
Complete Greek with Adjunct Fonts

C. Mylonas and R. Whitney

We present a set of good quality Greek fonts and a system for accessing the full Greek alphabet with all diacritic marks using 'adjunct' fonts without explicit font changing commands, and a system of Greek monitor characters permitting direct T_EXing.

Introduction. The project started with an innocuous attempt by one of the authors (it is obvious who) to learn T_EX for translating a Greek book on Mechanics, only to find that T_EX lacked the bold upright Greek lowercase letters used for symbolizing vectors such as ω and ϕ for angular velocity vectors. After some trials with variations of "poor man's bold" (*The T_EXbook*, p.386) it became clear that the only hope of getting good characters was to produce them with METAFONT. The beautiful pictures of *Computer Modern Typefaces* whetted the desire for complete fonts for writing Greek, especially as T_EX's Greek mathematical symbols were not intended for writing Greek text (*The T_EXbook*, p.430), and furthermore, they have to be entered with lengthy commands. At that time the ever helpful Barbara Beeton brought to our attention the excellent, original and efficacious Greek system and fonts of Professor Silvio Levy [1], which he graciously offered us. That is when the collaboration of the two authors started, the one ever entangled in problems resolved by the other. At first all efforts were concentrated on the design of the Greek characters. The problem of limited font capacity was postponed till the end. In this report, however, it seemed more useful to start with the requirements for a Greek font, which we then set to meet. Accordingly the following paragraphs describe the characters required in a complete Greek font and the constraints imposed by T_EX; the chosen system for accommodating all requirements and the development of the method of adjunct fonts; the commands for typesetting Greek; the design of a new family of Greek fonts; and the use of Greek monitor characters.

Greek fonts within T_EX's constraints. The biggest problem in font making for T_EX is the limited number of characters in each font. T_EX originally would only accept direct input of 128 symbols in each font, but this was increased to 256 in the new version T_EX 3 of 1990. Even this larger

capacity is insufficient for all characters and symbols of a complete Greek font, much more the smaller font size still in wide use. We shall show how two or more 128-position fonts can be interconnected so as to furnish most of the Greek characters, and how the same system could be applied to two 256-position fonts, which would then accommodate all Greek characters with room to spare for symbols useful in lexicography or instruction.

Classical Greek uses most of the first 295 symbols shown in Table I, and lexicography some or all of the last 65, making about 360 (without counting the new characters on line 4 or some of the symbols on block 6). The six accented vowels marked with a '-' sign in blocks 2 and 3 do not appear in Classical Greek, but classicists want them for indicating the pronunciation in ancient dialects. The characters in parentheses with asterisk at the end of blocks 2 and 7, and their uppercase counterparts in lines 13 and 9 seem to occur very rarely, if at all, in Classical Greek literature [2]. All these symbols do not fit even in a 256-position font. Furthermore, though over 64000 ligatures and kerns can be used in T_EX 3 and can be provided by METAFONT 2.7, only 256 are allowed in METAFONT 1.7 (we use PCMF v.1.7 [11]), so that we had to count and be sparing in their use. If all diacritized characters (i.e., characters with accent, breathing or iota subscript) were to be accessed as ligatures so as to permit automatic hyphenation, about 200 ligatures would be required for Classical Greek and many more for lexicography. Some 55 kerns would then be left for Classical Greek, whereas our Greek alphabet is less regular and requires more kerning than the Latin.

Modern Greek is written with a single accent and diaeresis but no breathings or iota-subscript (blocks 1 and 5 in Table I, and 15 characters of block 2). This reduces the number of characters to 103 (with the punctuation marks and numerals) and of ligatures to 23, so that a 128-position font is sufficient, with 233 kerns available. Even this number of kerns is not high: in the worst case every lowercase letter would need kerning with itself and every other, which with the 7 simply accented vowels, makes $24 \times 32 = 768$ kerns (no letter after a final sigma). The possible kerns between vowels with breathings (always first in a word) and the other unaccented letters is $56 \times 25 = 1400$. Another $24^2 = 576$ would be required for kerning uppercase letters, and 768 for uppercase followed by lowercase, bringing the maximum total to about 3500 kerns. Happily, many character pairs need no kerning and, of course, all

pair combinations do not normally occur, though the transliterated outlandish names seen today in the press contain surprising combinations. In the system described below we had to be content with 225 kerns, and we ignored the rarer and the less evident misspaciings, eagerly awaiting the full implementation of T_EX 3 and METAFONT 2.7 with the promised practically unlimited kerning.

No concern about kerning is indicated by Professor Levy who introduces an ingenious scheme for printing the character ‘s’ as final sigma ‘ς’ when at the end of a word and as middle sigma ‘σ’ otherwise, but uses 56 ligatures of the middle sigma ‘σ’ with every other letter and accented vowel. This dispensation from choosing the proper sigma is a luxury not enjoyed by any typist in Greece, but would be welcome if different keys weren’t anyway needed for the two sigmas in word processors producing Greek characters on the screen (see section *Greek Monitor Characters*). Another 128-position distribution was proposed by Haralambous and Thull [4] in their excellent compromise for Modern Greek, and a general 256-position distribution by Haralambous [5] was communicated to us after the submission of the present article.

