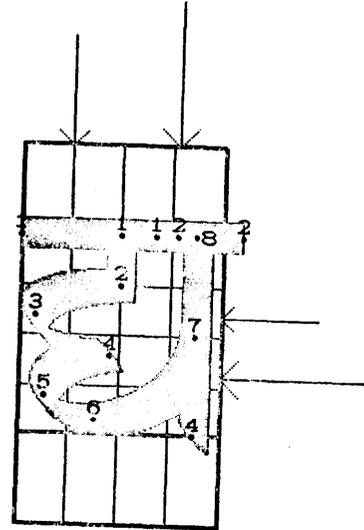
      draw 4{-1,0}..5{0,-1}..6{1,0}..7{0,1};

% Drawing of the top & vertical bar

      x8=1-1/exr+0.101; y8=h;
call verticalbarm(8,1,h,1);
call resttopbar(1,h);

fi.

```



Appendix B

%----- TEXINFO -----

% This portion contains the other necessary informations for TEX.
% Texinfo slant, sp, stretch, shrink, xht, quad, extrasp.
% It also contains lig & kern info.

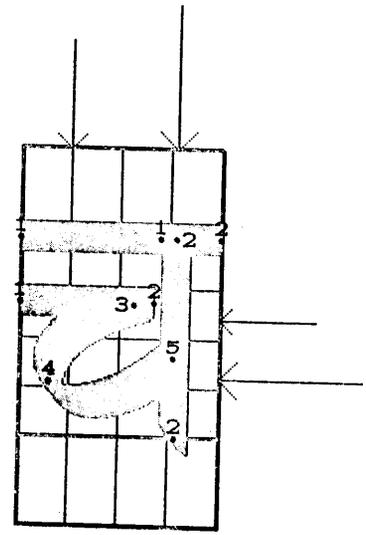
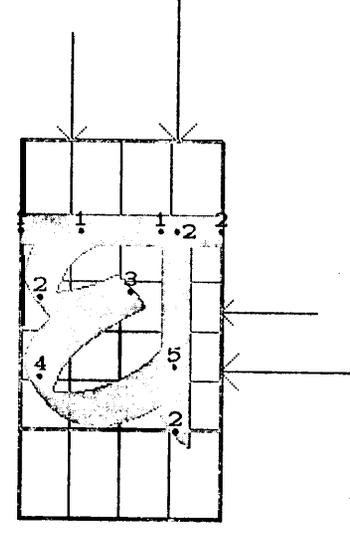
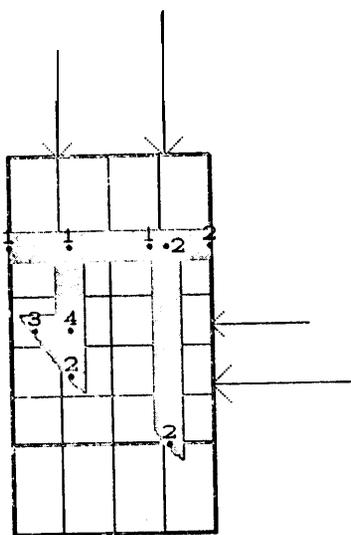
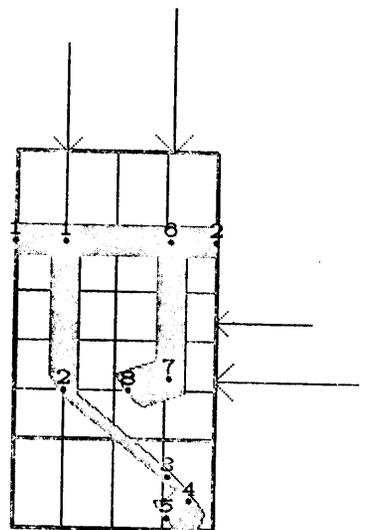
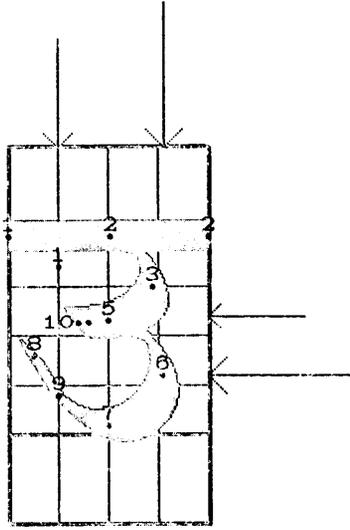
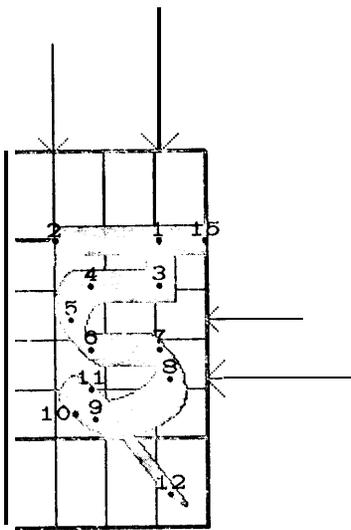
%.....

texinfo slant, 0.5ptsize, 0, 0, ph, 0.5ptsize, 0.5ptsize;

lig 'a':+= '7;
lig '7':4= '046;
lig 'b':+= '001;
lig 'c':+= '002;
lig 'd':+= '003;
lig 'f':+= '004;
lig 'h':+= '005;
lig 'i':+= '006;
lig 'j':+= '007;
li '007':h= '036;
lig 'o':+= '010;
lig 'p':+= '016;
lig 'q':+= '017;
lig 's':+= '020;
lig 't':+= '021;
lig 'u':+= '022;
lig 'v':+= '8;
lig 'w':+= '023;
lig 'x':+= '024;
lig 'y':+= '025;
lig 'z':+= '026;
lig '1':+= '027;
lig '2':+= '030;
lig '3':+= '031;
lig '031':0= '044;
lig '4':+= '032;
lig '5':+= '034;
lig '6':+= '9;

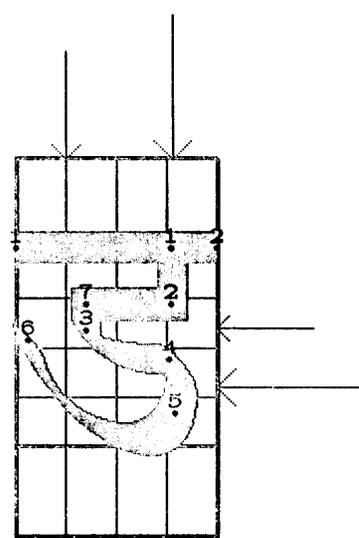
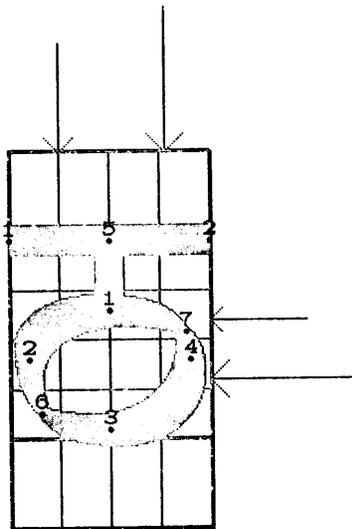
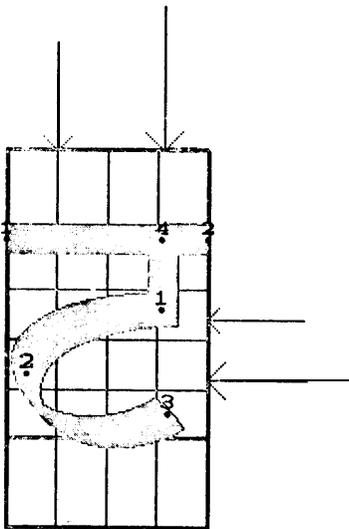
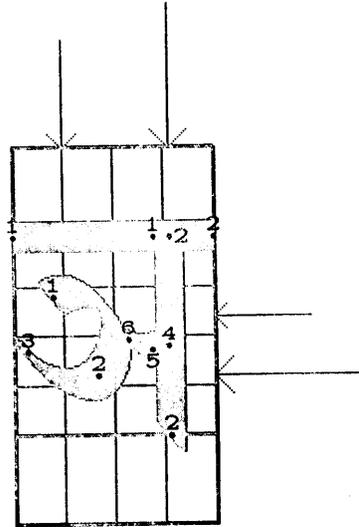
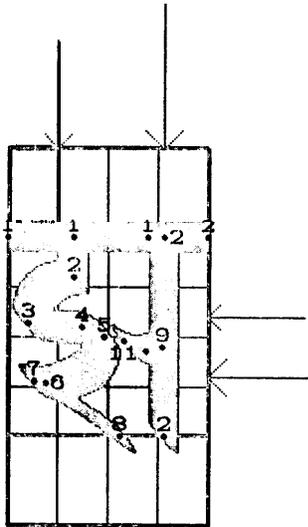
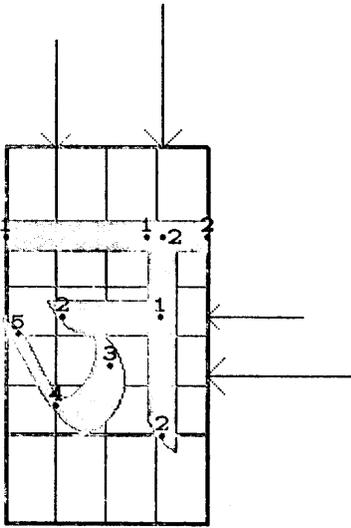
fi.

