Columbia University in the City of New York | New York, N.Y. 10027

J. F. TRAUB
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212 939-7013

18 February, 1997

Dear Gwen:

Enclosed is the abstract for the first talk that I ever gave on what was to become *information-based complexity*. George Forsythe chaired the session. I can still remember how he introduced me: "We'll let the paper speak for itself."

You might note that the conference proceedings went for $4.00.

Best,

Joe

Joe

J.F. Traub
Bell Telephone Labs
Murray Hill, N.J.

PREPRINTS

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ON FUNCTIONAL ITERATION AND THE CALCULATION OF ROOTS

by

J. F. Traub
Bell Telephone Laboratories, Incorporated
Murray Hill, New Jersey

This paper has the dual objectives of (1) setting theoretical limits to the rates of convergence of iteration processes towards the zeros of a function when the values of the function, or the values of the function and its derivatives, are available and (2) suggesting new families of computationally effective iteration formulas.

The proofs of the theorems stated, numerical verification of theoretical error estimates, various specific applications, and results concerning work on variations of the themes reported here, will appear later.

I. NOTATION AND DEFINITIONS

We wish to solve $f(x) = 0$ where $f(x)$ is a real valued function of a real variable. A root α is of multiplicity m if $f(x) = (x-\alpha)^m g(x)$ and $g(\alpha) \neq 0$. We define a sequence of approximants x_i. In Section II, the x_i will be generated by a one point iteration function via $x_{i+1} = F(x_i)$. In Section III, the x_i will be generated by a multipoint iteration function via $x_{i+1} = F(x_i, x_{i-1}, \ldots, x_{i-n})$. High derivatives of $f(x)$ are denoted by $f^{(\ell)}(x)$. Low derivatives are denoted by $f'(x), f''(x), f'''(x)$. $f^{(\ell)}(x_i)$ is often abbreviated by $f_i^{(\ell)}$ or $f^{(\ell)}$. For later convenience, we abbreviate f/f' by u.

Let $\varepsilon_i = x_i - \alpha$. F defines an iteration procedure of order p if

$$\lim_{i\to\infty} x_i = \alpha \text{ and } \lim_{i\to\infty}\left(\varepsilon_{i+1}/(\varepsilon_i)^p\right) = C_p \neq 0.$$

Iteration functions will be considered which involve the values of $f(x)$ and its derivatives. Thus $F(x) = G(x, f(x), f'(x), \ldots, f^{(s)}(x))$. If $F(x)$ involves the first s derivatives of $f(x)$ and is of order p, we write $F \varepsilon\, {}_sI_p$. We will assume that $f(x)$ and $F(x)$ are sufficiently regular in the neighborhood of α.

II. ONE POINT ITERATION FUNCTIONS

It is easy to show that if $x_{i+1} = F(x_i)$, then p is an integer and it is well known that a necessary and sufficient condition that F be of order p is that $F(\alpha) = \alpha$ and $F^{(\ell)}(\alpha) = 0$, $\ell = 1, 2, \ldots, p-1$, with $F^{(p)}(\alpha) \neq 0$. Furthermore, $C_p = F^{(p)}(\alpha)/p!$. For p fixed, there exist an infinite number of iteration functions of order p under the constraint of

<u>Theorem (1)</u> Let the order of F_1 be p_1 and the order of F_2 be p_2 where F_1 and F_2 are arbitrary iteration functions. Then $F_1(x) = F_2(x) + V(x)u^{p_1}$ where $p = \min[p_1, p_2]$ and $V(\alpha)$ exists. Conversely, let $F_1(x) = F_2(x) + V(x)u^{p}$, where the order of F_2 is p_2 and $V(\alpha) \neq 0$. If $p_2 \neq p$, then $p_1 = \min[p_2$, while if $p_2 = p$, then $p_1 \geq p$.

In [1], the author considered a method for constructing iteration functions arbitrary order for the case $m = 1$. In the notation of [1], let F be a polynomial in defined by $F_s^E \equiv x - u\sum_{j=0}^{s-1} Y_j u^j$. Let $D_j = f^{(j)}/f'$. We have

<u>Theorem (2)</u> Y_j is a polynomial in $D_1, D_2, \ldots, D_{j+1}$.

<u>Theorem (3)</u> Let $m = 1$. Then $F_s^E \in {}_sI_{s+1}$ and $C_{s+1} = Y_s(\alpha)$.

The importance of F_s^E is that we know its structure and by using Theorem (1) we can study general iteration functions of order p. We now state the <u>fundamental theorem</u>.

<u>Theorem (4)</u> Let $m = 1$. There exists an $F \in {}_sI_{s+1}$, and if $F \in {}_\ell I_{s+1}$, then $\ell \geq s$.

This theorem should come as no surprise to those familiar with iteration formulas. But it has never been formally stated and proved.

<u>Corollary (4.1)</u> If $m > 1$ and m is known, then there exists an $F \in {}_sI_{s+1}$ in which m appears explicitly, and if $F \in {}_\ell I_{s+1}$, then $\ell \geq s$.

<u>Corollary (4.2)</u> If $m > 1$ and m is not known, then there exists an $F \in {}_{s+1}I_{s+1}$, and if $F \in {}_\ell I_{s+1}$, then $\ell \geq s+1$.

<u>Theorem (5)</u> If F_s^E (which does not depend explicitly on m) is used when $m > 1$, then $F_s^E \in {}_sI_1$.

We conjecture that this is true for arbitrary F. A proof of an analogous theorem due to Bodewig appears incorrect. We have

<u>Conjecture (1)</u> Let $F \in {}_sI_{s+1}$ for $m = 1$ and assume that F does not depend explicitly on m. If F is used when $m > 1$, then $F \in {}_sI_1$.

A general estimate of C_p which does not involve the calculation of $F^p(\alpha)$ is given by

<u>Theorem (6)</u> Let $m = 1$. Let F be of order s+1. Let $G_s(x) = \left(F - F_s^E\right)/(u)^{s+1}$. Then $C_{s+1} = Y_s(\alpha) + G_s(\alpha)$.

---

[1] J. F. Traub, "On a Class of Iteration Formulas and Some Historical Notes," Comm. Assoc. Comp. Mach., June, 1961.

Corollary (4.2) assures us of the existence of an $F = {}_sI_{s+1}$, for $m > 1$, if m is known. Such a formula is given explicitly by

<u>Theorem (7)</u> Let $F_s^E(x,m) = x-u\sum_{j=0}^{s-1} T_{s,j}(m)Y_j(x)u^j$ where $T_{s,j}(m) = \sum_{\ell=j}^{s-1} e_{\ell,j}(m)$, and the $e_{\ell,j}(m)$ are given by the recursion formula
$(\ell+1)\, e_{\ell,j}(m) + (m(j+1) - \ell)\, e_{\ell-1,j}(m) - m(j+1)\, e_{\ell-1,j-1}(m) = 0$, with $e_{o,o} = m$, $e_{\ell-1,-1} = 0$, $e_{\ell,j} = 0$, for $\ell < j$. Then $F_s^E(x,m) = {}_sI_{s+1}$, for all

A general estimate of $C_{s+1}(m)$ for $F_s^E(x,m)$ is given by

<u>Theorem (8)</u> $C_{s+1}(m) = B_{s,s+1}(m,\alpha)$, where $B_{s,s+1}$ may be calculated from the recursion formula,

$$(\ell+2)B_{\ell+1,s} - (\ell+1)B_{\ell,s} + \sum_{k=\ell+1}^{s} kB_{\ell,k}B_{o,s+1-k} = 0, \text{ for } s > \ell+1,$$

and where $B_{o,\ell}$, for $\ell \geq 1$, is given by

$$\sum_{k=m}^{r} ka_kB_{o,r+1-k} = m\,a_r, \text{ with } a_r = f^{(r)}(\alpha)/r!.$$

III. MULTIPOINT ITERATION FUNCTIONS

It will be shown that with $x_{i+1} = F(x_i, x_{i-1}, \ldots, x_{i-n})$ the order of F is non-integral. Thus, for Section III, we define $\delta_i = |\varepsilon_i|$.

The secant method may be considered as constructed from Newton's formula with f_i' estimated from $x_i, x_{i-1}, f_i, f_{i-1}$. Then, as is well known, $\delta_{i+1} = K\delta_i\delta_{i-1}$. This difference equation has the characteristic equation $t^2-t-1 = 0$ and the solution $\delta_{i+1} = C(\delta_i)^p$ with $p = (1+\sqrt{5})/2 \simeq 1.62$. Thus, the order of the secant method compares favorably with the order of Newton's method while not requiring the calculation of any derivatives. This is important, for it is the calculation of f(x) and its derivatives which requires most of the computation time of an iteration procedure. We will give two broad generalizations of the secant method. We will estimate derivatives using n+1 points, rather than two points, and we will estimate $f_i^{(s)}$ rather than f_i'. The approximate differentiation formulas to be given are of interest in themselves.

Define $${}_n^*f_i^{(s)} = \sum_{\ell=0}^{s-1}\sum_{j=0}^{n} A_{\ell,j}^{s,n} f_{i-j}^{(\ell)},$$ where the $A_{\ell,j}^{s,n}$ are calculated by differentiating a Hermite interpolation formula s times. The general error term is given by

<u>Theorem (9)</u> Let ${}_n^*f_i^{(s)}$ be defined as above. Let $r = s(n+1)$ and let θ lie in the interval $(x_i, x_{i-1}, \ldots, x_{i-n})$. Let $h_j = x_i - x_{i-j}$. Then

$${}_n^*f_i^{(s)} - f_i^{(s)} = L_{r,s,n}\prod_{j=1}^{n}(h_j)^s \quad \text{with} \quad L_{r,s,n} = -f^{(r)}(\theta)s!/r!\,.$$

The general difference equation for the iteration error is given by

Theorem (10) Let $m = 1$ and let $F \varepsilon\, {}_sI_{s+1}$. Let ${}^*F$ be generated from F by estimating $f_i^{(s)}$ by ${}_n^*f_i^{(s)}$. Then

$$\delta_{i+1} = K_r \prod_{j=0}^{n} (\delta_{i-j})^s \quad \text{where} \quad K_r = |\, f^{(r)}(\alpha)/r!f'(\alpha)\,| .$$

We state a number of lemmas before giving the main theorem.

