The Design of TEX and METAFONT: A Retrospective

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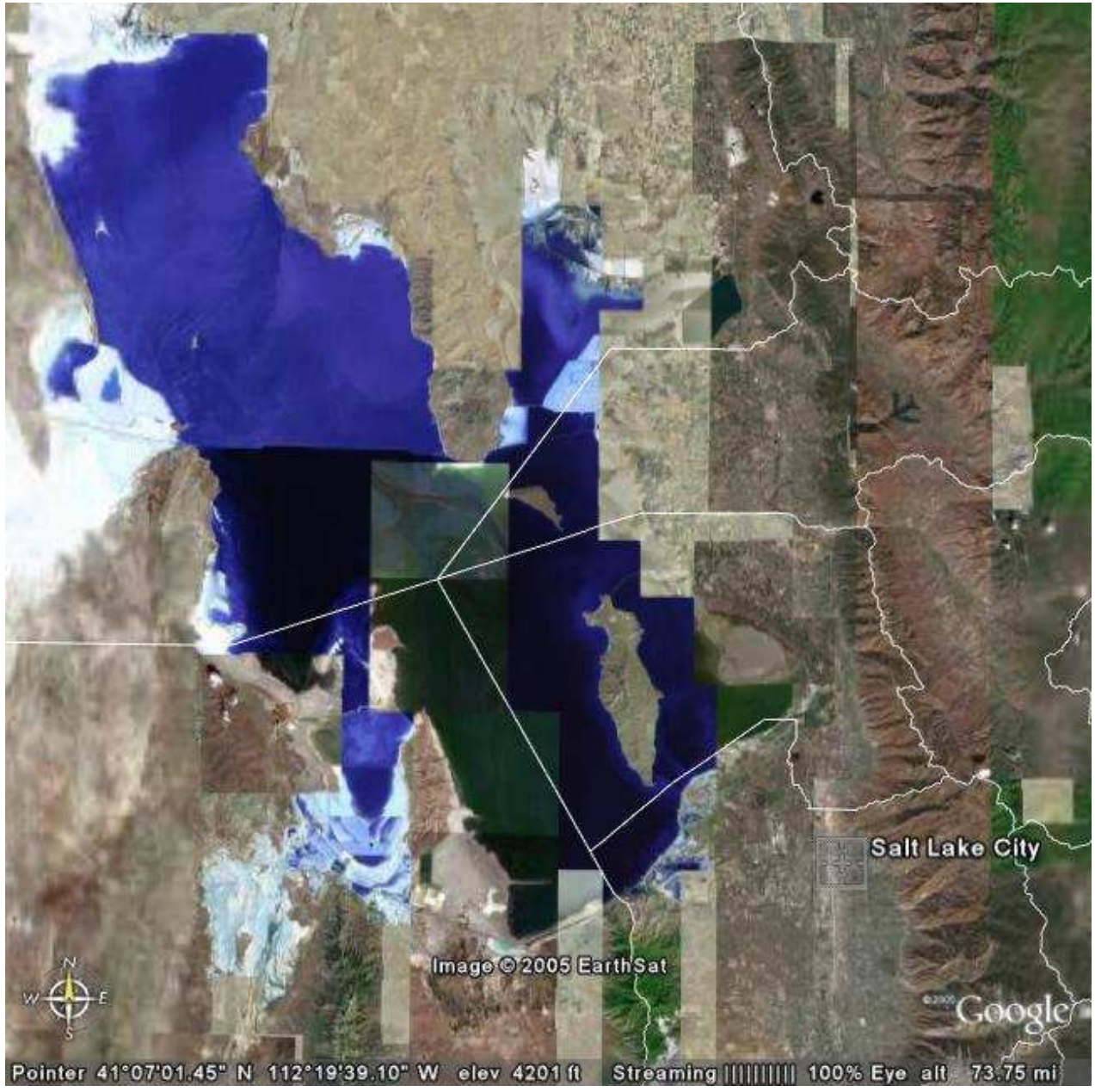
USA