The chosen system. It was felt that a “complete” and unique Greek font should be produced for typesetting both Modern and Classical Greek without font-changing commands and that it should include all the additional accents and pronunciation signs used in lexicography. In the absence of a large font size with unlimited ligatures and kerns, a system with the following characteristics was chosen:

a. The number of distinct characters in the Classical font was reduced to 187, without sacrificing its capabilities, by retaining only the diacritized vowels of blocks 2 and 3 in Table I, and abandoning the separate characters representing the vowels with iota subscript (block 7 and line 9), the uppercase vowels with accent-breathing on the left (line 8), and the diacritized vowels for lexicography (lines 12–14). These diacritics are instead entered correctly as separate characters, the accent-breathing before uppercase vowels and the iota subscript after vowels.

b. The iota subscript was made a separate character of zero width and a left offset which centers it under the plain or accented vowels α η ω when typed after them. The subscript is placed at the right of the uppercase Α Η Ω with the macro \I which offsets it by .4em (or with just “|” when with breathing). Subscripted vowels are mostly first or last letters in a word, and will run no risk of hyphenation if

separation after the first or before the last letter of a word is excluded. Internal subscript vowels are rare, and even more rarely will hyphenation occur at their subscript, but this should be checked. Likewise the accent-breathing to the left of uppercase vowels run no risk of hyphenation.

c. In lexicography, only main entry words or the word following them are diacritized with *brève* and *macron* or, when rarely capitalized, with accent or accent-breathing on the right or left. But main entries in a dictionary are always placed at the beginning of a line and need no hyphenation. The accent-breathings of Table I, line 12, and the accents of line 13 occur in rare uppercase words in lexicography or instruction and are entered on the right of the letter. The *brève* and *macron* of line 14 are entered with plain T_EX commands (*The T_EXbook*, p.52, 356), e.g. “\u o” gives “ö”.

d. The 103 Modern Greek characters double as Classical when the single accent is marked as a regular ‘acute’, as is done in most books in Greece [3], but not when it is shown as a novel triangular mark suggested by some Greek grammarians. The 192 independent Classical characters are then reduced to 89, of which 25 can be placed with the 103 characters of Modern Greek in one 128-position *main Greek font*. The question then remained how to sort out at least 64 classical characters into a separate 128-position *classical adjunct font*, and how to access them easily, preferably without explicit font-changing commands.

The solution was found by noting, first, that the 66 diacritized characters of Table I block 3 have the common trait of carrying a smooth or rough breathing, hence are entered with a leading symbol ‘>’ or ‘<’ followed by an optional accent and finally a vowel or ‘ρ’ with which they form ligatures, and second, that if these ‘breathed’ characters were placed in the classical adjunct font, the common breathing symbols could be made to act as commands to shift and access the compound character in that font, without any additional entry or any hint to the user that a second font is used. Adjunct fonts match the main fonts in style and magnification, and the shift is automatic to the matching adjunct font. The two fonts double the possible number of ligatures and may be easily joined into one (without any changes in the .tex files) when 256-position systems become available with sufficient kerns and ligatures. It would even be possible to fit most of the uppercase vowels with breathings in the adjunct font so as to access them by ligature, but this was not found

T A B L E II
PRESENT KEY CORRESPONDENCE

α	β	γ	δ	ε	ζ	η	θ	ι	κ	λ	μ	ν	ξ	ο	π	ρ	σ	ς	τ	υ	φ	χ	ψ	ω	ϝ					
a	b	g	d	e	z	h	↓	i	k	l	m	n	↓	o	p	r	↓	s	t	u	f	↓	y	↓	↓					
Not obvious							J						X			C							Q		W	V
Α	Β	Γ	Δ	Ε	Ζ	Η	Θ	Ι	Κ	Λ	Μ	Ν	Ξ	Ο	Π	Ρ	ϝ	Σ	Τ	Υ	Φ	Χ	Ψ	Ω	ϝ					
A	B	G	D	E	Z	H	↓	I	K	L	M	N	↓	O	P	R	↓	S	T	U	F	↓	Y	↓	↓					
Not obvious							J						X			C							Q		W	V
ˊ	ˋ	ˊ	ˋ	ˊ	ˋ	ˊ	ˋ	ˊ	ˋ	ˊ	ˋ	ˊ	ˋ	ˊ	ˋ	ˊ	ˋ	ˊ	ˋ	ˊ	ˋ	ˊ	ˋ	ˊ	ˋ					
ˊ	ˋ	ˊ	>	>ˊ	>ˋ	>ˊ	<	<ˊ	<ˋ	<ˊ	ˊ	ˋ	ˊ	ˋ	ˊ	ˋ	ˊ	ˋ	ˊ	ˋ	ˊ	ˋ	ˊ	ˋ	ˊ					
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,	.	:	/	?	;	!	ˊ	-	--	---	+	=	@	%																
[]	()	«	»	"	§	F	ς	ι	ϝ	,																		
[]	()	(())	""	\pg	\f	\s	\n	\p	\x																		

necessary as the separate accent-breathings worked perfectly. The required inputs for writing Greek are shown in section *Typesetting Greek* and on lines 7 and 8 of Table II. The only drawback of this system is the exclusion of kerning between characters of different fonts. But the adjunct font contains the vowels with breathing, which come always first in a word and may need kerning only on their right. This may frequently be circumvented by carefully adjusting the character margins (`adjust_fit`).