Lemma (11.1) The difference equation of Theorem (10) has the characteristic equation $P(n,s,t) = 0$, where $P(n,s,t) = t^{n+1} - s \sum_{j=0}^{n} t^j = 0$.

Lemma (11.2) Let s be a positive integer. Then the equation $P(n,s,t) = 0$ has a real root of multiplicity 1 between s and $s+1$ and all other roots are less than 1 in magnitude.

Lemma (11.3) Let $q = (p-1)/(r-1)$. The solution of the difference equation of Theorem (10) is given by $\delta_{i+1} = C_{q,r}(\delta_i)^p$ where $s < p < s+1$ and where $C_{q,r} = |\, K_r \,|^q$. Note that the solution of the difference equation is independent of F.

We are now ready to state the <u>fundamental theorem</u> of this part of the theory.

Theorem (11) Let $m = 1$. Let $F \varepsilon\, {}_sI_{s+1}$. Let
$${}^*F = G\left(x_i, f_i, \ldots, {}_n^*f_i^{(s)}\right) = G\left(x_i, f_i, \ldots, f_i^{(s-1)}, x_{i-1}, f_{i-1}, \ldots, f_{i-1}^{(s-1)}, \ldots, x_{i-n}, f_{i-n}, \ldots, f_{i-n}^{(s-1)}\right) = {}^*F(x_i, x_{i-1}, \ldots, x_{i-n}).$$
Then ${}^*F \,\varepsilon\, {}_{s-1}I_p$, with $s < p < s+1$, and $\lim_{n\to\infty} p = s+1$.

In particular, with $s = 2$, $n = 1$, we have

$$(3) \quad F = x-u - u^2\left({}_1^*f''/2f'\right); \quad {}_1^*f'' = -6(f_i - f_{i-1})/h_1^2 + 2\left(2f_i' + f_{i-1}'\right)/h_1 ;$$

$$\delta_{i+1} = |\, f^{(4)}(\alpha)/24f'(\alpha)\,|\,(\delta_i)^2(\delta_{i-1})^2 ; \quad C = |\, f^{(4)}(\alpha)/24f'(\alpha)\,|^{.58} ; \quad p = 2.73 .$$

This formula is particularly useful since it gives a formula of order $1 + \sqrt{3} \simeq 2.73$ while using no more information than Newton's formula.

Theorem (11) states that if old iteration information is used in a particular way, that is, to approximate $f_i^{(s)}$, all this old information adds less than one to the order of the iteration, per step. We conjecture that this is true no matter how the old information is used.

Conjecture (2) Let $m = 1$. Let $F = G\left(x_i, f_i, \ldots, f_i^{(\ell)}, x_{i-1}, f_{i-1}, \ldots, f_{i-1}^{(\ell)}, \ldots, x_{i-n}, f_{i-n}, \ldots, f_{i-n}^{(\ell)}\right)$ with G arbitrary. Let $F \varepsilon\, {}_\ell I_p$, with $p \geq s+1$. Then $\ell \geq s$. In particular, if no derivative information is used, it is impossible to construct an iterative method of order 2.

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18 February, 1997

Ms. Gwen Bell
450 Old Oak Court
Los Altos, CA 94022

Dear Gwen:

Enclosed is the requested iconograph. I hope this is the kind of thing you are looking for.

Also enclosed is a very brief biosketch as well as a longer one.

Pamela and I often think of you guys. Please give our best to Gordon.

With warm regards,

Joe

Joseph F. Traub

83 James Avenue
Atherton, CA 94027-2009
12 February 1997

Gwen Bell, Director
The Historical Collections
The Computer Museum
History Center
P. O. Box 3038
Stanford, CA 94309-3038

VIA FEDERAL EXPRESS TO: 450 Old Oak Court, Los Altos CA 94022

Dear Ms. Bell:

In response to your e-mail message of 2/7/97 to Paul Baran, please find the following four items:

1. The "five" sentences. (Sorry, it's a little longer.)

2. Some graphic pages for the 1964 RAND memoranda "On Distributed Communications" that first set out packet switching.

3. Copy of the first paper on the subject, published in the March 1964 issue of the *IEEE Transactions on Communications Systems.* I have also included a reprint of the article.

4. A copy of the 1965 RAND Recommendation to the Air Force to proceed with the development. Describes packet switching payoffs, how it would be done, costs and benefits, and a summary of each of the series of about a dozen memoranda describing the details.

The only physical artifact is a box of slides that Mr. Baran used in about 50 briefings around the country selling the concept of packet switching in the 1960's.

Yours truly,

Lee Shapiro

Lee Shapiro
Assistant to Paul Baran
(415) 323-4053 or
(415) 493-5971

From: Len_Shustek@ngc.com
Mime-Version: 1.0
Date: Wed, 26 Feb 1997 14:52:04 -0800
To: Dag Spicer <spicer@tcm.org>
Cc: "Gwen Bell" <bell@tcm.org>
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Status: RO

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Content-Description: cc:Mail note part

Sorry that I haven't had much time to spend on the text. Here's a start. Maybe later tonight I'll can do some more. -- Len

IBM 729 Magnetic Tape Unit

Introduced: 1957, for the IBM 709 computer
Medium: iron-oxide coated 1/2" mylar tape
Speed: 75 inches/second read/write, 500 inches/second rewind
Density: 7 tracks, 200 bits/inch (later 556 bpi and 800 bpi)
Throughput: 15,000 characters/second
Capacity: About 5 million characters on a 2400 foot reel

The 729 was the workhorse mass storage device for IBM mainframe computers of the late 50's and early 60's. It was the first to have the "two gap" head that allowed data to be read and checked while it was being written.

The vacuum columns that allow the tape to start and stop faster than the reels were introduced in 1953 with the 726 tape drive, and had been prototyped in the lab using a vacuum cleaner! Other companies used a higher-inertia tape reservoir with multiple spring-loaded pulleys, which had a greater tendency to snap the tape.

IBM 1403 Line Printer

Introduced: 1959, for the the 1401 data processing system
Print mechanism: Rotating type slug chain with hammers that strike through the paper from the other side
Print speed: 600 lines per minute, maximum
Chain speed: 90 inches per second
Paper speed: 6.6 inches per second when not printing
Number of columns: 100 or 130
Line spacing: 6 or 8 lines per inch
Character spacing: 10 characters per inch
Number of different characters: 48, with 5 repeat sets per chain

At the time of its introduction the 1403 printer was a radical innovation in high-speed printers but it quickly became the standard printer for IBM computer systems. Although there were faster wire-matrix printers from both IBM and CDC, the 1403 continued the tradition of high-quality formed characters that had been set a decade earlier by the 407 accounting machine.

The spacing of type slugs on the chain is wider than that of the print hammers. At each alignment point, every third hammer has the opportunity to fire if the type slug opposite it carries the desired character.

PDP-10 Cable Set

Mainframe computers consisted of many independent boxes connected together, often by cables that run underneath a raised floor. These are *some* of the cables needed to interconnect the components of a Digital Equipment Corporation PDP-10 computer.

Cray-2 Computer

Introduced: 1985
Speed: About 100 million floating point operations per second per processor
Processors: four background processors; one foreground processor
Clock: 4.1 nanosecond (243 Mhz)
Memory: 256 million 64-bit words

Seymour Cray is the legendary supercomputer designer who was killed in an automobile accident in October 1996. The Cray-2 was the second major computer designed by Cray Research Incorporated, which Cray formed after leaving Control Data Corporation in 1976.

Cooling is a major problem for supercomputers, and in the Cray-2 the circuit cards are totally immersed in an inert flurocarbon that had previously been used as a blood substitute. The computer was sometimes called the "bubble machine" because of the bubbles of vaporized coolant that arose from the warm cards.

Seymour Cray always felt that what a computer looked like was important. "I've enjoyed the aesthetics part of building computers ... clearly your own personality [is] being projected in the product."

Digital Equipment Corporation VAX 11/750

Introduced: 1979
Clock: 6 Megahertz
Microcode: 6K 80-bit words
Power consumption: about 3000 watts with typical peripherals

The 11/750 was the second of the VAX computers, and was designed for lower cost and lower performance. The standard machine implemented flaoting point operation in software (microcode), but an accelerator was a higher-priced option.

The VAX line of minicomputers was the successor to the earlier and very successful PDP-11 series. "VAX" meant "Virtual Address Extension", indicating the large address space compared to the earlier computers.