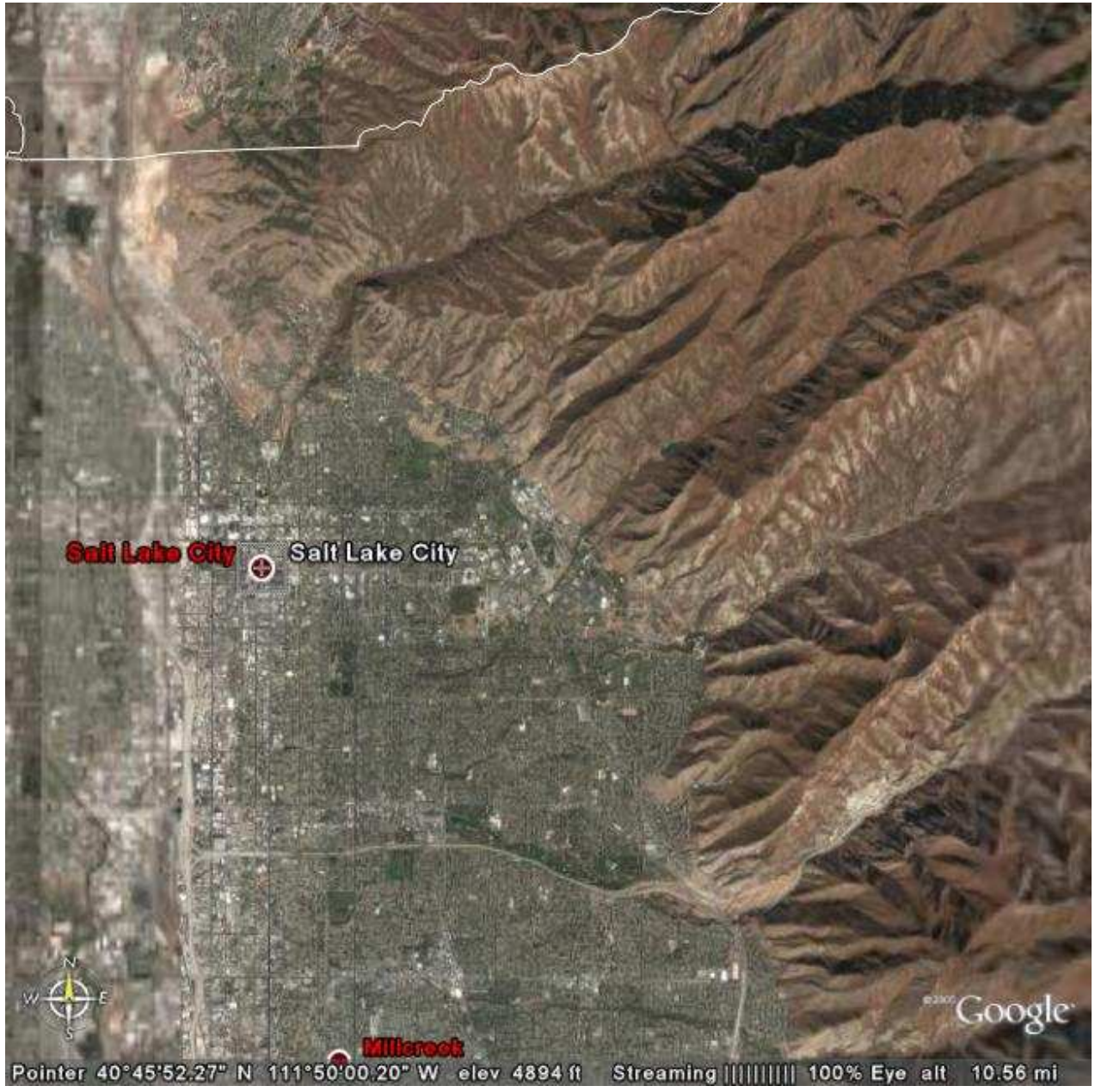
Where I came from

Where I came from (cont.)

Where I came from (cont.)

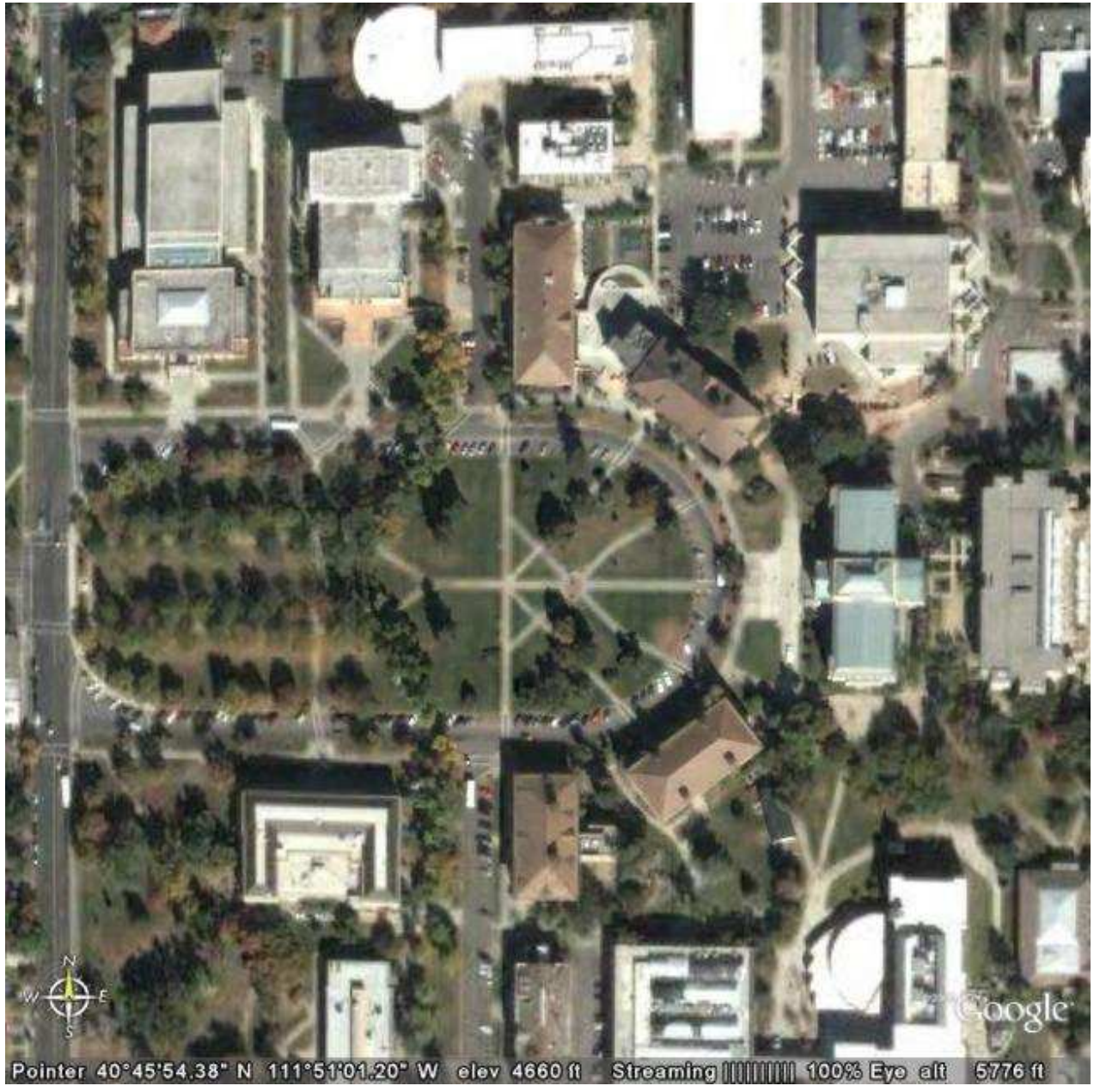


Where I came from (cont.)



