

The Multilingual Lion:^{*} T_EX learns to speak Unicode



Jonathan Kew
SIL International

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Abstract

Professor Donald Knuth's T_EX is a typesetting system with a wide user community, and a range of supporting packages and enhancements available for many types of publishing work. However, it dates back to the 1980s and is tightly wedded to 8-bit character data and custom-encoded fonts, making it difficult to configure T_EX for many complex-script languages.

This paper will focus on X_YT_EX, a system that extends T_EX with direct support for modern OpenType and AAT fonts and the Unicode character set. This makes it possible to typeset almost any script and language with the same power and flexibility as T_EX has traditionally offered in the 8-bit, simple-script world of European languages. X_YT_EX (currently available on Mac OS X, but possibly on other platforms in the future) integrates the T_EX formatting engine with technologies from both the host operating system (Apple Type Services, Text Encoding Converter) and auxiliary libraries (ICU, TECKit). Thus, it illustrates how such components can be leveraged to provide the benefits of Unicode within an existing software system.

This paper should be of interest to those involved in multilingual and multiscrypt publishing, as well as developers seeking to enhance legacy systems to take advantage of the benefits of Unicode. The merger of legacy and Unicode-based technologies means that the benefits of many years of development in the T_EX world become available for document production in a much wider range of languages.

Some background familiarity with T_EX may be helpful, but the paper's focus will be on the integration of Unicode technologies, not on technical details of T_EX itself. A general awareness of encodings, complex scripts, and font technologies will be assumed.

1 Background

The T_EX typesetting system has a 20-year history as a stable and reliable tool for producing well-formatted documents from marked-up source text, and offers a great deal of power, flexibility and extensibility by virtue of a powerful macro language. The extensive user community, especially in the academic world, has created a large collection of supporting packages for many different types of document.

For those unfamiliar with T_EX, a brief overview may be helpful. The T_EX processor reads a source document, recognizing characters as either text to be typeset or markup according to scanning rules and (customizable) character categories. It expands macros and executes commands (setting parameters

^{*}Why a multilingual *lion*? Because T_EX's logo is a lion; see Knuth's *The T_EXbook* (Addison Wesley: 1984) or other sources.

<i>Source text</i>	<i>Typeset result</i>	<i>Notes</i>
<code>\' {a}</code>	á	<code>\'</code> is one of various commands to add an accent to a letter
<code>\c {c}</code>	ç	an accent that attaches below the letter
<code>\aa</code>	å	special command for a specific character
<code>---</code>	—	implemented as a ligature in standard T _E X fonts
<code>\alpha</code>	α	one of many symbols available in <i>math mode</i>
<code>{\dn acchaa}</code>	अच्छा	requires use of a special preprocessor and custom fonts

Figure 1: Traditional T_EX input conventions for non-ASCII characters in 7-bit source text.

to control the typesetting process, for example), and forms the text into paragraphs and pages. Finally, a compact representation of the typeset pages is written out to a DVI (“device independent”) file; a subsequent device driver process reads this `.dvi` file and renders the pages to a specific destination such as a screen or printer. (In the case of X_YT_EX, to be discussed below, this output format has been extended and renamed XDV, and the default behavior is to automatically run an XDV-to-PDF processor, so that the effective output format is PDF.)

Over the years, T_EX has been used with many non-English languages, often using combinations of custom-encoded 8-bit fonts and different input encodings and conventions. However, T_EX’s roots are unquestionably in Latin-script typography; the system originally processed 7-bit text (usually ASCII), accessing 8-bit fonts for output. In 1989–90, Knuth extended the system to support 8-bit input text, and provided some enhancements for multilingual use, but support for many non-Latin and complex scripts remains difficult.

In addition to standard 8-bit codepages, there are ways of using T_EX’s programmability to allow input of additional text elements by representing them as character sequences. Some conventions are so widely used that many users think of them as a standard part of the T_EX program (though this is not really the case); others are associated with macro packages for particular languages; and still others are created just for specific projects. Figure 1 shows a few examples of typical T_EX input conventions for non-ASCII characters.

While these conventions can be extended almost indefinitely, they tend to clutter the source text; and they rely on a variety of custom-encoded fonts to provide all the symbols needed. Unicode offers the possibility of a far simpler model for typesetting multilingual text, where each character needed is represented in the source not by some sequence of commands, but as itself.

In the case of complex scripts such as Devanagari, solutions based on standard T_EX typically involve a custom preprocessor that performs the contextual analysis needed for proper rendering of the script, starting from some (often romanized) input convention, and emits special T_EX commands to access the appropriate glyphs from custom 8-bit fonts. While such solutions can work, they may be complex to use, and fragile in how they interact with various other macro packages for document formatting. And trying to combine several such solutions to create a highly multilingual document, using several complex scripts simultaneously, goes far beyond what typical users can be expected to achieve.

To address these issues, an extended version of T_EX known as X_YT_EX¹ has been developed. This is a Unicode-based multilingual typesetting system that works with existing “smart font” technologies to provide complex script support, within the framework of the formatting power, flexibility, and programmability of T_EX.

¹See <http://scripts.sil.org/xetex>. The name is typically pronounced something like *zee-tech*.

2 Examples of use

Before looking at what was involved in extending T_EX to support Unicode and smart font technologies for text rendering, I will show a few brief examples of X_YT_EX at work. Figures 2 to 5 illustrate how readily Unicode text now fits into the T_EX typesetting paradigm. In each case, the “raw” source (text and markup) is shown alongside the typeset result.

<code>\halign{#\hfil\quad#\hfil\cr</code>		
<code>\label UCA default&\label Tailoring:</code>	<i>UCA default</i>	<i>Tailoring: & Đ < dž <<< Dž <<< DŽ</i>
<code>\& Đ < dž <<< Dž <<< DŽ\cr</code>	dan	dan
dan& dan\cr	dubok	dubok
dubok& dubok\cr	džabe	đak
džabe& đak\cr	džin	džabe
džin& džabe\cr	Džin	džin
Džin& džin\cr	đak	Džin
đak& Džin\cr	Evropa	Evropa
Evropa& Evropa\cr}		

Figure 2: From a presentation about collation, using extended Latin letters. In standard T_EX, this could be done using control sequences to encode the accented letters, but X_YT_EX handles the Unicode text directly.