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Exhibit: list of people and materials

	16x20	Allen, Fran	11x14		Gwen email and ask	
D	16x20	Amdahl, Gene	8x10, 11X14		Amdahl 470 : Dag get module	heat sinks
	16x20	Bachman, C	11x14		Gwen call and ask	
	16x20	Backus, John	11x14		FORTRAN - Gwen call and ask	
	16x20	Basket, Forrest	11x14		Gordon	
	16x20	Bechtolsheim, A	20x24 mounted		SUN 1 -Bernard	
	16x20	Bell, Gordon	8x10, 11x14		Gordon choose	
	16x20	Birnbaum, Joel	11x14		Gwen email	
	16x20	Bloch, Erich	8x10		360 picture	
	16x20	Evans, Robert O	24X30 - console		360 front panel	
D	16x20	Brooks, Fred	0		360 --	specs
	16x20	Bricklin, Dan	11x14		Gwen email - with Bob F	
	16x20	Frankston, Bob	11x14		Gwen email - with Bob F	
	16x20	Catmull, Ed	11X14	pedestal?	Gwen call for "dolls"	
	16x20	Lasseter, John	11x14	pedestal?	Gwen call Catmull for "dolls"	
	16x20	Baran, Paul	11x14	IMP	IMP	
	16x20	Cerf, Vint	11x14	IMP	IMP	
	16x20	Roberts, Larry	8x10	IMP	IMP	
	16x20	Kahn, Bob	11x14	IMP	IMP	
	16x20	Bushnell, Nolan	20x24		Gwen call	
D	16x20	Clark, Wes	8x10, 11x14		LINC tape and photo	specs
	16x20	Cocke, John	8x10, 11x14		Gwen call	
	16x20	Brenners-Lee, T	11x14		Dag email	✓
	16x20	Corbato, F	11x14		Timesharing book - red book	
	16x20	Englebart, Douglas	8x10, 6x8		Gwen call	
	16x20	Faggin, Federico	0	pedestal	Busicom/4004	measure
	16x20	Hoff, Ted	0		Busicom/4004	
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	16x20	Forrester, Jay	14X14, 11x14		Core memory plane	
	16x20	Gates, Bill	0	pedestal	Altair	
	16x20	Geschke, Chuck	11x14			
	16x20	Gosling, Jim	11x14		Gwen email	
	16x20	Hamming, Richard	11x14		Gwen call	
	16x20	Heller, Andy	11x14		Gwen email	
	16x20	Hendrie, Gardner	8x10, 11x14		DDP 116 modele/manual	
	16x20	Hennesey, John	8x10, 11x14		MIPS chip	
	16x20	Herzfield, Andy	8x10		original MAC	
	16x20	Hewlett, Bill	8x10	pedestal	Bernard - oscillator	
	16x20	Kahn, Philippe	0	pedestal	Micral	
	16x20	Knuth, Don	11x14		stack of books	
	16x20	Kurtz, Tom	11x14		BASIC manual	
	16x20	Lampson, Butler	11x14	Alto	Alto & manual - with list	
	16x20	Metcalfe, Bob	11x14		Alto, plus great quote	
	16x20	Simonyi, Charles	11x14	Alto	Alto	
	16x20	Mandelbrot, Benoit	20x30		Oliver choose fractal	
	16x20	McCarthy, John	11x14		Lisp manual - red from MIT	
	16x20	Mead, Carver	30x40		Gwen call for great chip plot	
	16x20	Moore, Gordon	11x14		Moore's Law Graph	
	16x20	Patil, Suhas	11x14		Gordon retrieve	
	16x20	Patterson, David	11x14		Gordon retrieve	
	16x20	Pierce, John	11x14		Gwen call	
	16x20	Diffy, Whit	11x14		email	
	16x20	Rivest, Ron	11x14		email	
	16x20	Shoch, John	11x14		John choose	
	16x20	Stallman, Richard	11x14			
	16x20	Starkweather, Gary	8x10		laser printer - Dover	
	16x20	Stonebreaker, Micha	11x14		Gwen email/ (Gray)	
	16x20	Sutherland, Ivan	8x10, 11x14			
	16x20	Traub, Joe	11x14			
	16x20	Warnock, John	11x14			
	16x20	Wozniak, Steve	30x20		Apple 1.	

1/29/97

The Computer Museum

Computer History Center
P.O. Box 3038
Stanford, CA 94309-3038

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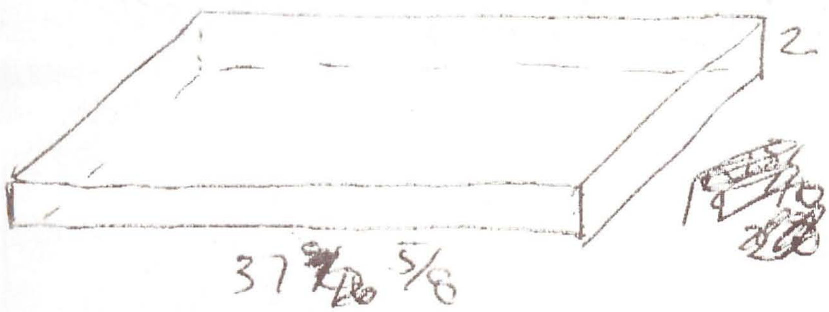

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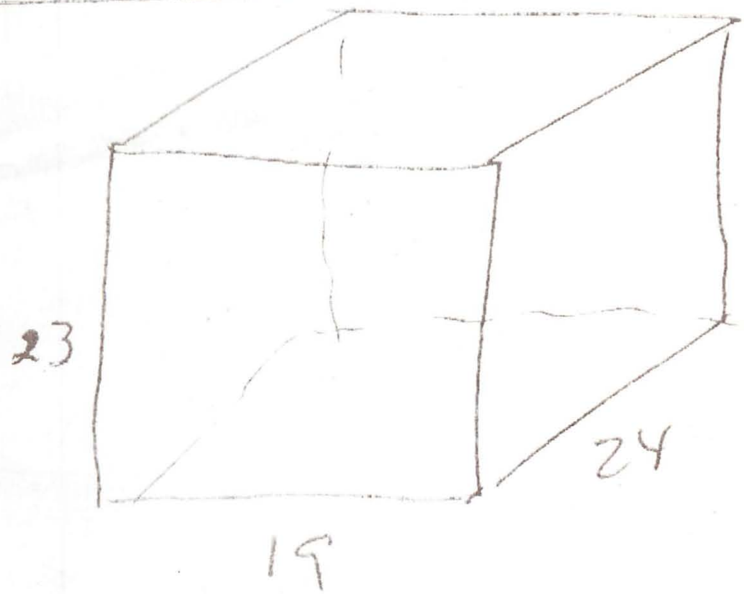

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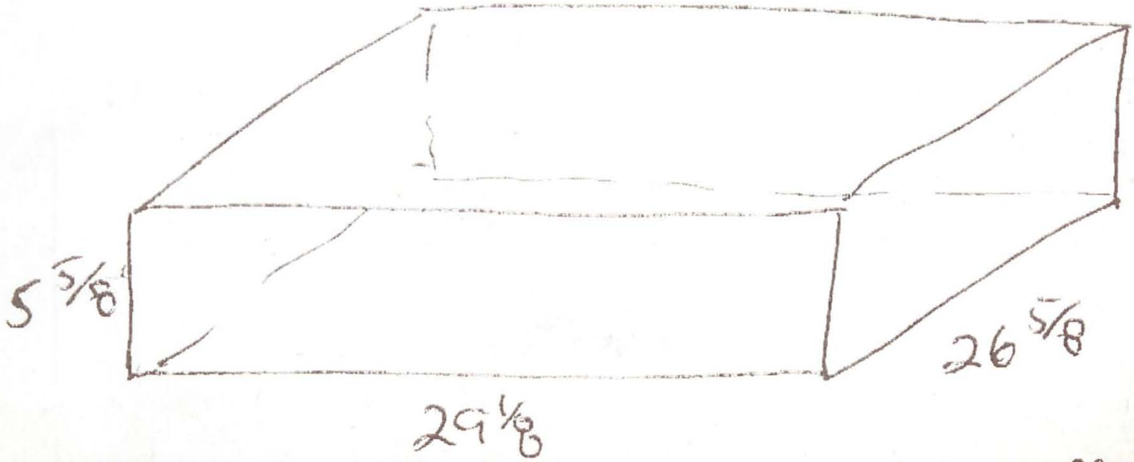