Where I came from (cont.)

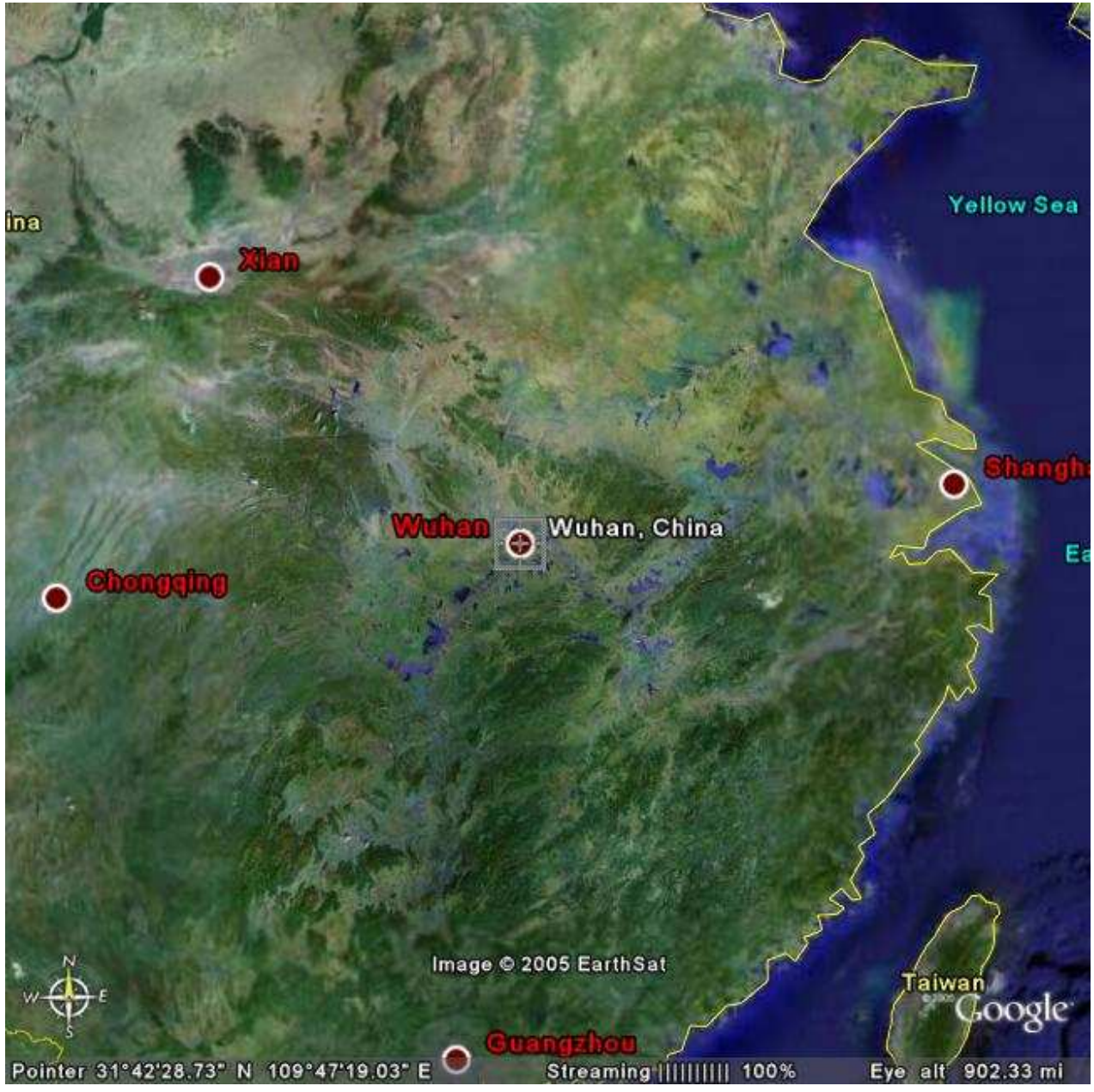
Where I came from (cont.)



TEX and METAFONT

Where I came from (cont.)

Where we are


Yellow Sea
Xian
Wuhan
Wuhan, China
Chongqing
Guangzhou
Taiwan
Image © 2005 EarthSat
Google
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Where we are (cont.)

Where we are (cont.)

In the Northern Capital

Prehistory (1452–1970)

- 500-year-long tradition of typesetting
- expert human typographers with decades of experience
- hand setting of type in lines and racks
- letters stored into upper and lower cases (bins)
- hot-lead process
- proprietary handmade punch-cut fonts
- typesetting on spread of two facing pages
- publishers have *editors* and *proofreaders*
- typesetting and book binding done by job shops

Typesetting on computers (1970–)

- expert human typographers, but now hampered by technology
- typographically substandard quality
- expensive and proprietary typesetting computer hardware and software
- optical font scaling
- proprietary optical fonts
- see NHFB's *25 Years of TEX and* METAFONT*: Looking Back and Looking Forward:* TUG'2003 *Keynote Address*, TUGboat **25**(1) 7–30 (2004)
- see DEK's *Digital Typography* (1999)

Knuth's sabbatical year (1977–1978)

- improve typesetting of *The Art of Computer Programming* books

> I didn't know what to do. I had spent 15 years writing those books, but if they were going to look awful I didn't want to write any more. How could I be proud of such a product?
>
> — DEK (1996 Kyoto Prize address)