<code>\font\han="STSong;color=660000" at 16pt</code>	書く	
<code>\font\rom="Gentium;color=000066" at 8pt</code>	ka-ku	
<code>\def\hc#1#2{\vtop{\hbox{\han #1}</code>	最も	
<code>\hbox{\kern10pt\rom #2}}}</code>	motto-mo	
<code>\vtop{\hc{書く}}{ka-ku}</code>	最後	
<code>\hc{最も}{motto-mo}</code>	sai-go	
<code>\hc{最後}{sai-go}</code>	働く	
<code>\hc{働く}{hatara-ku}</code>	hatara-ku	
<code>\hc{海}{umi}}</code>	海	
	umi	
<code>\font\label="Gentium Italic;color=006600" at 10pt</code>	<i>Thai</i>	<i>Korean</i>
<code>\def\listbox#1#2{\vtop{\hsize=60pt</code>	กรกฎาคม	계
<code>\hbox{\label #1}</code>	กรร	금
<code>\moveright10pt\ vbox{#2}}}</code>	กว่า	길
<code>\font\t="Thonburi;color=660000" at 11pt</code>	โกรธ	강
<code>\font\k="AppleMyungjo Regular;color=660000" at 13pt</code>	ขรม	갈
<code>\hbox{\listbox{Thai}</code>	ขวา	낙
<code>{\t กรกฎาคม\กรร\กว่า\โกรธ\ขรม\ขวา\โขยง\ควม}</code>	โขยง	남
<code>\listbox{Korean}</code>	ควม	
<code>{\k 계\금\길\강\갈\낙\남}}</code>		

Figure 3: Further fragments from the collation presentation, showing Asian scripts.

<pre>\font\arfont="Scheherazade:script=arab" at 13pt \def\ar#1{{\arfont \beginR #1\endR}} Burki, Rozi Khan. 1999. {\it \ar{نہیں؟} [Should we leave our language on its death-bed?]}. Tank, Pakistan: Muslim Book Agency.</pre>	<p>Burki, Rozi Khan. 1999. ماخا خوی زبان ته گور غاره زر ٿين؟ <i>[Should we leave our language on its death-bed?]</i>. Tank, Pakistan: Muslim Book Agency.</p>
<pre>Karimi, Abdul Hamid Khan. 1995. {\it \ar{بدا و رعش یناتس هوك روا لاج لوب یناتس هوك و درا} [Urdu-Kohistani conversation and Kohistani culture]}. Bahrain, Swat, Pakistan: Kohistan Adab Academy.</pre>	<p>Karimi, Abdul Hamid Khan. 1995. اردو کوهستانی بول چال اور کوهستانی شعر و ادب <i>[Urdu-Kohistani conversation and Kohistani culture]</i>. Bahrain, Swat, Pakistan: Kohistan Adab Academy.</p>

Figure 4: From the bibliography of a paper that cites some Arabic-script references. Note the unshaped Arabic characters in the source text shown here; how this actually appears to a user will depend on the capabilities of the text editor used.

<pre>\c 1 \s Mawu fe nya to Mawu Vi la dzi va \p \v 1 Le blema la, Mawu fo nu na mia togbuiwo zi gede to efe gbefadelawo dzi le mo vovovo nu. \v 2 Ke le egbe nkeke mamle siawo me la, Mawu fo nu na mi to Via dzi. Vi siae eya nuto tia be wanyi nuwo kata dome. Eyama ke dzie Mawu to wo xexame ha. \v 3 Vi lae de alesi Mawu fe nutikokoe le la fia, eye Mawu fe nonome tututue le eya ha si. Vi lae tso efe nya fe nus la le xexeme blibo la de te. Esi eyama klo miafe nuwo da vo la, eyi dabobo no anyi de Mawu Bubutoga si le dzifo ui la fe nudusime.</pre>	<p>Mawu fe nya to Mawu Vi la dzi va</p> <p>1¹Le blema la, Mawu fo nu na mia togbuiwo zi gedē to efe gbefādelawo dzi le mo vovovo nu. ²Ke le egbe nkeke mamle siawo me la, Mawu fo nu na mi to Via dzi. Vi siae eya nuto tia be wanyi nuwo katā dome. Eyama ke dzie Mawu to wo xexame hā. ³Vi lae de alesi Mawu fe nutikokoe le la fia, eye Mawu fe nonome tututue le eya hā si. Vi lae tso efe nya fe nus la le xexeme blibo la de te. Esi eyama klo miafe nuwo da vo la, eyi dabobo no anyi de Mawu Bubutoga si le dzifo vi la fe nudusime.</p>
<pre>\c 1 \s شئادپ ي ج ايند \p \v 1 ويك اديپ يك نامس آ ء نيمز ادخ م تاعورش \v 2 دنمس يهنا و .يئو ناري و ء بيترتيب نيمز تقو نا ادخ ناثم ي ج كئاپ ء وه ليكي ناس هـ دنوا ورجا ثم جو يك يئو اريق حور جي \v 3 يئو ي ت ينشور وس .يئو ينشور "ت وند مكح ادخ نهذت</pre>	<p>دنيا جي پيدائش</p> <p>1¹شروعات ۾ خدا زمين ۽ آسمان کي پيدا ڪيو. ²ان وقت زمين بي ترتيب ۽ ويران هئي. اونهي سمنڊ جو مٿاڇرو اوندهه سان ڍڪيل هو ۽ پاڻي جي مٿان خدا جي روح ڦيرا پئي ڪئي. ³تڏهن خدا حڪم ڏنو ته ”روشني ٿي.“ سو روشني ٿي پئي.</p>

Figure 5: Using a T_EX macro package designed for Scripture formatting, showing examples in both African (extended Latin script) and Pakistani (Arabic script) languages.

3 Extending the character set

The first step towards Unicode support in T_EX is to expand the character set beyond the original 256-character limit. At the lowest level, this means changing internal data structures throughout, wherever characters were stored as 8-bit values. As Unicode scalar values may be up to U+10FFFF, an obvious modification would be to make “characters” 32 bits wide, and treat Unicode characters as the basic units of text.

