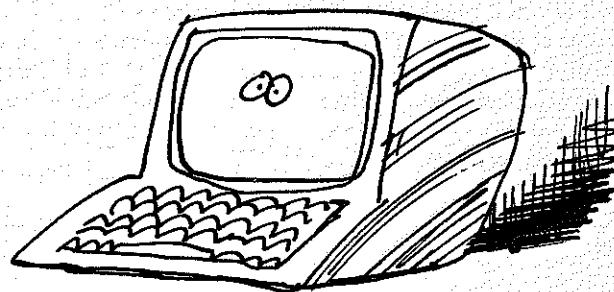


Also available by Larry Gonick, with Mark Wheelis

THE CARTOON GUIDE TO GENETICS

THE CARTOON GUIDE TO **COMPUTER SCIENCE**

Larry Gonick



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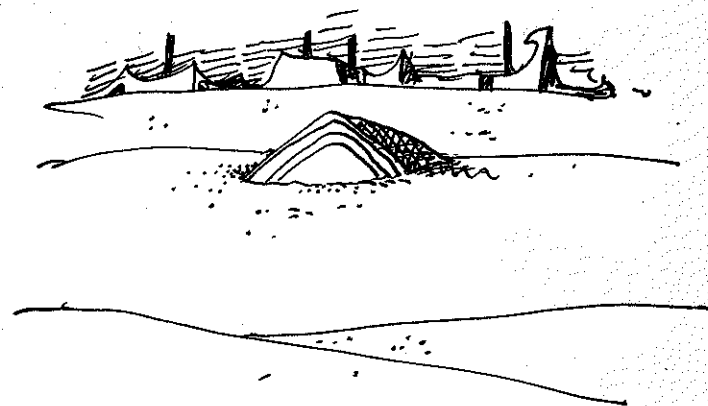
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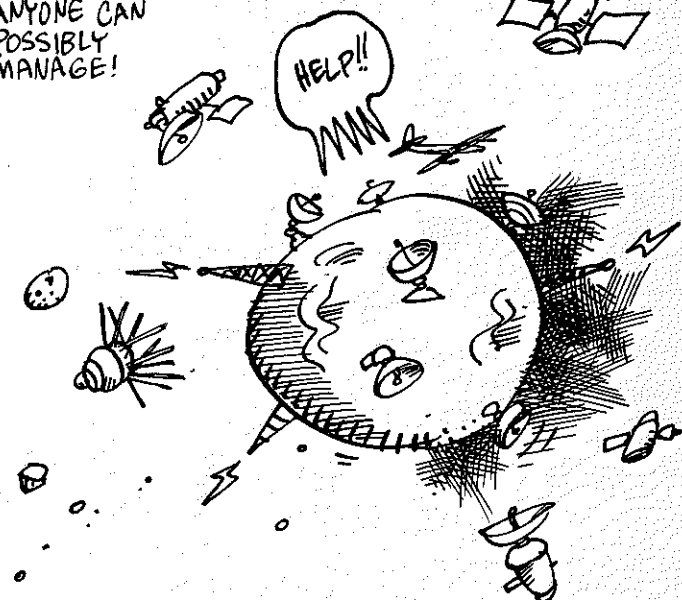
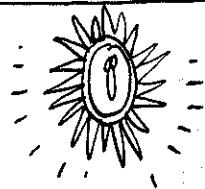
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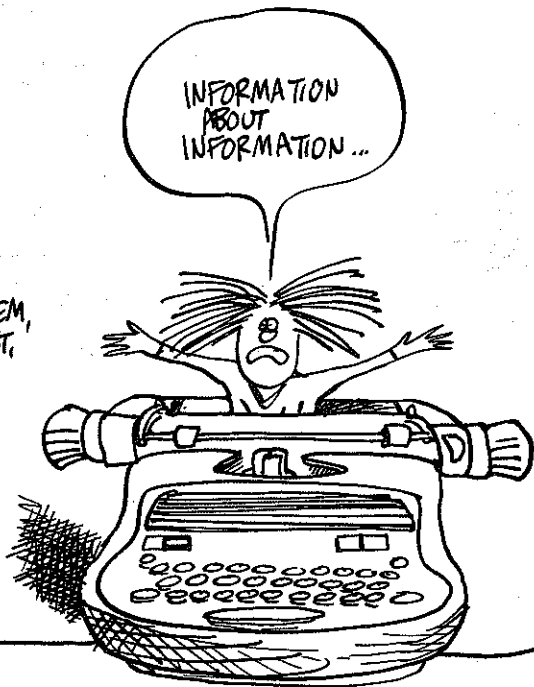


W E LIVE IN
THE AGE OF
EXCESS INFORMATION.
THANKS TO THE
TECHNOLOGICAL
MIRACLES OF THE
TWENTIETH CENTURY,
WE CITIZENS OF
EARTH ENJOY
INSTANT ACCESS
TO MORE
INFORMATION THAN
ANYONE CAN
POSSIBLY
MANAGE!



THERE'S INFORMATION ABOUT WEATHER, SPORTS, POLITICS, BUSINESS, CELEBRITIES, SCIENCE, ENTERTAINMENT, ART, RELIGION, BANKING, SOCIAL SECURITY, THE PHONE SYSTEM, THE STOCK MARKET, ADVERTISING, HISTORY, SUPERHEROES, TAXES, EDUCATION, CABLE T.V., TECHNOLOGY, OIL...

INFORMATION ABOUT INFORMATION...

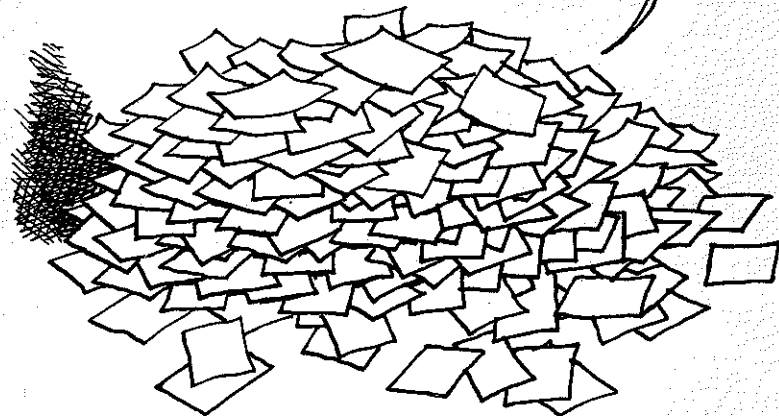


EEOH!
IT'S A TIDAL WAVE!

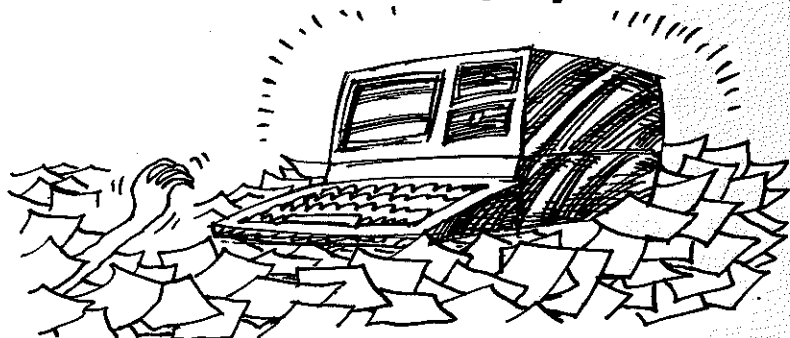


CLEARLY, THE AGE DEMANDS A PIECE OF TECHNOLOGY SOLELY DEVOTED TO STORING, CLASSIFYING, SORTING, COMPARING, COMBINING, AND DISPLAYING INFORMATION AT HIGH SPEED!

THAT, AND A SHOVEL...

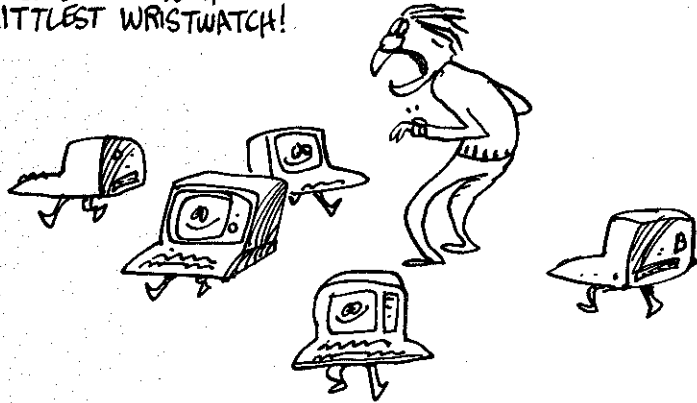


THAT PIECE OF EQUIPMENT IS THE **COMPUTER**.



THIS EXPLAINS WHY COMPUTERS ARE POPPING UP WHEREVER INFORMATION COUNTS, FROM THE BIGGEST BUSINESSES TO THE LITTLEST WRISTWATCH!

IT'S ENOUGH TO MAKE YOU PARANOID!



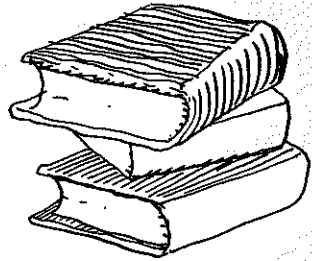
AND IT ALSO ACCOUNTS FOR THE FACT THAT BEFORE YOU CAN UNDERSTAND COMPUTERS, IT HELPS TO KNOW SOMETHING ABOUT INFORMATION FIRST—SUCH AS, FOR EXAMPLE, WHAT IT IS...



WHAT IS IT?
IT'S...
IT'S... AH...
UM... ER...
WHAT A STUPID QUESTION!

What is information?

IN THE EVERYDAY SENSE OF THE WORD, "INFORMATION" MEANS **FACTS**: THE SORT OF STUFF THAT FILLS NON FICTION BOOKS, AND CAN ONLY BE EXPRESSED IN WORDS.



IN THE WORLD OF COMPUTERS, HOWEVER, THE TERM HAS A MUCH BROADER MEANING.

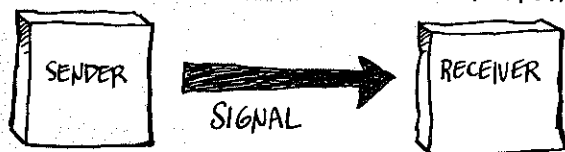


MEEP!

SHANNON ALSO BUILT AN ELECTRIC "MOUSE" THAT COULD BE PROGRAMMED TO RUN MAZES!

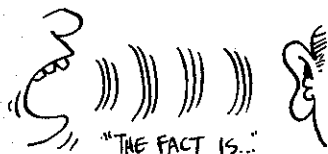
THE MODERN DEFINITION COMES FROM **CLAUDE SHANNON**, A BELL LABS ENGINEER, AMATEUR UNICYCLIST, AND FOUNDER OF THE SCIENCE OF **INFORMATION THEORY**.

ACCORDING TO SHANNON, INFORMATION IS PRESENT WHENEVER A SIGNAL IS TRANSMITTED FROM ONE PLACE TO ANOTHER.

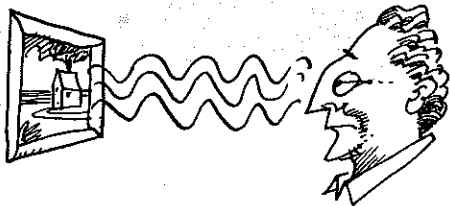


IT DOESN'T MATTER WHAT KIND OF SIGNAL IT IS.
FOR EXAMPLE:

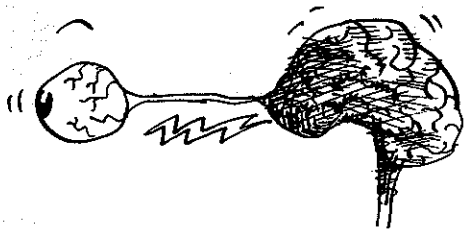
THE SIGNAL MAY BE IN THE FORM OF WORDS, THE MOST FAMILIAR KIND OF INFORMATION...



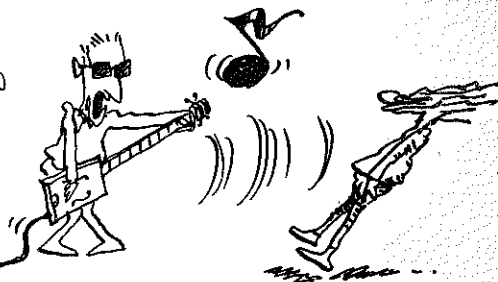
...BUT A PICTURE ALSO SENDS A SIGNAL, IN THE FORM OF LIGHT WAVES, TO OUR EYES. IT LOOKS AS IF PICTURES CONVEY INFORMATION!