Accordingly two interrelated 128-position fonts were used: the main font containing all characters, symbols, and punctuation marks used in Modern Greek, as well as the remaining simply accented vowels from blocks 1,2,4,5,6,10 of Table I (plus two new characters), and the adjunct font with the remaining vowels with breathing from blocks 2 and 4, plus some additional characters. The main font `gm10` and its adjunct `gp10` are shown in Table IV. Numerals, plain alphabets, simple accents and all punctuation marks have the same positions as in Levy and the corresponding characters in Computer Modern. The remaining characters in `gm10` and all of `gp10` are in unrelated positions.

The correspondence between Latin and Greek characters, shown in Table II, and the way of

entering the accents and breathings, are almost identical to Levy's, though we use 128-position fonts. Minor differences are the use of separate keys for middle and final sigma, and the introduction of some new characters. The key correspondence is mostly obvious: the non-obvious are specifically marked in Table II. S.A. Fulling [6] places only two characters in positions different from Levy's and ours, and suggests working for a consensus, and Y. Haralambous [5] is forming a special group for standardizing Greek \TeX . Such a standardization is most desirable, but it would require agreement with other major groups of users even of plain Greek, as it would be odd to use different keyboard conventions in \TeX - and non \TeX -Greek. Such groups are the classicists, who use some other variations, and the mass of users in Greece, whose support will be essential for a successful adoption, and who mostly use the IBM mapping with $\Theta \Xi X \Omega \Psi$ respectively on keys U J X V C.

Typesetting Greek. The macros used in Greek mode are gathered in the file `greekmac.tex`. To typeset a document in Greek one has only to enter `\input greekmac` at the start of the file and then the brief command `\[` to start Greek mode in font

gm10 (see *The Fonts* below), and finally `\]` to end it. When clashing with other T_EX extensions, e.g. with L^AT_EX, these commands may be redefined to `\(...\)`, at a loss only of the command `\(` in the concert format (*The T_EXbook*, p.409).

These commands replace Levy's longer `\begin-greek` and `\endgreek` (which can also be used), as well as his alternative `$` for starting and ending the Greek mode after the command `\greekdelims` which substitutes `\math` for the math-mode command `$`. Our `\[` and `\]` leave `$` untouched, they resemble delimiters, and have proved quite convenient during frequent alternations between Greek and English, especially when intermixed with math. All T_EX control sequences are valid in Greek mode, e.g., `\rm` switches to cmr10 and `\mz` back to gm10 (but for macros defined in Greek mode see Levy [1]).

Things get even simpler and T_EXing faster if one creates a new format file `greek.fmt` containing `greekmac.tex`, and dispenses with `\input greek-mac` in the text file (though `\[` will still be needed to start Greek). To T_EX one then enters

```
tex &greek <file>
```

In Greek mode one can write Modern Greek using only the acute accent, or Classical Greek with all diacritics, and can shift to other Greek or English fonts as shown in the following example of a Greek .tex file. Greek mode must be closed at the end of the file to avoid the T_EX complaint `\end` occurred inside a group at level 1.

```
\[ >Arq'h <ellhniko~u keim'enou.
\rm Or in Modern uniaccent Greek:
\mz Arq'h ellhniko'u keim'enou.
\rm Which means: \it Beginning of
Greek text. \]
```

This gives

```
'Αρχή ἐλληνικοῦ κειμένου.
Or in Modern uniaccent Greek:
Αρχή ελληνικού κειμένου.
Which means: Beginning of Greek text.
```

Accents and breathings are entered as shown in the 1st and 3rd of the next four lines, and produce the 2nd and 4th lines respectively:

```
'a 'i ~h >e >'a| >'h| >~a <h <'o <~w|
ά ι ἦ έ ᾶ ῆ ᾰ ῆ ὀ ῶ
A' I' H~ >E >'A\I H\I >~A <H <'O <~W|
A' I' H~ 'E 'A, H, 'A 'H 'O 'Ω
```

Typewriter mode *within* Greek mode should be enclosed in curly brackets: `{\tt ...}` as it causes a redefinition of the catcodes of `>`, `>`, `|`, which must revert to their greek-mode values. Mathmode works perfectly within Greek mode: the symbols `>`, `<`, `|` automatically regain their mathematical meaning and Greek fonts can be specified within mathmode

```
 $\mzb a \cdot b < |a| |b|$  gives:  $\alpha \cdot \beta < |\alpha| |\beta|$ 
```

Some Rare Occurrences. Although efforts were made to cover most of the requirements of Greek typesetting, some rare cases must be made up with improvised commands, as e.g., the rare characters shown at the end of Table I block 2 or vowels with macron plus breathing and accent like 'ō' found in only one book [7] reproducing a Greek text of the early 5th century B.C. and simulating the long vowels 'η' and 'ω' missing in that dialect. These characters are produced with macros such as `\mc` or `\br` for 'macron' or 'brève' with three parameters, the third being the diacritized vowel:

```
\mc>~o gives ὄ      \mc<'e gives ε̄
\br\ >o      ὀ      \br<~e      ε̃
```

When such characters appear frequently (in reference [7] there are several in each line) they could be placed in a new adjunct font accessed by the 'macron' and 'brève' symbols. For only 'e' and 'o' with macron there are 24 characters which could be fitted in the present adjunct font.