Appendix B

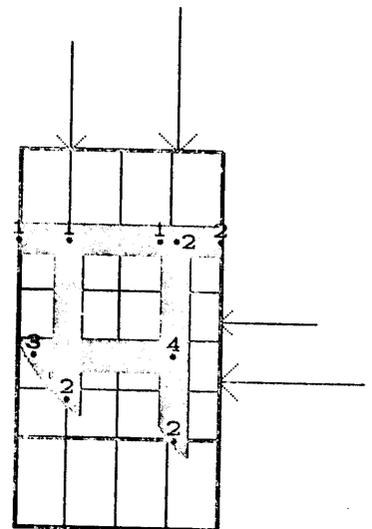
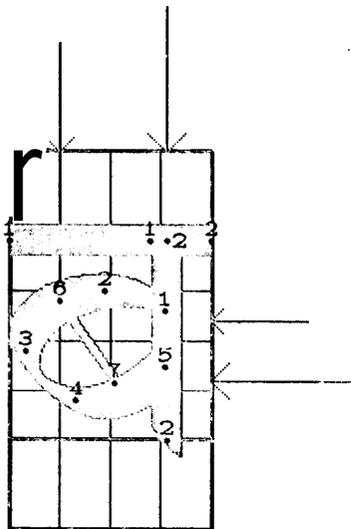
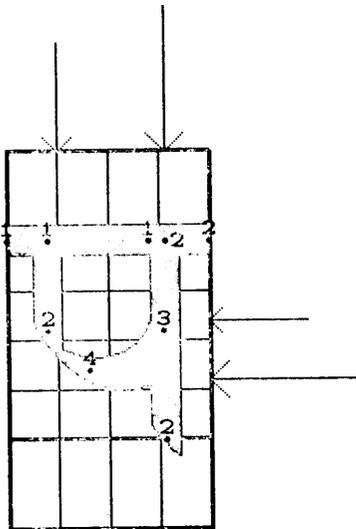
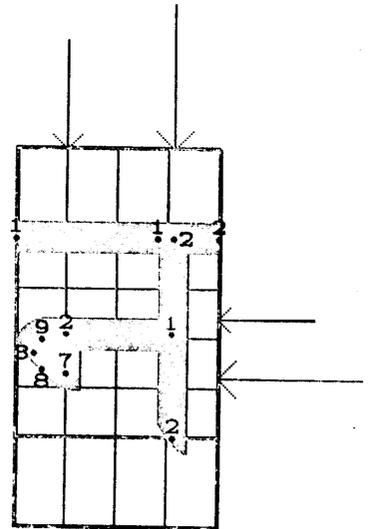
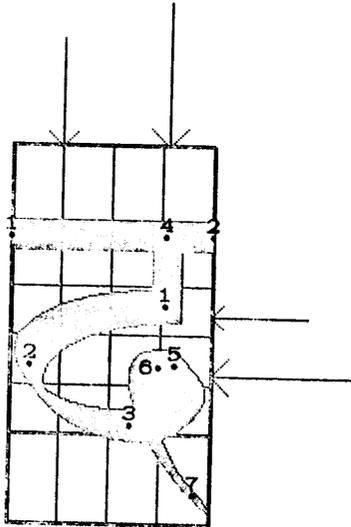
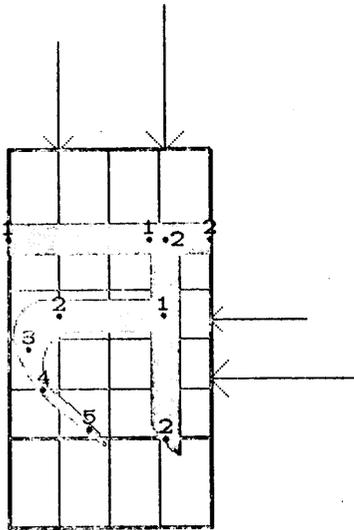


The Letters

Appendix B

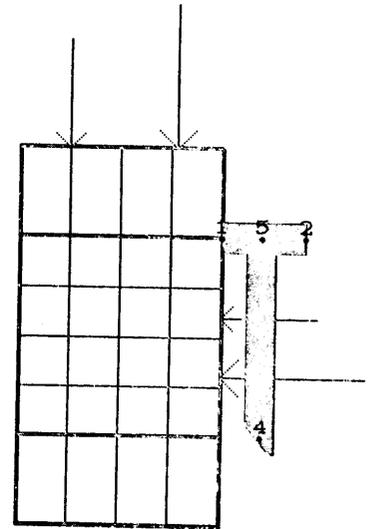
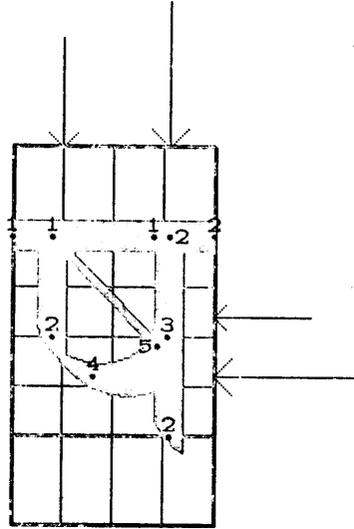
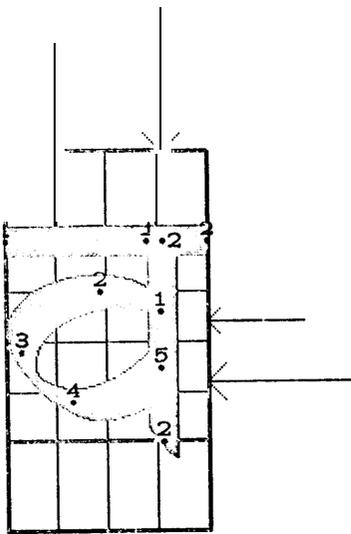
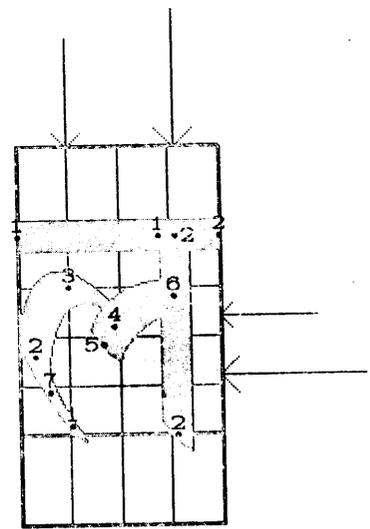
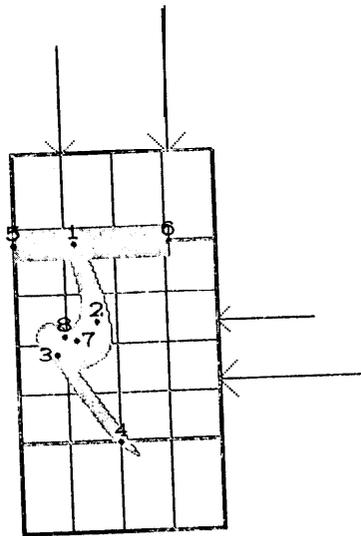
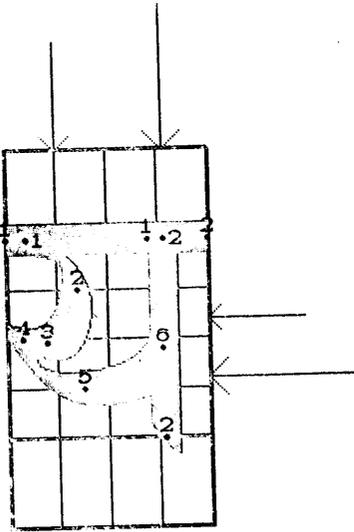


The Letters



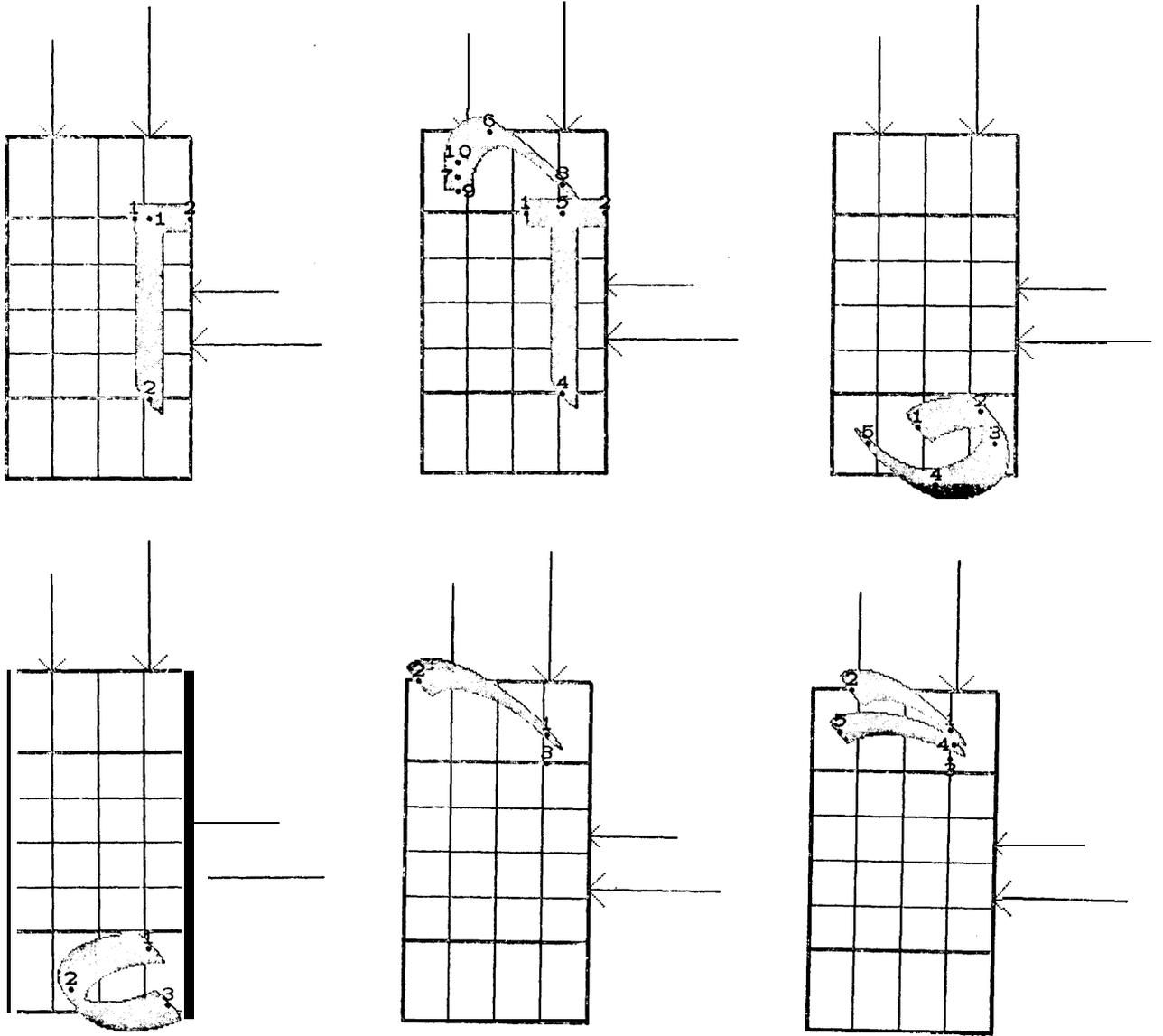
The Letters

Appendix B



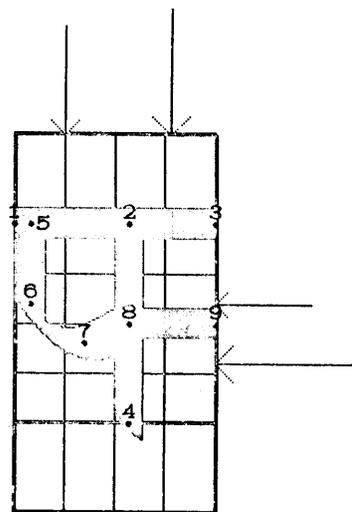
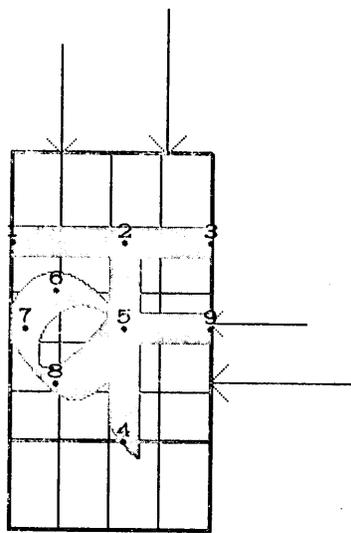
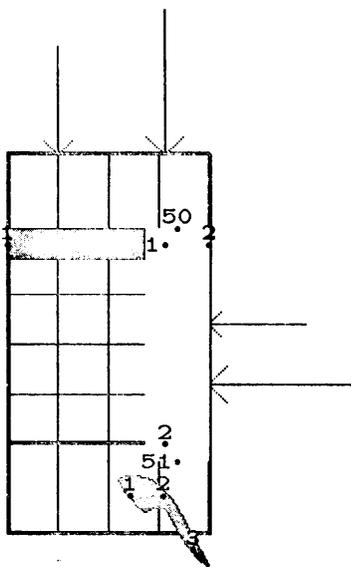
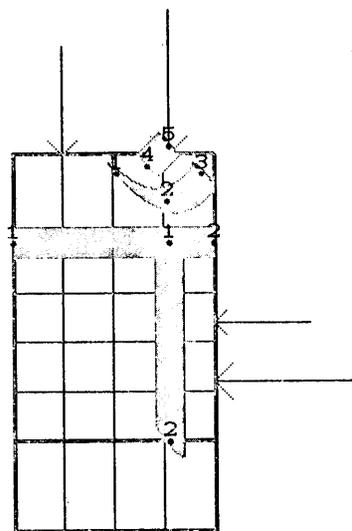
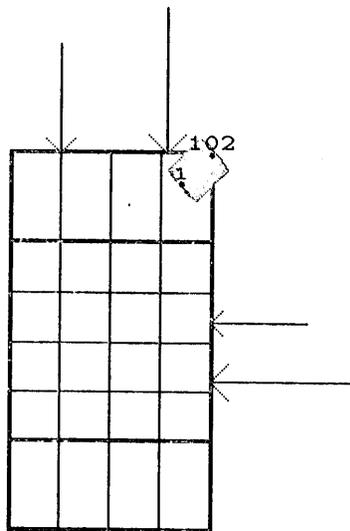
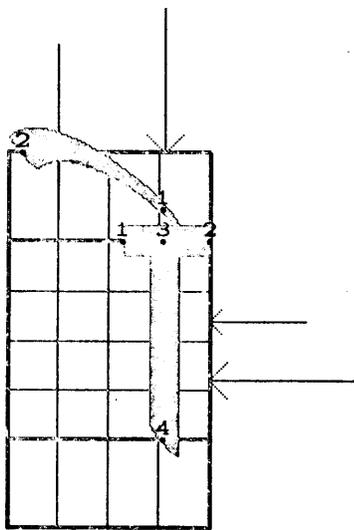
The Letters

Appendix B

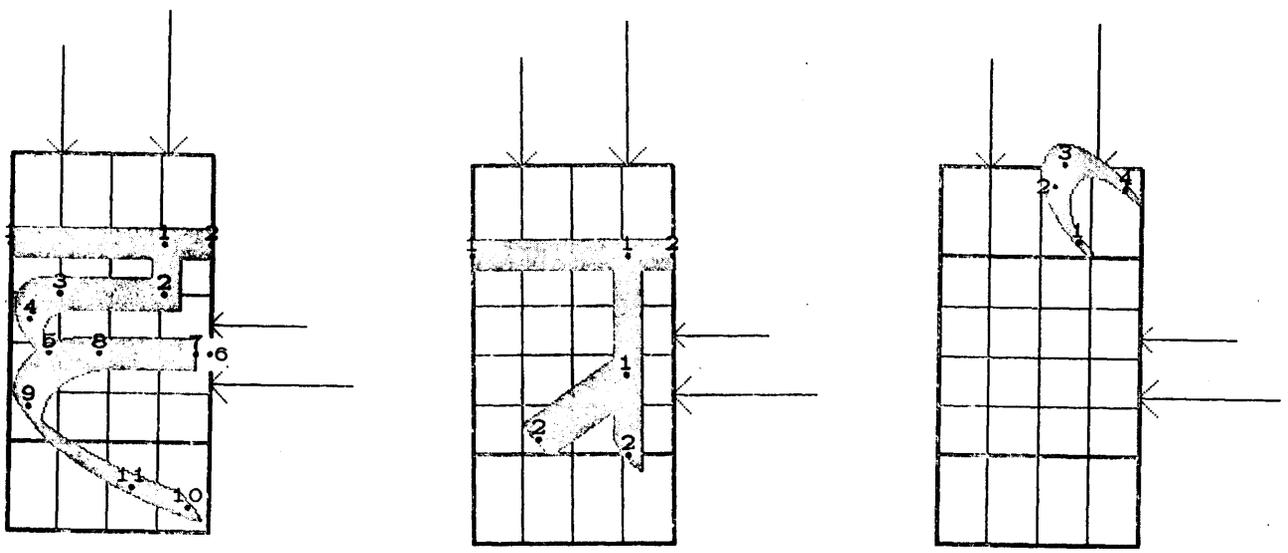


The Letters

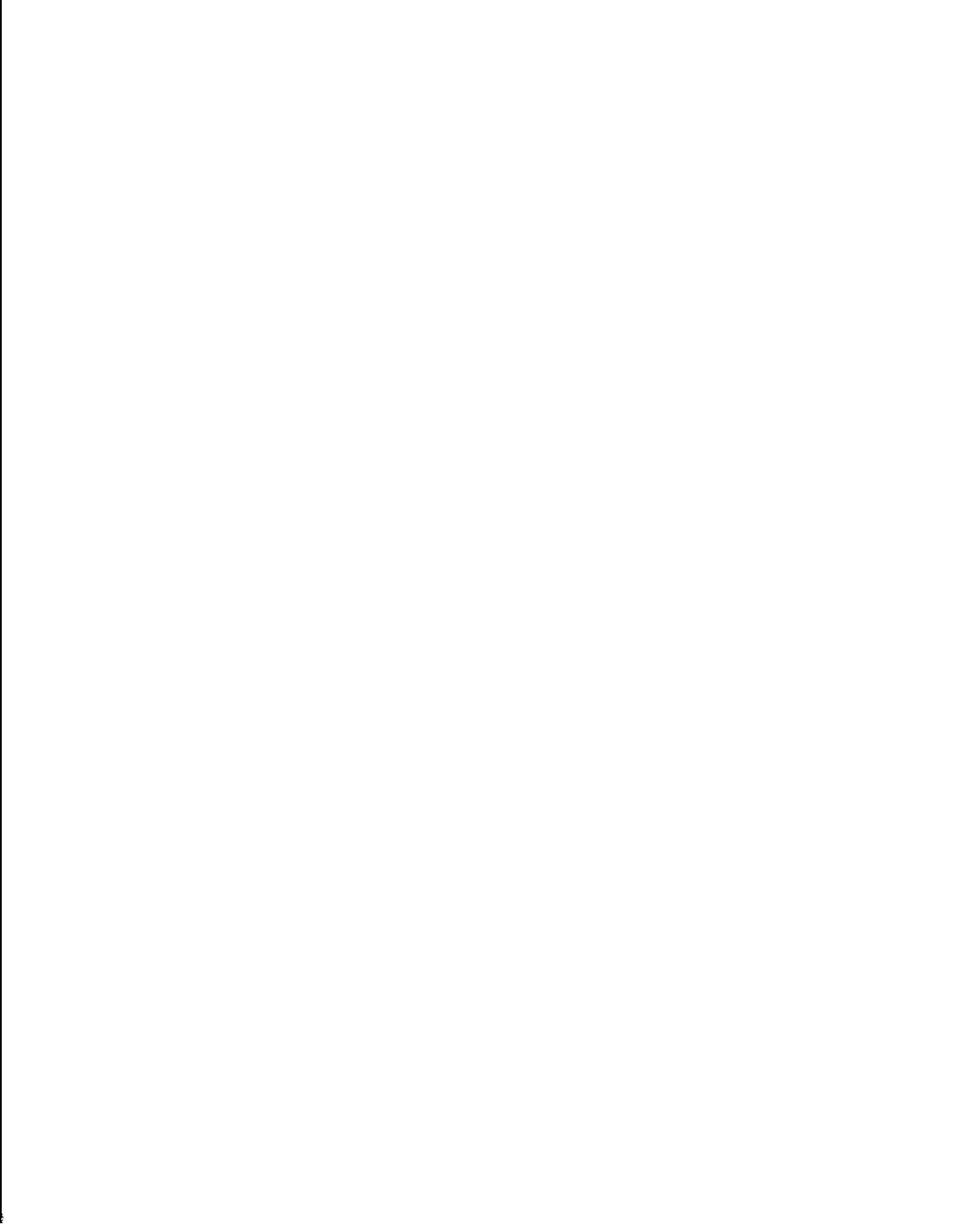
Appendix B



The Letters



The Letters



Appendix C

The Sample Pages

Typography is not considered as a branch of fine arts, rather it should be so good that the printing will be invisible. The sample pages are not designed to present a few pieces of artistic works, but only to give the readers an idea how the printing in NCSD fonts look like. In some cases the letters may seem to be ugly. It is because I could not prevent myself to show the readers `h o w M E T A F O N T` can generate a family of typefaces from a single definition of font.

A Song of Vidyapati

After seeing him the eyes fled off [the face]: it seemed as if the lotus, having discarded the sun was running away.

The moon and the lily met each other. I could hide my expression of love with trick.

O lady, I saw Madhava today. Having forsaken its gravity my bashfulness vanished away.

The knots of the lower garments became loose and fell on the ground. I was hiding my body under my body.

Even my own heart seemed to be of another person. In all the directions I was seeing Krishna and Krishna alone.

Vidyapati says etc.