However, in X_YT_EX a pragmatic decision was made to work internally with UTF-16 as the encoding form of Unicode, making “characters” in the engine 16 bits wide, and handling supplementary-plane characters using UTF-16 surrogate pairs. This choice was made for a number of reasons:

- The operating-system APIs that X_YT_EX expects to use in working with Unicode text require UTF-16, so working with this encoding form avoids the need for conversion at this interface.
- There are a number of internal tables in the T_EX program that are implemented as arrays indexed by character code. In standard T_EX, these arrays have 256 elements each. Enlarging them to 65,536 elements each, to index them by UTF-16 code values, is just about reasonable; enlarging them further, to allow direct indexing by Unicode scalar values, would make for extremely large arrays. To keep the memory footprint reasonable (both at runtime and for “dumped” macro collections), some kind of sparse array implementation would probably be needed, requiring significant additional development and testing, and perhaps impacting performance of key inner-loop parts of the T_EX system.
- These per-character arrays are used to implement character “categories”, used in parsing input text into tokens, as well as case conversions and “space factor” (a property used to modify word spacing for punctuation in Roman typography). In practice, it seems unlikely that there will be a great need to customize these character properties for individual supplementary-plane characters. They’re unlikely to be wanted as escape characters or other special categories of T_EX input; need not have the “letter” property that allows them to be part of T_EX control sequences; and probably don’t need to be included in automatic hyphenation patterns.

In view of these factors, X_YT_EX works with UTF-16 code units, and Unicode characters beyond U+FFFF cannot be given individually-customized T_EX properties. They can still be included in documents, however, and will render correctly (given appropriate fonts) as the UTF-16 surrogate pairs will be properly passed to the font system.

Another possible route would have been to use UTF-8 as the internal encoding form, retaining the existing 8-bit code units used in T_EX as characters. However, this would have made it impossible (without major revisions) to provide properties such as character category (letter, other printing character, escape, grouping delimiter, comment character, etc.), case mappings, and so on to any characters beyond the basic ASCII set; and it would also require conversion when Unicode text is to be passed to system APIs. Overall, therefore, UTF-16 was felt to be the most practical choice, and the appropriate T_EX data structures were systematically widened.

4 Implementing a character/glyph model

An important aspect of rendering Unicode text is the character/glyph model; it is assumed that the reader is familiar with this concept. Traditionally, T_EX does not have a well-developed character/glyph

model. Input text is a sequence of 8-bit codes, interpreted as character tokens or other (e.g., control sequence) tokens according to the scanning rules and character categories. These same 8-bit codes are used as access codes for glyphs in fonts. It is possible to remap codes by T_EX macro programming, and the “font metrics” (`.tfm`) files used by T_EX can include simple ligature rules (e.g., `fi` \mapsto `fi`), but the model is fairly rudimentary, and not adequate for script behaviors such as Arabic cursive shaping or Indic reordering. To support the full range of complex scripts in Unicode, a more complete character/glyph model is needed.

Rather than designing a text rendering system based on the Unicode character/glyph model from scratch, it seemed desirable to leverage existing implementations, allowing T_EX to take advantage of the “smart fonts” and multilingual text rendering facilities found in modern operating systems and libraries. At the time of writing, X_YT_EX supports two such rendering systems; it is possible that additional ones will be supported in future versions.

4.1 Using ATSUI on Mac OS X

The first smart-font rendering system implemented in X_YT_EX was the ATSUI² system under Mac OS X. ATSUI is the Mac OS X component that renders Unicode text using AAT³ fonts. The essential objects needed to render text with ATSUI are *text layouts* and associated *styles* (which in turn refer to *fonts* and other attributes).

In order for a system like ATSUI to render text correctly, it must be given complete runs of text, not individual characters; otherwise, behavior such as reordering and contextual glyph selection cannot happen. T_EX normally treats each character of text as an individual node in a list, with known (and fixed) dimensions. Paragraph layout consists of taking a list of such nodes, with intervening “glue” (potentially flexible space) and other items, and determining the best sequence of line-break positions and the final location of each character and other node.

When using ATSUI for Unicode text, however, X_YT_EX cannot treat each character (or, strictly speaking, UTF-16 code unit) as a separate node, to be measured and positioned individually. Instead, it collects sequences of characters that share the same font style, and calls ATSUI to measure such sequences (typically, entire words). A paragraph then consists of a list of such “word nodes”, each with its dimensions as determined by ATSUI, and intervening space and other nodes. The basic T_EX paragraphing algorithm applies just as well to these larger “chunks” as to traditional character nodes.

During formatting, then, X_YT_EX makes use of just a few basic ATSUI APIs, in order to measure each word (or similar fragment) of text; in particular:

ATSUCreateStyle, ATSUSetAttributes Create an ATSUI style object, and assign appropriate text attributes. One ATSUI style is associated with each font face and size combination requested by the T_EX document, and used whenever text in that particular style needs to be measured.

ATSUCreateTextLayout, ATSUSetTextPointerLocation, ATSUSetRunStyle Create an ATSUI text layout object, and associate a string of Unicode text and a style object with it.

ATSUGetUnjustifiedBounds Measure a range of text as rendered with the associated font and other attributes. This gives the T_EX paragraphing algorithm the measurements that it will use in laying out the text.

²Apple Type Services for Unicode Imaging; see <http://developer.apple.com/intl/atsui.html>.

³Apple Advanced Typography; see <http://developer.apple.com/fonts/TTRefMan/RM06/Chap6AATIntro.html>.

(In addition, a number of font-related ATSUI APIs are used to enumerate the fonts available in the system, determine what layout features the fonts support, etc.)

When X_YT_EX has completed layout for a paragraph of text, therefore, it has a list of lines each containing a list of “word nodes”; each such node contains a run of Unicode text and a reference to an ATSUI style. The T_EX system *does not know* the details of the actual glyphs that will be used to render the text, or precisely where they will be positioned; only the overall dimensions and position of each word. The glyph-level detail is left entirely to the ATSUI rendering system.

To illustrate this, figure 6 shows the trace output generated for a short fragment of text set as a single-line paragraph. Using a standard T_EX font, the line consists of a list of character nodes, with intervening “glue” (flexible space). Each character has an associated font, and its metrics will be looked up in the corresponding T_EX font metric (TFM) file. Note that T_EX has automatically inserted some kerns between adjacent letters; this is also controlled by the TFM file for this font. In contrast, using an AAT font, the text line consists simply of a list of complete words with intervening glue; T_EX does not deal with the individual characters. There may be kerning between letters here too, but the T_EX algorithms are unaware of it; it happens automatically as ATSUI measures or renders the words, and T_EX knows only their overall dimensions.