The fonts. In the multitude of Greek fonts with variable stroke width and most satisfying to Greek readers, we may distinguish two prevailing styles: one is the style of fonts called 'simple' (ἀπλά) in Greece, which we shall venture to call *Didot style* as it has a distinct relation to Didot's fonts and has probably evolved from them; the other of fonts tending generally to what is called *Elsevier* or *Times*. The *Didot* style is still amazingly close to the fonts used by the famed Parisian firm of Didot (18th - 20th century). François Ambroise Didot (1730-1804), apparently influenced by John Baskerville (1706-1775), created the *Didot* fonts in 'new style roman' (which in turn influenced Giambattista Bodoni, 1740-1813). He was said by Benjamin Franklin Bache (apprenticed to Didot by his grandfather Benjamin Franklin) to be 'the best printer of this age and even the best that has ever been seen'. Firmin Didot (1764-1836) created improved fonts, and Ambroise Firmin Didot (1790-1876) printed many Greek books, among them several of the eminent Greek scholar A.Korais in Paris, and sent printing presses and hundreds

of books to Greek towns even before the start of the Greek War of Independence (1821) [8]. Other printing presses were also brought to Greece from England and Italy, notably by Stanhope to Missolonghi, but *Didot* style fonts seem to have been generally adopted in Greece. A slight change in the fonts of Korais' books between 1807 and 1823 might possibly indicate the shift from François Ambroise to Firmin Didot fonts.

Didot type fonts are used in older Greek publications, in the government gazette (reminiscent of the font used in the first official printing of the Provisional Constitution of Greece enacted in Corinth in 1822), in several historical and philological treatises, in the Teubner classical editions (though more ornate), and in \TeX as Greek math symbols. The *Elsevier* or *Times* types of fonts are closer to the 'roman' style, and are mostly used in scientific books, novels and newspapers.

ο θ μ ρ κ

Didot style (almost Levy's [1])

ο θ μ ρ κ

Near *Times-Elsevier* style (*Euclid* font)

Some of the many differences between the two styles stand out as distinguishing characteristics: in *Didot* characters the thicker parts of curved lines are those sloping up toward the right (which happens in the letter 'O' when its internal oval is tilted toward the right) as in the first row in the figure above, whereas in the *Times-Elsevier* the thicker arcs are slightly sloping upward toward the left. The *Didot* have arms which get thicker toward their ends, a lowercase 'kappa' resembling an 'x', and the legs of 'mu' or 'rho' or of both generally curving toward the right, whereas the *Times-Elsevier* style has straight arms mostly of constant thickness and a lowercase 'kappa' resembling the uppercase. Both types can be upright or slanted, though some editions of the classics have slanted lowercase with conspicuous upright uppercase characters. Levy's fonts, as well as Haralambous' and Thull's are clearly related to the *Didot* upright. We wanted a style approaching the *Times-Elsevier*, which did not exist in \TeX , but with some aesthetic changes as well as practical ones, such as a preference for horizontal and vertical lines which print better at medium resolutions.

The character files in *Computer Modern Typefaces* and the corresponding character figures were of immense help, as were those of Levy, and served as models for ours. Without them our work would have been much harder. However, all character programs had to be redone to the new style, even those of the 14 uppercase letters similar in Greek and English and of some digits and punctuation marks, though their changes were minor. The lowercase characters presented the greatest difficulty, as they have quite different curves from the English and several intersecting or convoluted branches. The aim was to make a font pleasant and acceptable to readers accustomed to present day Greek publications, and causing no hesitation or delay for querying or appreciating unusual strokes.

One old ligature was re-introduced as a character in the Greek alphabet, after a search and comparison, necessarily inexpert, in Byzantine manuscripts of Mount Athos and of Patmos, and in early editions of Greek texts, such as the Estienne edition of the Homeric poems (Paris 1566), the Cambridge edition of the Suidas Lexicon (1705), and in more recent publications. It is a pity that some of these beautiful characters cannot be fitted into today's rather rigid font styles. The new character is a ligature of omicron 'o' with upsilon 'u' over it, making an infinity sign with the open end uppermost: 'ϛ, ϛ̄'. It first appears in a manuscript of about 512 AD and regularly after about 880 AD [9], and was used in renaissance editions of the classics and later up to about 200 years ago. Some people, including one of the authors, use it in handwriting today. It may be remembered from Byzantine icons of Mary "MOTHER OF GOD", i.e., "MHTHP ΘEOY", abbreviated by iconographers to "MP Θϛ".