दरसने लोचन दीघर धाव दिनमणि तेजि कमल जनि जाव ॥
कुमुदिनि चान्द मिलल सहवास कपटे नुकाबिअ मदन विकाश ॥
साजनि माधव देखल आज महिमा छाडि पलाएल लाज ॥
नीवी ससरि भूमि पलि गेलि देह नुकाबिअ देहक सेरि ॥
अपनेजो हिदय बुझावए आन एकसर सब दिस देखिअ कान्ह ॥
भनइ विद्यापतीत्यादि ।

The above example is set using ncsd10 font. Let us now use ncsdsl font and see how it appears.

दरसने लोचन दीघर धाव दिनमणि तेजि कमल जनि जाव ॥
कुमुदिनि चान्द मिलल सहवास कपटे नुकाबिअ मदन विकाश ॥
साजनि माधव देखल आज महिमा छाडि पलाएल लाज ॥
नीवी ससरि भूमि पलि गेलि देह नुकाबिअ देहक सेरि ॥
अपनेजो हिदय बुझावए आन एकसर सब दिस देखिअ कान्ह ॥
भनइ विद्यापतीत्यादि ।

The same example is now set using ncsdb'b font. I know it won't look good, but will give you an idea of the font.

दरसने लोचन दीधर धाव दिनमणि तेजि कमल जनि जाव ॥
कुमुदिनि चान्द मिलल सहवास कपटे नुकाबिअ मदन विकाश ॥
साजनि माधव देखल आज महिमा छाडि पलाएल लाज ॥
नीवी ससरि भूमि पलि गेलि देह नुकाबिअ देहक सेरि ॥
अपनेजो हिदय बुझावए आन एकसर सब दिस देखिअ कान्ह ॥

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भनइ विद्यापतीत्यादि ।

THE COLLECTION



संग्रह



दरसने लोचन दीघर धाव दिनमणि तेजि कमल जनि जाव ॥
कुमुदिनि चान्द मिलल सहवास कपटे नुकाबिअ मदन विकाश ॥
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DEMONSTRATION

by Pijush Ghosh

This page is generated using *tulika* METAFONT and *lekhani* TEX. Before going to the next paragraph try to guess what is the meaning of the **graphical patterns in the** third paragraph. Anyway, guessing won't help. So go ahead.

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क ख ग घ ङ च छ छ च ङ घ ग ख क ॥

गा गि गी गु गू गृ गे गै गो गौ गं ॥

का कि की कु कू कृ के कै को कौ कं ॥

का कु खा खु गा गु घि घु ची चो छा छै ॥

कखग खगघ घङच काग गाक गुकग कगुग किगो ॥

Yes this is only 0.01 percent of it, but in near future you are going to get at least one font of the script. This font will be designated *as Novice Calligrapher's Simple Devanagari* or **ncsd**.

01-Sep-1982

Department of Computer Science
Stanford University

(Canon, an IMPRINT-10 printer output)

NCSD10

	0	1	2	3	4	5	6	7
'000		ए	र	ट	ट	उ	इ	उ
'010	ण						र	श
'020	ए	न	र	ड	भ	म	र	ल
'030	ट	इ	र		रु		ज	
'040					श्र	घ	क्ष	
'050							।	
'060	र	ल	व	श	ष	स	ह	क
'070	फ	ह						
'100		अ		इ	ई	उ	ऊ	ऋ
'110	ए	ऐ					।	।
'120	ि	ी						ी
'130	ौ		:					
'140		क	ख	ग	घ	ङ	च	छ
'150	ज	झ	ञ	ट	ठ	ड	ढ	ण
'160	त	थ	द	ध	न	प	फ	ब
'170	भ	म	य					

Nagari, 'city-writing', or its modern form known as DEVANAGARI ('divine' or 'royal Nagari) is perhaps the most important of Indian scripts. It is used for writing Sanskrit, the classical language of India. Devanagari is the basic script for a number of Indo-Aryan languages, notably Hindi and Marathi but also Maithili, Hihari, Rajasthani. In Nepal it serves for writing Nepali and the Tibeto-Burman language Newari.

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देवनागरी भारत की प्रधान लिपि है , जिसमें संस्कृत लिखी जाती हैं ।

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THE COLLECTION



संग्रह



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	0	1	2	3	4	5	6	7
'000		ए	र	ट	ट	उ	इ	उ
'010	ण						र	श
'020	ए	न	र	ड	भ	म	र	ल
'030	ट	इ	र		र		ज	
'040					श्र	घ	क्ष	
'050							।	
'060	र	ल	व	श	ष	स	ह	क
'070	फ	ह						
'100		अ		इ	ई	उ	ऊ	ऋ
'110	ए	ऐ					।	।
'120	ि	ी						ी
'130	ौ		:					
'140		क	ख	ग	घ	ङ	च	छ
'150	ज	झ	ञ	ट	ठ	ड	ढ	ण
'160	त	थ	द	ध	न	प	फ	ब
'170	भ	म	य					

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NCSDBB

	0	1	2	3	4	5	6	7
'000		र	र	ट	ट	उ	इ	उ
'010	प						त	ड
'020	द	न	ट	ट	र	म	र	र
'030	ट	श	ट		र		ज	
'040					श्र	द्य	क्ष	
'050							।	
'060	र	ल	व	श	ष	स	ह	क
'070	फ	म						
'100		अ		इ	ई	उ	ऊ	ऋ
'110	ए	ऐ					।	।
'120	ि	ी						ी
'130	ौ		ः					
'140		क	ख	ग	घ	ङ	च	छ
'150	ज	झ	ञ	ट	ठ	ड	ढ	ण
'160	त	थ	द	ध	न	प	फ	ब
'170	भ	म	य					

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you have to use NCSDBB font (big and bold) with the following key sequence, 'rU2tOe0Q xO0p aQ u;S0t P1Pu 6V, Ph5yUY 5Y5+aTp P1bQ hOpQ 6VY.' A better way is to mark the key tops with proper symbols and type the text directly.

DEVANAGARI CHARACTER SET

generated by Pijush Ghosh
using TEX and METAFONT of D.E.Knuth

Few Examples

डोनल्ड कनुथ् Donald Knuth एन्ड and मेटाफन्ट METAFONT ॥
स्कट् किम् Scott Kim एन्ड and इनभासीन्स inversions ॥

Few Examples

डोनल्ड कनुथ् Donald Knuth एन्ड and मेटाफन्ट METAFONT I I
स्कट् किम् Scott Kim एन्ड and इनभासीन्स inversions ॥

Few Examples

डोनल्ड कनुथ् Donald Knuth एन्ड and मेटाफन्ट METAFONT ॥
स्कट् किम् Scott Kim एन्ड and इनभासीन्स inversions ॥

Few Examples

डोनल्ड कनुथ् Donald Knuth एन्ड and मेटाफन्ट METAFONT ॥
स्कट् किम् Scott Kim एन्ड and इनभासीन्स inversions ॥

Few Examples

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Few Examples

डोनल्ड कनुथ् Donald Knuth एन्ड and मेटाफन्ट METAFONT ॥
स्कट् किम् Scott Kim एन्ड and इनभासीन्स inversions ॥

DEVANAGARI CHARACTER SET (funny pen)

generated by *Pijush Ghosh*

using TEX and METAFONT of *D.E.Knuth*

Few Examples

डोनल्ड कनुथ् *Donald Knuth* एन्ड *and* मेटाफन्ट *METAFONT I I*

स्कॅट् किम् *Scott Kim* एन्ड *and* इन्भासीन्स *inversions* ॥

Few Examples

डोनल्ड कनुथ् *Donald Knuth* एन्ड *and* मेटाफन्ट *METAFONT* ॥

स्कॅट् किम् *Scott Kim* एन्ड *and* इन्भासीन्स *in versions* ॥

Few Examples

डोनल्ड कनुथ् *Donald Knuth* एन्ड *and* मेटाफन्ट *METAFONT* ॥

स्कॅट् किम् *Scott Kim* एन्ड *and* इन्भासीन्स *inversions* ॥

Few Examples

डोनल्ड कनुथ् *Donald Knuth* एन्ड *and* मेटाफन्ट *METAFONT* ॥

स्कॅट् किम् *Scott Kim* एन्ड *and* इन्भासीन्स *inversions* ॥

Few Examples

डोनल्ड कनुथ् *Donald Knuth* एन्ड *and* मेटाफन्ट *METAFONT* ॥

स्कॅट् किम् *Scott Kim* एन्ड *and* इन्भासीन्स *inversions* ॥

DEVANAGARI CHARACTER SET (flat)

generated by Pijush Ghosh
using *TEX* and *METAFONT* of D.E.Knuth

Consonants

क_a ख_b ग_c घ_d ङ_e ॥ च_f छ_g ज_h झ_i ञ_j ॥
ट_k ठ_l ड_m ढ_n ण_o ॥ त_p थ_q द_r ध_s न_t ॥
प_u फ_v ब_w भ_x म_y ॥ य_z र₀ ल₁ व₂ ॥
श₃ ष₄ स₅ ह₆ ॥

Vowels

अ_A आ_{AN} इ_C ई_D उ_E ऊ_F ऋ_G
ए_H ऐ_I ओ_{AW} औ_{AX} अं_{AY} अः_{AZ} ॥

Vowel-markers or Matras

क_a का_{a0} कि_{Pa} की_{aQ} कु_{aR} कू_{aS}
कृ_{aT} के_{aU} कै_{aV} को_{aW} कौ_{aX} कं_{aY} कः_{aZ} ॥

Half consonants

क्₇ ख्_{char'001} ग्_{char'002} घ्_{char'003} च्_{char'004}
... प्_{char'022} फ्₈ ... स्_{char'034} ह्₉ ॥

Special Symbols

।. stop sign ˘ ˙ ˚ +

Few Examples

डोनल्ड क्नुथ् Donald Knuth

स्कॉट् किम् Scott Kim

॥

॥

Note Complex Conjuncta are not shown.