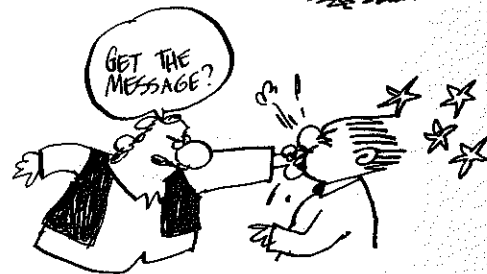
FURTHERMORE, OUR EYE SENDS A PATTERN OF ELECTRIC IMPULSES UP THE OPTIC NERVE TO THE BRAIN. THAT SIGNAL CARRIES INFORMATION, TOO!!



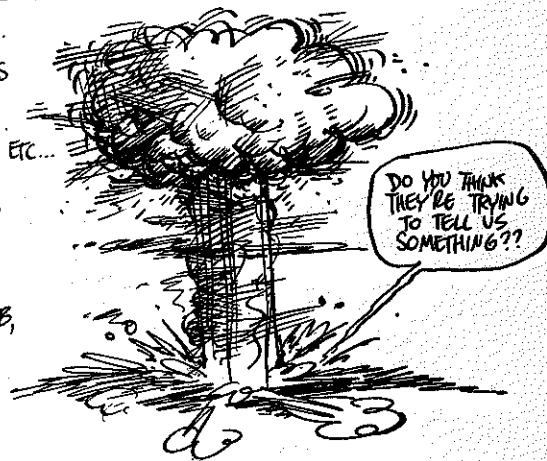
MUSIC IS A SIGNAL OF SORTS, CONVEYING INFORMATION IMPOSSIBLE TO PUT INTO WORDS...



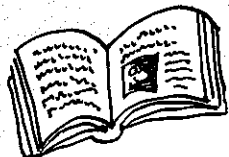
FOR THAT MATTER, A PUNCH IN THE MOUTH IS NOT WITHOUT ITS INFORMATION VALUE!



SO YOU SEE... INFORMATION COMES IN MANY FORMS: VERBAL, VISUAL, MUSICAL, ETC, ETC ETC... ALL OF WHICH CAN BE HANDLED BY COMPUTERS. WHY A COMPUTER CAN DELIVER A HYDROGEN BOMB, NOT JUST A PUNCH IN THE MOUTH!!

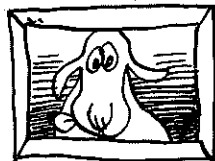
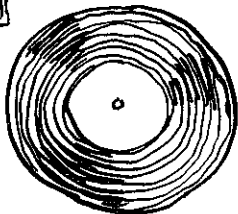


ALL THOSE SIGNALS, INCLUDING A PUNCH IN THE MOUTH, CAN BE RECORDED IN SOME WAY... SUGGESTING THAT INFORMATION CAN BE STORED AS WELL AS TRANSMITTED AND RECEIVED...



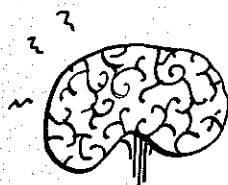
IN BOOKS...

ON AUDIO AND VIDEO DISKS...



IN PAINTINGS OR DRAWINGS...

ON TAPE...

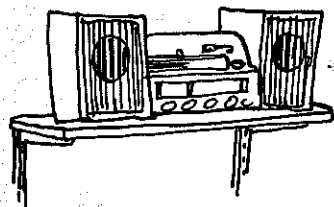


IN THE HUMAN MEMORY...



IN DIAGRAMS, ETC!

THE POINT OF THIS IS TO TRANSMIT THE SAME MESSAGE MANY TIMES...



AND OF COURSE, ITEMS OF INFORMATION CAN BE COMBINED IN VARIOUS WAYS.



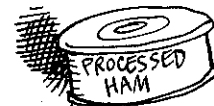
AND YOU CAN VERB ANY WORD IN THE LANGUAGE!



WE REFER TO THE STORAGE, TRANSMISSION, COMBINATION AND COMPARISON OF MESSAGES AS

INFORMATION PROCESSING.

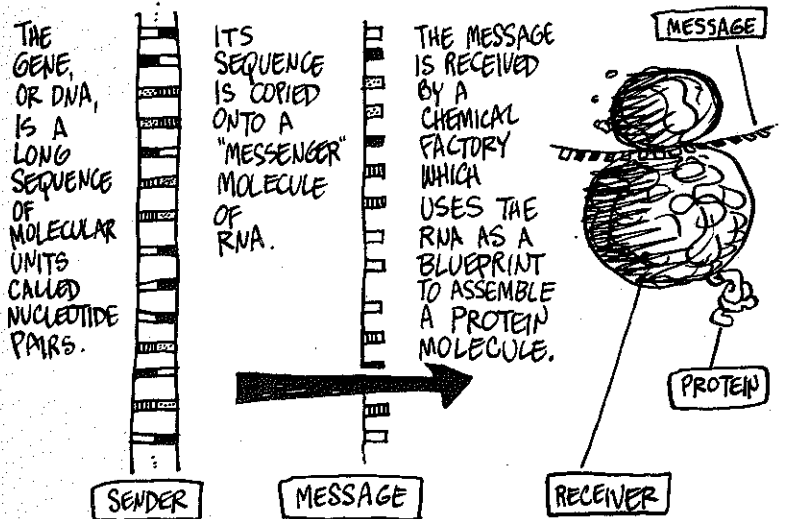
(ALTHOUGH THE COMPUTER INDUSTRY IS GUILTY OF TURNING MANY NOUNS INTO VERBS - ACCESS, INPUT, INTERFACE - "PROCESS" WAS ALREADY A VERB, THANKS TO THE FOOD BUSINESS...)



TO APPRECIATE THE POWER OF INFORMATION,
CONSIDER ANOTHER EVERYDAY EXAMPLE:

LIFE ITSELF.

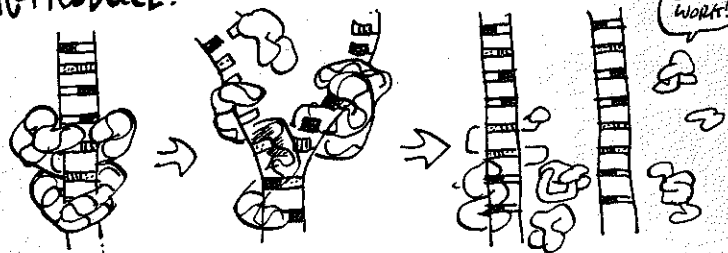
HERE'S LIFE IN A SINGLE PANEL:



IN OTHER WORDS, THE
PROTEIN IS BUILT
ACCORDING TO
INFORMATION
STORED IN THE GENE.

FOR DETAILS,
SEE THE CARTOON
GUIDE TO
GENETICS!

THE TRICK IS THIS: CERTAIN PROTEINS HELP DNA TO
REPRODUCE.



WHAT HAPPENS THEN? IF DNA ENCODES PROTEINS THAT HELP
DNA TO REPRODUCE, THEN MORE OF THOSE PROTEINS WILL BE
BUILT, MORE DNA WILL BE COPIED...ETC! MOREOVER, IF
THE DNA ENCODES OTHER PROTEINS WHICH PROTECT IT IN
VARIOUS WAYS, AND OTHERS TO ATTACK AND DESTROY
RIVAL DNA AND PROTEINS...

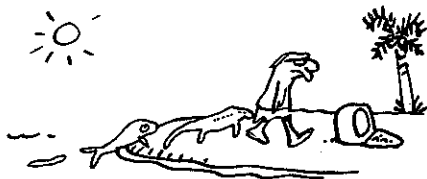
THEN THAT DNA-PROTEIN SYSTEM WILL REPRODUCE ITSELF AGAIN
AND AGAIN — AND THAT'S WHAT YOU CALL A LIFE FORM.

SO LIFE
ITSELF
IS A
MOLECULAR
INFORMATION
PROCESSOR,
WHICH HAS
BEEN
RUNNING
AUTOMATICALLY
FOR
OVER
**3 BILLION
YEARS !!**



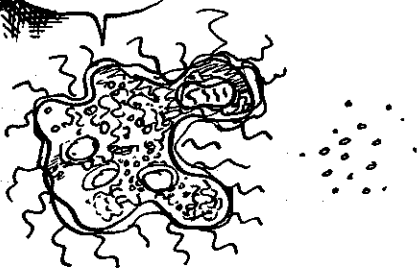
The Evolution of the Computer

IT MAY BE GOING TOO FAR TO SAY THAT COMPUTERS HAVE BEEN EVOLVING FROM THE BEGINNING...



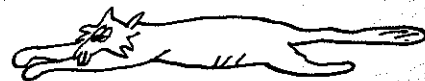
BUT FROM EARLY TIMES, LIFE FORMS HAVE BEEN INCREASING THEIR INFORMATION-PROCESSING ABILITIES. EVEN AN AMOEBA RECEIVES CHEMICAL SIGNALS TELLING IT WHERE THE FOOD IS!

OTHERWISE, I'D HAVE TO EAT EVERYTHING!



ALL THE SENSES ARE WAYS OF RECEIVING SIGNALS:

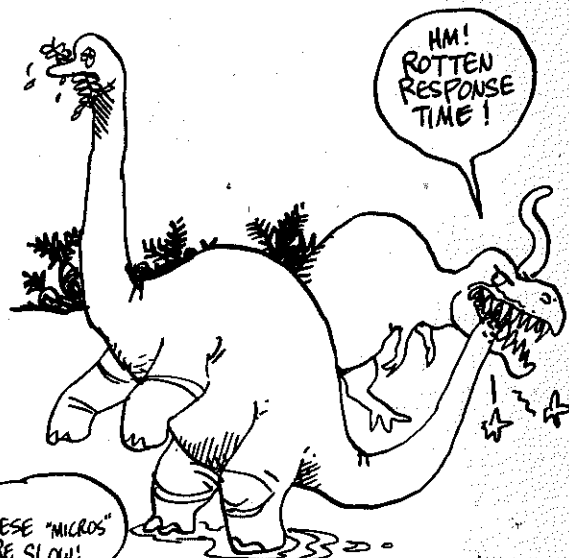
BUT THEN WE CALL IT PURR-CEIVING!



THE EYES PERCEIVE A RANGE OF ELECTROMAGNETIC RAYS; THE EARS RESPOND TO PRESSURE IN THE AIR; THE NOSE REACTS TO VARIOUS MOLECULES; SO DO THE TASTE BUDS; AND THE SENSE OF TOUCH IS A WAY OF RECEIVING A PUNCH IN THE MOUTH!

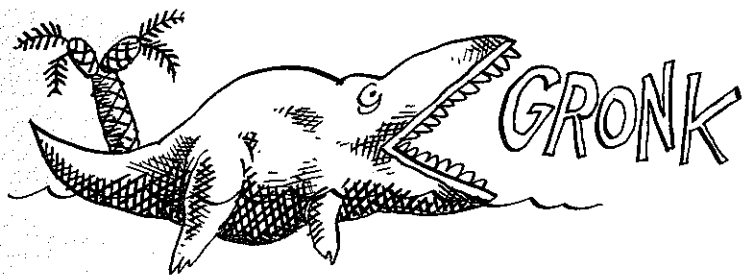
SENSORY IMPRESSIONS ARE TRANSMITTED ELECTRICALLY ALONG THE NERVES AND COORDINATED BY THE BRAIN — NATURE'S FIRST ATTEMPT TO BUILD A COMPUTER !!

HM! ROTTEN RESPONSE TIME!

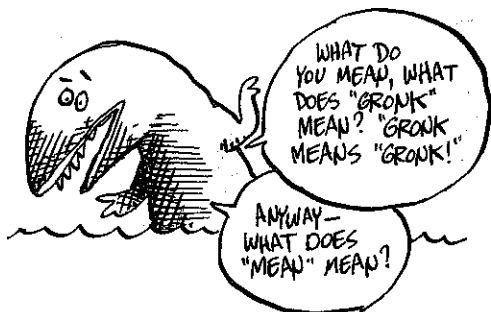


THESE "MICROS" ARE SLOW!

BESIDES TRANSMITTING INFORMATION WITHIN THEIR OWN BODIES, ANIMALS ALSO SENT MESSAGES TO EACH OTHER:

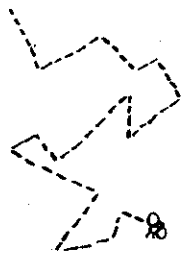


NOTE AGAIN: THESE DO NOT NECESSARILY CONVEY INFORMATION THAT CAN BE EXPRESSED IN WORDS!