<code>\font\AATfont="Times Roman" \AATfont</code>	T_EX (or X_YT_EX) using a legacy font with .tfm metrics:
<code>\setbox0=\vbox{The quick brown fox.}</code>	<code>> \box1=</code>
<code>\showbox0</code>	<code>\vbox(6.94444+1.94444)x469.75499</code>
	<code>.. \hbox(6.94444+1.94444)x469.75499, glue set 356.6715fil</code>
<code>\font\TeXfont=cmr10 \TeXfont</code>	<code>.. \hbox(0.0+0.0)x20.0</code>
<code>\setbox1=\vbox{The quick brown fox.}</code>	<code>.. \TeXfont T</code>
<code>\showbox1</code>	<code>.. \TeXfont h</code>
	<code>.. \TeXfont e</code>
X_YT_EX using an AAT font:	<code>.. \glue 3.33333 plus 1.66666 minus 1.11111</code>
<code>> \box0=</code>	<code>.. \TeXfont q</code>
<code>\vbox(8.0+2.0)x469.75499</code>	<code>.. \TeXfont u</code>
<code>.. \hbox(8.0+2.0)x469.75499, glue set 363.10948fil</code>	<code>.. \TeXfont i</code>
<code>.. \hbox(0.0+0.0)x20.0</code>	<code>.. \TeXfont c</code>
<code>.. \AATfont The</code>	<code>.. \kern-0.27779</code>
<code>.. \glue 2.5 plus 1.66666 minus 0.83333</code>	<code>.. \TeXfont k</code>
<code>.. \AATfont quick</code>	<code>.. \glue 3.33333 plus 1.66666 minus 1.11111</code>
<code>.. \glue 2.5 plus 1.66666 minus 0.83333</code>	<code>.. \TeXfont b</code>
<code>.. \AATfont brown</code>	<code>.. \TeXfont r</code>
<code>.. \glue 2.5 plus 1.66666 minus 0.83333</code>	<code>.. \TeXfont o</code>
<code>.. \AATfont fox.</code>	<code>.. \kern-0.27779</code>
<code>.. \penalty 10000</code>	<code>.. \TeXfont w</code>
<code>.. \glue(\parfillskip) 0.0 plus 1.0fil</code>	<code>.. \TeXfont n</code>
<code>.. \glue(\rightskip) 0.0</code>	<code>.. \glue 3.33333 plus 1.66666 minus 1.11111</code>
	<code>.. \TeXfont f</code>
	<code>.. \TeXfont o</code>
	<code>.. \kern-0.27779</code>
	<code>.. \TeXfont x</code>
	<code>.. \TeXfont .</code>
	<code>.. \penalty 10000</code>
	<code>.. \glue(\parfillskip) 0.0 plus 1.0fil</code>
	<code>.. \glue(\rightskip) 0.0</code>

Figure 6: Using tracing commands to examine X_YT_EX’s internal structures for text using an AAT font, compared to the same text with a standard T_EX font.

After document formatting is complete, the X_YT_EX “back-end” (actually a separate process, `xdv2pdf`) reads the `.xdv` file that encodes the formatted document, and creates a PDF version for viewing or printing. To do this, it “renders” the page encoded in the `.xdv` file through the Mac OS X Quartz graphics system, with a PDF file as the rendering destination. At this point, it again uses ATSUI APIs, loading each text string into an `ATSUTextLayout`, assigning the proper style, and calling `ATSUDrawText` to image the text into the PDF being constructed.

4.2 Using OpenType via ICU Layout

While the initial implementation of X_YT_EX was based on Apple’s ATSUI rendering system, the increasing availability of fonts with OpenType layout features led to a desire to also support this font technology. The system was therefore extended by incorporating the OpenType layout engine from ICU⁴. (In addition to the actual layout engine, X_YT_EX makes use of ICU’s implementation of the Unicode Bidi Algorithm.) The main functions used in the typesetting process include:

ubidi_open, ubidi_close, ubidi_setPara, ubidi_getDirection, ubidi_countRuns, ubidi_getVisualRun

Before laying out glyphs, it is necessary to deal with bidirectional layout issues; most “chunks” X_YT_EX needs to measure will be unidirectional, but this is not always the case. With mixed-direction text, each direction run is measured separately.

LayoutEngine::layoutChars, getGlyphs, getGlyphPositions The ICU `LayoutEngine` class is used to perform the actual layout process, and retrieve the list of glyphs and positions. The resulting array of positioned glyphs is stored within the “word node” in X_YT_EX’s paragraph list.

Internally, ICU-based OpenType rendering is handled in a very different way from ATSUI rendering. With ATSUI, the output of the typesetting process includes the original Unicode strings and the appropriate font descriptors; the PDF-generating back-end then reuses ATSUI layout functions to actually render the text into the PDF destination. In the case of OpenType, however, the typesetting process retrieves the array of positioned glyphs that result from the layout operation, and records this; the back-end then merely has to draw the glyphs as specified, not repeat any of the text layout work.

When the T_EX source calls for a particular font, X_YT_EX looks for specific layout tables within the font (e.g., `morx` for AAT, or `GSUB` for OpenType) to determine which layout engine to use, and instantiates either an ATSUI style or an ICU `LayoutEngine` as appropriate. (In the event that a font supports both layout technologies, X_YT_EX currently chooses the OpenType engine by default, but users can explicitly specify which to use.) The difference in the implementation of the two technologies is, however, entirely hidden from the main T_EX program, which simply deals with “word nodes”, forming them into paragraphs and pages once they’ve been measured by the appropriate smart-font engine.

4.3 Hyphenation support

Implementing “word nodes” as “black boxes” within the main T_EX program made it easy to form paragraphs of such words, without extensive changes to the rest of T_EX. A complication arose, however, in that T_EX has an automatic hyphenation algorithm that comes into effect if it is unable to find satisfactory line-break positions for a paragraph. The hyphenation routine applies to lists of character

⁴IBM’s open-source project, International Components for Unicode; see <http://oss.software.ibm.com/icu/>.

nodes representing runs of text within a paragraph to be line-broken. But at this level, the program sees Unicode “word nodes” as indivisible, rigid chunks.