We assigned this character to the key 'v, V' instead of accessing it as a ligature of 'o' and 'u' because some people will not want the diphthong 'μζ οψ' to turn up automatically as a 'v'. Separate characters had to be made of 'v' with every accent and placed in the main font, and with accent-breathing in the adjunct font, so there are now eight vowels 'α ε η ι ο υ ω ϛ' with all corresponding diacritics. This character is presented to former colleagues in Engineering and Applied Math at Brown University who had been inquiring about additional Greek characters for use as symbols of newly introduced quantities. It also affords a significant shortening of Greek text, as the 'οψ' diphthong may occur quite frequently, as in the following line

Αυτούς τους κουφούς ανθρώπους
Αυτός τες κερφός ανθρώπες

TABLE III
THE NEW GREEK FONTS

Font gm10	ΑΒΓΔΕΖΗΘΙΚΛΜΝΞΟΠΡΣΤΥΦΧΨΩΩ	αβγδεζηθικλμνξοπρσςτυφχψωω
Font gmb10	ΑΒΓΔΕΖΗΘΙΚΛΜΝΞΟΠΡΣΤΥΦΧΨΩΩ	αβγδεζηθικλμνξοπρσςτυφχψωω
Font gmss10	ΑΒΓΔΕΖΗΘΙΚΛΜΝΞΟΠΡΣΤΥΦΧΨΩΩ	αβγδεζηθικλμνξοπρσςτυφχψωω
Font gmssb10	ΑΒΓΔΕΖΗΘΙΚΛΜΝΞΟΠΡΣΤΥΦΧΨΩΩ	αβγδεζηθικλμνξοπρσςτυφχψωω
Font gmsl10	ΑΒΓΔΕΖΗΘΙΚΛΜΝΞΟΠΡΣΤΥΦΧΨΩΩ	αβγδεζηθικλμνξοπρσςτυφχψωω
Font gmslb10	ΑΒΓΔΕΖΗΘΙΚΛΜΝΞΟΠΡΣΤΥΦΧΨΩΩ	αβγδεζηθικλμνξοπρσςτυφχψωω
Font gmssl10	ΑΒΓΔΕΖΗΘΙΚΛΜΝΞΟΠΡΣΤΥΦΧΨΩΩ	αβγδεζηθικλμνξοπρσςτυφχψωω
Font gmsslb10	ΑΒΓΔΕΖΗΘΙΚΛΜΝΞΟΠΡΣΤΥΦΧΨΩΩ	αβγδεζηθικλμνξοπρσςτυφχψωω
Font gc10	ΑΒΓΔΕΖΗΘΙΚΛΜΝΞΟΠΡΣΤΥΦΧΨΩΩ	ΑΒΓΔΕΖΗΘΙΚΛΜΝΞΟΠΡΣΤΥΦΧΨΩΩ
Font gcsl10	ΑΒΓΔΕΖΗΘΙΚΛΜΝΞΟΠΡΣΤΥΦΧΨΩΩ	ΑΒΓΔΕΖΗΘΙΚΛΜΝΞΟΠΡΣΤΥΦΧΨΩΩ
Font gcss10	ΑΒΓΔΕΖΗΘΙΚΛΜΝΞΟΠΡΣΤΥΦΧΨΩΩ	ΑΒΓΔΕΖΗΘΙΚΛΜΝΞΟΠΡΣΤΥΦΧΨΩΩ
Font gcssl10	ΑΒΓΔΕΖΗΘΙΚΛΜΝΞΟΠΡΣΤΥΦΧΨΩΩ	ΑΒΓΔΕΖΗΘΙΚΛΜΝΞΟΠΡΣΤΥΦΧΨΩΩ

Three additional symbols were designed to complete the Greek numerals, which run as follows

α' 1	ι' 10	ρ' 100
β' 2	κ' 20	σ' 200
γ' 3	λ' 30	τ' 300
δ' 4	μ' 40	υ' 400
ε' 5	ν' 50	φ' 500
stigma ζ' 6	ξ' 60	χ' 600
ζ' 7	ο' 70	ψ' 700
η' 8	π' 80	ω' 800
θ' 9	koppa ι' 90	sampi ρ' 900

The regular alphabetic Greek numerals are entered as letters of a regular Greek font with the last one primed. The three additional symbols for 6, 90, 900 are in the adjunct fonts and are entered as `\s \n \p`, giving: 'ζ ι ρ'. Thousands are represented with the same symbols and a low left subscript entered as `\x` before the first digit of the numeral. E.g., `\x a'` gives ,α' (1000), `\x \p ρ'` gives ,ρ' (900,000), and `\x a \p \n a'` gives ,α ρ ι α' (1991). If the *Didot* style is preferred for numerals, the Levy font could be called, as was done for the two α's of the greek

numeral for 1991 which look more archaic. Finally a digamma 'F' (entered as `\f`) was placed in the main fonts to satisfy classicists, and the new symbol 'δ' (entered as `C`) was introduced for representing the Greek drachma (δραχμή) in analogy with the \$-sign. Uppercase Greek numerals for epigraphic use have been given by I. Haralambous [4].

The same character programs were used with suitable parameter files to create a regular font, a bold, a sans serif and a sans serif bold font, as well as the corresponding four slanted fonts, all in magsteps 0, .5, 1, 2 and 3. They are 128-character Modern Greek fonts with names starting with GM, and each has a "classical" adjunct font with a corresponding name starting with GP. In addition, four *Caps-Small-Caps* fonts were made with names starting with GC at the same magnifications, as well as four fonts of 9, 8, and 7 points for Greek subscripts in math mode. All are listed below with, hopefully, recognizable provisional names, which can later be changed to conform with a standardized font-naming scheme as described by Karl Berry [10].

gm10 gmb10 gmss10 gmssb10

gp10	gpb10	gpss10	gpssb10
gmsl10	gmslb10	gmssl10	gmsslb10
gpsl10	gpslb10	gpssl10	gmpslb10
gc10	gcs10	gcss10	gcssl10
gm9	gmb9	gm8	gm7

The fonts of the top row at zero magnification are entered with `\mz`, `\mbz`, `\mssz`, `\mssbz`. For magnification 1 the last 'z' changes to 'un', and for magnification 2 to 'tw', provided all these fonts have been defined. \TeX 3 accepts these extra fonts without difficulty, but earlier versions may give the error message "`! TeX capacity exceeded, sorry.`" calling for an increase of the font memory. The various fonts are shown in Table III, and samples of Greek text in the page following it.