ALSO:

THESE MESSAGES ARE NOT ALWAYS IN THE FORM OF SOUNDS. DOGS COMMUNICATE BY WAGGING THEIR TAILS, AND BEES CAN DESCRIBE THE PRECISE LOCATION OF A FLOWER BY "DANCING."



WHEN HUMANS BEGAN COMMUNICATING, THEY PROBABLY WEREN'T MUCH DIFFERENT FROM ANY OTHER ANIMAL.

"GRONK"



BUT AS THE BRAIN INCREASED IN SIZE AND "COMPUTING POWER," LANGUAGE BECAME MORE EXPRESSIVE.

The reason?

PEOPLE COULD REMEMBER AND USE MORE WORDS. THE MORE WORDS THEY USED, THE GREATER THE NUMBER OF POSSIBLE MESSAGES — WHICH IS ANOTHER WAY OF SAYING THEY COULD SEND MORE INFORMATION.

THE SKY IS BLUE...

THE SKY IS BLUE AND FLECKED WITH CLOUDS...

THE SKY, CLEARING AFTER YESTERDAY'S RAIN, IS BLUE AND FLECKED WITH CLOUDS.

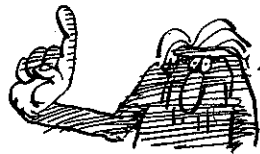
GRONK

ALONG WITH WORDS
CAME THE RULES
FOR COMBINING WORDS:
THE LAWS OF
GRAMMAR
AND **LOGIC**.

IF YOU COME OUT **AND**
APOLOGIZE, **THEN** WE WILL
NOT FLAY YOU ALIVE,
UNLESS WE CHANGE OUR
MINDS...



IN TIME, HOWEVER, IT
APPEARED THERE WAS A
SPECIAL TYPE OF WORD
WITH ITS OWN SPECIAL
RULES... NAMELY —



WAIT
ONE
MINUTE...
LET
GUESS...

NUMBERS



YOU CAN
COUNT
ON THEM!

NUMBERS ARE PRECISE... RELIABLE...
YOU CAN ADD, SUBTRACT AND
MULTIPLY NUMBERS... "ONE PLUS
ONE" MAKES SENSE, BUT AS THEY
SAY, YOU CAN'T ADD GRAPES AND
REINDEER.



EXCEPT
IN MY GRAPE
AND REINDEER
STEW...

NUMBERS ARE ALSO UNIQUE IN THAT YOU "DO THEM" ON
YOUR FINGERS, WHILE OTHER PARTS OF LANGUAGE HAPPEN
MAINLY IN YOUR HEAD... YES, COUNTING HAS BEEN
DIGITAL* FROM THE BEGINNING!



HOW MANY
DAYS IN
A MONTH?



SIMPLE!
ONE, TWO,
THREE, FOUR, FIVE,
SIX, SEVEN,
EIGHT, NINE...



TEN...



AHEM!
WHILE I'M
SURE THIS
QUESTION HAS
AN ANSWER,
THE CURRENT
GENERATION OF HARDWARE
SEEMS
INADEQUATE
TO THE TASK...



SAY!



THESE GENIUSES CERTAINLY
CAN STRAIN THE OLD SOCIAL
FABRIC...



NINETEEN...

* "DIGIT" MEANS FINGER!

NOW, HAVING COUNTED,
WAS THERE SOME
WAY TO SAVE
THE RESULT?

YES!!
AFTER
COMPUTATION,
AMPUTATION!

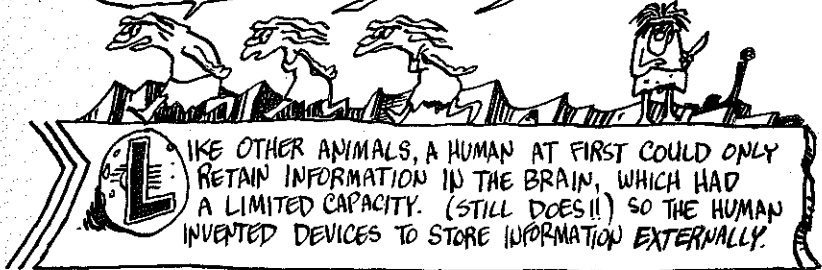
YOU'RE
MAD!



EXCUSE ME...
I HAVE TO GO PUT
MY HANDS TO BETTER
USE...

WASH THE
WOLF...

SHARPEN
ROCKS...



THE EARLIEST
KNOWN EXAMPLES
OF EXTERNAL
STORAGE ARE
ABOUT 20,000 YEARS
OLD, LIKE THIS
TALLY BONE,
APPARENTLY USED
TO COUNT THE
DAYS OF THE MONTH.

NOW I
CAN KEEP
TRACK OF MY
INTERNAL
STORAGE!



AROUND THE SAME TIME, CAVE DWELLERS WERE BEGINNING
TO STORE ANOTHER KIND OF INFORMATION AS WELL:
THEY PAINTED REALISTIC ANIMALS ON THE WALLS OF
THEIR CAVES — NO ONE KNOWS WHY!



SEVERAL THOUSAND YEARS LATER, THE SUMERIANS
DEvised A SYSTEM TO REPRESENTING THEIR ENTIRE
LANGUAGE IN PICTURES:



CALL IT
"VISI-TALK!"

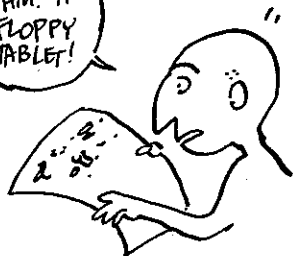
AND SO WRITING WAS BORN!

UNTIL SOMEONE CAN IMPROVE ON LANGUAGE ITSELF, WRITING WILL BE THE ULTIMATE HUMAN SYSTEM OF INFORMATION STORAGE. IT'S NEARLY UNIVERSAL! PEOPLE ALL AROUND THE WORLD INVENTED SYMBOL SYSTEMS TO ENCODE SPOKEN LANGUAGE. OF COURSE, TECHNIQUES VARIED FROM PLACE TO PLACE...



THE SUMERIANS WROTE ON CLAY TABLETS, WHILE THE EGYPTIANS USED SOFT PAPYRUS.

HM! A FLOPPY TABLET!



CHINESE WRITING BEGAN WITH MESSAGES TO THE GODS INKED ON TORTOISE SHELLS.

THEY DIDN'T ASK THE GOD OF TORTOISES!



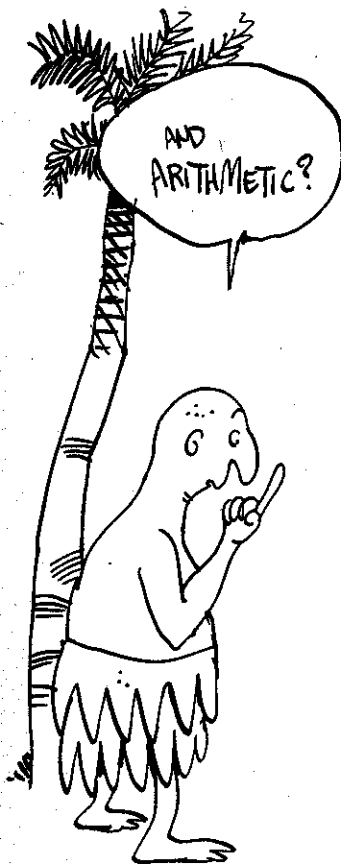
THE INCAS USED A SYSTEM OF KNOTTED CORDS.



GREAT! NOW THAT WE'VE STORED ALL THAT INFORMATION, HOW DO WE FIND IT AGAIN?

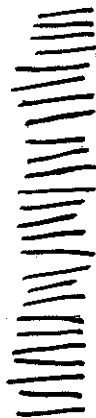


WE'LL RETURN TO THAT POINT LATER!



AND ARITHMETIC?

ALL THE EARLY CIVILIZATIONS HAD WAYS OF REPRESENTING NUMBERS THAT WERE FAR ADVANCED OVER THE STONE AGE TALLY BONE, ON WHICH THE NUMBER IS SIMPLY MADE BY PILING UP 1'S. NOT TOO USEFUL...



I CALL THIS NUMBER "SMERG."



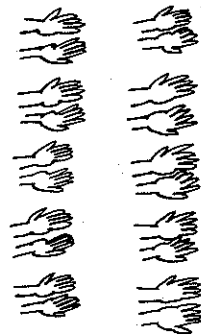
SOMETIME BETWEEN TALLY BONE AND CIVILIZATION, PEOPLE BECAME ACCUSTOMED TO COUNTING BY FIVES AND TENS — FOR AN OBVIOUS REASON: IT WAS HANDY.



LET'S CALL
TEN A "HANDFUL"
AND DO SOME
COUNTING.
FIRST COME
SOME NUMBERS
LIKE
"TWO HANDFULS
AND THREE"



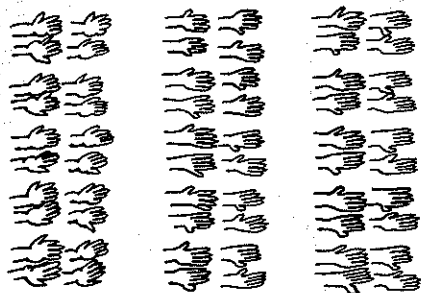
AFTER A
WHILE,
YOU REACH
A
HANDFUL
OF
HANDFULS
(TEN TENS,
OR A
HUNDRED).



THEN COMES A HANDFUL OF HANDFULS AND ONE...

" " " " " Two
" " " " " :
" " " " " A HANDFUL...

EVENTUALLY YOU'RE
LOOKING AT
NUMBERS LIKE
THIS:

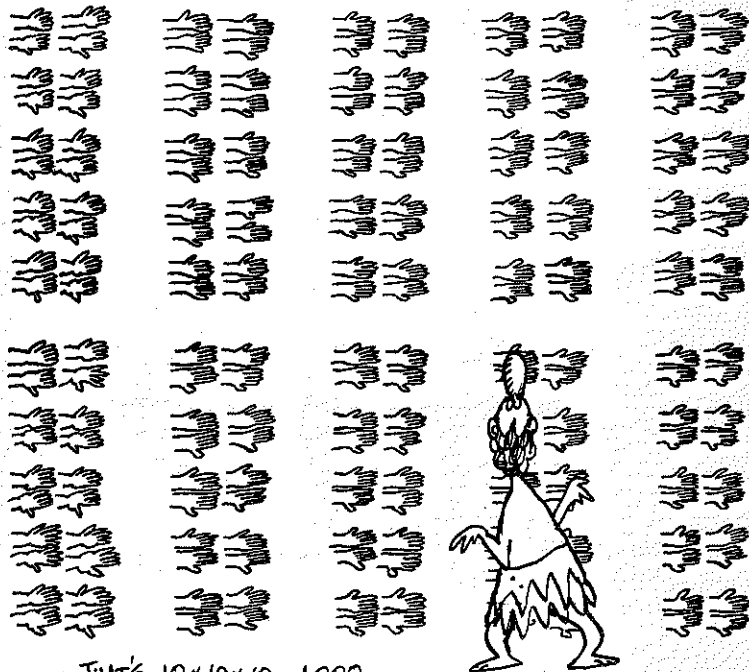


OR: "THREE HANDFULS OF
HANDFULS, FOUR HANDFULS,
AND SEVEN."



A
MOUTH-
FUL!

AND THEN — A HANDFUL OF HANDFULS OF HANDFULS:



THAT'S $10 \times 10 \times 10 = 1000$.

NEXT COMES

TEN THOUSAND..
A HUNDRED THOUSAND..
A THOUSAND THOUSAND..
TEN THOUSAND THOUSAND..


EACH OF WHICH IS
A HANDFUL OF
THE ONE BEFORE!



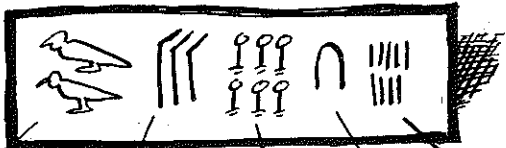
THIS IS
GETTING OUT
OF HAND!