Explicit discretionary hyphens may be included in T_EX input, and these continue to work in X_YT_EX, as they become “discretionary break” nodes in the list of items making up the paragraph. The word fragments on either side, then, would become separate nodes in the list, and a line-break can occur between them.

In order to reinstate hyphenation support, therefore, it was necessary to extend the hyphenation routine so as to be able to extract the text from a word node, use T_EX’s pattern-based algorithm to find possible hyphenation positions within the word, and then replace the original word node with a sequence of nodes representing the (possibly) hyphenated fragments, with discretionary hyphen nodes in between.

A final refinement proved necessary here: once the line-breaks have been chosen, and the lines of text are being “packaged” for justification to the desired width, any unused hyphenation points are removed and the adjacent word (fragment) nodes re-merged. This is required in order to allow rendering behavior such as character reordering and ligatures, implemented at the smart-font level, to occur across hyphenation points. With an early release of X_YT_EX, a user reported that OpenType ligatures in certain words such as *different* would intermittently fail (appearing as *different*, without the *ff* ligature). This was occurring when automatic hyphenation came into effect and a discretionary break was inserted, breaking the word node into sub-words that were being rendered separately.

5 Backward compatibility

The original motivation for the X_YT_EX project was to provide a typesetting solution that worked with Unicode and complex scripts, via smart font technologies. However, it soon became clear that many existing T_EX users, with no complex-script requirements, nevertheless found the integration with the host platform’s font management to be very attractive, and wished to use X_YT_EX and native Mac OS X fonts with existing T_EX (or more commonly L^AT_EX⁵) documents. There is a huge legacy of pre-Unicode T_EX documents and resources, and it is helpful for users to be able to continue working with these materials, while at the same time beginning to take advantage of the extended capabilities of X_YT_EX.

5.1 Traditional T_EX input conventions

Existing T_EX and L^AT_EX documents often use ASCII-based sequences to represent accented and other “extended” characters not directly available in the input character set. The macro packages that implement these commands map them to known character codes in particular font encodings.

To allow such documents to be typeset using standard Unicode-compliant fonts in place of the custom-encoded fonts previously used, Ross Moore (an early X_YT_EX user) has provided a package⁶ for L^AT_EX that maps several hundred such control sequences to the correct Unicode codepoints. Using this package, many existing L^AT_EX documents that use extended Latin and other “special” characters can be typeset using Unicode fonts, without needing to actually convert the encoding of the source text.

⁵Probably the most widely-used T_EX macro package, offering extensive support for structured markup and many document types and style options; see <http://www.latex-project.org/>. This paper is an example of the use of the L^AT_EX formatting package with X_YT_EX.

⁶See the *utf8accents* package, available from http://scripts.sil.org/xetex_related.

5.2 Legacy source document encodings

As initially designed, X_YT_EX assumed that all input text is encoded in Unicode; it would read input files as either UTF-8 or UTF-16. Existing ASCII documents, of course, are also valid UTF-8 and therefore could be used directly. This includes documents that use ASCII-based T_EX conventions for accents and other extended characters, as mentioned above.

However, some T_EX users have documents encoded with 8-bit codepages such as ISO Latin-1, MacRoman, Windows Cyrillic, etc. With the original “pure Unicode” implementation of X_YT_EX, it was impossible to process such files; they would be assumed to be UTF-8, but on encountering values > 127, the bytes would be misinterpreted as UTF-8 sequences rather than as individual characters. (In standard T_EX, with purely byte-oriented input, such files can of course be read; and the characters can be remapped through T_EX macro programming, if (as often occurs) there is a mismatch between the encodings of input text and the fonts to be used.

To enable users to process such files with X_YT_EX, without requiring a separate conversion to Unicode first, more flexible input encoding support was eventually added to the system. A new command `\XeTeXinputencoding` was implemented, which allows the user to request on-the-fly conversion from another character encoding into Unicode as the source text is read.

The `\XeTeXinputencoding` command requires one parameter, the name of the desired encoding. A number of options are supported. First, `utf8` or `utf16` will set the system to direct Unicode input; `auto` restores the default behavior, which is to detect the Unicode encoding form from the initial bytes of the file. The special name `bytes` causes X_YT_EX to read individual byte values as separate code units, treating them as character codes 0–255. While this is unlikely to represent the correct Unicode interpretation of the source text, it may be useful if these codes are to be processed by existing T_EX macros rather than used directly as text characters.

Finally, any Internet encoding name known to the Mac OS X Text Encoding Converter⁷ may be specified. In this case, X_YT_EX calls TEC to perform encoding conversion as it reads the input text. Just a few basic TEC APIs are sufficient for this task:

TECGetTextEncodingFromInternetName Used by `\XeTeXinputencoding` to look up the encoding name specified, and determine if it is known to the operating system.

CreateTextToUnicodeInfo Initialize the mapping information needed by TEC to convert between a particular legacy encoding and Unicode.

ConvertFromTextToUnicode Convert a buffer of text from the external legacy encoding into Unicode.

Note that although at the time of writing, X_YT_EX relies on TEC for encoding conversion of input text, this may change in a future release. A future version will probably use either ICU or GNU *libiconv* functions instead of TEC. This would be in the interests of portability to operating systems other than Mac OS X.

It is also possible that the input mapping support will be extended to allow the use of SIL’s TECKit⁸ to directly support custom user-defined byte encodings. This would involve a minor extension to the `\XeTeXinputencoding` command, allowing users to specify the name of a TECKit mapping file as an alternative to the name of a standard legacy codepage.

⁷A standard component of the Mac OS; see http://developer.apple.com/documentation/Carbon/Reference/Text_Encodin_sion_Manager/index.html.