- reproduce look of *Linotype Modern 8a* fonts of earlier editions
- 0.x-MIPS departmental computers (notably, 16-bit PDP-11 and 36-bit PDP-10)
- computer use still cost $$$$ for many people

Computers in 1977

- mainframes: IBM and the BUNCH (BURROUGHS, UNIVAC, NCR, CDC, and HONEYWELL), clones (AMDAHL, Russian ES, FUJITSU, HITACHI, NEC, RCA, SIEMENS, WANG), ICL, PHILLIPS, TEXAS INSTRUMENTS, XEROX
- minicomputers: DATA GENERAL, DEC PDP-n, GE, HARRIS, INTERDATA, PERKIN-ELMER, PRIME, SDS, VARIAN, ...
- XEROX PARC: first workstations
- microcomputers based on INTEL 8080, MOS 6502, TEXAS INSTRUMENTS TMS1000, ZILOG Z80, ...

PDP-10 computers

DEC PDP-10 ran several different operating systems, including:

- BBN TENEX
- Compuserve modified 4S72
- DEC TOPS-10
- DEC TOPS-20
- MIT ITS (Incompatible Time Sharing System)
- On-Line Systems' OLS-10
- Stanford WAITS (Westcoast Alternative to ITS)
- TYMSHARE AUGUST and TYMCOM-X

PDP-10 contributions

PDP-10 systems hosted many important developments:

- ETHERNET, TCP/IP, and ARPANET backbone [SRI, UCB, UCLA, UCSB, Utah]
- Brian Reid's document-formatting and bibliographic system, SCRIBE [CMU]
- Richard Stallman's EMACS editor [MIT]
- Ralph Gorin's SPELL [Stanford]
- Mark Crispin's mail client, MM [Stanford]
- Frank da Cruz's KERMIT [Columbia]
- Bill Gates and Paul Allen simulate Intel 8080 to develop MS-DOS

PDP-10 programming languages

- ALGOL 60
- BASIC
- BCPL (Basic/BBN Combined Programming Language)
- BLISS [DEC and Carnegie-Mellon University (CMU)]
- C (early 1983)
- COBOL 74
- FORTH
- FORTRAN 66 and FORTRAN 77
- several dialects of LISP, including MACLISP [MIT], INTERLISP [BBN and XEROX], and PSL (Portable Standard Lisp) [Utah]

PDP-10 programming languages (cont.)

- MACRO, MIDAS, and FAIL assemblers
- MACSYMA [MIT], REDUCE [Utah] and MAPLE [Waterloo]
- PASCAL [Hamburg/Rutgers/Sandia] (late 1978)
- shell-scripting language PCL (Programmable Command Language) [DEC, CMU, and FUNDP] (early 1980s)
- SAIL (Stanford Artificial Intelligence Language) [ALGOL 60 *with zillions of extensions*]
- SIMULA 67
- SNOBOL

PDP-10 editors

- TECO (Text Editor and Corrector) [DEC]

  The most powerful and dangerous programming language and text editor ever invented. . . . advanced TECO addiction has been known to cause nightmares about infinite loops four characters long. . . . Not recomended for use via modem connections in bad weather, since at first glance many TECO programs are indistinguishable from line noise.

- TV (screen editor derived from TECO) [DEC]
- E (WAITS): with TV, DEK's editor until his switch to EMACS and UNIX about 1990
- EDIT [DEC]
- EMACS (EDitor MACroS) [built on TECO] [MIT]

PDP-10 document-formatting systems

- DIGITAL STANDARD RUNOFF [TEX later used as a backend for VAX VMS manuals]
- Larry Tesler's PUB document formatting system
- Brian Reid's SCRIBE [model for LATEX and BIBTEX, but licensed and proprietary] [CMU]

PDP-10 architecture

- large, but clean, instruction set
- 744 instructions, augmented at XEROX PARC with 472 9-bit instructions for INTERLISP)
- 36-bit words [octal notation: 7777777,,765432]
- 18-bit address (262,144 words, 1.25MB), later extended to 30-bit (5GB), but only 23-bit addresses ever implemented in hardware (8,388,608 words, 40MB)
- external symbols stored in RADIX50 encoding with characters [A–Z0–9% .$] [4 bits of flags, 32 bits with six characters: $2^{32} > 40^6$ and $40_{10} = 50_8$]
- bytes of any size from 1 to 36 (thus, efficient access to packed fields in records and structures)

PDP-10 architecture (cont.)

- filesystem records byte count and byte size

```
@vdir hello.*

   TOPS20:<BEEBE.C>
 HELLO.C.1;P777700   1 99(7)   12-Jan-2005 07:09:41 BEEBE
   .FAI.2;P777700    1 1870(7) 12-Jun-2005 08:11:40 BEEBE
   .PRE.2;P777700    1 12(7)   12-Jun-2005 08:11:40 BEEBE
   .REL.1;P777700    1 113(36) 12-Jun-2005 08:11:16 BEEBE

 Total of 4 pages in 4 files
```

- text files normally 7-bit ASCII, with low-order bit set to 1 to mark a line number in EDIT files
- 8-bit bytes allow sharing files with UNIX via NFS

PDP-10 architecture (cont.)

- largest signed integer: $2^{35} - 1 = 34,359,738,367$
- single-precision floating-point precision: 27 bits (8D)
- double-precision floating-point precision: 62 bits (18D)
- floating-point range: 1.17e-38 . . . 1.70e+38
- much later: UTF-9 and UTF-18 Unicode support

PDP-10 architecture (cont.)