THE ANCIENTS FOUND TWO BASIC WAYS TO TRANSLATE THIS INTO WRITING:

ONE, THE EGYPTIAN SYSTEM, USED A DIFFERENT SYMBOL FOR EACH NEW HANDFUL.

| = ONE ∩ = TEN ⊙ = HUNDRED
 I = THOUSAND ∟ = TEN THOUSAND  = HUNDRED THOUSAND

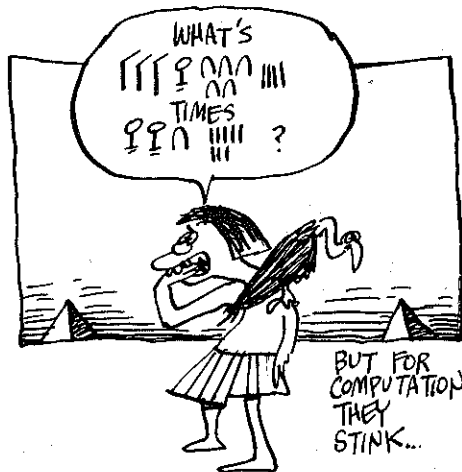
THEN YOU JUST PILE THEM UP:



TWO HUNDRED THOUSANDS THREE TEN THOUSANDS SIX THOUSANDS ONE TEN NINE UNITS

OR 236,019


ASIDE FROM HAVING A CERTAIN GRAPHIC CHARM, THESE NUMERALS ARE VERY EASY TO READ, ONCE YOU'RE USED TO THEM (JUST AS "3 BILLION" READS QUICKER THAN "3000 000 000").



ON THE OTHER HAND, THE CHINESE USED THE POSITION OF NUMERALS TO INDICATE THEIR VALUE. FIRST THEY COUNTED FROM ONE TO NINE:

| || ||| |||| ||||| T TT TTT TTTT
 1 2 3 4 5 6 7 8 9

FROM WHICH (FOR EXAMPLE):



TWO HUNDRED THOUSANDS THREE TEN THOUSANDS SIX THOUSANDS NO HUNDREDS ONE TEN NINE UNITS

OR 236,019.

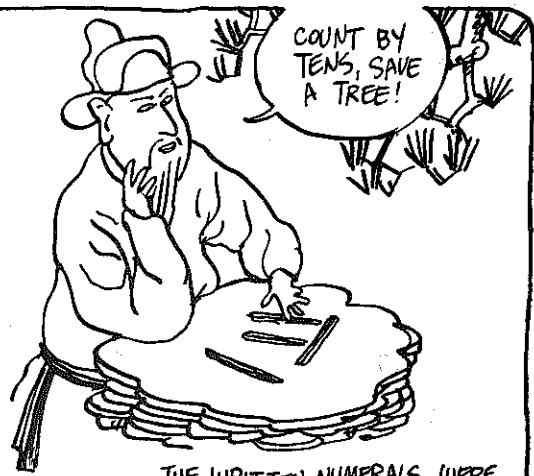
EXCEPT FOR THE UNFAMILIAR NUMERALS, THIS SYSTEM IS NEARLY THE SAME AS OUR OWN.

THE ONLY DIFFERENCE IS THAT IT LACKED A SYMBOL FOR ZERO. THE CHINESE JUST LEFT A BLANK INSTEAD.



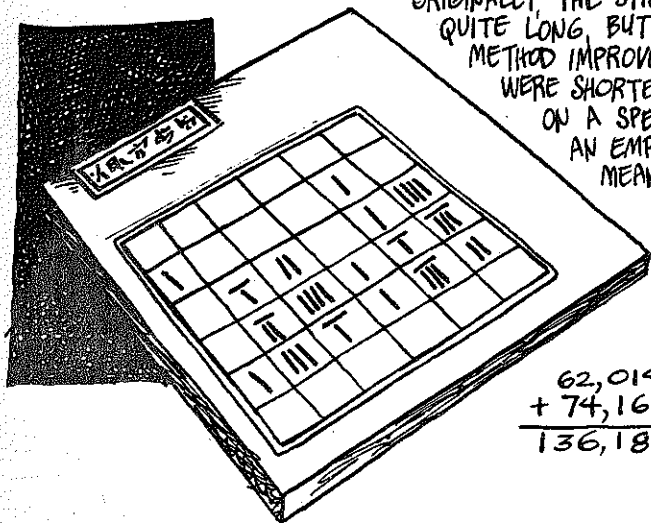
IN PRACTICE, THIS WAS MUCH LESS OF A PROBLEM THAN IT MIGHT HAVE BEEN, BECAUSE THE CHINESE DID NOT CALCULATE ON PAPER !!!

THE CHINESE SYSTEM WAS BASED ON CALCULATION WITH STICKS. ONE PILE OF STICKS KEPT TRACK OF THE ONES, ANOTHER THE TENS, ETC. AMONG OTHER THINGS, THIS KEPT THE NUMBER OF STICKS WITHIN REASON.



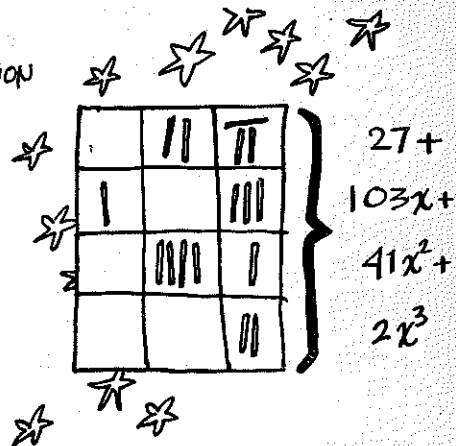
THE WRITTEN NUMERALS WERE JUST DRAWINGS OF THESE "STICK FIGURES."

ORIGINALLY, THE STICKS WERE QUITE LONG, BUT AS THE METHOD IMPROVED, THE STICKS WERE SHORTENED FOR USE ON A SPECIAL GRID. AN EMPTY SQUARE MEANT ZERO.



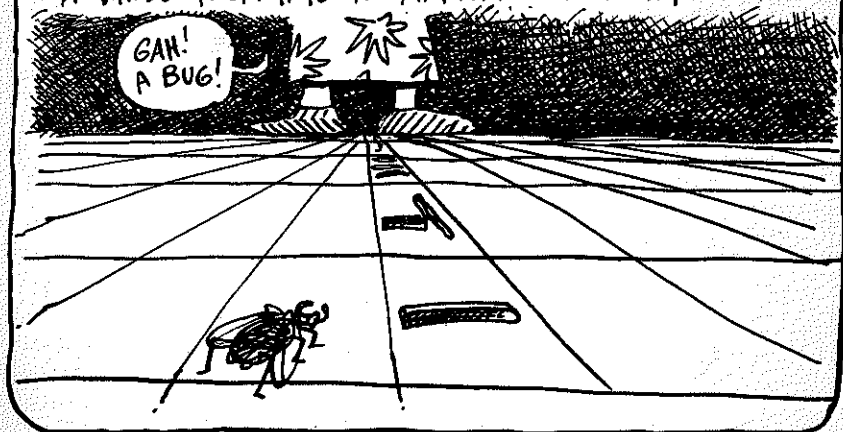
$$\begin{array}{r} 62,014 \\ + 74,168 \\ \hline 136,182 \end{array}$$

BESIDES ADDITION, SUBTRACTION, MULTIPLICATION AND DIVISION, THIS SWAN-PAN, OR "ARITHMETIC TABLE," WAS ALSO APPLIED TO ALGEBRA AND THE SOLUTION OF EQUATIONS. ENTRIES IN THE SQUARES BECAME THE COEFFICIENTS OF ALGEBRAIC EXPRESSIONS.



THIS TECHNIQUE HAD THE PICTURESQUE NAME OF "THE METHOD OF THE CELESTIAL ELEMENT."

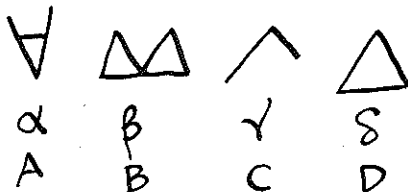
AFTER BORROWING THE DESIGN, THE JAPANESE USED IT TO CALCULATE π (PI) TO 50 DECIMAL PLACES. ONE JAPANESE MATHEMATICIAN WAS SAID TO HAVE CONVERTED A WHOLE ROOM INTO A "MAINFRAME" SWAN-PAN.



MEANWHILE, BACK AT THE MEDITERRANEAN, THEY HAD MADE TWO GREAT INVENTIONS: THE

ALPHABET & ABACUS.

THE ALPHABET RANKS AS ONE OF THE GREAT IDEAS IN THE HISTORY OF INFORMATION.



Before

THE ALPHABET, A SEPARATE SYMBOL WAS NEEDED FOR EVERY WORD (OR EVERY SYLLABLE, IN SOME CASES). TO LEARN WRITING, ONE HAD TO MEMORIZE THOUSANDS OF SYMBOLS.

WE CHINESE ARE STILL SADDLED WITH PICTOGRAMS!



After

DECOMPOSING LANGUAGE INTO MORE BASIC SOUNDS, THE NUMBER OF SYMBOLS WAS REDUCED TO FEWER THAN 30. NOW, ANY IDIOT COULD LEARN TO READ!

WHEREAS PREVIOUSLY, ONLY IDIOTS WITH LEISURE COULD LEARN...



THERE'S A LESS OBVIOUS ADVANTAGE OF THE ALPHABET, BUT NO LESS IMPORTANT:

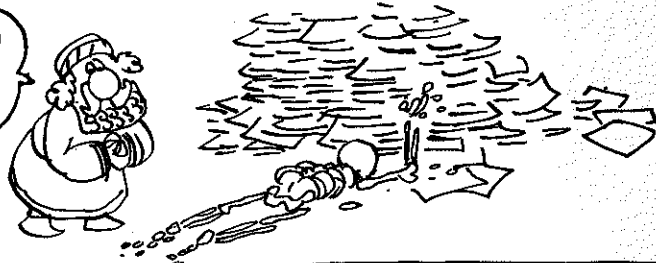
alphabetical order.



BACK ON PAGE 22 WE MENTIONED THE PROBLEM OF HOW TO FIND INFORMATION ONCE IT'S BEEN STORED.

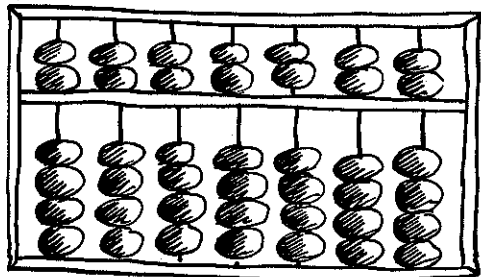
WITH THOUSANDS OF PICTOGRAMS, ANY FILING SYSTEM HAS TO BE COMPLICATED, BUT GIVEN THE ORDER OF AN ALPHABET, YOU CAN PUT WORDS IN ORDER, TOO. IMAGINE USING A PHONE BOOK, DICTIONARY, OR LIBRARY, WITHOUT ALPHABETICAL ORDER!

A VICTIM OF HIS FILING SYSTEM!



COMPUTERS SPEND A GOOD PART OF THEIR TIME JUST PUTTING THINGS IN ORDER!

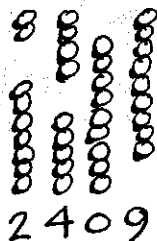
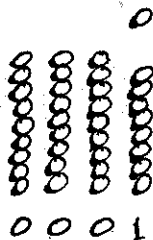
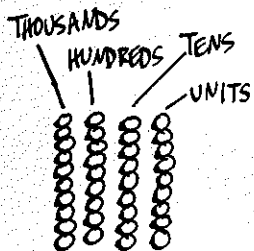
THE ABACUS, ORIGINALLY A PRODUCT OF THE MIDDLE EAST, IS A FULL-BLOWN HAND-HELD DECIMAL CALCULATOR.



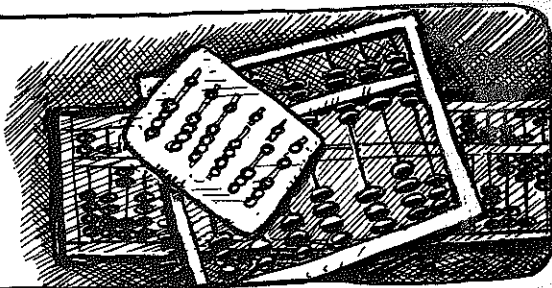
LIKE THE ALPHABET, THE ABACUS WAS SIMPLE, SYSTEMATIC AND SPEEDY. IN ITS SIMPLEST FORM, AN ABACUS WAS JUST A FEW COLUMNS OF PEBBLES. A PEBBLE IN A GIVEN COLUMN IS WORTH TEN PEBBLES IN THE COLUMN TO ITS IMMEDIATE RIGHT. NUMBERS ARE ENTERED BY PUSHING UP PEBBLES.

WHAT DOES IT DO?

MAKE UNEMPLOYED SCRIBES...



THE ABACUS HAS SEEN MANY INCARNATIONS AND BEEN USED IN MOST PARTS OF THE OLD WORLD.

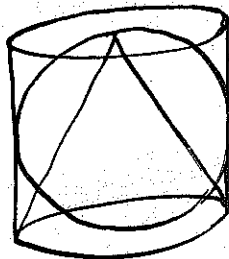


WE KNOW FROM PICTURES THAT THE ANCIENT GREEKS HAD THE ABACUS, BUT THEIR MATHEMATICIANS NEVER DISCUSSED IT. (GREEK INTELLECTUALS LOOKED DOWN ON THE WORK OF THE HANDS...)