DEVANAGARI CHARACTER SET (funny font 1)

generated by Pijush Ghosh

using TEX and METAFONT of D.E.Knuth

Consonants

क_a ख_b ग_c घ_d ङ_e ॥ व_f छ_g ज_h ञ_i झ_j ॥
ट_k ठ_l ड_m ढ_n ण_o ॥ त_p थ_q द_r ध_s न_t ॥
प_u फ_v ब_w भ_x म_y ॥ य_z र₀ ल₁ व₂ ॥
श₃ ष₄ स₅ ह₆ ॥

Vowels

अ_A आ_{AN} इ_C ई_D उ_E ऊ_F ऋ_G
ए_H ऐ_I ओ_{AW} औ_{AX} अं_{AY} अः_{AZ} ॥

Vowel-markers or Matras

क_a का_{a0} कि_{Pa} की_{aQ} कु_{aR} कू_{aS}
कृ_{aT} के_{aU} कै_{aV} को_{aW} कौ_{aX} कं_{aY} कः_{aZ} ॥

Half consonants

क्₇ ख्_{char'001} ग्_{char'002} घ्_{char'003} च्_{char'004}
... प्_{char'022} फ्₈ ... स्_{char'034} ह्₉ ॥

Special Symbols

।. stop sign ' " , +

Few Examples

डोनाल्ड क्नुथ् Donald Knuth एन्ड and मेटोफन्ट METAFONT I ।
स्कॉट् किम् Scott Kim एन्ड and इन्वर्सेन्स inversions ॥

(Note: Complex Conjuncts are not shown.)

DEVANAGARI CHARACTER SET (too much elongated)

generated by Pijush Ghosh

using TEX and METAFONT of D.E.Knuth

consonants

क_a ख_b ग_c घ_d ङ_e ॥ च_f छ_g ज_h ष_i ञ_j ॥

ट_k ठ_l ड_m ढ_n ण_o ॥ त_p थ_q द_r ध_s न_t ॥

प_u फ_v ब_w भ_x म_y ॥ य_z र₀ ल₁ व₂ ॥

श₃ ष₄ स₅ ह₆ ॥

Vowels

अ_A आ_{AN} इ_C ई_D उ_E ऊ_F ऋ_G

ए_H ऐ_I ओ_{AW} औ_{AX} अं_{AY} अः_{AZ} ॥

Vowel-markers or Matras

क_a का_{a0} कि_{Pa} की_{aQ} कु_{aR} कू_{aS}

कृ_{aT} के_{aU} कै_{aV} को_{aW} कौ_{aX} कं_{aY} कः_{aZ} ॥

Half consonants

क्₇ ख्_{char'001} ग्_{char'002} घ्_{char'003} च्_{char'004}

... प्_{char'022} फ्₈ ... स्_{char'034} ह्₉ ॥

Special Symbols

|. stop sign ' " , +

Few Examples

डोनल्ड क्नुथ Donald Knuth एन्ड and मेटाफन्ट METAFONT ॥

स्कॉट् किम् Scott Kim एन्ड and इनभार्सीन्स inversions I I

(Note: Complex Conjuncts are not shown.)

DEVANAGARI CHARACTER SET (funny font 2)

generated by Pijush Ghosh

using TEX and METAFONT of D.E.Knuth

Consonants

क_a ख_b ग_c घ_d ङ_e ॥ च_f छ_g ज_h ञ_i झ_j ॥

ट_k ठ_l ड_m ढ_n ण_o ॥ त_p थ_q द_r ध_s न_t ॥

प_u फ_v ब_w म_x य_y ॥ य_z र₀ ल₁ व₂ ॥

श₃ ष₄ स₅ ह₆ ॥

Vowels

अ_A आ_{AN} इ_C ई_D उ_E ऊ_F ऋ_G

ए_H ऐ_I ओ_{AW} औ_{AX} अं_{AY} अः_{AZ} ॥

Vowel-markers OR Matras

क_a का_{a0} कि_{Pa} की_{aQ} कु_{aR} कू_{aS}

कृ_{aT} के_{aU} कै_{aV} को_{aW} कौ_{aX} कं_{aY} कः_{aZ} ॥

Half consonants

क्₇ ख्_{char'001} ग्_{char'002} घ्_{char'003} च्_{char'004}

... प्_{char'022} फ्₈ ... स्_{char'034} ह्₉ ॥

Special Symbols

l. stop sign ' " , +

Few Examples

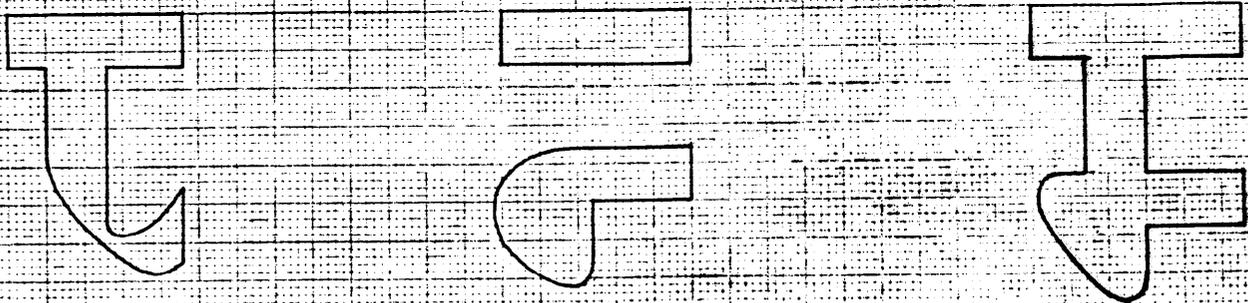
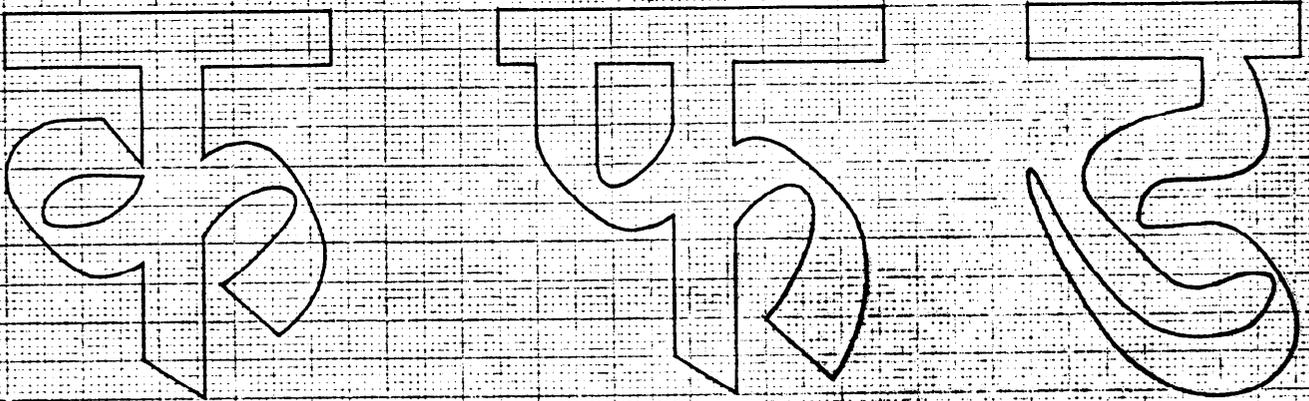
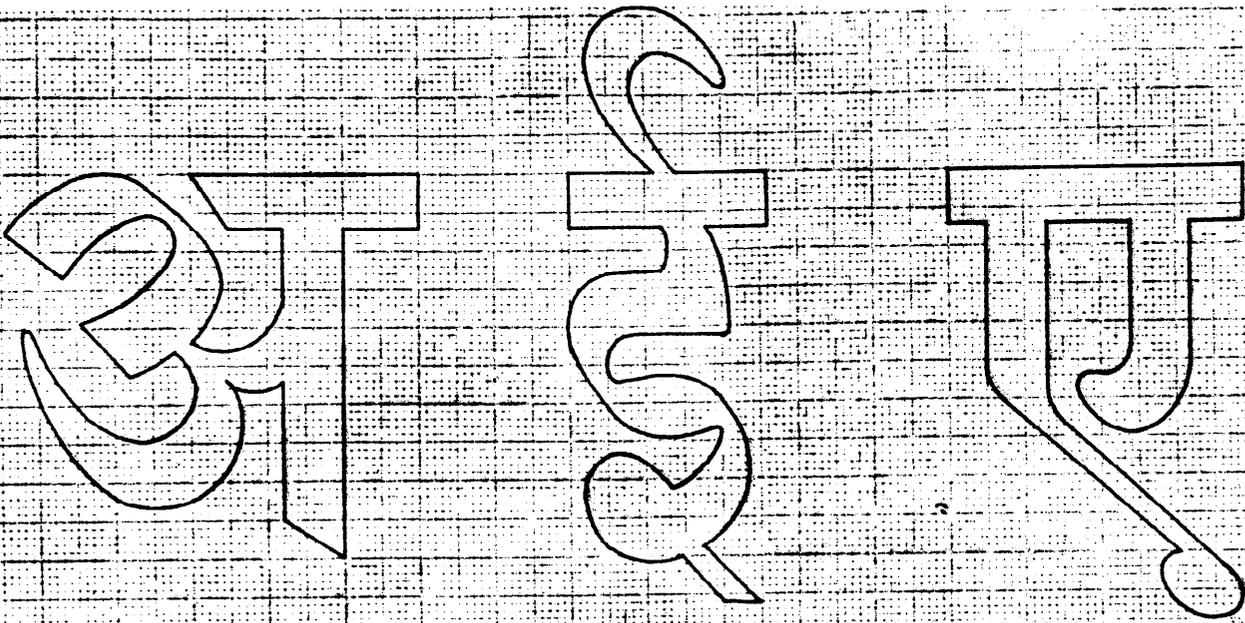
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स्कॉट् किम् Scott Kim एन्ड and इनवर्सिन्स inversions ॥

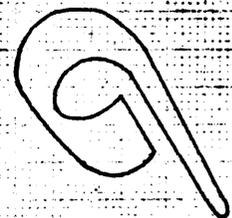
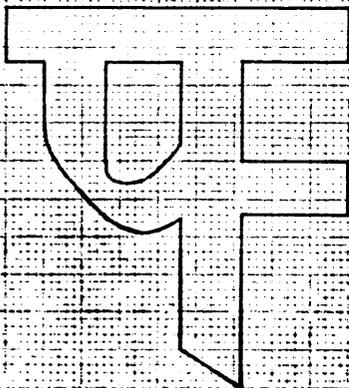
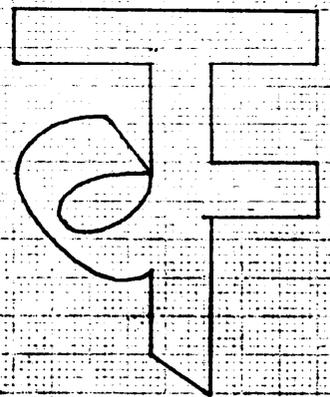
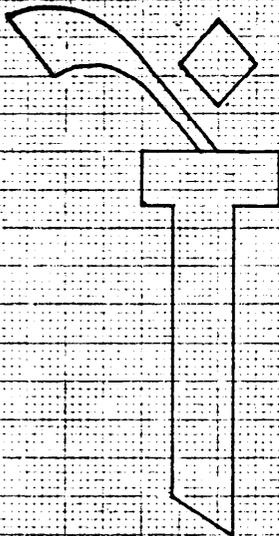
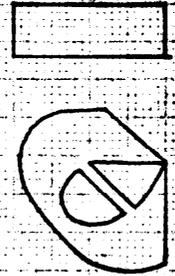
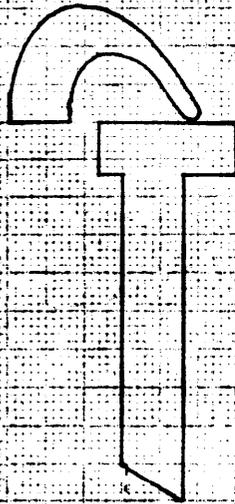
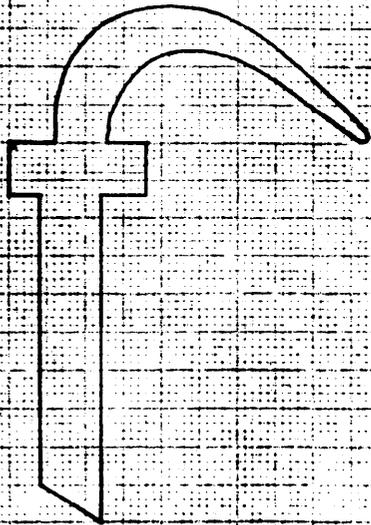
(Note: Complex Conjuncts are not shown.)