⁸Text Encoding Conversion toolkit; see <http://scripts.sil.org/teckit>.

```

; TEckit mapping for TeX input conventions <-> Unicode characters
LHSName "TeX-text"
RHSName "UNICODE"

pass(Unicode)
U+002D U+002D      <> U+2013 ; -- -> en dash
U+002D U+002D U+002D <> U+2014 ; --- -> em dash

U+0027             <> U+2019 ; ' -> right single quote
U+0027 U+0027      <> U+201D ; '' -> right double quote
U+0022             > U+201D ; " -> right double quote

U+0060             <> U+2018 ; ` -> left single quote
U+0060 U+0060      <> U+201C ; `` -> left double quote

U+0021 U+0060      <> U+00A1 ; !' -> inverted exclam
U+003F U+0060      <> U+00BF ; ?' -> inverted question

```

Figure 7: The TEckit source file `tex-text.map`, defining a font mapping for X_YT_EX that provides compatibility with the conventions of legacy T_EX fonts.

5.3 Font mappings using TEckit

Widely-used T_EX keyboarding conventions such as `\' {e} ↦ 'é` or `\pounds ↦ '£` are implemented via T_EX macros (and therefore easily adapted for Unicode-compliant fonts, by modifying the macro definitions). In addition, there are a few established conventions that are implemented as ligature rules associated with standard T_EX fonts; these include `--- ↦ '—` (em-dash), `? ↦ '¿`, and a few more. In principle, smart font technologies such as AAT and OpenType could implement these same ligatures, providing the same behavior as traditional T_EX fonts. But as these conventions are peculiar to the T_EX world, it is not realistic to expect them to be provided in mainstream, general-purpose fonts.

Although it would usually be possible to simulate these ligatures via macro programming, it is difficult to ensure that reprogramming widely-used text characters such as the hyphen, question mark, and quotation marks will not interfere with other levels of markup in the source document. Instead, X_YT_EX provides a mechanism known as “font mappings”, whereby a mapping of Unicode characters is associated with a particular font, and applied to all strings of text being measured or rendered in that font. This is implemented using the TEckit mapping engine.

While TEckit was primarily designed to convert between legacy byte encodings and Unicode, it can also be used to perform transformations on a Unicode text stream, using the same mapping language and text conversion library; figure 7 shows the *tex-text* mapping that is provided to support normal T_EX conventions. When associated with a standard Unicode-compliant font in X_YT_EX, this has the effect of implementing the legacy T_EX conventions for dashes and quotes, as shown in figure 8, without requiring any T_EX-specific features in the smart fonts themselves.

While this mechanism, associating a mapping defined in terms of Unicode character sequences, was first devised in order to support legacy T_EX input conventions, it can also be applied in other ways. For example, figure 9 shows how it is possible to typeset a single fragment of input text in two scripts by giving different font specifications, one of which includes a transliteration mapping.

<pre>\font\TestA="Times New Roman" at 9pt \TestA !'Typing ``quotes'`---and dashes---the \TeX\ way!\par \bigskip \font\TestB="Times New Roman: mapping=tex-text" at 9pt \TestB !'Typing ``quotes'`---and dashes---the \TeX\ way!\par</pre>	<pre>!'Typing ``quotes"---and dashes---the T_EX way! ıTyping “quotes”—and dashes—the T_EX way!</pre>
---	--

Figure 8: Using the *tex-text* font mapping to support legacy typing conventions. (The source document is of course plain text; color is added for clarity here and in other figures.)

<pre>\begin{centering} \def\SampleText{Unicode - это уникальный код для любого символа,\ независимо от платформы,\ независимо от программы,\ независимо от языка.\par} \font\gen="Gentium" at 9pt \gen \SampleText \bigskip \font\gentrans="Gentium: mapping=cyr-lat-iso9" at 9pt \gentrans \SampleText \end{centering}</pre>	<pre>Unicode - это уникальный код для любого символа, независимо от платформы, независимо от программы, независимо от языка. Unicode - èto unikal'nyj kod dlâ lûbogo simvola, nezavisimo ot platformy, nezavisimo ot programmy, nezavisimo ot âzyka.</pre>
---	---

Figure 9: Using a font mapping for on-the-fly transliteration while typesetting.

5.4 Math typesetting

One of T_EX’s traditional strengths is in mathematical typesetting. It was designed to enable authors to readily typeset complex equations and similar displays, with precise control over details of layout and spacing, and with many aspects of math formatting handled automatically. Figure 10 shows an example of T_EX input using math mode, alongside the typeset result.

Standard T_EX macro packages provide commands to access many hundreds of math and other technical symbols, and these are mapped to the appropriate characters in a selection of specialized fonts. In Unicode many such symbols now have their own codepoints, and so it should be possible to typeset such material using standard Unicode-compliant fonts, rather than the custom-encoded math and symbol fonts normally used with T_EX.

However, this is not as simple as it may sound. T_EX’s math typesetting features rely on specialized font metric information associated with the math fonts, in addition to the glyphs themselves. This is necessary to provide accurate typesetting of complex constructs. Unfortunately, this means that users cannot simply tell X_YT_EX to use a Unicode-compliant font for math; not only will the standard T_EX math commands access the wrong glyphs, but also, even if the T_EX macros are redefined using Unicode values, such fonts will still not work in math mode because of the lack of extended font metric information.

$$\begin{aligned}
 & \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} e^{-(x^2+y^2)} dx dy \\
 &= \int_0^{2\pi} \int_0^{\infty} e^{-r^2} r dr d\theta \\
 &= \int_0^{2\pi} \left(-\frac{e^{-r^2}}{2} \Big|_{r=0}^{r=\infty} \right) d\theta \\
 &= \pi.
 \end{aligned}$$

Figure 10: An example of math typesetting, one of T_EX’s strengths. X_YT_EX supports legacy T_EX fonts and math mode, as shown here, but does not currently extend these capabilities.

To address this issue, it will be necessary to provide these additional font metrics for any Unicode fonts that are to be used for math typesetting; and it will also be necessary to extend additional data structures in X_YT_EX that are currently limited to 8-bit codes. It may be possible to make use of work from the Omega project (see section 7.3) to facilitate this, but at the time of writing, X_YT_EX is limited to using legacy 8-bit T_EX fonts for math typesetting.

6 Advanced font features

In order to take full advantage of the multilingual support and sophisticated typographic features offered by modern font technologies, we need to go beyond merely specifying a font and rendering a sequence of Unicode characters. Correct rendering may depend on the language of the text, as different languages sometimes require different visual results even for the exact same Unicode characters.