THE TOOL OF SHOPKEEPERS!

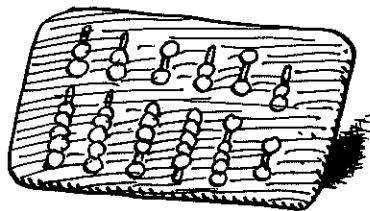


THIS MAY HAVE BEEN WHY GREEK MATHEMATICIANS CONCENTRATED ON GEOMETRY...



The Romans

ALSO USED THE ABACUS. THEIRS CONSISTED OF MARBLES SLIDING ON A GROOVED BRONZE PLATE:



IT CONTRIBUTED A COUPLE OF MATHEMATICAL WORDS TO ENGLISH:

IN LATIN,

CALX

MEANT LIMESTONE OR MARBLE...

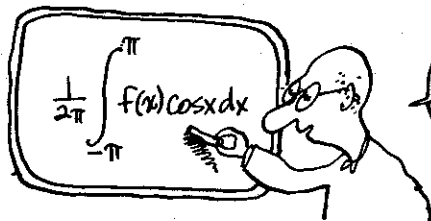
So

CALCULUS

WAS AN ABACUS PEBBLE... AND DOING ARITHMETIC WAS

CALCULATION.

THE ROMANS DID NOT CALCULATE WITH ROMAN NUMERALS!!



FROM WHICH COMES "CHALK!"

WHAT'S MXVIII TIMES CLXVI?

BEATS ME! I LOST MY MARBLES...



THE ROMAN EMPIRE DECLINED...

PHAW! COMPUTER GAMES!

...AND FELL...
ROME WAS SACKED...
CHRISTIANITY ROSE FROM ITS ASHES...
CLASSICAL LEARNING VANISHED IN THE WEST...
AND ONLY A FEW MATH PROBLEMS REMAINED LEGITIMATE, LIKE COMPUTING THE DATE OF EASTER...
OR HOW MANY ANGELS FIT ON THE HEAD OF A PIN...



SIX! COUNT 'EM YOURSELF!

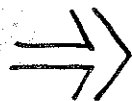
+++IN SUM?++++

ANCIENT TIMES
WERE REALLY THE

AGE OF
CALCULATORS.



ET TO?
ET THREE!



ALTHOUGH THE ANCIENTS HAD WAYS OF WRITING
NUMBERS, THEY RARELY CALCULATED IN
WRITING.

THIS IS NOT SO EASY TO APPRECIATE FOR THOSE OF US
WHO WERE RAISED ON PENCIL AND PAPER.

SO THE NEXT
TIME YOU
HEAR SOMEONE
COMPLAIN THAT
ELECTRONIC
CALCULATORS
ARE
RUINING
ARITHMETIC...

HOW CAN
WE REMEMBER
OUR MULTIPLICATION
TABLES?

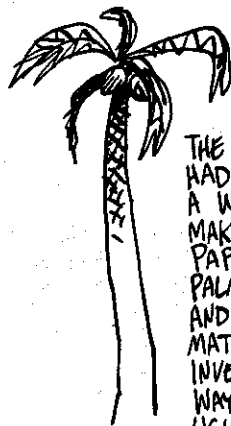


...SIMPLY REPLY THAT
PEOPLE SURVIVED WITH
CALCULATORS FOR
MORE THAN 4000 YEARS!!

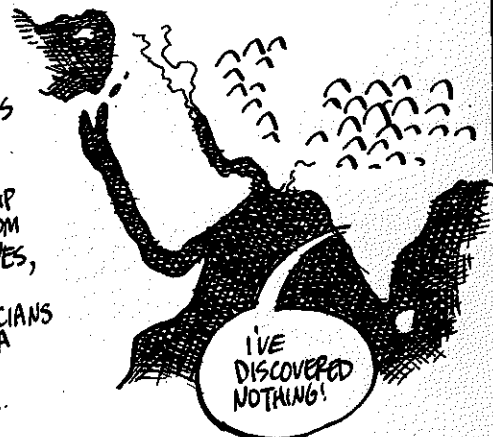


Much to do about **NOTHING**

AS FAR AS CALCULATION GOES, THE AGE
OF PAPER BEGAN IN INDIA, ABOUT
650 A.D.

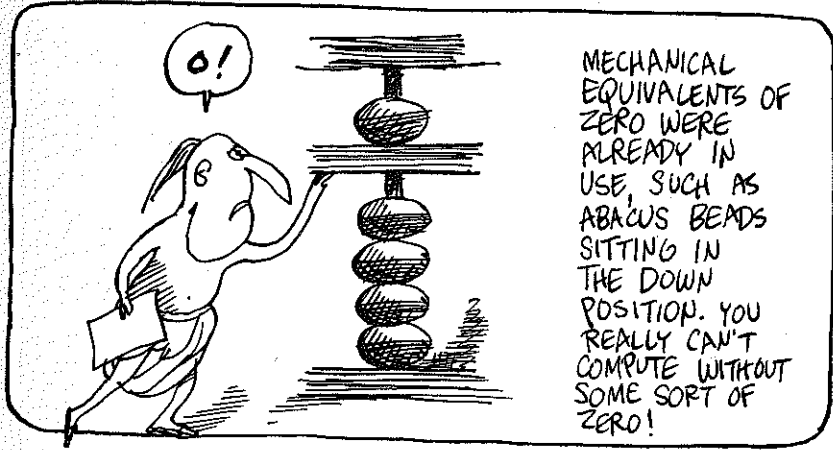


THE INDIANS
HAD FOUND
A WAY TO
MAKE CHEAP
PAPER FROM
PALM LEAVES,
AND THEIR
MATHEMATICIANS
INVENTED A
WAY OF
USING IT...



TO DO SO, THEY DEvised A SYMBOL FOR **ZERO**!



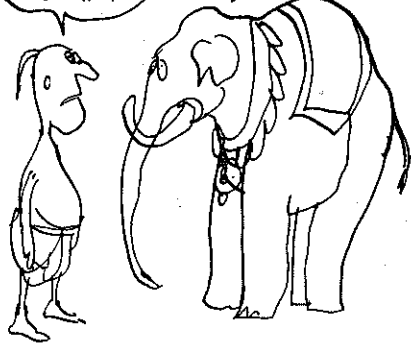


MECHANICAL EQUIVALENTS OF ZERO WERE ALREADY IN USE, SUCH AS ABACUS BEADS SITTING IN THE DOWN POSITION. YOU REALLY CAN'T COMPUTE WITHOUT SOME SORT OF ZERO!

WHY HADN'T ANYONE THOUGHT OF PUTTING IT IN WRITING BEFORE? MAYBE BECAUSE WRITING WAS FOR REPRESENTING SPOKEN LANGUAGE, AND NOBODY SAYS -

ONE HUNDRED, NO TENS AND SIX!

IS THAT PEDANTIC OR VEDANTIC?



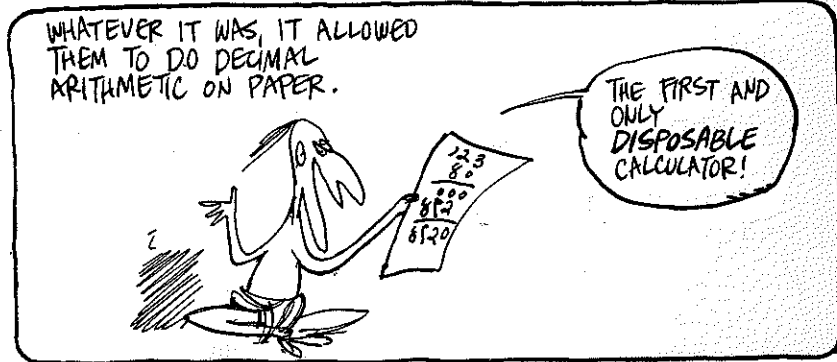
BUT FOR SOME REASON, THE HINDUS INVENTED A WRITTEN ZERO!

१ २ ३ ४ ५ ६ ७ ८ ९ ०

WE MAY NEVER KNOW EXACTLY WHAT INSPIRED THEM.



I JUST LOOKED IN MY BEGGING BOWL AND THERE IT WAS...

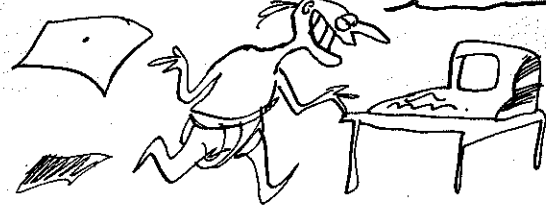


WHATEVER IT WAS, IT ALLOWED THEM TO DO DECIMAL ARITHMETIC ON PAPER.

THE FIRST AND ONLY DISPOSABLE CALCULATOR!

AND SO BEGAN THE AGE OF PENCIL AND PAPER, A MERE 1300 YEARS AGO - PRETTY BRIEF COMPARED WITH THE AGE OF CALCULATORS!!

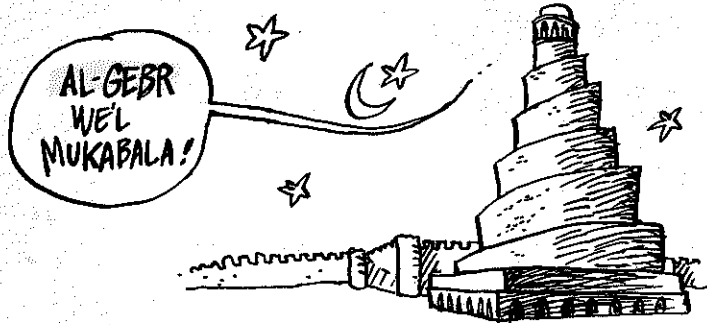
AH WELL... EASY COME, EASY GO...



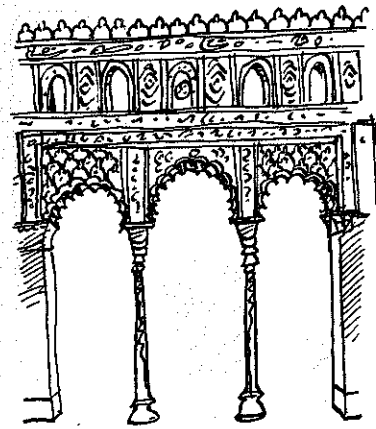
THE INDIAN MATH WAS PICKED UP BY THE **ARABS**, WHO SPREAD IT ALL THE WAY WEST TO SPAIN.



AROUND THE YEAR 830, A PERSIAN SCHOLAR WROTE THE STANDARD TEXT BOOK ON THE SUBJECT. HIS NAME WAS MOHAMMED IBN MUSA ABU DJEFAR, BUT HE WAS KNOWN AS **AL-KHWARISMI**. AND THE SUBJECT OF HIS BOOK?



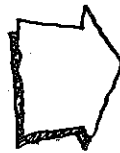
OR **ALGEBRA**, FOR SHORT.



BY THE 1100'S, MUSLIM CIVILIZATION HAD GROWN SO MAGNIFICENT THAT THE EUROPEANS WERE BEGINNING TO WONDER...



A FEW INTREPID INFIDELS WENT TO LIVE AMONG THE ARABS, LEARNED THEIR LANGUAGE, SNUCK INTO THEIR UNIVERSITIES, AND TRANSLATED THEIR CLASSICS INTO LATIN.



IN AL-KHWARISMI'S BOOK THEY FOUND THE INDIAN NUMERALS.



AL-KHWARISMI
AL-KARISMI
ALGARISMI
ALGORISMI

PRONOUNCED OFTEN ENOUGH, THE MATHEMATICIAN'S NAME WAS TURNED INTO

ALGORISM

WHICH IS WHAT THE EUROPEANS CALLED THE NEW SYSTEM OF CALCULATION.



YETH,
VERY
NITHE...

FROM THE SAME ROOT COMES

ALGORITHM

A COMPUTER WORD WE'LL EXPLORE IN A BIT...

THIS "ALGORISM"
CAUGHT ON
ONLY SLOWLY
AT FIRST. THE
MERCHANTS
DISLIKED IT
BECAUSE IT WAS
TOO EASY TO FALSIFY,
THEY SAID...

YOU CAN TURN THIS
"0" INTO 6 OR 9...
3 LOOKS TOO MUCH
LIKE 8, ETC..

THAT'S
WHY I
LIKE IT!



... AND EVERYONE AGREED IT WAS A PAIN
TO MEMORIZE MULTIPLICATION TABLES..