For The Future Designers

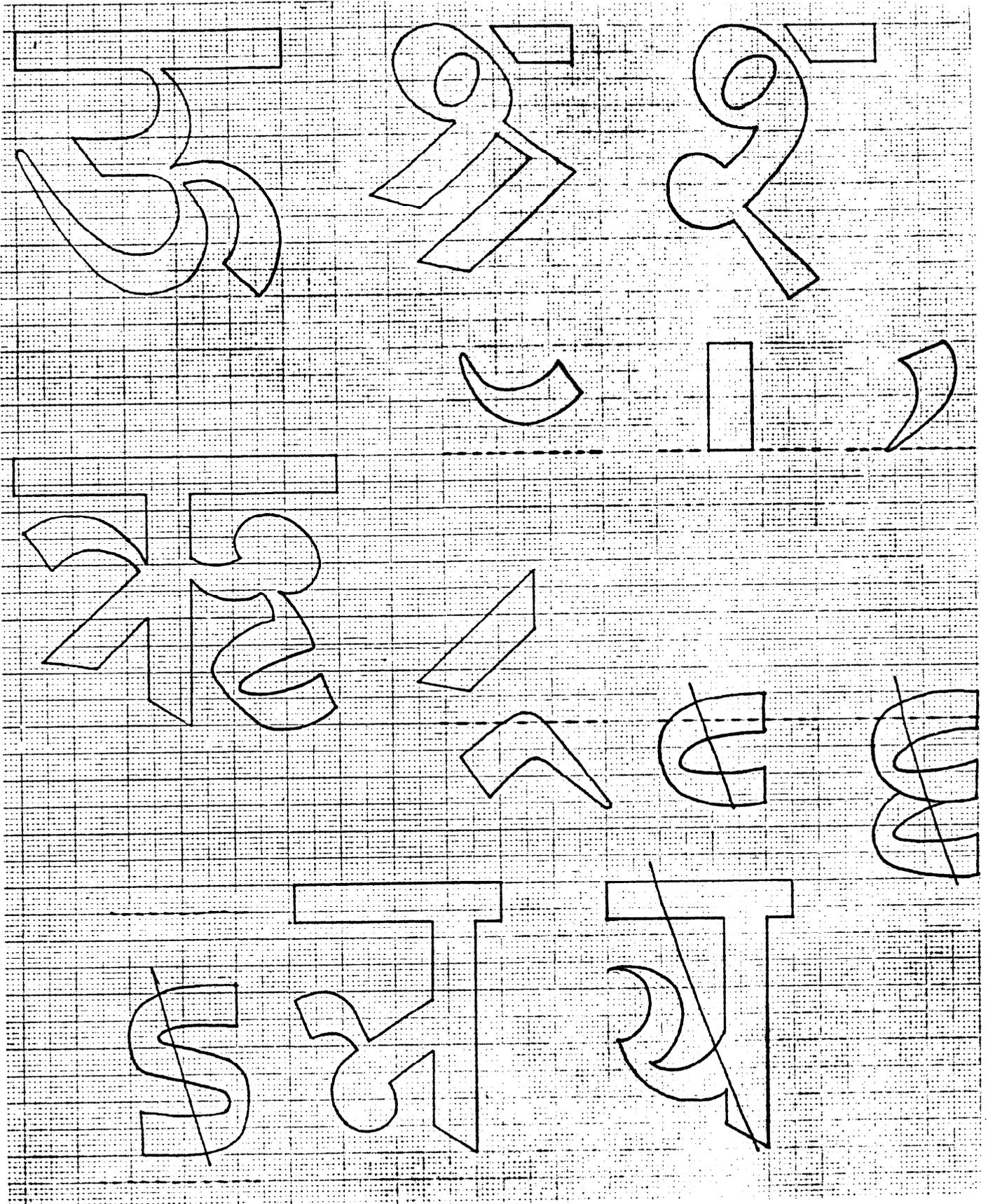
The following pages contain nicely drawn Devanagari letters on the graph sheets for the designers of the future. They are designed by R.K. **Joshi**, one **of** the most famous calligraphers of India. They were specifically designed for digitization, which can be done either by **METAFONT** system or some other systems like **IKARUS**. However, I expect anybody who wants to use these drawings as model of his design would be kind enough to take permission from **Mr. Joshi**.

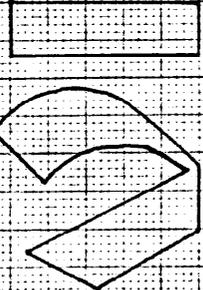
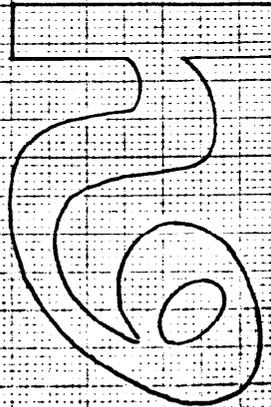
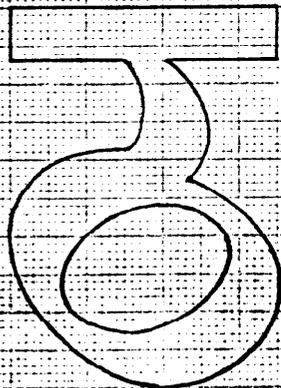
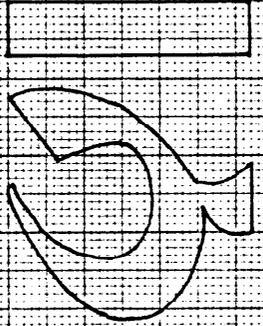
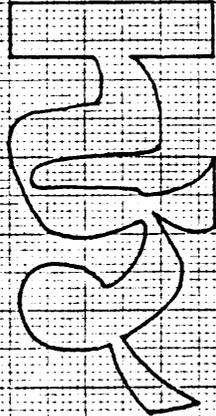
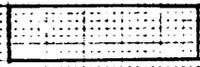
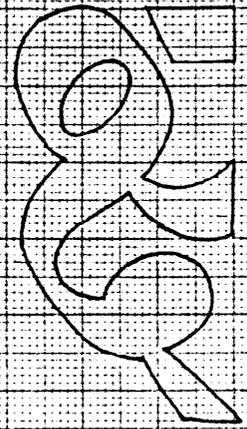
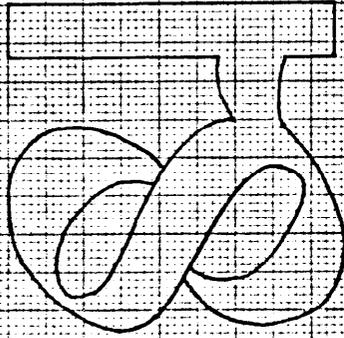
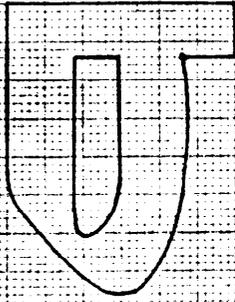


Appendix D

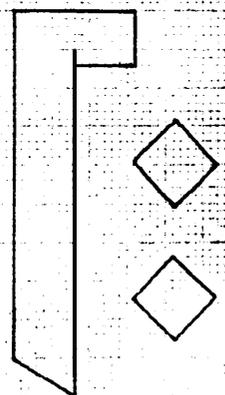
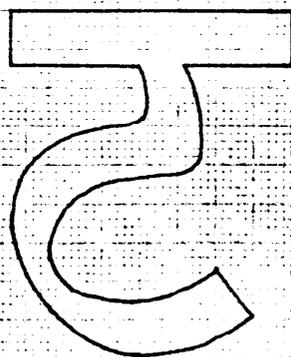
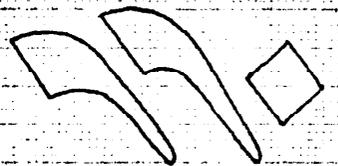
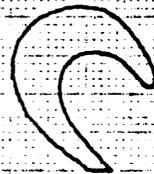
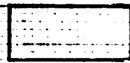
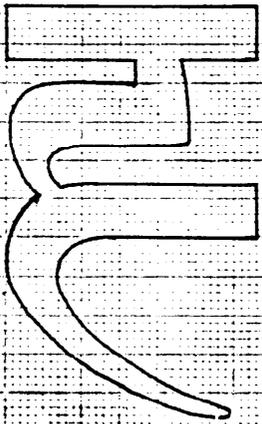
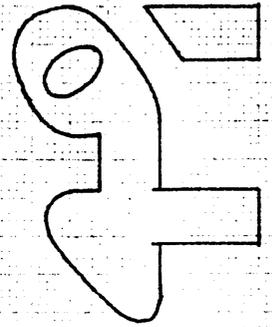
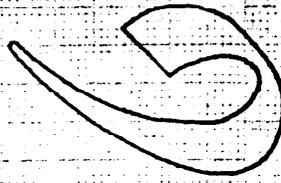