For example, Turkish uses both of the characters *i* (U+0069 LATIN SMALL LETTER *i*) and *ı* (U+0131 LATIN SMALL LETTER DOTLESS *i*). But many Latin-script fonts include an *fi* ligature in which the dot of the *i* is assimilated into the top of the *f*. Such a ligature is appropriate for most languages, and improves the appearance of the rendered text; and typical OpenType or AAT fonts will contain ligature rules that automatically use it wherever the sequence *f i* occurs in the text stream. However, in Turkish it becomes a problem because the distinction between *i* and *ı* is lost. Figure 11 illustrates this issue.⁹

<pre>\font\txfont="Adobe Garamond Pro" at 8pt \txfont Apple, HP, IBM, JustSystem, Microsoft, Oracle, SAP, Sun, Sybase, Unisys ve endüstrinin diğer ileri gelen firmaları Evrensel Kod Standardını desteklemektedirler. Evrensel Kod, XML, Java, ECMAScript (JavaScript), LDAP, CORBA 3.0, WML vb. gibi modern standartlar tarafından ISO/IEC 10646 uyarlanması resmi yoludur.</pre>	<p>Apple, HP, IBM, JustSystem, Microsoft, Oracle, SAP, Sun, Sybase, Unisys ve endüstrinin diğer ileri gelen firmaları Evrensel Kod Standardını desteklemektedirler. Evrensel Kod, XML, Java, ECMAScript (JavaScript), LDAP, CORBA 3.0, WML vb. gibi modern standartlar tarafından ISO/IEC 10646 uyarlanması resmi yoludur.</p>
---	--

Figure 11: Turkish text showing the necessity for language-specific font rendering. Note how the automatic use of the *fi* ligature obscures the distinction between *i* and *ı*, which are separate letters in Turkish.

An increasing number of OpenType fonts provide a solution to this problem, in the form of support

⁹Sample Turkish text from the Unicode web site, <http://www.unicode.org/standard/translations/turkish.html>.

```

\font\txfont="Adobe Garamond Pro:
  language=TUR" at 8pt
\txfont
Apple, HP, IBM, JustSystem, Microsoft, Oracle, SAP, Sun,
Sybase, Unisys ve endüstrinin diğer ileri gelen fırmaları Evrensel
Kod Standardını desteklemektedirler. Evrensel Kod, XML, Java,
ECMAScript (JavaScript), LDAP, CORBA 3.0, WML vb. gibi modern
standartlar tarafından ISO/IEC 10646 uyarlanmasının resmi yoludur.

```

Figure 12: Using the Turkish language support in an OpenType font to ensure correct rendering of `fı` sequences.

for multiple “language systems”. The font developer can provide tables within the font that substitute different glyphs, enable different subsets of the possible ligatures, etc., depending on the selected language. X_YT_EX supports this capability by allowing a font specification in the T_EX document to include a language tag. If the specified language tag is supported by the font, X_YT_EX will render the font according to those OpenType rules instead of the default behavior. Figure 12 shows how the Turkish example can be corrected by adding the proper language tag to the font declaration.

Another issue is that some Unicode characters have alternative possible glyph shapes (within a single typeface design). For example, the character U+014A LATIN CAPITAL LETTER ENG has four possible designs in the Doulos SIL typeface: Ŋ Ŏ Ő Œ. These are all legitimate renderings of the same Unicode character, the uppercase version of *eng* (ŋ). By default, text rendered in Doulos SIL will use the first of these forms. But in some language communities, a different form may be preferred—or may even be required for readability.

One solution to this would be to use different language systems within the OpenType tables to access the alternate *Eng* glyphs. In practice, however, this is more difficult to arrange than the Turkish case. This character is used in many lesser-known and little-documented languages, and so font developers cannot reasonably be expected to provide all the appropriate language system mappings.

An alternative approach is through user-selectable *font features*. These are another mechanism for controlling exactly how a given font renders text. Rather than associating variant glyphs or other options with a particular language, the options can be made available as individual “features” that can be enabled or disabled as required. So the Doulos SIL font, for example, has a feature named *Uppercase Eng alternates*, with four possible settings, and the character U+014A can be displayed as any of the four available glyphs according to the feature setting chosen.

X_YT_EX allows such features to be included as part of the font specification used to load a particular font for typesetting. Figure 13 shows how the same text can be typeset either with the default glyphs provided in Doulos SIL or using alternate forms for particular characters. This mechanism enables the user to achieve culturally-appropriate rendering of the Unicode text without requiring the font developer to be aware of the proper choices of glyph variants for each language where the font may be used.

7 X_YT_EX and other T_EX extensions

The X_YT_EX project is just one of a number of extended versions of T_EX that have been created over the years, and it may be useful to give a brief comment on its relationship to some other projects.

```

\font\Doulos="Doulos SIL/AAT" at 10pt
\font\DoulosAlt="Doulos SIL/AAT:
  Alternate forms=Literacy alternates,
  Small v-hook straight style;
  Uppercase Eng alternates=Capital N with tail"
  at 10pt
\Doulos
Xɔsee na Mose ɔɔ Nɔutitotɔŋkeke la anyi, eye wɔna
wohlẽ uu ɔe ɔɔtrutiwo ŋu bene dɔla si atsrɔ̃
ŋgɔgbeviwo la nagawɔ nuvevi Israel viwo ya o.\par
\bigskip
\DoulosAlt
Xɔsee na Mose ɔɔ Nɔutitotɔŋkeke la anyi, eye wɔna
wohlẽ uu ɔe ɔɔtrutiwo ŋu bene dɔla si atsrɔ̃
ŋgɔgbeviwo la nagawɔ nuvevi Israel viwo ya o.\par

```

Figure 13: Using optional font features to control the rendering of specific Unicode characters. This may be for stylistic reasons, or may be required for readability in a particular language community.

7.1 T_EX_GX

T_EX_GX¹⁰ is an important ancestor of X_YT_EX, in that it pioneered the model of integrating the T_EX formatting system with a host platform’s smart-font rendering technology. T_EX_GX relied on Apple’s now-obsolete QuickDraw GX graphics system for Mac OS 7–9, and was still based on 8-bit legacy encodings, not Unicode. However, it did adapt T_EX’s scanning and paragraphing routines to treat entire words as units to be passed to an external text layout system, as well as extending the `\font` command to load fonts from the host platform and to access optional features. These extensions have been incorporated largely unchanged into X_YT_EX.