1	2	3	4	5	6	7	8	9	
1	2	3	4	5	6	7	8	9	1
	4	6	8	10	12	14	16	18	2
		9	12	15	18	21	24	27	3
			16	20	24	28	32	36	4
				25	30	35	40	45	5
					36	42	48	54	6
						49	56	63	7
							64	72	8
								81	9

MOAN



BUT IT DID CATCH ON —
NOT NECESSARILY BECAUSE IT
WAS FASTER THAN THE
ABACUS — IT WASN'T — BUT
BECAUSE, AS THE ARABS
KNEW, IT ENCOURAGES
ABSTRACT SYMBOL-MANIPULATION:
FIRST ALGEBRA, AND LATER
THE CALCULUS AND ALL
OTHER HIGHER MATHEMATICS.

$$ax + b = 0$$

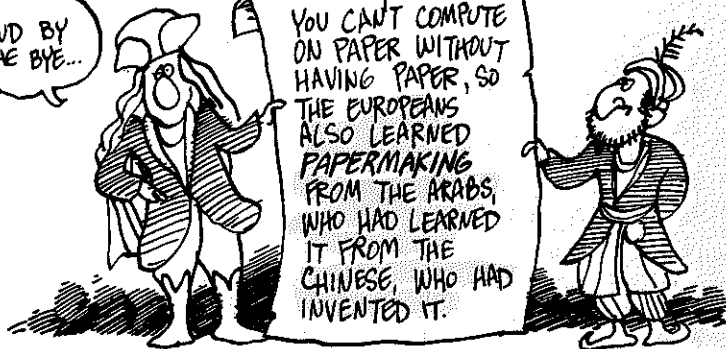
$$ax = -b$$

$$x = \frac{-b}{a}$$



AND BY
THE BYE...

YOU CAN'T COMPUTE
ON PAPER WITHOUT
HAVING PAPER, SO
THE EUROPEANS
ALSO LEARNED
PAPERMAKING
FROM THE ARABS,
WHO HAD LEARNED
IT FROM THE
CHINESE, WHO HAD
INVENTED IT.



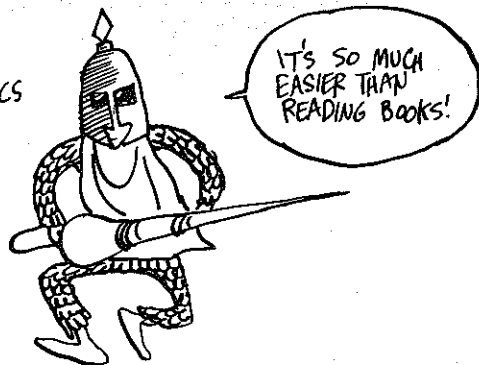
IN EXCHANGE, THE
CHINESE TOOK
THE **ABACUS**
AND RAPIDLY
MADE IT THEIR
NO. 1 CALCULATOR.
FROM CHINA
THE ABACUS
SPREAD TO JAPAN,
WHERE — NEED
I SAY IT? —
ITS DESIGN
WAS IMPROVED!

I THINK
WE CAN MAKE
IT WITH ONE
LESS BEAD...



BUT BACK TO ALGORISM... ⇒

WHILE EUROPEAN SCHOLARS WERE TRANSLATING THE CLASSICS IN ARAB LIBRARIES, THE **CRUSADERS** WERE DOING THEIR BEST TO DESTROY ISLAMIC CIVILIZATION.

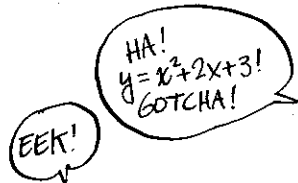


THIS DOUBLE-PRONGED ACTION OF TRANSLATION AND DESTRUCTION LED TO THE GROWTH OF EUROPEAN LEARNING AND POWER KNOWN AS:

The RENAISSANCE.



MILITARY ADVANCES OFTEN GO HAND IN HAND WITH MATHEMATICAL ONES.



IN THE 1500'S, NICCOLO TARTAGLIA (1499-1559) COMPUTED THE PATHS OF CANNONBALLS (AN IMPORTANT PROBLEM IN THE LATER HISTORY OF COMPUTERS, AS WE'LL SEE).

JUST OVER A CENTURY LATER, ISAAC NEWTON UNIFIED THE MOTIONS OF CANNONBALLS AND PLANETS WITH THE THEORY OF **GRAVITATION**, ONE OF THE AGE OF PENCIL AND PAPER'S CROWNING GLORIES.



HOWEVER, THE THEORY INTRODUCED SOME REAL COMPUTATIONAL HORRORS...

THE WORST WAS THE **THREE BODY PROBLEM**, WHICH ASKS FOR A MATHEMATICAL DESCRIPTION OF THE MOTIONS OF THREE BODIES — SUN, EARTH, AND MOON, FOR EXAMPLE — ACTING UNDER THE INFLUENCE OF GRAVITY. THIS TURNS OUT TO BE INCREDIBLY DIFFICULT AND TEDIOUS!

WE'RE REACHING THE LIMITS OF PAPER!



SO A NUMBER OF SCIENTISTS BEGAN THINKING AGAIN ABOUT CALCULATION BY MACHINE...

John NAPIER (1550-1617),

A HALF-MAD SCOT MOST FAMOUS FOR LOGARITHMS, DEvised "NAPIER'S BONES."

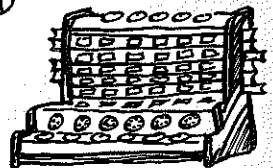


THESE WERE SIMPLY MULTIPLICATION TABLES ON A STICK.

THE FIRST REAL MACHINE WAS BUILT BY **Wilhelm SCHICKARD** (1592-1635).

IT COULD ADD, SUBTRACT, MULTIPLY, AND DIVIDE... BUT WAS LOST IN THE 30-YEAR WAR.

SCHICKARD HIMSELF DIED OF PLAQUE AND COULDN'T DEFEND HIS PRIORITY, SO...



Blaise PASCAL (1623-1662)

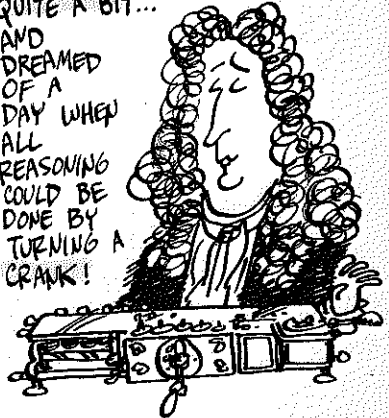
USUALLY GETS CREDIT FOR BUILDING THE FIRST CALCULATOR HIS "PASCALINE" COULD ONLY ADD AND SUBTRACT.



Gottfried Wilhelm LEIBNIZ (1646-1716)

IMPROVED PASCAL'S DESIGN QUITE A BIT...

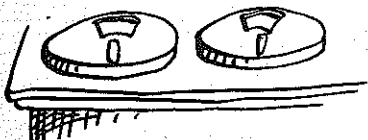
AND DREAMED OF A DAY WHEN ALL REASONING COULD BE DONE BY TURNING A CRANK!



DURING THE 1700'S,
MORE SUCH MACHINES
WERE BUILT, BUT
ALL FELL FAR
SHORT OF BEING
ANYTHING LIKE
A GENERAL-PURPOSE
COMPUTER.



FOR EXAMPLE: IN EVERY CASE, THE USER ENTERED
NUMBERS BY SETTING A ROW OF WHEELS OR KNOBS ...



... AND THEN
TURNED THE
APPROPRIATE
CRANK TO ADD
OR MULTIPLY.

ANOTHER WAY
OF SAYING THE
SAME THING:



THE **INPUT**
CONSISTED ONLY OF THE
NUMBERS TO BE COMBINED.

AS WILL BE PLAIN
SOON ENOUGH, AN
ALL-PURPOSE COMPUTER
MUST ALSO BE ABLE TO
DO MORE: IT MUST READ
INSTRUCTIONS
ABOUT WHAT TO DO
WITH THOSE NUMBERS!!

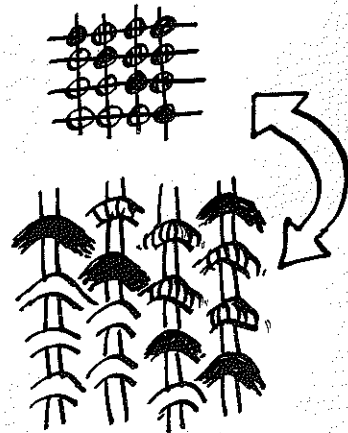


WELL, I
WAS ONLY
TRYING TO
MAKE AN
ADDING
MACHINE...

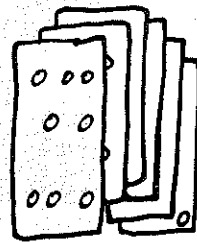
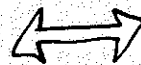
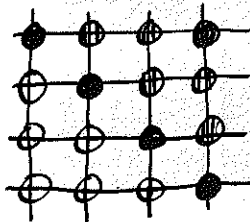
THE GERM OF THIS IDEA CAME NOT FROM THE LAB OR
A SCIENTIST'S STUDY, BUT THE SOOTY FACTORIES OF THE



YOU MAY NEVER
HAVE THOUGHT OF
A **WEAVER'S LOOM**
AS AN INFORMATION
PROCESSOR, AND
YET: IT TRANSLATES
AN ABSTRACT
DESIGN INTO A
PATTERN OF COLORS,
CREATED BY
LOOPING OVER EACH
COLORED THREAD
AT THE
APPROPRIATE PLACE.



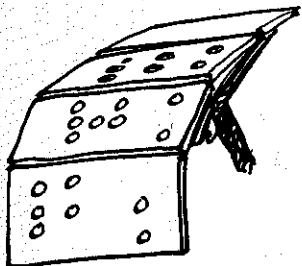
IN THE MID-1700'S, A SYSTEM WAS INVENTED FOR
REPRESENTING THESE PATTERNS ON **PUNCHED**
CARDS.



WITH AN OLD-FASHIONED
HANDLOOM, THE WEAVER
READ THE CARDS,
BUT IN 1801, JOSEPH MARIE

JACQUARD

INVENTED A POWER
LOOM WITH AN
AUTOMATIC CARD READER.



IN WENT THE CARDS, OUT CAME THE CLOTH...

AND OUT GO
THE JOBS!



THE JACQUARD LOOM WORKED SO WELL THAT THOUSANDS
OF UNEMPLOYED WEAVERS RIOTED AND NEARLY KILLED
THE INVENTOR.

ACROSS THE ENGLISH
CHANNEL, JACQUARD'S
IDEA SET OFF A
CHAIN REACTION IN THE
BRAIN OF

CHARLES BABBAGE

(1792-1871),

WHO HAS BECOME KNOWN
AS THE "FATHER OF
THE COMPUTER."

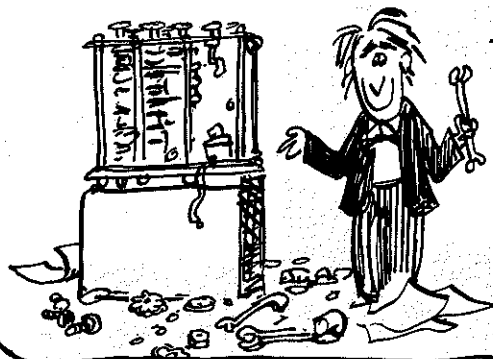


I SEE NO
FAMILY
RESEMBLANCE!



FOR SEVERAL YEARS BABBAGE, A CAMBRIDGE MATH PROFESSOR,
HAD BEEN WORKING ON A LARGE MECHANICAL CALCULATOR HE
CALLED "THE DIFFERENCE ENGINE."

MY ORIGINAL
BRAINSTORM...



IT WOULD HAVE
COMPUTED MATHEMATICAL
TABLES, IF THE
INVENTOR HAD EVER
BEEN ABLE TO FINISH IT.

IN 1822, BABBAGE APPLIED TO THE ROYAL SOCIETY FOR FUNDS TO BUILD THE DIFFERENCE ENGINE, AND THEY GAVE HIM A SIZABLE GRANT.



HE HIRED A MASTER MACHINIST AND WENT TO WORK... BUT BABBAGE COULDN'T RESIST THINKING UP NEW IMPROVEMENTS IN THE MIST OF PRODUCTION!

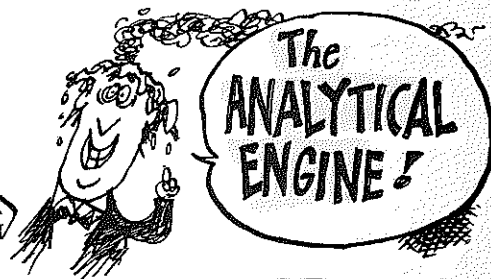


JOLLY GOOD SHOW, OLD CHAP!!! NOW TRY IT AGAIN, ACCORDING TO THE NEW SPECS!