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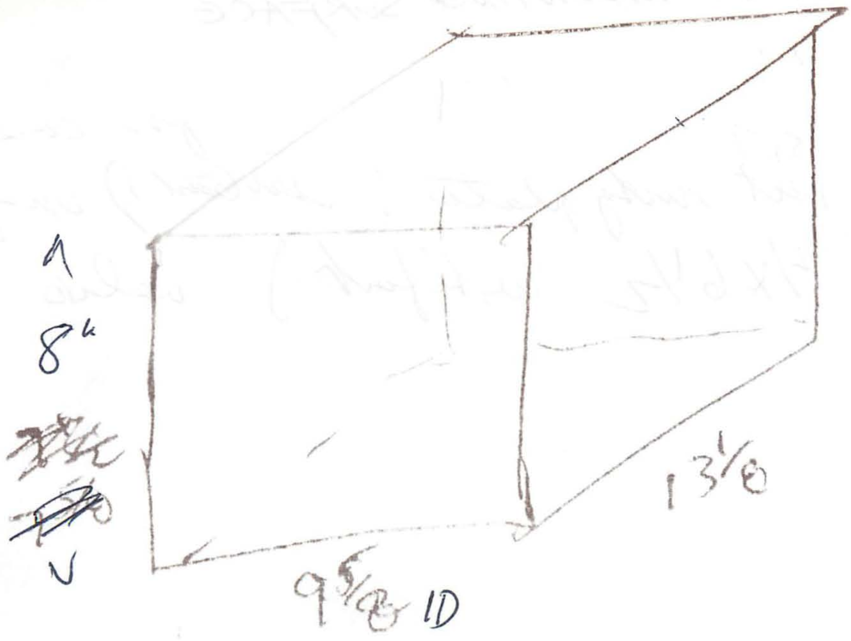
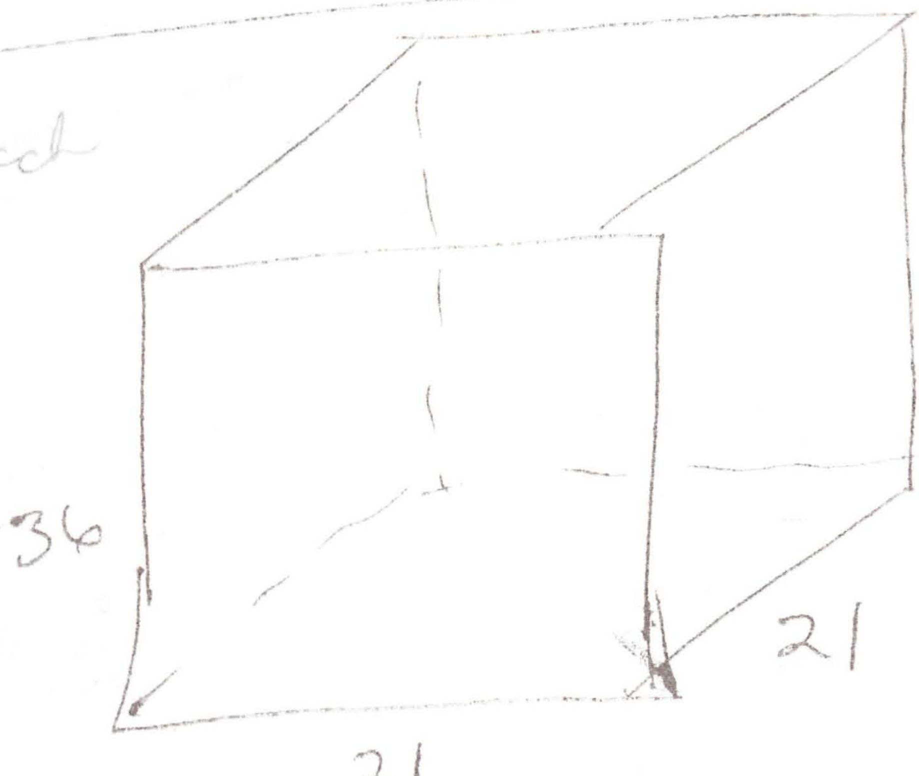


(2) each



DAG SPICER
THE COMPUTER MUSEUM

Tel: 408 562 7937
Fax: 408 988 2874

— BLACK MOUNTING SURFACE

— " "

for core plane

5x7
text mtg plate? [illegible] } on-frame

6"x (4x6½ artifact) velcro

FABRICATION Order ☑ Quote ☐

Customer: Computer Museum Contact: Dag

Address: ____

Phones: Home ____

City ____ State ____ Zip ____ Work (408)512 7937 Fax ____

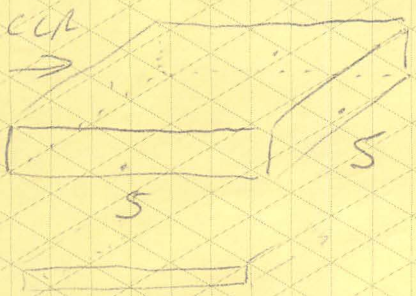
Quantity 1 of each Order Date ____ Due Date ____ **Quote Firm for 30 Days**

Intended Use Display ☐ Utility ☐ **Material** ____ Thickness ____ Color ____

Measurement Inside ☒ Outside ☐ **Tolerance** Plus ☐ ____ Minus ☐ ____

Edge Finish Saw Cut ☐ Router Cut ☐ Sand ☐ Flame ☐ Buff ☐ Bevel ☐ Other ☐

(1.) 1/8 CLR



Material 3.50
Lab 30.00
35.50 + tax

1/4 BLACK BASE, SCREWED in at side only (BRASS SCREWS)

MIPS WAFER

(2.) Make base (1/4 BLACK) for 5 x 7 UNFRAME, SCREWED (BRASS) on 4 sides, MOUNT CIRCUIT BOARD to Base w/BRASS SCREWS.

Material $5.32 (INCL FRAME)
Labor 10.00
15.32 + tax

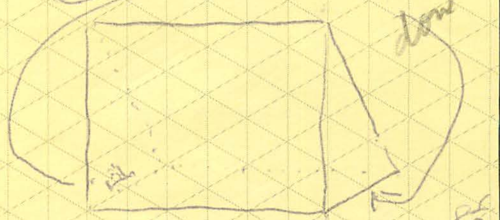
DDP-16 PCB

(3.) make base (1/4 BLACK) for 11 x 14 UNFRAME, BRASS SCREWS on 4 sides, MOUNT CIRCUIT BOARD w/BRASS SCREWS (See Mike)

FRAME + 1/4 BLACK — 17.66
Labor 10.00
27.66 + tx

PDP 6 PCB

(4.) Sand Flat ✓ done



4. Glue 1/4 WHITE BASE HERE (See MIKE)

Mat 5.57
Labor 20.00
25.57 + tax

CORE

Instructions and Comments ____

Material $	
Labor	
Subtotal	104.05
Sales Tax	+
Total $	TAP charge
Deposit	
Balance $	
S.O. # or Zippo #	

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Dublin CA • 510 828-7744 .... fax 510 828-1179
El Cerrito CA • 510 525-3508 .... fax 510 525-4503
Fremont CA • 510 796-3550 .... fax 510 796-0444
Mountain View CA • 415 962-8430 .... fax 415 962-0572
Pittsburg CA • 510 778-1223 .... fax 510 778-6024
Pleasant Hill CA • 510 798-0420 .... fax 510 798-0360
Portland OR • 503 230-0770 .... fax 503 230-1275
Sacramento CA • 916 481-7584 .... fax 916 481-3036
Sacramento CA • 916 429-9551 .... fax 916 429-9579
San Francisco CA • 415 864-7360 .... fax 415 864-3177
San Jose CA • 408 292-8685 .... fax 408 292-0161
San Jose CA • 408 265-6400 .... fax 408 265-1479
San Leandro CA • 510 357-3755 .... fax 510 357-4761
San Mateo CA • 415 344-7127 .... fax 415 344-5706
San Rafael CA • 415 454-6393 .... fax 415 454-8385
Santa Rosa CA • 707 544-5772 .... fax 707 544-0630
Stockton CA • 209 957-2036 .... fax 209 957-0177
Tigard OR • 503 230-0770 .... fax 503 230-1275
TAP Plastics Inc • Corporate Office • Dublin CA 94568

TAP
THE FANTASTIC PLASTIC PLACE

Salesperson: Mike Store # 19

Customer P.O. # ____ Date ____ Customer Authorization ____

FABRICATION Order ☒ Quote ☐

Customer: *Computer Museum* Contact: *Dag*

Address: ____________ Phones: Home ____________

City ____________ State ____ Zip ____ Work *(408) 5627937* Fax ____________

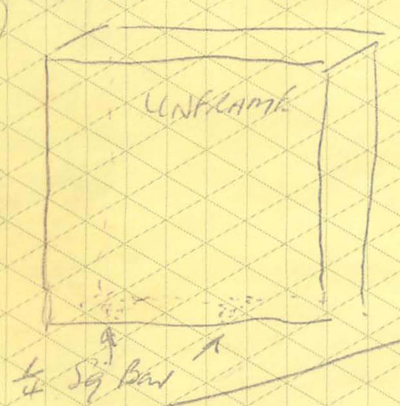
Quantity ________ Order Date ________ Due Date ________ **Quote Firm for 30 Days**

Intended Use Display ☐ Utility ☐ **Material** ________ Thickness ________ Color ________

Measurement Inside ☒ Outside ☐ **Tolerance** Plus ☐ ________ Minus ☐ ________

Edge Finish Saw Cut ☐ Router Cut ☐ Sand ☐ Flame ☐ Buff ☐ Bevel ☐ Other ☐

(5.)



8 X10 UNFRAME for Book, resting on 1/4 Sq Bar w/ 1/4 BLACK BACKING secured w/ 4 BRASS SCREWS.

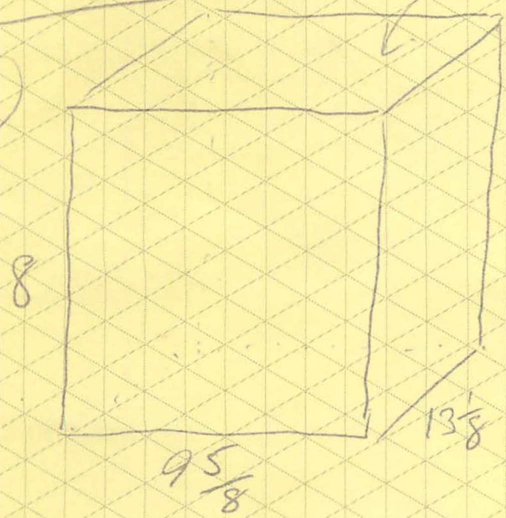
UNFRAME	*4.75*
1/4 BLACK	*4.50*
1/4 BAR	*1.00*
LABOR	*15.00*

$25.25 + tax.

CANCELLED

1/8 CLR + 1/4 BLACK BACK

(6.)