7.2 ε-T_EX

ε-T_EX¹¹ is a widely-used extended version of T_EX that adds a number of new commands to the language, while retaining compatibility with the standard program. It is in fact used by many installations as the default ‘T_EX’ program, and an increasing number of macro packages assume that ε-T_EX features are available.

X_YT_EX is implemented as an extension of ε-T_EX, so that it benefits from the enhancements provided in that system. In particular, support for bidirectional paragraph layout, needed for languages such as Arabic and Hebrew, is inherited from ε-T_EX.

7.3 Omega, Aleph

Omega¹² is an ambitious project that extends T_EX to work with 16-bit character codes and provides a mechanism of input and output filters (“Omega transformation processes”). These can perform complex

¹⁰See <http://www.sil.org/computing/texgx.html>.

¹¹See <http://www.tug.org/tex-archive/systems/e-tex/v2/>.

¹²See <http://omega.enstb.org/> and <http://www.tex.ac.uk/cgi-bin/texfaq2html?label=omega>.

transformations both as text is read from a file (to support different encodings) and between the internal character codes and font access codes.

Aleph¹³, formerly known as e-Omega, is a project that aims to merge features of Omega and ϵ -T_EX, and to provide a more stable platform than Omega, which has been undergoing major restructuring and appears to face a somewhat uncertain future.

Omega (and therefore Aleph) provides a very powerful mechanism for supporting multilingual typesetting and complex scripts. However, because (like T_EX itself) it is intended to be platform-independent, it does not take advantage of available text systems such as ATSUI; instead, all complex script behavior must be implemented through Omega's own OTP mechanisms. This is both a strength and a weakness: a strength in that the mechanism is both powerful and portable; but a weakness in that configuring fonts (especially for complex scripts) to work with Omega is a non-trivial programming task, beyond the capabilities of many users.

In contrast, one of the key ideas of X_YT_EX is that it should *not* be necessary to re-implement complex script and typographic behavior that has already been defined by the developers of AAT and OpenType fonts. If a user's computer system supports a given writing system, with appropriate fonts and rendering behavior, this should be immediately usable in the typesetting system; no laborious, technical configuration procedure should be needed. This gives X_YT_EX a major ease-of-use advantage, but comes at a price: the typesetting system is now dependent on the host platform's font technology, in a way that standard T_EX is not, and so documents may not be readily portable to other platforms.

While X_YT_EX does not share Omega's complex-script features, taking an entirely different approach to text rendering, it does use ideas from Omega with regard to the "widening" of character codes within the T_EX engine from 8 to 16 bits.

7.4 pdfT_EX

One more T_EX extension is worth mentioning here: pdfT_EX¹⁴ is an extended version of T_EX that provides the option to generate PDF output, instead of the traditional DVI that requires post-processing with a device-specific driver. It includes a number of additional commands to enhance the resulting PDF files with bookmarks, interactivity, and so on.

While X_YT_EX also generates PDF output, this is actually accomplished by generating "extended DVI" output, and then rendering this to PDF as a subsequent process. This is less efficient than pdfT_EX's direct PDF generation, and makes it more difficult to integrate some of the advanced PDF features (although to some extent, this can still be done through the traditional DVI-to-device driver model).

At present, then, X_YT_EX is entirely separate from pdfT_EX. Integration of X_YT_EX's Unicode and font support with pdfT_EX's PDF generation and extended PDF features would provide an even more attractive typesetting system, but would require significant development effort; at the time of writing, no such effort is under way.

8 Future directions

This paper has discussed how Unicode and multilingual/multi-script support has been integrated into the T_EX system, providing users with a powerful typesetting system that handles virtually any language for which an appropriate "smart font" is available. However, X_YT_EX should still be considered somewhat

¹³See <http://www.tex.ac.uk/cgi-bin/texfaq2html?label=aleph>.

¹⁴See <http://www.tug.org/applications/pdftex/>.

experimental, a “work in progress”, and there is considerable scope for further enhancement. A few possible directions for further work include:

Graphite support Another smart font technology, besides AAT and OpenType, is SIL International’s Graphite¹⁵ system. This could be integrated as a third text rendering option within X_YT_EX.

Alternate platforms Currently, X_YT_EX is available only on Mac OS X. It was initially developed on this platform by taking advantage of specific Mac OS X technologies (especially ATSUI for Unicode text layout, and Quartz2D for graphics/PDF rendering). However, there is considerable interest in porting to other operating systems.

pdfT_EX integration As suggested above, it would seem ideal to merge X_YT_EX’s Unicode and advanced-font-technology support with pdfT_EX’s PDF generation.

Unicode math font support This has also been mentioned above; currently, only legacy 8-bit fonts can be used for math typesetting. Fully supporting Unicode for math will probably require coordination among font developers and T_EX macro writers, as well as extensions to the X_YT_EX system itself.

Line-breaking without spaces Writing systems that do not use spaces between words are currently not well supported in X_YT_EX. Line-breaking and paragraph layout relies on recognizing potential line break positions, primarily at spaces, and so will not work in languages such as Thai or Chinese. It is possible to work around this by use of zero-width spaces in the source text, but ideally the paragraphing algorithm should be extended to handle such writing systems correctly.

While these are offered as examples of how X_YT_EX, or perhaps some future system modeled on the current project, might be developed further, this does *not* constitute a commitment to implement any particular feature!

A good forum for further suggestions, questions, contributions, and other feedback is the X_YT_EX mailing list¹⁶ created by interested users shortly after the first public release of a test version, and currently including some 130-plus users. The input of this group has been invaluable in shaping X_YT_EX, particularly with regard to issues of compatibility with legacy documents and major macro packages such as L^AT_EX and ConT_EXt¹⁷. I would like to thank all those who have reported bugs, helped isolate problems, asked helpful and thought-provoking questions, suggested enhancements, contributed T_EX macros, and encouraged and supported the X_YT_EX project in many ways.

¹⁵See <http://scripts.sil.org/RenderingGraphite>.

¹⁶See <http://www.tug.org/mailman/listinfo/xetex>.

¹⁷A macro package designed with similar general-purpose aims to the more widely-known L^AT_EX, but intended to reflect more recent ideas about markup, etc.; see <http://www.pragma-ade.com/>.