- stack-based architecture (thus, recursion trivial)
- clean system call interface (JSYS)
- `set trap jsys /all`
- DDT (Dynamic Debugging Tool) sits in high address space and can debug any program written in any programming language
- DDT is the default command processor on MIT ITS

TOPS-20 features

- MONITOR (kernel) and EXEC (command processor) programmed in efficient assembly language
- supports 50 to 100 simultaneous users on terminal connections, thanks to PDP-11 front end
- command-line help

```
@? Command, one of the following:
 ACCESS          ADVISE          APPEND
 ARCHIVE         ASSIGN          ATTACH
 BACKSPACE       BLANK           BREAK
 ...
 UNATTACH        UNDECLARE       UNDELETE
 UNKEEP          UNLOAD          UNMAP
 VDIRECTORY      WDIRECTORY
```

TOPS-20 features (cont.)

- command-line completion and prompt [KERMIT & MM]

```
@comPILE (FROM) ? confirm with carriage return
  or one of the following:
 /10-BLISS       /36-BLISS       /68-COBOL
 /74-COBOL       /ABORT           /ALGOL
 ...
 /RELOCATABLE    /SAIL            /SEARCH
 /SIMULA         /SNOBOL          /STAY
 /SYMBOLS        /WARNINGS
```

- tree-structured file system PS:<BEEBE.MF.CM>
- file ownership; 18-bit protection code (user, group, other)
- append, delete, execute, list, read, write access bits

TOPS-20 features (cont.)

- case-insensitive filenames
- Ctl-V quotes special characters in filenames
- optional quotas in directories
- file generation numbers

```
@vDIRECTORY (VERBOSE, OF FILES) pdp10.c.*
  TOPS20:<BEEBE.HOC36>
PDP10.C.3;P777752   8 19892(7) 21-Jan-2005 09:03:35 BEEBE
     .4;P777752     8 19897(7) 21-Jan-2005 10:38:55 BEEBE
     .5;P777752     8 19899(7) 21-Jan-2005 10:52:40 BEEBE
```

- tape archives with online directory entries
- DELETE, UNDELETE, and EXPUNGE
- ATTACH and DETACH

TOPS-20 features (cont.)

- user and system logical names

```
@define TEXINPUTS: TEXINPUTS:,
                   ps:<jones.tex.inputs>
$^Edefine TEXINPUTS: ps:<tex.inputs>,
                     ps:<tex.new>
```

- search path support built-in to MONITOR, so all programs and programming languages can use it

```
@iNFORMATION (ABOUT) lOGICAL-NAMES (OF) sys:
Job-wide:
sys: => SYS:,TEX:
System-wide:
sys: => PS:<SUBSYS>,DOMAIN:,UNS:,SAI:,FUN:,
        HLP:,DSK:
```

Choosing a programming language

- assembly code tedious, would not survive hardware
- BLISS expensive and tied to DEC systems
- C not yet available
- COBOL awful: `MULTIPLY A BY B GIVING C.`
- FORTRAN most portable, but no recursion, no data structures beyond arrays, no low-level byte I/O, no decent character string support, six-character names
- LISP great, but inefficient and Babel of dialects
- PASCAL first available in late 1978
- SAIL won

Filename scanning in SAIL

```
internal saf string array fname[0:2] # file name, extension, and directory;
internal simp procedure scanfilename # sets up fname[0:2];
begin integer j,c;
fname[0]_fname[1]_fname[2]_null;
j_0;
while curbuf and chartype[curbuf]=space
    do c_lop(curbuf);
loop    begin c_chartype[curbuf];
        case c of begin
        [pnt] j_1;
        [lbrack] j_2;
        [comma][wxy][rbrack][digit][letter];
        else done
          end;
        fname[j]_fname[j]&lop(curbuf);
        end;
end;
```

SAIL conditional compilation

```
# changed to ^P^Q when debugging METAFONT;
define DEBUGONLY = ^Pcomment^Q
...
# used when an array is believed to require
# no bounds checks;
define saf = ^Psafe^Q

# used when SAIL can save time implementing
# this procedure;
define simp = ^Psimple^Q

# when debugging, belief turns to disbelief;
DEBUGONLY redefine saf = ^P^Q

# and simplicity dies too;
DEBUGONLY redefine simp = ^P^Q
```

Stanford extended ASCII character set

000	$\cdot$	001	$\downarrow$	002	α	003	β
004	$\wedge$	005	$\neg$	006	ϵ	007	π
010	λ	011	γ	012	δ	013	$\int$
014	$\pm$	015	$\oplus$	016	∞	017	∇
020	$\subset$	021	$\supset$	022	$\cap$	023	$\cup$
024	$\forall$	025	$\exists$	026	$\otimes$	027	$\leftrightarrow$
030	_	031	$\rightarrow$	032	~	033	$\neq$
034	$\leq$	035	$\geq$	036	$\equiv$	037	$\vee$
040–135 as in standard ASCII							
				136	$\uparrow$	137	$\leftarrow$
140–174 as in standard ASCII							
		175	$\Diamond$	176	}	177	^

SAIL limits affect METAFONT

- 19 buffers for disk files
- no more than 150 characters/line
- initialization handled by a separate program module to save memory (INIMF, INITEX, VIRMF, and VIRTEX)
- bias of 4 added to `case` statement index to avoid illegal negative cases
- character raster allocated dynamically to avoid 128K-word limit on core image
- magic TENEX-dependent code to allocate buffers between the METAFONT code and the SAIL disk buffers because *there is all this nifty core sitting up in the high seg . . . that is just begging to be used*

PDP-10 address space affects TEX

Table	1984	2004	Growth
strings	1819	98002	53.9
string characters	9287	1221682	131.5
memory words	3001	1500022	499.8
control sequences	2100	60000	28.6
font info words	20000	1000000	50.0
fonts	75	2000	26.7
hyphen. exceptions	307	1000	3.3
stack positions (i)	200	5000	25.0
stack positions (n)	40	500	12.5
stack positions (p)	60	6000	100.0
stack positions (b)	500b	200000	400.0
stack positions (s)	600	40000	66.7

PDP-10 address space and TEX

- compact table storage with limit number of indexing bits
- table sizes determined at compile time (fixed in 1990s)
- font and DVI files: compact, and complex, binary format
- roman and Greek letters crammed into text fonts
- Computer Modern fonts designed with only 128 glyphs in a font
- although 256 characters/font, only 16 different widths and heights, one of which must be zero
- hundreds of text fonts, but only 16 math families
- before 1989, only one preloaded hyphenation table

PDP-10 address space and TEX (cont.)