MEANWHILE, HIS HYPERACTIVE MIND KEPT TURNING TO NEW PROJECTS: LIFE INSURANCE TABLES, LIGHTHOUSE SIGNALS, GLASS CUTTING, AND EVEN VOLCANOES. (HE KICKED INTO A LIVE ONE!!)



THAT'S HOW MATTERS STOOD WHEN JACQUARD'S PUNCHED CARDS SET OFF BABBAGE'S NEW BRAINSTORM, A MACHINE HE CALLED:



BECAUSE IT SO CLOSELY RESEMBLED A COMPUTER, LET'S TAKE A CLOSER LOOK AT THE ANALYTICAL ENGINE, AS BABBAGE IMAGINED IT. ITS COMPONENTS INCLUDED—

THE MILL:

AT THE ENGINE'S HEART WOULD BE A GREAT NUMBER-CRUNCHER, AN ADDING MACHINE ACCURATE TO 50 DECIMAL PLACES. BABBAGE CALLED THIS THE MILL.



HOW DID IT KNOW WHAT TO DO?



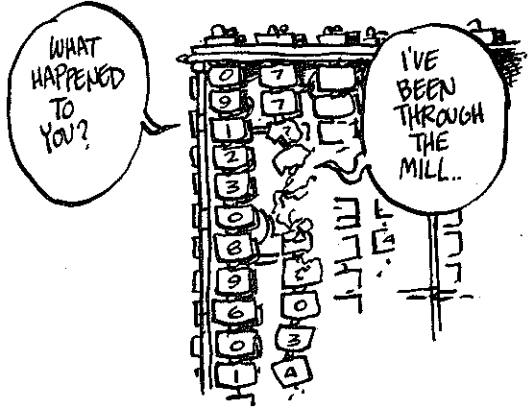
THE INSTRUCTIONS TO THE MILL WOULD BE READ IN ON PUNCHCARDS.

THAT IS, THE PUNCHCARDS CONVEYED NOT ONLY THE NUMBERS TO BE CRUNCHED BUT ALSO THE PATTERN OF CRUNCHING!!

SO THE MACHINE WOULD NEED A SPECIAL CARD-READING INPUT DEVICE.

TO RETAIN NUMBERS FOR FUTURE REFERENCE, BABBAGE ENVISIONED A MEMORY UNIT, OR **STORE**.

THIS WAS TO BE A BANK OF 1000 "REGISTERS," EACH A DEVICE CAPABLE OF STORING ONE 50-DIGIT NUMBER. THESE NUMBERS COULD EITHER BE INPUT FROM THE CARDS OR THE RESULT OF COMPUTATIONS IN THE MILL.









HAVE I FORGOTTEN ANYTHING?



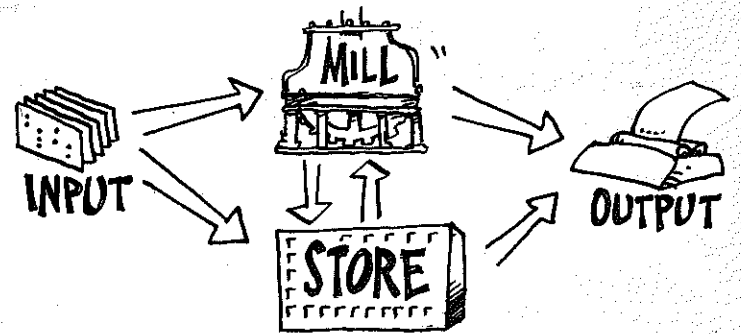
FINALLY, THE **OUTPUT!**

BABBAGE DESIGNED THE WORLD'S FIRST AUTOMATED TYPE SETTER TO PRINT THE RESULTS OF COMPUTATIONS.

A PUNCHCARD COULD DO ONE OF THE FOLLOWING THINGS:

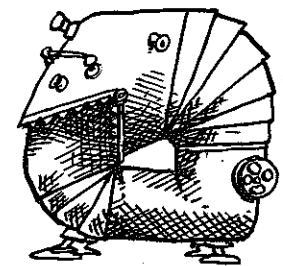
-  INPUT A NUMBER TO THE STORE
-  INPUT A NUMBER TO THE MILL
-  MOVE A NUMBER FROM THE MILL TO THE STORE
-  MOVE A NUMBER FROM THE STORE TO THE MILL
-  INSTRUCT THE MILL TO PERFORM AN OPERATION
-  OUTPUT A NUMBER FROM EITHER STORE OR MILL

WHICH MAY BE SUMMARIZED IN THIS DIAGRAM:



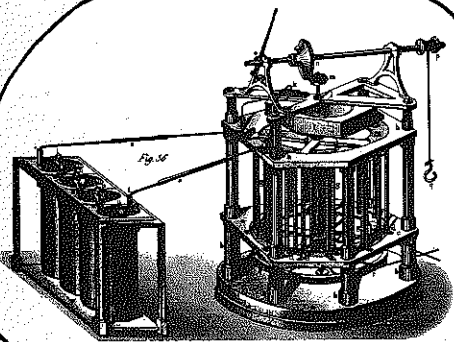
IN PARTICULAR, A RESULT FROM THE MILL COULD BE STORED FOR FUTURE REFERENCE, THEN RETURNED TO THE MILL

WHEN NEEDED. AS BABBAGE PUT IT, THE ANALYTICAL ENGINE COULD "EAT ITS OWN TAIL." VERY FLEXIBLE!



YOU HAVE TO BE FLEXIBLE TO EAT YOUR OWN TAIL...

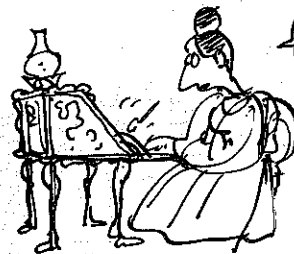
SO FAR, THESE IDEAS WERE STILL ON THE DRAWING BOARD. NOW BABBAGE BEGAN LOOKING FOR SYMPATHETIC SOULS WHO COULD HELP PUT HIS PLANS INTO OPERATION.



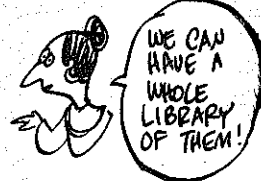
THE MOST SYMPATHETIC WAS
ADA AUGUSTA,
 LADY LOVELACE, DAUGHTER
 OF THE POET LORD BYRON
 AND AN ENTHUSIASTIC
 AMATEUR MATHEMATICIAN.
 IF CHARLES BABBAGE IS THE
 COMPUTER'S FATHER, ADA
 LOVELACE IS ITS MOTHER!!



ADA BECAME
 THE FIRST
PROGRAMMER:
 SHE WROTE OUT
 ACTUAL SEQUENCES
 OF INSTRUCTIONS
 FOR THE
 ANALYTICAL ENGINE...



SHE INVENTED THE **SUBROUTINE:** A SEQUENCE OF INSTRUCTIONS WHICH CAN BE USED AGAIN AND AGAIN IN MANY CONTEXTS.



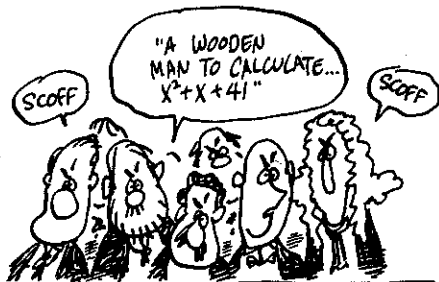
SHE RECOGNIZED THE VALUE OF **LOOPING:** THERE SHOULD BE AN INSTRUCTION THAT BACKS UP THE CARD READER TO A SPECIFIED CARD, SO THAT THE SEQUENCE IT INITIATES CAN BE EXECUTED REPEATEDLY.



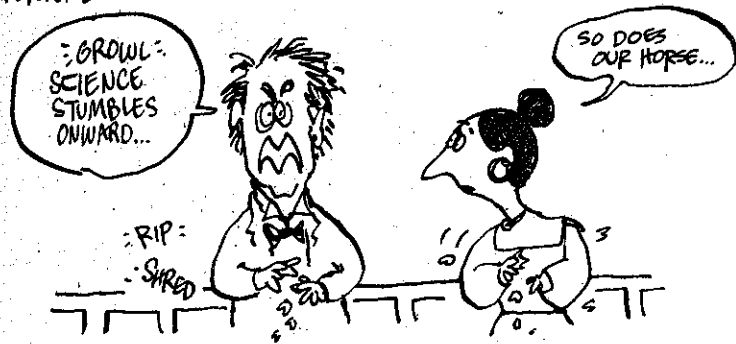
AND SHE DREAMED UP THE **CONDITIONAL JUMP:** THE CARD READER COULD "JUMP" TO ANOTHER CARD IF SOME CONDITION IS SATISFIED.



NOT BAD FOR A MACHINE THAT NEVER EXISTED... THE GOVERNMENT REFUSED TO SUPPORT IT, IN VIEW OF BABBAGE'S TRACK RECORD WITH THE DIFFERENCE ENGINE. THEY CALLED IT:



DESPERATE FOR FUNDS, BABBAGE COOKED UP A "SCIENTIFIC" RACETRACK BETTING SCHEME — AND SQUANDERED ADA'S FORTUNE.



THE STORY ENDED UNHAPPILY: ADA DIED YOUNG... AND BABBAGE NEVER FINISHED THE ANALYTICAL ENGINE, WHICH BECAME THE FIRST EXAMPLE OF—

BABBAGE'S LAW:

COMPUTERS ARE NEVER BUILT ON TIME!

THE ILL-STARRED INVENTORS WERE AHEAD OF THEIR TIME. NOTHING EQUIVALENT TO THE ANALYTICAL ENGINE EXISTED UNTIL THE 1940'S.

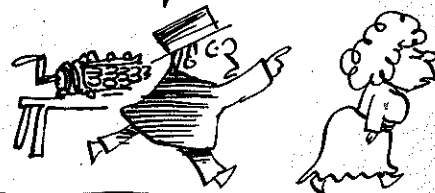


ALMOST AS LATE AS OUR HORSE...

IN THE MEANTIME, MATTERS PROGRESSED IN TWO DIRECTIONS:

ON THE ONE HAND WERE MECHANICAL CALCULATORS: SEVERAL ENGINEERS BUILT BABBAGE-INSPIRED DIFFERENCE ENGINES. FOR SOME REASON, THESE NEVER CAUGHT ON...

YOU DON'T WANT TO COMPUTE X^2+X+41 IN YOUR VERY OWN LIVING ROOM?



ON THE OTHER HAND WERE THE PUNCHCARD MACHINES, BEGINNING WITH THE CENSUS TABULATORS DESIGNED BY

HERMAN HOLLERITH (1860-1929)

INSPIRED, AS BABBAGE HAD BEEN, BY THE JACQUARD LOOM, HOLLERITH INVENTED A MACHINE PURELY FOR ACCUMULATING AND CLASSIFYING INFORMATION.



BECAUSE THIS WAS A NEW SORT OF JOB FOR A MACHINE— AND THE KIND FOR WHICH COMPUTERS ARE IDEALLY SUITED— LET'S TAKE A CLOSER LOOK.

THIS IS A LITTLE LIKE PREDICTING YESTERDAY'S WEATHER...

BEFORE HOLLERITH, THE CENSUS BUREAU PROCESSED ALL DATA BY HAND... SLOWLY. THE 1880 CENSUS TOOK 7½ YEARS TO ANALYZE!



THEN AS NOW, THE CENSUS FORM CONSISTED OF A SERIES OF MULTIPLE CHOICE QUESTIONS...



HOW MANY CHILDREN DO YOU HAVE?
 a) 0-2 b) 3-7 c) 8-20
 d) MORE THAN 20
 WHAT'S YOUR RELIGIOUS PREFERENCE?
 a) MILITANT HINDU b) I.W.W.
 c) FUNDAMENTALIST VEGETARIAN
 d) OTHER
 ETC...



FROM THIS, ONE WANTED TO FIND:

THE TOTAL NUMBER OF CITIZENS...

HOW MANY HAD 0-2 CHILDREN...

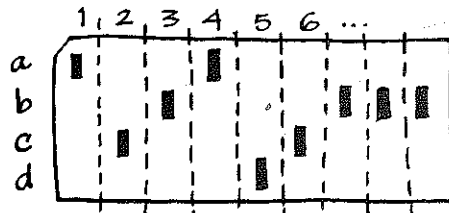
HOW MANY WERE MILITANT HINDUS...
 ETC!