MOUNT ON 1/4 BLACK, ANCHOR PRINTER TO MAINFRAME W/ METAL BRACKETS

16.59 Mat
45.00 Labor
61.59 + tax.

BUSICOM CALCULATOR

Instructions and Comments ____________

Material $	
Labor	
Subtotal	*86.84*
Sales Tax	
Total $	
Deposit	
Balance $	*TAP Charge*
S.O. # or Zippo #	

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Cupertino CA • 408 252-8600 ... **fax** 408 252-3517	**San Jose CA** • 408 292-8685 ... **fax** 408 292-0161
Dublin CA • 510 828-7744 ... **fax** 510 828-1179	**San Jose CA** • 408 265-6400 ... **fax** 408 265-1479
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Fremont CA • 510 796-3550 ... **fax** 510 796-0444	**San Mateo CA** • 415 344-7127 ... **fax** 415 344-5706
→ **Mountain View CA** • 415 962-8430 ... **fax** 415 962-0572	**San Rafael CA** • 415 454-6393 ... **fax** 415 454-8385
Pittsburg CA • 510 778-1223 ... **fax** 510 778-6024	**Santa Rosa CA** • 707 544-5772 ... **fax** 707 544-0630
Pleasant Hill CA • 510 798-0420 ... **fax** 510 798-0360	**Stockton CA** • 209 957-2036 ... **fax** 209 957-0177
Portland OR • 503 230-0770 ... **fax** 503 230-1275	**Tigard OR** • 503 230-0770 ... **fax** 503 230-1275
Sacramento CA • 916 481-7584 ... **fax** 916 481-3036	**TAP Plastics Inc** • Corporate Office • Dublin CA 94568
Sacramento CA • 916 429-9551 ... **fax** 916 429-9579	

Salesperson *Mike* Store # *19*

Customer P.O. # ________ Date ________ Customer Authorization ________

TAP
THE FANTASTIC PLASTIC PLACE

FABRICATION

Order ☑ Quote ☐

Customer *Computer Museum* Contact *Dag*

Address ______

Phones: Home ______

City ______ State ____ Zip ______ Work *(408) 562 7937* Fax ______

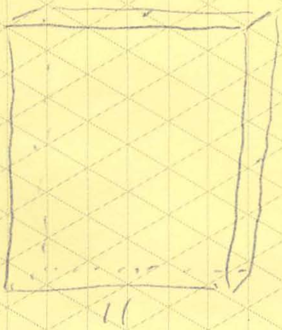
Quantity *5* Order Date ______ Due Date ______ **Quote Firm for 30 Days**

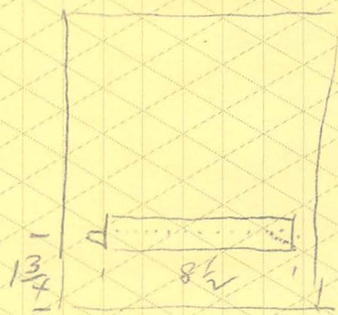
Intended Use Display ☐ Utility ☐ **Material** ______ Thickness ______ Color ______

Measurement Inside ☐ Outside ☐ **Tolerance** Plus ☐ ______ Minus ☐ ______

Edge Finish Saw Cut ☐ Router Cut ☐ Sand ☐ Flame ☐ Buff ☐ Bevel ☐ Other ☐

(9) 5/ 11 x 14 UNFRAMES w/ 1/4 BLACK BASE secured to UNFRAME w/ BRASS SCREWS (4). MOUNT 1/2 x 1/2 x 8 1/2 L Bracket (1/8 CLR)





CANCELLED

UNFRAMES	*45.00*
1/4 BLACK	*43.30*
1/8 CLR	*2.00*
Labor	*75.00*
	165.30 + tax

Instructions and Comments ______

Material $ ______

Labor ______

Subtotal *165.30*

Sales Tax ______

Total $ ______

Deposit ______

Balance $ *TAP Charge*

S.O. # or Zippo # ______

Salesperson *Mike* Store # *19*

Customer P.O. # ______ Date ______ Customer Authorization ______

TAP

THE FANTASTIC PLASTIC PLACE

FABRICATION Order ☑ Quote ☐

Customer Computer Museum Contact Dag [illegible]

Address

Phones: Home

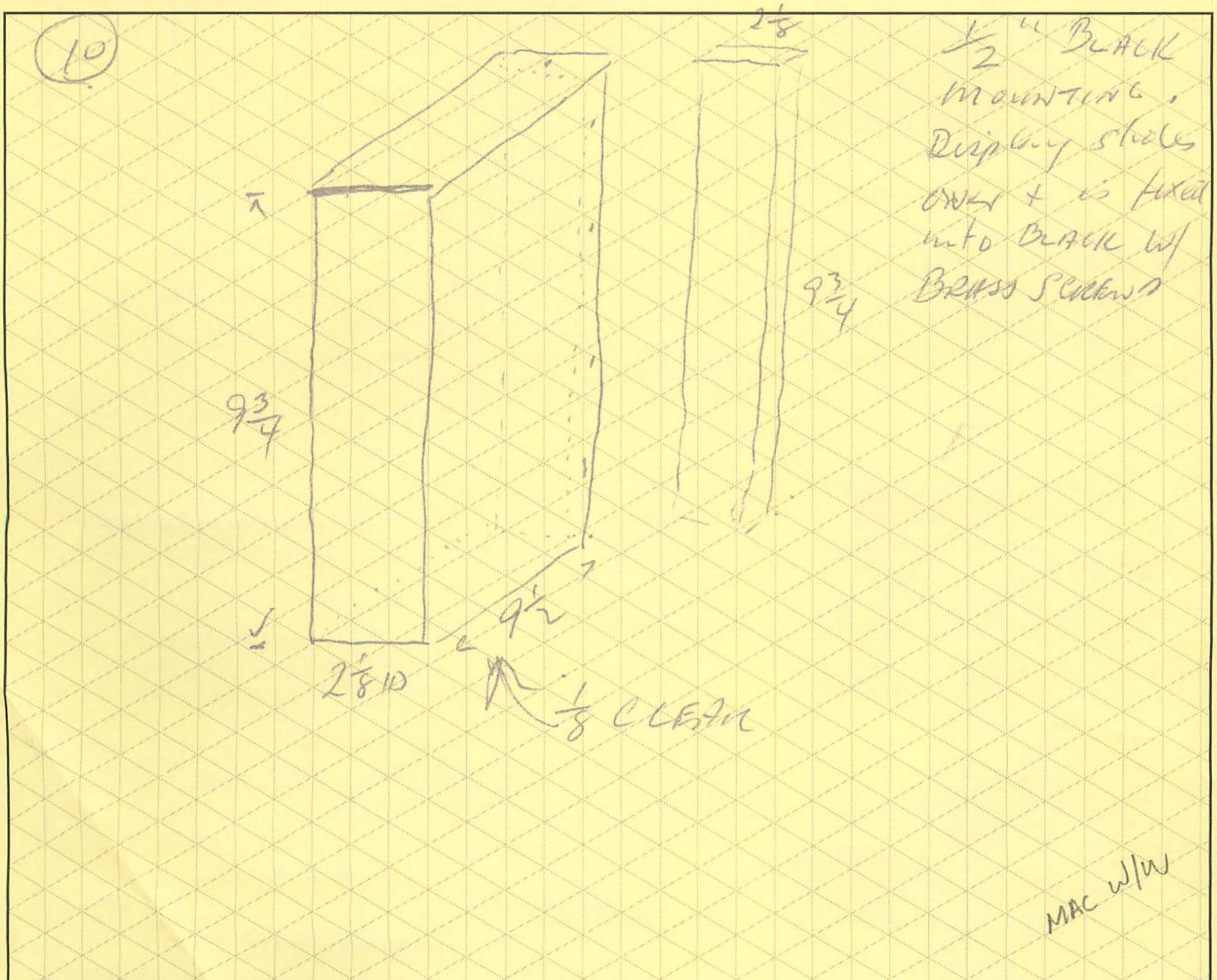
City State Zip Work (408) 5627937 Fax

Quantity 1 Order Date Due Date **Quote Firm for 30 Days**

Intended Use Display ☐ Utility ☐ **Material** Thickness Color

Measurement Inside ☑ Outside ☐ **Tolerance** Plus ☐ Minus ☐

Edge Finish Saw Cut ☐ Router Cut ☑ Sand ☐ Flame ☐ Buff ☐ Bevel ☐ Other ☐



Instructions and Comments

Material $	14-02
Labor	40- W
Subtotal	54-02
Sales Tax	
Total $	
Deposit	
Balance $	
Zippo #	

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TAP Plastics Inc • Corporate Office • Dublin CA 94568

TAP
THE FANTASTIC PLASTIC PLACE

Salesperson Store #

Customer P.O. # Date Customer Authorization

HOW MANY PEOPLE
HAVE A **CHANCE**
OF DRAMATICALLY
AFFECTING THE WAY
THE **WORLD WORKS**?
WHEN ONE OF THOSE
CHANCES COMES ALONG,
TAKE IT — **COME TO ACM97.**

ACM97

THE NEXT 50 YEARS OF COMPUTING

Conference, ***March 3 - 5, 1997***
Exposition, ***March 1 - 4, 1997***
San Jose, California, USA

ACM97

Conference Speakers March 3-5, 1997

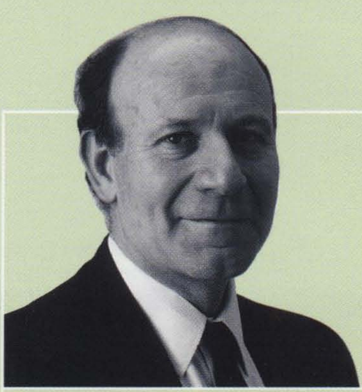
**Senior Researcher,
Microsoft Corporation**

GORDON BELL

Considered as the "Father of the Minicomputer," Bell led the National Research Network panel that became the NII/GII, and was one of the authors of the first High Performance Computer and Communications Initiative. He has written widely about computer structures and start-up companies: *High Tech Ventures: The Guide to Entrepreneurial Success* describes the Bell-Mason Diagnostic for analyzing new ventures.

Speaking on: The folly of prediction. Bell will explore the absurdity of straightforward extrapolation of current trends over the next 50 years. Can the development of technology and its impacts be extrapolated from current trends? By the year 2047, Bell says, One Chip Systems (OCSs) of up to 300,000 terabyte memories will support all information in Cyberspace; and asks whether we will then be able to build the long-forecasted systems that hear, see, and remember everything.