- fixed-length buffer limits input line length
- `trip` and `trap` tests apply only to `initex` and `inimf`, not `virtex` and `virmf`, which are compiled separately and used untested as TEX and METAFONT
- word boundaries known to TEX, but not recorded in DVI file
- cryptic error messages: *you can't do that in horizontal mode!*

Reimplement TEX and METAFONT

- increasing interest by user community
- *American Mathematical Society* needs archival, extensible, low-cost, portable, reliable, solid, and very-long-lasting, typesetting and font design systems that authors can use too
- typesetting of many technical documents by different authors on PDP-10s exposes design deficiencies and font infelicities of SAIL-coded TEX78 and METAFONT78
- wider use outside PDP-10 world needs a more portable implementation language
- coding must be of superb quality, and published for anyone to read, use, and reuse

Switching languages: 1980–1982

- C still not available
- MAINSAIL (MAchine INdependent SAIL) (1979) had not been ported much, and was commercial product
- PASCAL has many flaws

> PASCAL, at least in its standard form, is just plain not suitable for serious programming. . . . This botch [confusion of size and type] is the biggest single problem in PASCAL. . . . I feel that it is a mistake to use PASCAL for anything much beyond its original target. In its pure form, PASCAL is a toy language, suitable for teaching but not for real programming.
>
> — Brian Kernighan: *Why* PASCAL *is not my favorite programming language* (1981)

Switching languages (cont.)

- PASCAL language is small and available on several other systems, and thus, only viable choice
- write in subset of PASCAL, avoiding awkward parts (fixed-length strings, poor I/O, nested procedures, useless sets, dynamic memory allocation without freeing on some systems)
- hide the mess with TANGLE and WEAVE preprocessors
- use *literate programming*: interleaved fragments of prose and code, with automatically-generated name indexes: see DEK's *TEX: The Program*, METAFONT*: The Program* (1986), and *Literate Programming* (1992)
- TEX and METAFONT (20K lines each) were *severe* stress tests for almost all PASCAL compilers

Filename scanning in PASCAL

```
PROCEDURE Scanfilename;
 LABEL 30;
BEGIN
 beginname;
 WHILE buffer[curinput.locfield] = 32 DO
  curinput.locfield := curinput.locfield+1;
 WHILE true DO
 BEGIN
  IF (buffer[curinput.locfield] = 59) OR
     (buffer[curinput.locfield] = 37) THEN
     GOTO 30;
  IF NOT morename(buffer[curinput.locfield])
   THEN GOTO 30;
  curinput.locfield := curinput.locfield+1;
 END;
30:
    endname;
END;
```

TEX and METAFONT ports

- Thea Hodge ports early TEX in PASCAL to CDC Cyber (1980)
- Monte Nichols: VAX VMS (1981)
- Lance Carnes and David Fuchs independently port TEX and METAFONT in PASCAL to 16-bit INTEL 8086 on IBM PC (1981–1982)
- Sao Khai Mong translates METAFONT from SAIL to FORTRAN for HARRIS systems (1982)
- Lance Carnes: HP-3000 (1982) (10–30 sec/page; cf. 1065 pages/sec on 2.6GHz AMD64 today)
- Irene Bunner and John Johnson: HP-1000 (1983)
- Susan Plass: IBM mainframe (EBCDIC charset) (1983)

TEX and METAFONT ports (cont.)

- others: PDP-11, Z8000, APOLLO, M68000 (1983)
- Bart Childs brings TEX to DATA GENERAL (1983), PRIME (1984), and CRAY supercomputer (1988)
- Pavel Curtis and Howard Trickey spend months patching UNIX PASCAL compiler to finally get TEX and METAFONT on Berkeley UNIX (1983)
- Pierre Mackay and Rick Furuta make complete UNIX distribution of TEX and METAFONT (1983)
- Barry Smith and David Kellerman, PASCAL compiler developers at OREGON SOFTWARE, bring TEX and METAFONT to VAX VMS and new APPLE MACINTOSH (1984)

TEX and METAFONT ports (cont.)

- Pat Monardo at Berkeley produces COMMON TEX, a translation of TEX from PASCAL to C (1986–87)
- Klaus Guntermann: ATARI ST (1987)
- WEB2C community project now source of TEXlive and most other TEX implementations