We give the name of *Euclid* to these fonts not so much for the shortest paths of the arms of the characters, which they mostly follow, being straight, but in honor of an earlier Euclid, archon of Athens in 403 B.C. when the Ionic form of the Greek alphabet was officially accepted, i.e. the greek alphabet as we know it today.

Hyphenation. English hyphenation leads to many in Greek text. Greek hyphenation rules are simple and have been discussed [4] and hyphenation patterns have been announced [12], but they may not fully apply to Classical Greek. We are working on hyphenation patterns for strictly Greek text, using the initial version of PCTeX 3.0 [11] without multilingual capabilities. With enhanced hyphenation capabilities these patterns should work also for mixed language texts.

The Greek Monitor Characters. The word processor PC-Write [13], mentioned years ago in the *TUGboat* as using only ASCII characters hence suitable for writing and editing \TeX files, and used for the last four years by one of the authors, came out recently in a shorter version, PC-Write Lite, capable of using foreign fonts both onscreen and for printing, and with the facility for creating the monitor fonts on a 8×14 pixel matrix. We used it to make the set of simple Greek letters in the displayed screen photograph. These characters are defined in a new edit control file `ED.GRK`, where they are given positions above the regular 128 ASCII characters and are assigned to the corresponding English keys as in Table II. As used presently, every text file `<file>.grk` meant to display Greek characters onscreen must have the extension `.grk` which directs PC-Lite to select the edit control file `ED.GRK`. At present the `<Caps-Lock>` key shifts

α β γ δ ε ζ η θ ι κ λ μ ν
ξ ο π ρ σ τ υ φ χ ψ ω ϝ Ϸ

Α Β Γ Δ Ε Ζ Η Θ Ι Κ Λ Μ Ν
Ξ Ο Π Ρ Σ Τ Υ Φ Χ Ψ Ω ϝ Ϸ

Greek screen characters designed with PC-Write Lite.

between English and Greek characters during word processing and in case of errors `<ALT-^>` transcribes the letter before the cursor. To print Greek from the word processor one should match or transcribe the positions of the screen characters to those of the printer fonts he acquires.

The major problem remained, however, of how to \TeX a file with Greek characters in positions above the 128th ASCII when all Greek \TeX characters are below the 128th. The problem was solved with the kind help of Mr. Mark Zehr of Quicksoft, who patiently instructed us on how to create a new printer control file for transcribing the Greek file into an English one with the character correspondence of Table II. We call this file `PR.TEX` and rename it `PR.DEF` for making the transcription. Furthermore a so-called 'dot-command' must be written at the top of `<file>.grk` for directing the output to `<file>.tex`

`<ALT-G>.0:<file>.tex`

Pressing `<ALT-C>` from the open file in PC-Lite, transcribes the Greek `<file>.GRK` to the English `<file>.TEX` of the same name but a `.TEX` extension. When \TeX ed this gives the proper Greek or English text as specified by the font commands. This method works with all \TeX versions.

However, we also found another solution usable with \TeX 3. We made a Greek-to-Latin character substitution file `grk_eng.tex` which is called by `greekmac` and operates automatically during \TeX ing of the Greek `<file>.grk`, independently of the word processor, remaining harmlessly unused with the English characters. It requires \TeX commands to be in English because \TeX reads them before the character substitution and does not recognize them in Greek. In \TeX ing one should now include the extension `.grk`

`tex <file>.grk` or
`tex &greek <file>.grk`

Seeing Greek characters on the screen makes reading easier and more pleasant, and helps prevent all the mistypings of the characters with a 'not obvious' English correspondence (Table II).

If hard copy of the (un- \TeX ed) Greek file is desired and Greek printer fonts are not available, one should be content with the English transcription which can be printed without actually creating the file `<file>.tex`. Without the dot line `“.0:...”` in the text file, the pressing of `<ALT-@>` directs the transcription of `<file>.GRK` to the printer (provided `PR.TEX` has been renamed `PR.DEF`).

Summary and Conclusion. We presented a new set of Greek fonts with all the required characters for Modern and Classical Greek, in regular, bold, sans serif, sans serif bold, upright and slanted, and the corresponding caps-small-caps fonts, each placed in a pair of 128-position groups; and a system which accesses both groups as if they were a single 256-character font, though without kerning between characters in different groups. The system can be easily extended to use three 128-position groups or, with 256-code systems, two or more 256-position groups of characters as if they were one large font, provided each group is composed of characters with a common trait which may be used for shifting access to that group. This method of shifting to adjunct fonts should be useful for languages with large numbers of characters.