The Folly of Prediction



**Director of HP Laboratories,
Hewlett-Packard**

JOEL BIRNBAUM

A pioneer in the development of distributed computer system architecture, real-time data acquisition, analysis and control, and RISC processor architecture, Birnbaum has been elected to the National Academy of Engineering and is a board member of the Corporation for National Research Initiatives, the Technion University of Israel, the Tech Museum of Innovation, and the Euphrat Museum of Art.

Speaking on: Evolution and impacts of electronic and non-electronic, biological and optical computing technologies.

Non-Electronic Computing

FOR IMMEDIATE RELEASE

media information

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212-320-2217
ptulupman@tsipr.com

The Computer History Center:
Carol Welsh
415-323-1909
welsh@tcm.org

Special "Wizards and Their Wonders" Exhibit From Computer History Center To Kick Off "ACM97: The Next Fifty Years of Computing" Conference and Exposition

San Jose, California, February 27, 1997. "ACM97: The Next Fifty Years of Computing" will be ushered in on February 28 by "Wizards and Their Wonders," a unique exhibit sponsored by the Computer Museum's History Center and featuring one-of-a-kind computer artifacts and specially-commissioned photographs of the inventors taken by famed photographer Louis Bachrach. "Wizards and Their Wonders" will be unveiled at a special reception on February 28, 1997 from 6:30 - 9 PM in the foyer of the San Jose Convention Center in San Jose, California, and will remain on display free to the public throughout the ACM97 conference and Exposition.

The exhibit is part of ACM97: The Next Fifty Years of Computing," a conference and Exhibition about the far future of computing to be held March 1-5, 1997, also at the San Jose Convention Center. ACM97 will spark discussion and debate, with insights and comment from global leaders in industry, academia, research, government and conference participants. Associated with ACM97 is a web site (www.acm.org/acm97/) and a specially commissioned book, "Beyond Calculation," published by Copernicus.

The Museum's Founding President and former President of the ACM, Gwen Bell, said "We're delighted to be ushering in the ACM97 festivities with this special exhibit. It's especially appropriate since the ACM is celebrating its fiftieth anniversary this year. Our exhibit gives people a chance to look back on the past fifty years as they begin to speculate about the next fifty.

"In addition to key pieces from the Computer Museum History Center, we'll have many one-of-a-kind artifacts generously loaned from private collections. We're especially pleased that Louis Bachrach has provided us with special portraits of the many computer pioneers represented in the exhibit."

-more-

Among the many artifacts on display will be Gary Starkweather's "engine" for the first laser printer; a framed Apple 1 board on loan from Scott Cook; one of the first core memory planes from Jay Forrester's Whirlwind computer; and a console from an IBM 360/40 mainframe computer. Also featured will be the prototype of the Busicom calculator, which was the first commercial product to feature a microprocessor, the Intel 4004. Among the many specially commissioned portraits will be those of Erich Bloch, Fred Brooks, and Bob Evans.

Together they will examine the long-term future of information technology and its impacts. The Conference runs from March 3 -5. Tens of thousands of people are expected to attend the Exposition portion of ACM97, which is free and open to the public for from March 1 through March 4. The Exposition will transform the convention center into a world of high-tech pavilions and computer-animation theaters highlighting a variety of computing domains and will demonstrate how each will impact our future.

About the History Center

Since its inception, the History Center has played a significant role in industry events with a historical theme. The History Center opened with a celebration of the 25th anniversary of the microprocessor in San Jose at the annual Microdesign Resources Conference. One result was a 25-year timeline poster produced jointly with Microdesign Resources. Additionally, the History Center provided artifacts and curatorial assistance to Intel, Microsoft, and Ziff-Davis for a museum on the microprocessor at the 1996 Fall COMDEX. For more information about the Computer Museum and the History Center, visit www.tcm.org

About ACM97:

ACM97 is the celebration of the 50th anniversary of the ACM (Association for Computing). Tens of thousands of people are expected to attend the Exposition portion of ACM97 that is free and open to the public. It will feature high-tech pavilions and computer-animation theaters highlighting a variety of computing domains and will demonstrate how each will affect our future.

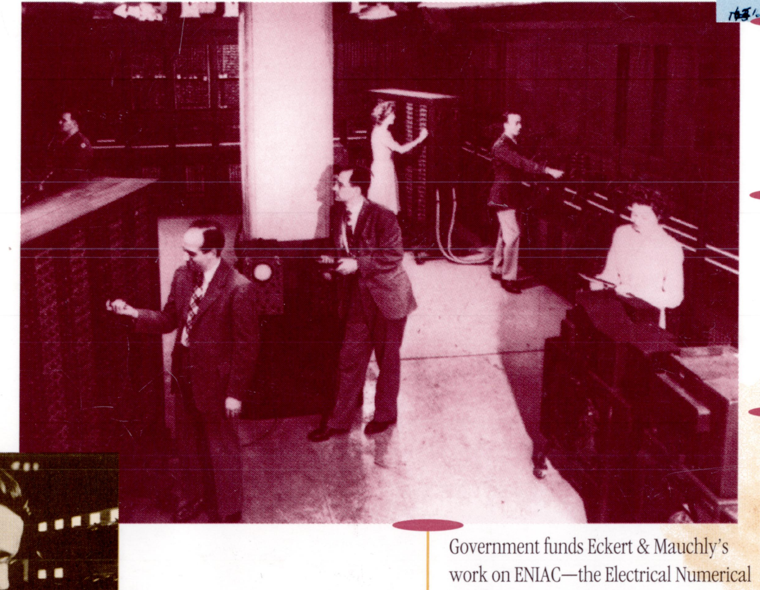
Nearly two thousand futurists, policy makers and thought leaders will attend a three-day series of presentations by some of the industries foremost authorities. The ACM97 web site (www.acm.org/acm97/) will serve as a continuing forum for discussion on the long-term future of computing, and an associated book entitled "Beyond Calculation, The Next 50 Years of Computing" will be published by Copernicus, a division of Springer-Verlag and distributed at ACM97 and worldwide thereafter.

-End-

The first society in computing presents:

The History of Electronic Computing

(The βeta Release)




Dickinson files patent for electronic storage element

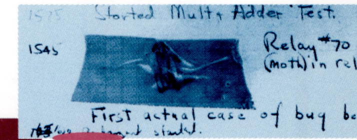
First color TV broadcast

Konrad Zuse completes the Z3
64 word memory, 3 secs/multiplication

Colossus helps British crack German codes

Government funds Eckert & Mauchly's work on ENIAC—the Electrical Numerical Integrator and Computer—for use in computing ballistics tables
Use of subroutines
18,000 tubes, 360 multiplications/sec

Harvard Mark I dedicated
6 secs/multiplication



September 9, 1945: first "bug" logged at 15:45 hours (Grace Murray Hopper—Distinguished Service Award)

John von Neumann's EDVAC report on the idea of a general purpose, stored-program computer

Vannevar Bush's article, "As We May Think," appears in *Atlantic Monthly*, foreseeing use of Hypertext.

John von Neumann begins influential IAS project at Princeton

Herman Goldstine invents flowcharts

First computer company—the Eckert-Mauchly Corporation—is founded

First transistor (Bell Labs)

Association for Computing Machinery founded

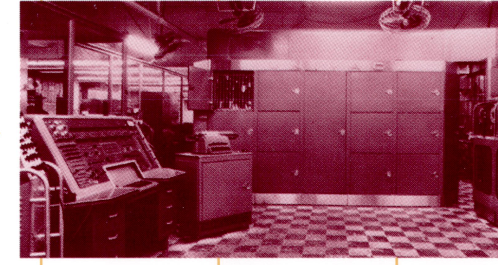
1940

1945

"I thought [computers] would be a universally applicable idea, like a book is. But I didn't think it would develop as fast as it did, because I didn't envision we'd be able to get as many parts on a chip as we finally got. The transistor came along unexpectedly. It all happened much faster than we expected."
–*J. Presper Eckert*
co-inventor of ENIAC
Speaking in 1991.

Manchester Mark I goes operational (Experimental stored-program computer)
800 multiplications/sec

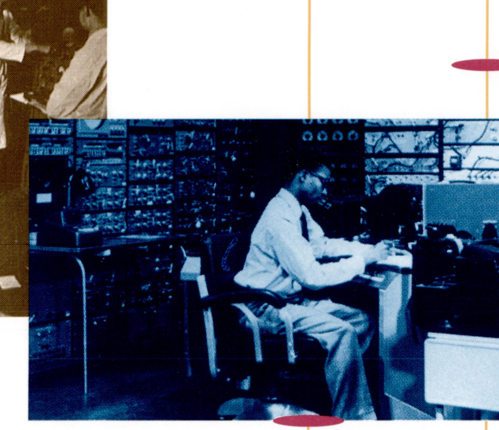
Alan Turing's letter to the *London Times* on artificial intelligence



EDSAC, the first production stored program computer, runs its first program (Maurice Wilkes—Turing Award, Eckert-Mauchly Award)

Remington-Rand acquires Eckert-Mauchly (the latter having lost crucial contracts due to McCarthy trials)

Microprogramming announced by Wilkes



Forrester and Everett design Whirlwind at MIT

IEEE Computer Society founded

Census Bureau takes delivery of Remington-Rand UNIVAC I
16,000 pounds
5,000 vacuum tubes
1,000 calculations/sec.
$159,000 (later units, $250,000)

First programming error at Census Bureau, June 16

Grace Murray Hopper (Distinguished Service Award) describes compiler

IBM 701 "Defense Calculator"

Alan Turing dies

UNIVAC I program correctly predicts outcome of Eisenhower-Stevenson election. Initial forecast, based on very early results, is doubted and withheld from broadcast.