Thanks to 664 TUGboat authors

786 Anonymous 112 Beeton 39 Childs 33 Hoenig 32 Eijkhout 32 Mittelbach 29 Knuth 27 Goossens 24 Burbank 24 Haralambous 22 Thiele 21 Clark 21 MacKay 21 Rahtz 20 Hosek 20 Taylor 19 Price 17 Beebe 17 Fuchs 16 van der Laan 15 Fine 15 Flynn 14 Poppelier 12 Carnes 12 Damrau 12 Whidden 11 Jett 11 Salomon 11 Smith 10 Beccari 10 Hagen 10 Pfeffer 10 Rowley 10 Tobin 9 Braams 9 Furuta 9 Gibbons 9 Moore 9 Rokicki 9 Spivak 8 Bzyl 8 Downes 8 Guenther 8 Lammarsch 8 Morris 8 Nichols 8 Schöpf 8 Whitney 7 Berdnikov 7 Carlisle 7 Crawford 7 Fox 7 Jackowski 7 Lamport 7 Milligan 7 Plaice 7 von Bechtolsheim 7 Wonneberger 7 Yap 6 Abbott 6 Ferguson 6 Hendrickson 6 Kellerman 6 Kelly 6 Ogawa 6 Plass 6 Platt 6 Schrod 6 Vulis 5 Berry 5 DeCorte 5 Dietsche 5 Doherty 5 Doob 5 Durst 5 Díaz 5 Fairbairns 5 Feruglio 5 Gaulle 5 Guntermann 5 Horn 5 Jeffrey 5 Kinch 5 Lapko 5 Murphy 5 Preston 5 Reid 5 Sauter 5 Voÿ 5 Zabala 5 LaTeX project team 4 Adams 4 Alexander 4 Barnhart 4 Breitenlohner 4 Brown 4 Damerell 4 Hefferon 4 Henderson 4 Hobby 4 Jackson 4 Lesenko 4 Malyshev 4 McKay 4 Neuwirth 4 Nieland 4 Partl 4 Roegel 4 Rogers 4 Sewell 4 Siebenmann 4 Sojka 4 Story 4 Taupin 4 Thedford 4 Thull 4 Trevorrow 4 Welland 4 Wittbecker 4 Wujastyk 3 Appelt 3 Bartlett 3 Beck 3 Cameron 3 DeLand 3 Doumont 3 Dunn 3 Frisch 3 Fujita 3 Girou 3 Glendown 3 Greene 3 Grätzer 3 Hall 3 Harris 3 Hodge 3 Hoover 3 Knappen 3 Lemberg 3 Luvisetto 3 Makhovaya 3 Mann 3 Maus 3 McClure 3 Nickalls 3 Olsák 3 Palais 3 Pandey 3 Raman 3 Sofka 3 Sowa 3 Spragens 3 Sterken 3 Vanderburg 3 Veselý 3 Wang 3 Wichura 2 André 2 Arnon 2 Arthur 2 Aurbach 2 Barnett 2 Barroca 2 Becker 2 Beeman 2 Bennett, Jr. 2 Bigelow 2 Billawala 2 Canzii 2 Cohen 2 Detig 2 Dunne 2 Eppstein 2 Finston 2 Fulling 2 Fuster 2 Föÿmeier 2 Greenwade 2 Grosso 2 Hafner 2 Hoekwater 2 Hornbach 2 Incerpi 2 Ion 2 Hefferon 2 Jones 2 Jürgensen 2 Kawaguti 2 Keller 2 Kennedy 2 Kneser 2 Kolodin 2 Langmyhr 2 Latterner 2 Laugier 2 Lavagnino 2 Lavaud 2 Lawson 2 Lee 2 Levy 2 Lovell 2 Lucarella 2 Machi 2 Marsden 2 McGaffey 2 McKinstry 2 McPherson 2 Miyabe 2 Mohr 2 Mooney 2 Nagy 2 Naugle 2 Ness 2 NTGFWG 2 Osborne 2 Patashnik 2 Perlis 2 Pianowski 2 Pickrell 2 Pierce 2 Piff 2 Pittman 2 Popineau 2 Pournader 2 Píska 2 Radel 2 Reckdahl 2 Rhead 2 Rodgers 2 Rose 2 Rubinstein 2 Saarela 2 Saludes 2 Schröder 2 Sherrod 2 Siegman 2 Skoupý 2 Southall 2 Stolleis 2 Strzelczyk 2 Syropoulos 2 Tanaka 2 Team 2 Thimbleby 2 Thánh 2 Toledo 2 Trabb-Pardo 2 Tsuga 2 Tulett 2 Ugolini 2 Weiss 2 Williams 2 Winter 2 Woolf 2 Zlatuska 2 Znamenskii 2 Zubrini¢ 1 Abrahams 1 Aiello 1 Akwai 1 Anagnostopolous 1 Anagnostopoulos 1 Andrews 1 Andulem 1 Aphalo 1 Arseneau 1 Asher 1 Aslaksen 1 Attali 1 Auerbach 1 Babu 1 Baker 1 Baldwin, Jr. 1 Ballantyne 1 Baragar 1 Barden 1 Barr 1 Batzinger 1 Baxter 1 Bayart 1 Bazargan 1 Bazargan 1 Bell, II 1 Bennett 1 Benson 1 Berendt 1 Berns 1 Berryman 1 Bien 1 Birkhahn 1 Bischof 1 Black 1 Blair 1 Bland 1 Blanford 1 Boes 1 Bolek 1 Bolland 1 Bonnetain 1 Bos 1 Boston 1 Bouche 1 Broeren 1 Brosnan 1 Brouard 1 Bruna 1 Bryan 1 Brüggemann-Klein 1 Bujdosó 1 Bunner 1 Burnette 1 Burns 1 Burt 1 Burykin 1 Bush 1 Calvani 1 Carmody 1 Carr 1 Casselman 1 Caviness 1 Celoni 1 Chapman 1 Chen 1 Cheswick 1 Chow 1 Christiansen 1 Code 1 Cole 1 Collins 1 Comenetz 1 Committee 1 Company 1 Conrad 1 Crisanti 1 Cumiskey 1 Cuoco 