With 256-position fonts it would seem advantageous to place all characters and symbols of unaccented Greek in the lower 128 positions, where they may then be easily separated into a 128-position Modern Greek font for the less fortunate users of the smaller size fonts. Several empty lower-128 positions may be filled with classical Greek characters such as accented vowels (without breathing). Vowels with breathings and other symbols of Classical Greek or lexicography would seem better placed in the upper 128 positions, to be easily converted into a 128-code adjunct font for writing Classical Greek even with the smaller size fonts.

Conversely with the system of virtual fonts one could join our main and adjunct font into one 256-position font, or select 256 characters for any particular application from several 128- or 256-position adjunct fonts, with kerning even between characters of different original fonts.

The purpose of this article is to present the work we have done and the system of adjunct fonts

we have devised. Our coding scheme is described in order to show how this system makes possible the use of two 128-position fonts as if they were one 256-position font, and not as a candidate for standardization, though we hope that it shows some useful possibilities for future standardization work. It should be kept in mind, however, that a suitable transliteration program similar to the one we presented could automatically match a particular coding to an established standard.

Remarks. METAFONT is an excellent font-making system permitting the precise creation of characters of any design, and we were delighted to use it. The individual fontmaking steps are reasonably rapid but must be repeated so many times that the whole font-making process becomes quite long. Even the use of a RAM-disk containing all necessary files does not speed-up the process significantly. The acceptance of each character and of the font as a whole is purely a matter of aesthetics, and requires repeated changes in the program file followed by judging the display of the enlarged character. This cycle is repeated some 10 to 20 times for each character, even more with complex characters like ‘ξ’, a process lasting from about a half to two days for each character, less for the same character in a different font. The satisfactory character is then formed in proofmode and printed, only to be found awry or deficient in some details. A new cycle of corrections follows and usually produces a print which survives only a few hours before crying faults are discovered. The cycle is repeated with decreasing frequency until the proof survives a week or two. New changes are then made for certain groups of characters or when a macro of wider application is introduced, or when forming accents and breathings and making the macros for their precise positioning over each vowel. After all characters are done, the font is created with METAFONT, preferably at a few magnifications, each taking from 9 to 12 minutes on a PC AT compatible at 8MHZ, and the uniformity and compatibility of the characters is checked and adjusted after several printouts, each ending with a re-creation of the corrected font. In particular the characters ϕ ψ ω required special attention and re-designing in order to come out symmetric on an HP Laserjet IIP printer (early attempts on a 180DPI dot matrix printer were hopeless). Finally the kerning is adjusted in several steps from spacing estimates made on printouts of matrices containing all possible character pairs, each step requiring a new fontmaking. The whole process, together with

learning the tricks of METAFONT, lasted almost two year (which is not bad – not referring to quality – in comparison with the years taken by Louis XIV's commission to design the Royal Alphabet [14] or with the duration of the "Euler Project" [15]), but additional adjustments have been postponed until additional kerning is available. Here are some of the thoughts and wishes which kept recurring during this long process.

1. METAFONT does not use the coprocessor for calculating points and curves and pixels, but works with some internal process of its own. Would the use of the coprocessor speed things up, and how could this be achieved?
2. Could an extension of METAFONT be made to recalculate only the altered parts of a character and, even better, show the change on the displayed character?
3. Could an extension of METAFONT remake single characters or adjust kerns without recreating the full font?

Acknowledgment. We wish to thank several friends who helped us. Without Barbara Beeton's great help with advice and information this project would not have started. Professor S. Levy's kind offer of all program files of his excellent Greek system and fonts made it possible for us to start our system at an advanced stage. Professor Alan Boegehold of the Classics Department at Brown University and presently chairman of the Managing Committee of the American School of Classical Studies at Athens read the original draft and advised us on sources of ancient scripts. His criticism led to changes which significantly simplify the typesetting of Greek. David Durand kindly helped one of the authors correct several errors, and Elli Mylonas, project manager of the PANDORA program [2], did the search for diacritized vowels in the classical literature. We are grateful to all.

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◇ C.Mylonas	◇ Ron Whitney
Κουντουριώτη 5	T _E X Users Group
14563 Κηφισιά	r fw@Math.AMS.com
Athens, Greece	

or at times:
Engineering, Brown University
Providence, R.I. 02906

SAMPLE TEXTS in GM10 and GMSSL10.