IBM 702, 650
Drum memory

First use of magnetic core memory, on Whirlwind (Jay Forrester)

1950

First assembler—Nat Rochester on IBM 701

ACM launches *Journal of the ACM*

ENIAC turned off for the last time

GE's UNIVAC put to work on payroll: first commercial application

First direct keyboard input to a computer — Whirlwind

ERMA at Bank of America revolutionizes commercial banking

Digital Equipment Corporation (Ken Olsen) and CDC Corporation founded.

First FORTRAN program is run (John Backus)

First photograph scanned, processed, and redisplayed by computer

Datamation started as *Research and Engineering*

Air Force SAGE
40,000 square feet for each two-system installation,
3 megawatts of power per system,
30,000 tubes per system,
4K x 32 bit word magnetic core memory

LISP (John McCarthy at MIT—Turing Award)

ALGOL 58

Vol 1, No 1 of *Communications of the ACM*

1955

IBM 1401
Transistors

Whirlwind shut down

December: DEC announces PDP-1
4K 18 bit words of core, paper tape, CRT, $159,000

Backus-Naur Form (Backus received Turing Award)

Robert Noyce (TI) conceives idea for integrated circuit on Jan. 23, gives public demo of IC on March 24. Jack Kilby (Fairchild) independently develops IC.

Early warning system detects rising moon as incoming missles

November: first sale of PDP-1 to Bolt, Berenak, and Newman.

COBOL

First volume of *Computing Reviews*

IBM 7090

1960

Burroughs 6500 (Burroughs designs were first to be based on software objectives, e.g., Algol)

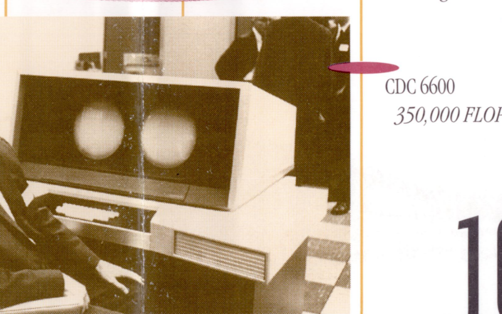
CTSS Time-sharing system (Corbató at MIT—Turing Award)

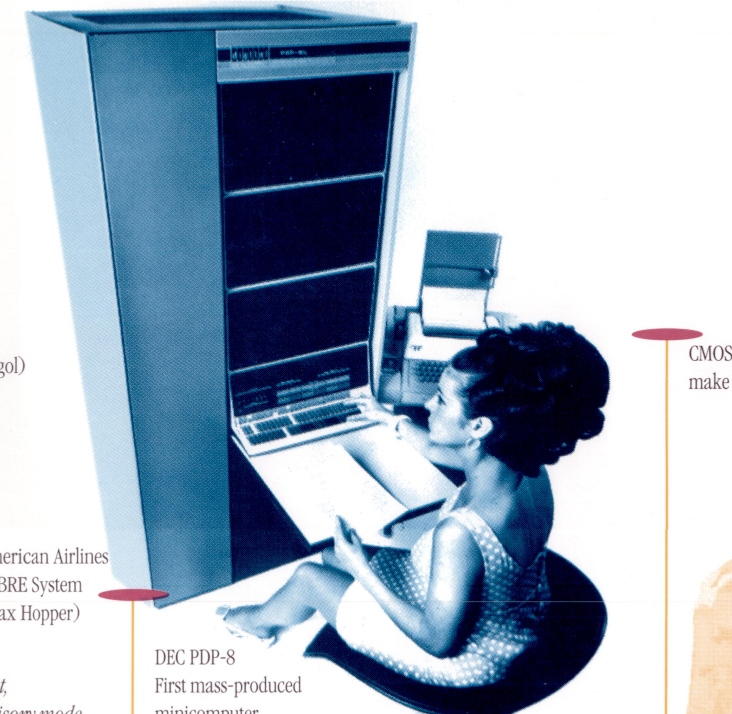
IBM STRETCH
Operating system concept, interrupts, timer, supervisory mode, I/O channels

First computer science department (Purdue)

American Airlines SABRE System (Max Hopper)

SKETCHPAD
Ivan Sutherland (Turing Award)
Interactive drawing tool (precursor to CAD), constraint solver, WYSIWYG (What You See is What You Get)





DEC PDP-8
First mass-produced minicomputer.

IBM 360
Binary addressing, cheap feasible time-sharing, virtual memory
(Fred Brooks—Distinguisted Service Award)

PL/1

Chip in a DIP (Dual Inline Package)

BASIC, Kemeny and Kurtz

1st Design Automation Conference

CDC 6600
350,000 FLOPS

Ivan Sutherland demonstrates stereo head-mounted display with position sensors—the first "virtual reality helmet" (Turing Award)

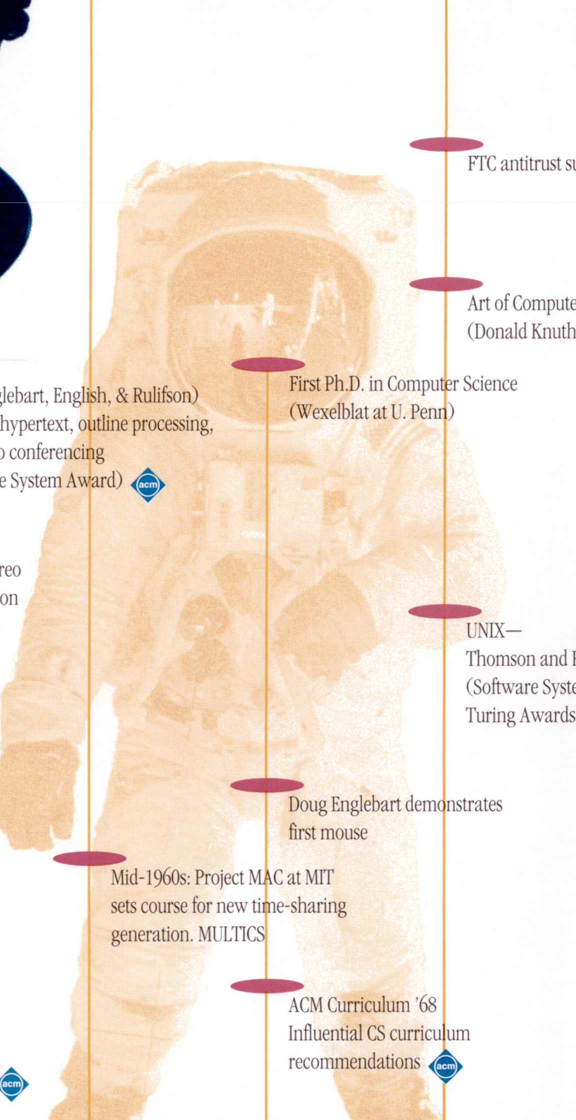
APL (Ken Iverson at IBM—Turing Award)

Eliza (Weizenbaum)

First Turing Award(Alan Perlis)

NLS (Englebart, English, & Rulifson) pioneers hypertext, outline processing, and video conferencing (Software System Award)

1965



CMOS integrated circuits (eventually to make up 40% of global market)

Mid-1960s: Project MAC at MIT sets course for new time-sharing generation. MULTICS

First Ph.D. in Computer Science (Wexelblat at U. Penn)

Doug Englebart demonstrates first mouse

ACM Curriculum '68
Influential CS curriculum recommendations

Dijkstra's letter to *CACM:* "Go To Statement Considered Harmful" (Turing Award)

Edgar Codd (Turing Award) proposes relational database model to IBM (Software System Award for resulting System R)

FTC antitrust suit against IBM

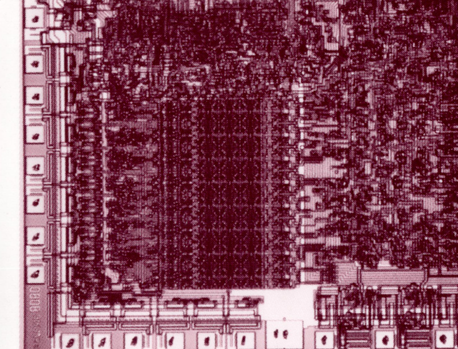
Art of Computer Programming, Vol. 1 (Donald Knuth—Turing Award)

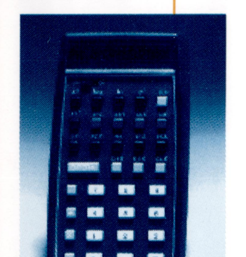
UNIX—
Thomson and Ritchie at AT&T (Software System Award, Turing Awards)

Floppy diskette

IBM designer Gene Amdahl (Eckert-Mauchly Award) forms Amdahl Corp., makers of mainframes plug-compatible with IBM. Competition leads to dramatic change in IBM prices.

1970





Pascal (Niklaus Wirth—Turing Award)

First advertisement for a micro-processor—Intel offers its 4004 (Robert Noyce and Ted Hoff) in Electronics News. It is a 4 bit micro, ~60,000 instructions per second (ENIAC on a chip), for ~$300.

"Poketronic"—first pocket calculator

Intel 8008

Smalltalk at Xerox PARC (Software System Award)

Nolan Bushell's PONG creates first video game fad

Hewlett Packard HP-35 calculator
$395

Seymour Cray (Eckert-Mauchly Award) founds Cray Research

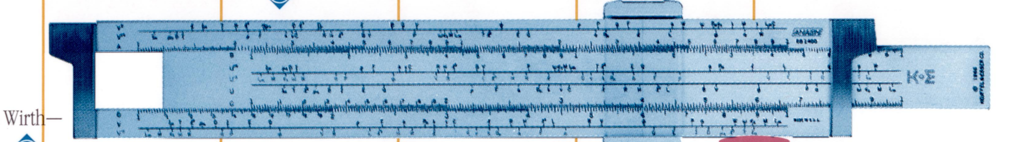
Pacemakers with chips, computed tomography debut

Winchester disk drives

George Albrecht starts *People's Computer Company*, first personal computing newsletter, early user group.