1 Curtis 1 Cutter 1 Daniels 1 DeMeritt 1 Denk 1 de Rezende1 Deschene 1 Dobrowolski 1 Dooley 1 Doyle 1 Dreyhaupt 1 Duggan 1 Dupree 1 Dyck 1 Dyson 1 Désarménien 1 Eck 1 Ehrbar 1 Emch 1 Epshtein 1 Erpenbeck 1 Esfahbod 1 Eterevksy 1 Farley 1 Felippa 1 Feng 1 Fernandez 1 Fina 1 Forkosh 1 Formigoni 1 Franchi-Zannettacci 1 Fulling 1 Fuÿ 1 Gaffey 1 Gaffey 1 Garavelli 1 Gariepy 1 Gelderman 1 Genolini 1 Geyer-Schulz 1 Gibson 1 Gorbunova 1 Gordon 1 Gostanza 1 Goucher 1 Gourlay 1 Graham 1 Granger 1 Grant 1 Grimm 1 Grinchuk 1 Grineva 1 Grobelnik 1 Guoan 1 Gurari 1 Guthery 1 Ha 1 Haagen 1 Hagen-Wittbecker 1 Hailperin 1 Halverson 1 Hamano 1 Hamilton 1 Hamlin 1 Hammond 1 Hampson 1 Hargreaves 1 Harrison 1 Haskell 1 Haus 1 Hawkins 1 Hayashi 1 Heck 1 Heidrich 1 Hendricks 1 Hendryx 1 Hennings 1 Hickey 1 Hirst 1 Hofmann 1 Hogue 1 Hohti 1 Holmes 1 Horstman 1 Horstmann 1 Howell 1 Hunter 1 Huszár 1 Höppner 1 Jaegermann 1 Jalbert 1 Janishevsky 1 Janishewsky 1 Jansen 1 Jeffrey 1 JiríZlatuska 1 Johnson 1 Jurriens 1 Kabelschacht 1 Kakiuchi 1 Kakugawa 1 Kanerva 1 Kastrup 1 Kean 1 Kempson 1 Kim 1 Kitajima 1 Kleine 1 Kletzing 1 Knuutila 1 Koch 1 Kohlmayr 1 Kopriva 1 Koren 1 Kostin 1 Koutný 1 Krapp 1 Krick 1 Krstev 1 Kruse 1 Kubek 1 Kubik 1 Kuiken 1 Kumar 1 Kusumi 1 Kuypers 1 LaFrenz 1 Lachmann 1 Lankford 1 Larsson 1 LeHardy 1 LeVeque 1 Leban 1 Leinartas 1 Levien 1 Levin 1 Lewenberg 1 Liang 1 Lichtenwalder 1 Liebl 1 Lillqvist 1 Lindner 1 Lipkin 1 Lipp 1 Lively 1 Love 1 Ludden 1 Luyten 1 Løfstedt 1 Maclenan 1 Mailhot 1 Mallett 1 Mamrak 1 Marle 1 Marriott 1 Martin 1 Matulka 1 Mauw 1 McWorter 1 Messer 1 Michailovsky 1 Misáková 1 Mladeni¢ 1 Modest 1 Mong 1 Morgan 1 Moye 1 Mylonas 1 Nash 1 Nearing 1 Neumann 1 Nicole 1 Nieppraschk 1 Nikulina 1 Noot 1 Nowacki 1 Obermiller 1 Obrecht 1 Ogawa 1 Ohno 1 Ohta 1 Olejniczak-Burkert 1 Oliver 1 Olsak 1 Oprea 1 O'Searcoid 1 Otten 1 Ovchenkov 1 Píska 1 Pappas 1 Parker 1 Pavan 1 Paxton 1 Payne 1 Penny 1 Perry 1 Petrycki 1 Pierson 1 Pilenga 1 Pind 1 Pizer 1 Porrat 1 Przechlewski 1 Puente 1 Radhakrishnan 1 Rahz 1 Rajkumar 1 Ramasubramanian 1 Ratner 1 Rattey-Hicks 1 Reed 1 Reese 1 Rei 1 Renfrow 1 Rhoads 1 Richer 1 Richter 1 Riesel 1 Riley 1 Rosenschein 1 Roth 1 Russell 1 Ryan 1 Rynning 1 Ry¢ko 1 Rülling 1 Saito 1 Samarin 1 Samuel 1 Sankar 1 Sannella 1 Sawdey 1 Scherer 1 Schmitt 1 Schulze 1 Schwab 1 Schwartz 1 Schwarzkopf 1 Schwer 1 Semenzato 1 Senn 1 Seyfarth 1 Shawyer 1 Shukla 1 Siegel 1 Signell 1 Sivunen 1 Skoupý 1 Slepukhin 1 Smet 1 Sommeling 1 Sperberg-McQueen 1 Starks 1 Stenerson 1 Stokes 1 Stovall 1 Strelkov 1 Strokov 1 Stromquist 1 Sullivan 1 Sutor 1 Swanson 1 Swift 1 Swonk 1 Sydoriak 1 TWGTDS 1 Technites 1 Thain 1 Thanh 1 Thompson 1 Thorup 1 Thulin 1 Thành 1 Toal 1 Tofsted 1 Tolksdorf 1 Topping 1 Totland 1 Travis 1 Trehan 1 Trickey 1 Tulei 1 Turtia 1 Tutelaers 1 van den Dobbelsteen 1 van der Meer 1 van Herwijnen 1 van Knippenberg 1 van Weenen 1 van Zandt 1 Varian 1 Verna 1 Vesilo 1 Vieth 1 Vinogradov 1 Vogel 1 Vollbrecht 1 Vsesvetsky 1 Wald 1 Walker 1 Walsh 1 Walter 1 Watt 1 Wester 1 Wettl 1 Whidden 1 Wilcox 1 Willadt 1 Wilson 1 Winograd 1 Wolf 1 Wolfe 1 Wolinski 1 Wong 1 Wood 1 Wright 1 Yanai 1 Yarmola 1 Youngen 1 Zalmstra 1 Zapf 1 Znamenskaya 1 Zocchi 1 Zupanic 1 Zýka 1 Zbikowski 1 Sevecek 1 Znidar

The End

THE BEATLES
JULY/AUGUST 1969

[2005 − 1969 = 36 (BITS IN A PDP-10 WORD)]