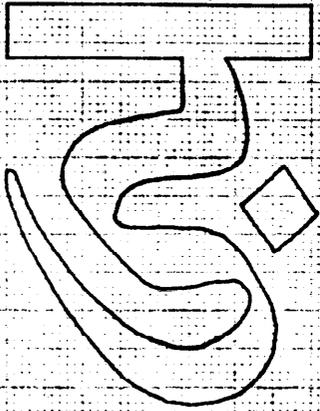


Appendix D

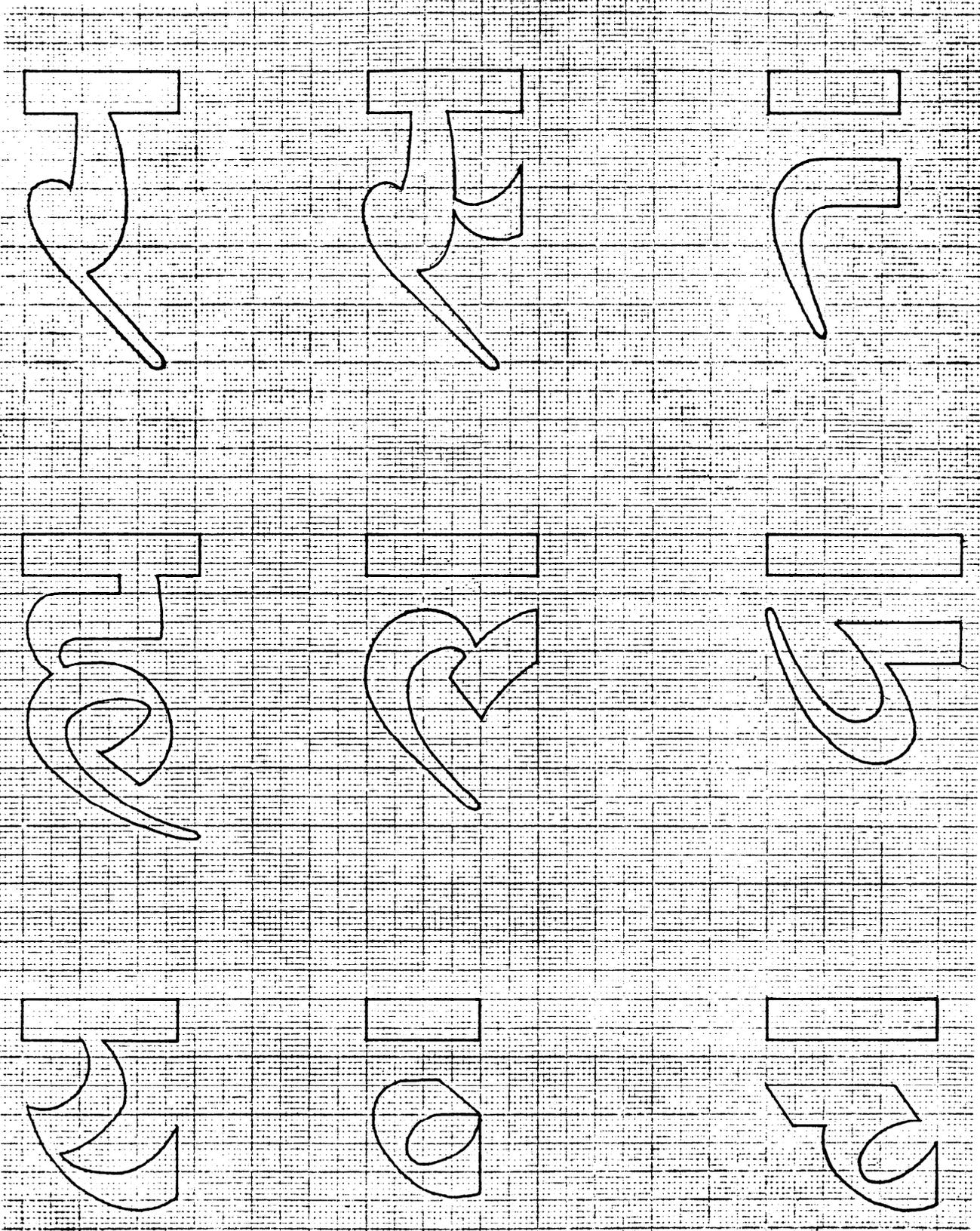




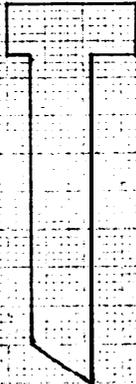
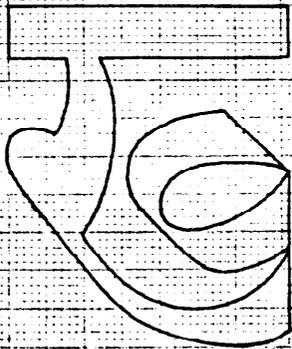
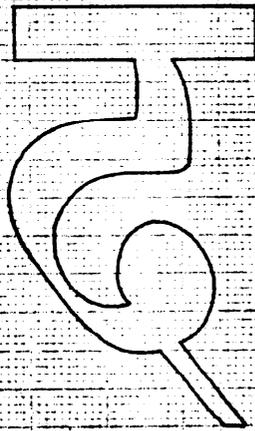
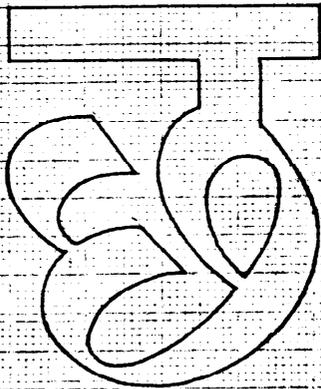
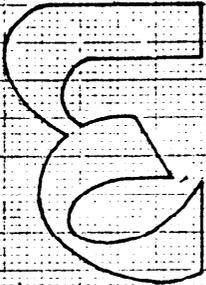
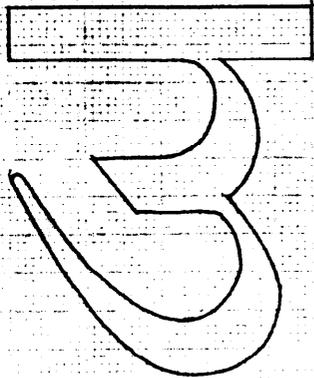
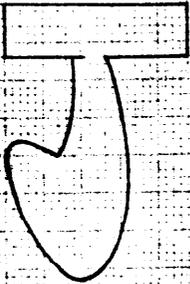
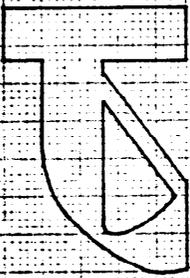
Appendix D



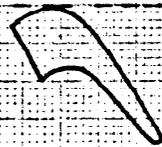
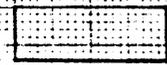
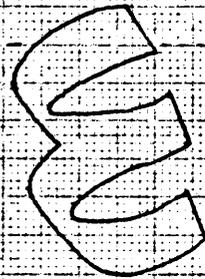
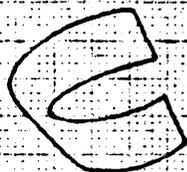
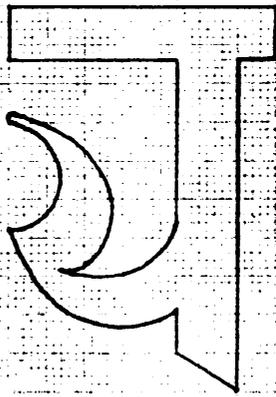
Appendix D



Appendix D



Appendix D



Extra Characters For High Quality Printing

Traditionally most of the conjunct consonants are given completely separate graphical forms. Nowadays for the ease of composition, they are frequently represented by writing the constituent half forms of the consonants side by side, or the full consonants followed by *halant* marks. However, for very high quality printing those graphic idioms are still in use. In Appendix E, I am adding almost an exhaustive list of the conjunct consonants of Devanagari script for the ambitious printers.