IBM System 370

Ethernet (Metcalfe at Xerox PARC—Grace Murray Hopper Award)



Thomson and Ritchie describe UNIX in *Communications of the ACM*, followed by broad distribution to universities.

Intel 8080

First SIGGRAPH

David Ahl starts *Creative Computing* magazine

DECSystem 10 ships. VAX project begins. (Gordon Bell—Eckert-Mauchly Award)

First microcomputer BASIC—Bill Gates and Paul Allen

First issue of *BYTE* magazine

Three key chips:
Zilog Z80
MOS 6502
Motorola 6800

John Cocke (Turing Award, Eckert-Mauchly Award) begins RISC project at IBM T. J. Watson labs. Also RISC projects at Berkeley and Stanford.

MITS Altair on cover of *Popular Electronics*—dawn of hobbyist desktop computing.
8080, 256 bytes RAM, $498 assembled, $2500 with peripherals.

ACM starts *Transactions* series

1975

Alan Kay and Adele Goldberg's Dynabook paper sets goals for personal computing

Smithsonian receives last Keuffel & Esser slide rule

Cray-1 supercomputer
138 MegaFLOPS

Adventure—Crowther and Woods. First adventure game.

Radio Shack TRS80

Apple II
6502, 16K RAM, 16K ROM, peripherals and display: $1298

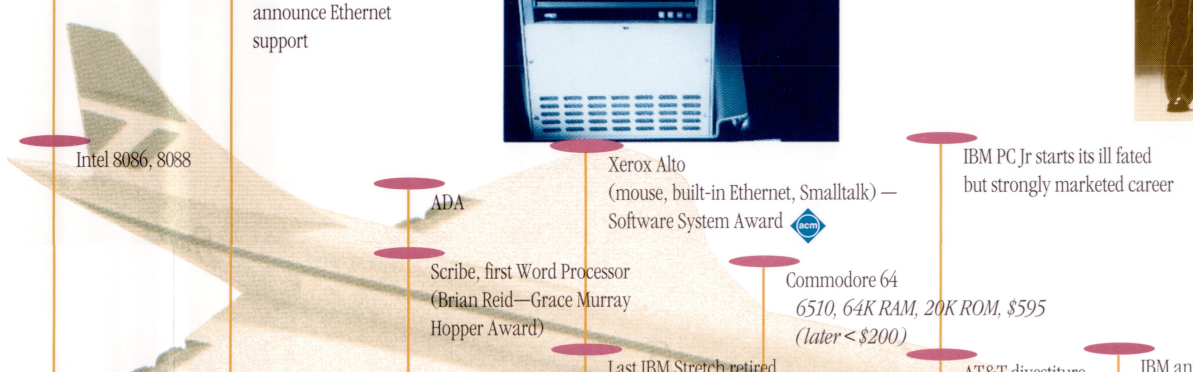
Commodore PET
6502, 4K RAM, 14K ROM, peripherals: $595

CP/M—Gary Kildall

Visicalc (Software System Award)—Dan Bricklin (Grace Murray Hopper Award), Bob Frankston

Intel 8086, 8088

ACM Curriculum '78 widely used as a model for undergraduate programs



Xerox, DEC, and Intel announce Ethernet support

NORAD: 50 false alerts in 1979, including a simulated attack whose outputs accidentally triggered a live scramble.

First COMDEX show

Public information services: Compuserve and The Source are founded

George Tate launches Ashton Tate, dBase II

ADA

Scribe, first Word Processor (Brian Reid—Grace Murray Hopper Award)

64 kilobit dynamic RAM

32-bit micros:
Motorola 68000
Intel 80186
NS 16000

1980

Xerox Alto (mouse, built-in Ethernet, Smalltalk) — Software System Award

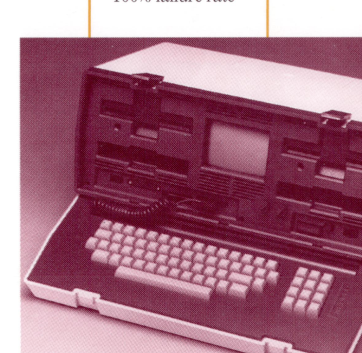
Last IBM Stretch retired

Hayes 300 Smartmodem with AT command set

Xerox Star—first commercially available workstation with "Desktop" interface

IBM PC

A year after its announcement, the doomed Apple III ships, suffers nearly 100% failure rate



First commercially successful portable: Osborne I
23lbs, Z80, 64K RAM, CP/M

Commodore 64
6510, 64K RAM, 20K ROM, $595 (later < $200)

SONY announces compact disk technology

Gaithersburg Conference (Considered 1st CHI Conference)

IBM PC Jr starts its ill fated but strongly marketed career

AT&T divestiture

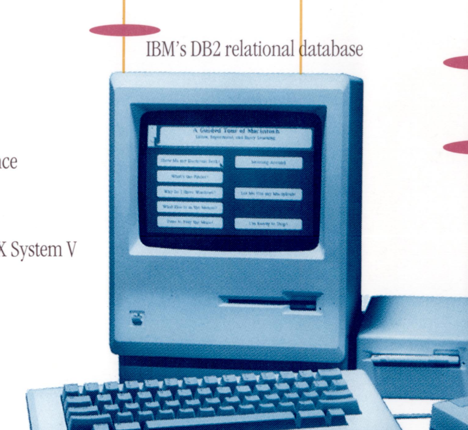
Apple's Lisa foreshadows the Macintosh. RIP 1985, partly due to $10K price.

Microsoft announces Windows

UNIX System V

IBM antitrust suit withdrawn

IBM's DB2 relational database



Apple Macintosh
68000, 128K RAM, $2495

Commodore Amiga, Atari 520 ST

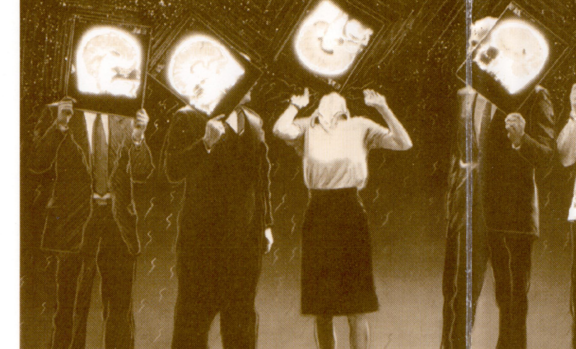
C++

Japanese mechanic killed by malfunctioning Kawasaki robot

Microsoft ships Windows

Aldus PageMaker for Macintosh launches desktop publishing trend

1985



Max Headroom debuts

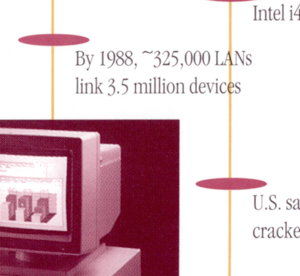
First conference on object oriented systems: OOPSLA 86

Large computer-induced stock market swings

Connection Machine (Danny Hillis)

Adobe Postscript (Software System Award)

Video display terminal safety is a continuing concern, as is repetitive motion syndrome.



IBM PS/2
OS/2

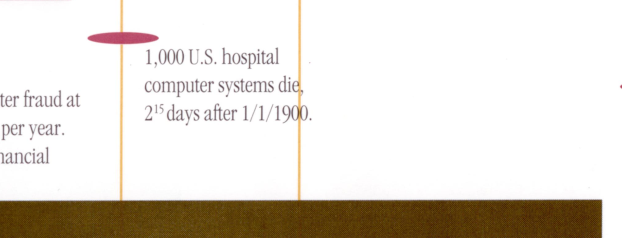
FBI estimates average computer fraud at $650K, for a total of $3B - 5B per year. $1.5M average for fraud in financial institutions.

Hypercard

4 megabit dynamic RAM chips

First Computer Bowl

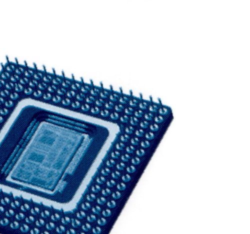
By 1988, ~325,000 LANs link 3.5 million devices



NeXT Cube

Robert Morris' worm floods ARPANet

"Cuckoo's Egg" hacker



Intel i486, i860

U.S. satellite positioning system cracked by 14 year-old

1,000 U.S. hospital computer systems die, 2^{15} days after 1/1/1900.

14 year-old boy cracks TRW credit, orders $11,000 in merchandise.
12 year-old arrested for tapping TRW credit files.

Motorola 68040

AT&T congestion attributed to SWITCH...IF...BREAK in SS-7 switching system.

ACM/IEEE-CS Currculum '91 includes computer engineering and liberal arts programs

Internet Engineering Task Force conducts meeting via packet audio across the Internet

Apple announces "Personal Digital Assistant"

Number of distinct strains of computer viruses has grown from five in early 1988 to over 1,000 by early 1992.

Intel P5 chip.
~100 MIPS,
~3.5M transistors

IBM/Apple/Motorola PowerPC

1990

Note: This is a work in progress, not intended to be a definitive history of electronic computing. Influential people and significant events have no doubt been omitted. A future version will incorporate reader feedback. Send suggestions, corrections, and comments to Timeline Comments, Member Services Department, ACM, 1515 Broadway, New York, NY 10036, or email TIMELINE@ACMVM.BITNET.

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