Τὴ γλῶσσα, αὐτὸ το σπαρταριστὸ ἀπὸ ζωὴ δημιούργημα τοῦ ἀνθρώπινου πνεύματος, δὲν τὴν κατασκευάζουν οἱ γλωσσολόγοι, οὔτε οἱ δάσκαλοι στὰ σχολεῖα. Τὴν γλῶσσα τὴν πλάθει πρῶτα ὁ λαὸς καὶ μὲ τὴν καθημερινὴ του ὁμιλία, ἀλλὰ καὶ μὲ τὶς εὐγενέστερες ἐκδηλώσεις του, ὅπως π.χ. τὸ δημοτικὸ τραγούδι. Τὴν πλάθουν ὅμως καὶ κορυφαῖοι εἴτε στὴν ἔκφραση αὐστηρὰ λογικῶν διανοημάτων (μαθηματικῶν, νομικῶν) εἴτε στὴν ἔκφραση συναισθημάτων. Τὴν πλάθουν καὶ οἱ δυὸ αὐτοὶ ὅταν ἔχουν καὶ αἰσθητικὸ αἰσθητήριο εἴτε βοηθημένοι ἀπὸ τὴν καθαρότητα τῆς λογικῆς των σκέψης, εἴτε ἀπὸ το χάρισμα ποὺ τοὺς δόθηκε μὲ λέξεις, ποὺ πάντα ἔχουν καὶ ἓνα λογικὸ νόημα, νὰ ἐκφράζουν τὸ ἄλογο. Γι' αὐτὸ ὅταν θέλωμε νὰ καταλάβωμε το πνεῦμα μιᾶς γλώσσας δὲν θὰ καταφύγωμε στὶς γραμματικὲς καὶ τὰ συντακτικὰ, ἀλλὰ στὰ κείμενα τῶν μεγάλων συγγραφέων. Αὐτοὶ ὑπαγορεύουν στοὺς γλωσσολόγους τοὺς νόμους τῆς γλώσσας καὶ ὄχι οἱ γλωσσολόγοι στοὺς δημιουργοὺς τῆς γλώσσας.

From K.Tsatsos: Glossa kai Ethnos, Efthini, 112, 1981, 145-8.

Γωνιακὴ ταχύτητα συναρτήσῃ των γωνιῶν τῶ Euler. Το στερεὸ περιστρέφεται με τοπικὸ σπιν $\dot{\psi} = \dot{\psi} \mathbf{k}''$ στο πλαίσιο $Ox''y''z''$ (Σχ. 15.2) πρ περιστρέφεται με ἓνα μετοχικὸ ρυθμὸ κλωνισμὸ $\dot{\theta} = \dot{\theta} \mathbf{k}'$ ως προς το πλαίσιο $Ox'y'z'$, πρ κι' αὐτὸ περιστρέφεται με ἓνα μετοχικὸ ρυθμὸ μεταπτώσεως $\dot{\phi} = \dot{\phi} \mathbf{K}$ ως προς το $Oxyz$. Τα $\dot{\phi}$, $\dot{\theta}$, $\dot{\psi}$ εἶναι διανυσματικὲς γωνιακὲς ταχύτητες πρ με διαδοχικὲς συνθέσεις ως τοπικῆς καὶ μετοχικῆς δίνων τὴν ολικὴ γωνιακὴ ταχύτητα ω τῶ στερεῶ

$$\omega = \dot{\phi} + \dot{\theta} + \dot{\psi}.$$

C.M.: MECHANICS II, Rigid Body Dynamics, 2nd Ed. Athens, 1984.

	Density	Total
Strain Energy:	$w(\epsilon_{ij}^t) = \int_0^{\epsilon_{ij}^t} \sigma_{ij} d\epsilon_{ij},$	$W = \int_V w(\epsilon_{ij}^t) dV$
Complementary Energy:	$\vartheta(\sigma_{ij}^t) = \int_0^{\sigma_{ij}^t} \epsilon_{ij} d\sigma_{ij},$	$\vartheta = \int_V \vartheta(\sigma_{ij}^t) dV$

TABLE IV

Font GM10 x 1.44

Adjunct Font GP10 x 1.44

'0	'1	'2	'3	'4	'5	'6	'7		'0	'1	'2	'3	'4	'5	'6	'7
á	á	é	ή	í	ó	ύ	ώ	'00x	ǎ	ě	ň	ı	ǒ	ǔ	ǖ	ǘ
à	à	è	ή	ì	ò	ù	ώ	'01x	ǎ	ě	ň	ı	ǒ	ǔ	ǖ	ǘ
ã	ã	ë	ñ	ï	ó	-	õ	'02x	ǎ	ě	ň	ı	ǒ	ǔ	ǖ	ǘ
—	“	“	ü	İ	,	ũ	õ	'03x	ǎ	ě	ň	ı	ǒ	ǔ	ǖ	ǘ
F	!	-	ı	ı	%	"	'	'04x	ǎ	ě	ň	ı	ǒ	ǔ	ǖ	'
(	)	*	+	,	-	.	/	'05x	ǎ	ě	ň	ı	ǒ	ǔ	ǖ	ǘ
0	1	2	3	4	5	6	7	'06x	ǎ	ě	ň	ı	ǒ	ǔ	ǖ	ǘ
8	9	:	.	ı	=	ÿ	;	'07x	"	"	"	"	'	'	'	'
@	A	B	ß	Δ	E	Φ	Γ	'10x	ρ	A	A		ρ	E	H	Ω
H	I	Θ	K	Λ	M	N	O	'11x	H	I	ς	ι	ϑ	Ο	ξ	Ο
Π	X	P	Σ	T	Y	Θ	Ω	'12x			P			Y	Θ	Ω
Ξ	Ψ	Z	[	§	]	ü	.	'13x	ǎ	ě	ň	ı	ǒ	ǔ	ǖ	ǘ
'	α	β	σ	δ	ε	φ	γ	'14x	'	α				ε		
η	ι	θ	κ	λ	μ	ν	ο	'15x	η	ι						ο
π	χ	ρ	ς	τ	υ	ϑ	ω	'16x			ρ			υ	ϑ	ω
ξ	ψ	ς	«	.	»	~	“	'17x					.	.	~	“