Appendix E

क	ka	क्य	klya	ग	g	क्या	nktya	व	ca
क		k	क्व	kva	गघ	gdha	क्या	nktra	व
क	kr	क्य	krya	प्र	gna	क्या	nkya	च	cca
क	kka	क	kṣa	ग्य	gya	क्या	nkra	च	ccha
कख	kkha	क		kṣ	ग्र	gra	क्या	nkṣa	च
क	кта	क	kṣma	गल	gla	क्या	nkha	च	chra
क	ktha	क्य	kṣya	म	gva	क्या	nkhya	च	chva
क	ktya	क्य	kṣva	घ	gha	क्या	nga	च	cña
क	ktva	क	ksa	घ		ghna	क्या	ngya	च
क	kna	क	kha	घ	ghma	क्या	ngra	च	cya
क	kma	क		kh	घ	ghya	क्या	ngha	च
क	kmya	क	kh	घ	ghya	क्या	nghya	च	chra
क	kya	क	kh	घ	ghra	क्या	nghra	च	chrya
क	kra	क	khya	ड	na	क्या	ina	च	ja
क		krya	क	ga	ड	nka	क्या	ima	
क	kla	क	ga		ड	nkta	क्या	nsa	च

Appendix E

ज	<i>ja</i>	झ	<i>dya</i>	त्स	<i>tsna</i>	ध	<i>dhya</i>	ष	<i>pya</i>
ञ	<i>jj</i>	ढ	<i>dha</i>	त्स्य	<i>tsya</i>	ध्र	<i>dhra</i>	प्र	<i>pra</i>
ज्व	<i>jjva</i>	ढः	<i>rha</i>	थ	<i>tha</i>	ध्व	<i>dhva</i>	प्रथ	<i>pla</i>
ज्झ	<i>jjha</i>	झ	<i>dhya</i>	थः	<i>th</i>	न	} <i>na</i>	प्रथस	<i>psa</i>
ज्ज	<i>jma</i>	झ्र	<i>dhra</i>	थ्य	<i>thya</i>	नः		} <i>n</i>	प्रथसः
ज्य	<i>jya</i>	ण	<i>na</i>	थ्यः	<i>da</i>	नः	} <i>nyhya</i>		प्रथस्य
ञ	<i>jra</i>	णः	<i>n</i>	थ्य्य	<i>du</i>	नः		} <i>nta</i>	प्रथस्यः
ञ्व	<i>jva</i>	ण्य	<i>nta</i>	थ्य्यः	<i>dru</i>	न्य	} <i>nty</i>		प्रथस्यः
ञ्झ	<i>jña</i>	ण्यः	<i>ntha</i>	थ्य्य्य	<i>dū</i>	न्यः		} <i>nitra</i>	प्रथस्यः
ञ्ज	<i>jñ</i>	ण्य्य	<i>nda</i>	थ्य्य्यः	<i>drū</i>	न्य्य	} <i>ntha</i>		प्रथस्य्य
ञ्झ	<i>jha</i>	ण्य्य्य	<i>ndra</i>	थ्य्य्य्य	<i>dr</i>	न्य्य्य		} <i>nda</i>	प्रथस्य्य्य
ञ्ज	<i>na</i>	ण्य्य्य्य	<i>ndrya</i>	थ्य्य्य्यः	<i>dga</i>	न्य्य्य्य	} <i>ndra</i>		प्रथस्य्य्य्य
ञ	<i>n̄</i>	ण्य्य्य्य्य	<i>ndha</i>	थ्य्य्य्य्य	<i>dgra</i>	न्य्य्य्य्य		} <i>ndva</i>	प्रथस्य्य्य्य
ञ्व	<i>n̄ca</i>	ण्य्य्य्य्यः	<i>nna</i>	थ्य्य्य्य्य्य	<i>dgha</i>	न्य्य्य्य्य्य	} <i>ndha</i>		प्रथस्य्य्य्य्य
ञ्ज	<i>n̄cma</i>	ण्य्य्य्य्य्य	<i>nya</i>	थ्य्य्य्य्य्यः	<i>dda</i>	न्य्य्य्य्य्य्य		} <i>ndhya</i>	प्रथस्य्य्य्य्य
ञ्य	<i>n̄cya</i>	ण्य्य्य्य्य्य्य	<i>nva</i>	थ्य्य्य्य्य्य्य	<i>ddya</i>	न्य्य्य्य्य्य्य	} <i>ndhra</i>		प्रथस्य्य्य्य्य्य
ञ्झ	<i>n̄cha</i>	ण्य्य्य्य्य्य्य	<i>ta</i>	थ्य्य्य्य्य्य्यः	<i>ddra</i>	न्य्य्य्य्य्य्य्य		} <i>ndhva</i>	प्रथस्य्य्य्य्य्य
ञ्ज	<i>n̄chra</i>	ण्य्य्य्य्य्य्य्य	} <i>t</i>	थ्य्य्य्य्य्य्य्य	<i>ddva</i>	न्य्य्य्य्य्य्य्य	} <i>nna</i>		प्रथस्य्य्य्य्य्य
ञ्ज	<i>n̄ja</i>	ण्य्य्य्य्य्य्य्य		त्क	थ्य्य्य्य्य्य्य्यः	<i>ddha</i>		न्य्य्य्य्य्य्य्य्य	} <i>ndhya</i>
ञ्ज	<i>n̄jma</i>	ण्य्य्य्य्य्य्य्य	त्क	थ्य्य्य्य्य्य्य्य्य	<i>ddhya</i>	न्य्य्य्य्य्य्य्य्य	} <i>nny</i>	प्रथस्य्य्य्य्य्य	
ञ्य	<i>n̄jya</i>	ण्य्य्य्य्य्य्य्य	त्क	थ्य्य्य्य्य्य्य्य्यः	<i>ddhva</i>	न्य्य्य्य्य्य्य्य्य		} <i>npra</i>	प्रथस्य्य्य्य्य्य
ट	<i>ta</i>	ण्य्य्य्य्य्य्य्य	त्क्य	थ्य्य्य्य्य्य्य्य्य	<i>dna</i>	न्य्य्य्य्य्य्य्य्य	} <i>npha</i>		प्रथस्य्य्य्य्य्य
ट्व	<i>tka</i>	ण्य्य्य्य्य्य्य्य	त्क्यः	थ्य्य्य्य्य्य्य्य्य	<i>dba</i>	न्य्य्य्य्य्य्य्य्य		} <i>nma</i>	प्रथस्य्य्य्य्य्य
ट्झ	<i>tta</i>	ण्य्य्य्य्य्य्य्य	त्क्य्य	थ्य्य्य्य्य्य्य्य्य	<i>dbra</i>	न्य्य्य्य्य्य्य्य्य	} <i>nya</i>		प्रथस्य्य्य्य्य्य
ट्ज	<i>ttha</i>	ण्य्य्य्य्य्य्य्य	त्क्य्यः	थ्य्य्य्य्य्य्य्य्य	<i>dbha</i>	न्य्य्य्य्य्य्य्य्य		} <i>nva</i>	प्रथस्य्य्य्य्य्य
ट्य	<i>ttya</i>	ण्य्य्य्य्य्य्य्य	त्क्य्य्य	थ्य्य्य्य्य्य्य्य्य	<i>dbhya</i>	न्य्य्य्य्य्य्य्य्य	} <i>nsa</i>		प्रथस्य्य्य्य्य्य
ट्य्व	<i>ttya</i>	ण्य्य्य्य्य्य्य्य	त्क्य्य्यः	थ्य्य्य्य्य्य्य्य्य	<i>dma</i>	न्य्य्य्य्य्य्य्य्य		} <i>pa</i>	प्रथस्य्य्य्य्य्य
ट्य्झ	<i>ttya</i>	ण्य्य्य्य्य्य्य्य	त्क्य्य्य्य	थ्य्य्य्य्य्य्य्य्य	<i>dya</i>	न्य्य्य्य्य्य्य्य्य	} <i>P</i>		प्रथस्य्य्य्य्य्य
ट्य्ज	<i>ttya</i>	ण्य्य्य्य्य्य्य्य	त्क्य्य्य्य	थ्य्य्य्य्य्य्य्य्य	<i>dra</i>	न्य्य्य्य्य्य्य्य्य		} <i>pta</i>	प्रथस्य्य्य्य्य्य
ट्य्य	<i>ttya</i>	ण्य्य्य्य्य्य्य्य	त्क्य्य्य्य	थ्य्य्य्य्य्य्य्य्य	<i>drya</i>	न्य्य्य्य्य्य्य्य्य	} <i>ptya</i>		प्रथस्य्य्य्य्य्य
ट्य्य्व	<i>ttya</i>	ण्य्य्य्य्य्य्य्य	त्क्य्य्य्य	थ्य्य्य्य्य्य्य्य्य	<i>dva</i>	न्य्य्य्य्य्य्य्य्य		} <i>ptya</i>	प्रथस्य्य्य्य्य्य
ट्य्य्झ	<i>ttya</i>	ण्य्य्य्य्य्य्य्य	त्क्य्य्य्य	थ्य्य्य्य्य्य्य्य्य	<i>dvya</i>	न्य्य्य्य्य्य्य्य्य	} <i>ptya</i>		प्रथस्य्य्य्य्य्य
ट्य्य्ज	<i>ttya</i>	ण्य्य्य्य्य्य्य्य	त्क्य्य्य्य	थ्य्य्य्य्य्य्य्य्य	<i>dvra</i>	न्य्य्य्य्य्य्य्य्य		} <i>pna</i>	प्रथस्य्य्य्य्य्य
ट्य्य्य	<i>ttya</i>	ण्य्य्य्य्य्य्य्य	त्क्य्य्य्य	थ्य्य्य्य्य्य्य्य्य	<i>dha</i>	न्य्य्य्य्य्य्य्य्य	} <i>ppa</i>		प्रथस्य्य्य्य्य्य
ट्य्य्य्व	<i>ttya</i>	ण्य्य्य्य्य्य्य्य	त्क्य्य्य्य	थ्य्य्य्य्य्य्य्य्य	<i>dh</i>	न्य्य्य्य्य्य्य्य्य		} <i>ppha</i>	प्रथस्य्य्य्य्य्य
ट्य्य्य्झ	<i>ttya</i>	ण्य्य्य्य्य्य्य्य	त्क्य्य्य्य	थ्य्य्य्य्य्य्य्य्य	<i>dhna</i>	न्य्य्य्य्य्य्य्य्य	} <i>pma</i>		प्रथस्य्य्य्य्य्य
ट्य्य्य्ज	<i>ttya</i>	ण्य्य्य्य्य्य्य्य	त्क्य्य्य्य	थ्य्य्य्य्य्य्य्य्य	<i>dhma</i>	न्य्य्य्य्य्य्य्य्य			

Appendix E

य	<i>ya</i>	ः	<i>ṣ</i>	ह	<i>hṇa</i>	ह्य	<i>hya</i>	ह्र	<i>hra</i>
र	<i>y</i>	क्	<i>ṣka</i>	ह्र	<i>hna</i>	ह्र	<i>hra</i>	क	<i>la</i>
य	<i>-ya</i>	ष्ट	<i>ṣṭa</i>	ह्र	<i>hma</i>	ह्र	<i>hla</i>	क	<i>lha</i>
य्य	<i>yya</i>	श	<i>ṣṭya</i>						
य्र	<i>yra</i>	श्र	<i>ṣṭra</i>						
य्रा	<i>yra</i>	श्र्य	<i>ṣṭrya</i>						
र	<i>ra</i>	ह	<i>ṣṭva</i>						
रु	<i>ru</i>	ष्ठ	<i>ṣṭha</i>						
रि	<i>rii</i>	श्र्य	<i>ṣṭhya</i>						
ल	<i>la</i>	श्र्य	<i>ṣṭhrya</i>						
ल	<i>l</i>	ष	<i>ṣṇa</i>						
ल्ल	<i>lka</i>	ष	<i>ṣṇa</i>						
ल्ल	<i>lga</i>	प्र	<i>ṣṇra</i>						
ल्ल	<i>lpa</i>	प्र	<i>ṣṇra</i>						
ल्ल	<i>lma</i>	प्र	<i>ṣṇra</i>						
ल्ल	<i>lya</i>	ष	<i>ṣṇya</i>						
ल्ल	<i>lla</i>	ष	<i>ṣṇya</i>						
ल्ल	<i>lva</i>	स	<i>ṣa</i>						
व	<i>va</i>	स	<i>s</i>						
व	<i>v</i>	स	<i>ska</i>						
व्य	<i>vya</i>	स	<i>skha</i>						
व्र	<i>vra</i>	स	<i>sta</i>						
व्र	<i>vra</i>	स	<i>stra</i>						
श	<i>śa</i>	स	<i>stha</i>						
श	<i>śa</i>	स	<i>sna</i>						
श	<i>śa</i>	स	<i>spa</i>						
श	<i>śa</i>	स	<i>spha</i>						
श	<i>śa</i>	स	<i>sma</i>						
श	<i>śca</i>	स	<i>smya</i>						
श	<i>ścya</i>	स	<i>sya</i>						
श	<i>śna</i>	स	<i>sra</i>						
श	<i>śya</i>	स	<i>sva</i>						
श	<i>śra</i>	स	<i>ssa</i>						
श	<i>śla</i>	ह	<i>ha</i>						
श	<i>śva</i>	ह	<i>his</i>						
श	<i>śśa</i>	ह	<i>hū</i>						
ष	<i>ṣa</i>	ह	<i>hr</i>						