AS WELL AS SUCH THINGS AS:



HOW MANY FUNDAMENTALIST VEGETARIANS HAVE MORE THAN 20 CHILDREN?

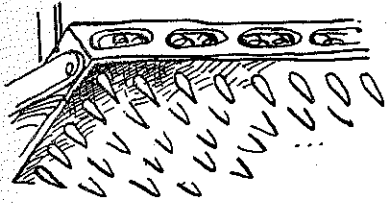
HOLLERITH PROPOSED TO PUT EACH PERSON'S RESPONSES ON A SINGLE PUNCHED CARD THE SIZE OF AN 1880 DOLLAR BILL. TO OVER-



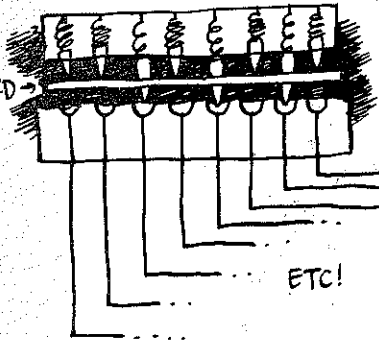
SIMPLIFY SLIGHTLY, EACH COLUMN REPRESENTED ONE QUESTION. THE HOLE IN A GIVEN COLUMN INDICATED THE ANSWER TO THAT QUESTION.

THIS CARD SHOWS RESPONSES OF 1-a, 2-c, 3-b, 4-a, 5-d, ETC...

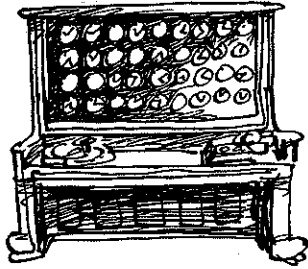
THE CARDS WERE "READ" BY A DEVICE CONSISTING OF A GRID OF LITTLE PINS MOUNTED ON SPRINGS AND WIRED ELECTRICALLY.



WHEN BROUGHT INTO CONTACT WITH THE CARD, ONLY THOSE PINS LYING OVER A HOLE WOULD PASS THROUGH. EACH OF THESE DIPPED INTO A SMALL CUP OF MERCURY, COMPLETING AN ELECTRICAL CIRCUIT.



EACH CUP WAS WIRED TO A COUNTER, WHICH ADVANCED EACH TIME AN ELECTRIC PULSE ARRIVED.



AND SO THE RUNNING TOTALS OF EVERY POSSIBLE RESPONSE WERE CONTINUOUSLY DISPLAYED!



DOES IT COUNT UNEMPLOYED WORKERS?

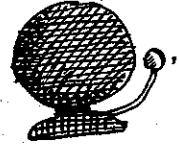
THE TABULATOR ALSO HELPED ANSWER QUESTIONS SUCH AS: "HOW MANY PEOPLE WHO ANSWERED 2-a ALSO ANSWERED 3-c?"

MEANING: HOW MANY MILITANT HINDUS LIVE IN KANSAS?

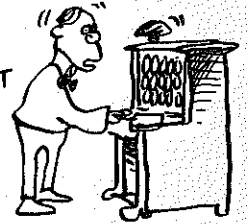


HERE'S HOW:

FIRST, ARRANGE A BELL TO RING WHENEVER A CARD WITH 2-a IS ENTERED.



THEN RUN THROUGH ALL CARDS, PULLING OUT ALL THOSE THAT RING THE BELL.



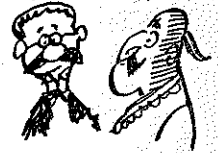
THIS CREATES A STACK OF ALL THE MILITANT HINDU CARDS. RUN THESE THROUGH THE TABULATOR AGAIN.



THE MACHINE THEN SHOWS ALL THE TOTALS FOR MILITANT HINDUS.

HOW MANY DO LIVE IN KANSAS?

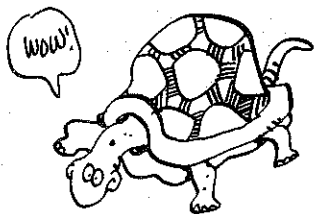
ZERO!



THIS SORT OF JOB - ANALYZING AND COMPARING LARGE AMOUNTS OF INFORMATION - IS NOW KNOWN AS?

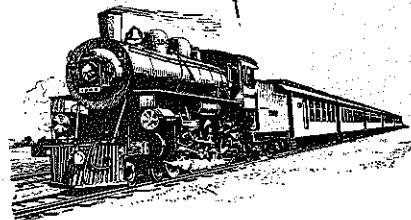
DATA PROCESSING.

THE HOLLERITH TABULATOR CUT THE DATA PROCESSING TIME FOR THE 1890 CENSUS BY **TWO THIRDS**, TO $2\frac{1}{2}$ YEARS. THIS SOUNDS LONG NOW, BUT AT THE TIME, IT WAS IMPRESSIVE!!



HOLLERITH FOUNDED A COMPANY TO MANUFACTURE HIS CARD-OPERATED DATA PROCESSORS, AND HE FOUND A NUMBER OF TAKERS:

A RAILROAD COMPANY USED THE TABULATOR FOR AUDITING FREIGHT STATISTICS...
A TOOL MANUFACTURER TURNED IT TO COMPILING COSTS, ANALYZING PAYROLL, AND MANAGING INVENTORY...
A WHOLESALER HOUSE NEEDED IT TO KEEP TRACK OF MERCHANDISE, SALES, SALESMEN, CUSTOMERS, ETC ETC ETC...



THIS COMPANY IS GOING SOMEWHERE!

SO HOLLERITH'S COMPANY DID FAIRLY WELL... LATER, IT GOT INTO COMPUTERS, TOO... AND DID WELL... YOU MAY HAVE HEARD OF IT... TODAY IT'S CALLED

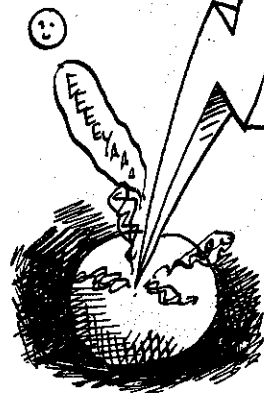
IBM.

So BIG, IT DOESN'T FIT IN THE PANEL!



IN CASE YOU HADN'T NOTICED, HOLLERITH'S TABULATOR USED

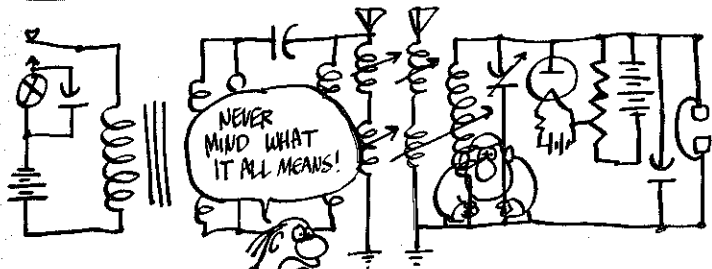
ELECTRICITY.



THIS BRINGS US TO THE 20TH CENTURY AND ITS ELECTRIC MARVELS, RADIO, TELEPHONE, THE LIGHT BULB, WHICH ALL PLAY A ROLE IN THE FINAL EPISODES OF COMPUTER EVOLUTION...

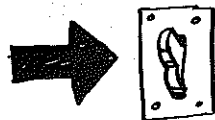
HELLO? I'D LIKE TO REPORT MY THUNDER STOLEN...



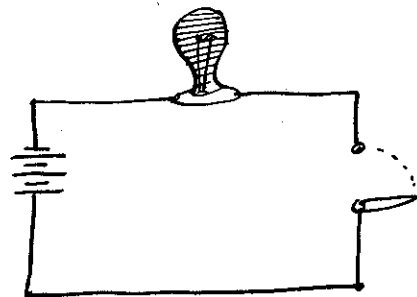
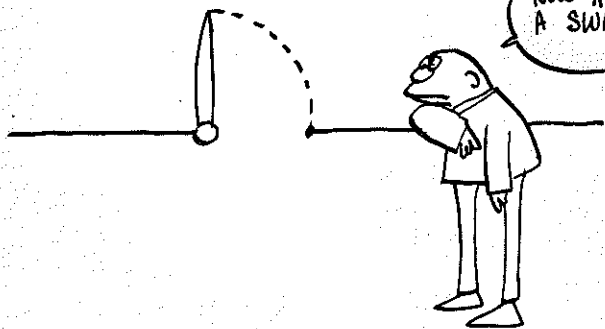


IN THE MIDST OF ALL THIS COMPLEX CIRCUITRY SOME RESEARCHERS FOCUSED ON THE SIMPLEST ELECTRICAL PART OF ALL:

THE SWITCH

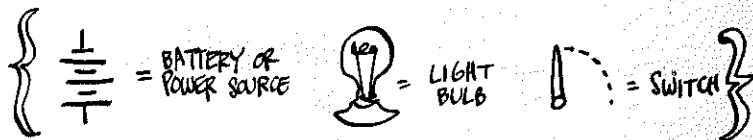
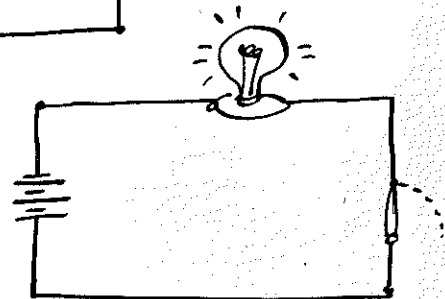


A SWITCH IS ANY KIND OF DEVICE WHICH CAN OPEN OR CLOSE AN ELECTRIC CIRCUIT.



WHEN THE SWITCH IS OPEN, IT BREAKS THE CIRCUIT, AND NO CURRENT FLOWS THROUGH THE LIGHT BULB.

WHEN THE SWITCH IS CLOSED, THE CIRCUIT IS COMPLETE AND THE BULB LIGHTS UP.

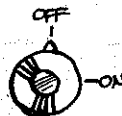


A FEW FAMILIAR SWITCHES:

TOGGLE SWITCHES



ROTARY SWITCHES



PUSHBUTTON SWITCHES

A LESS FAMILIAR SWITCH IS THE **TELEPHONE**

SWITCH. YOU CAN'T SEE IT, BUT IT COMPLETES THE CONNECTION BETWEEN YOUR PHONE AND THE ONE YOU'VE DIALED.

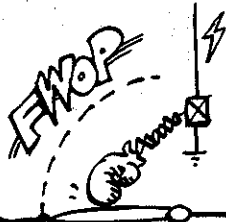


IN THE OLD DAYS, THIS HAD TO BE DONE BY HAND —

THE OPERATOR'S WORK STATION WAS CALLED A **SWITCHBOARD**, AFTER ALL!



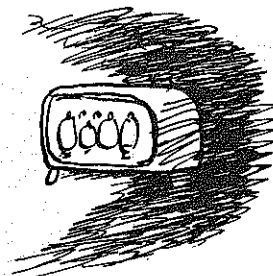
THEN THE PHONE CO., IN ITS WISDOM, CAME UP WITH THE **AUTOMATIC RELAY**. ON RECEIVING AN ELECTRIC SIGNAL, THIS SWITCH WOULD CLOSE AND "RELAY" YOUR CALL TO THE RIGHT PLACE.



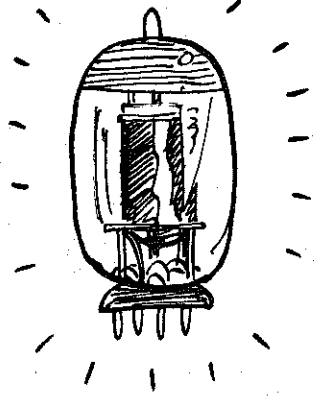
THE TELEPHONE RELAY COULD SWITCH MUCH FASTER THAN THE HUMAN HAND — ABOUT 5 TIMES PER SECOND! IT MADE THE SWITCHBOARD OPERATOR OBSOLETE...



BUT IT COULDN'T HOLD A CANDLE TO ANOTHER TYPE OF SWITCH INVENTED EVEN EARLIER: THE **VACUUM TUBE**.



REMEMBER WHEN TUBES USED TO GLOW IN THE BACK OF THE RADIO? YOU DON'T? SIGH...



THE TUBE CAN ALSO BE FLIPPED ON AND OFF LIKE A SWITCH, SO FAST YOU CAN'T EVEN SEE IT FLICKER: IT JUST GLOWS... BUT IT CAN SWITCH AS OFTEN AS

1,000,000
TIMES PER SECOND!!!





NOT LONG AFTER THESE SWITCHES WERE INVENTED, PEOPLE REALIZED THAT THEY COULD BE COMBINED INTO COMPUTER COMPONENTS!

WHAT IS,

PATTERNS OF SWITCHES CAN BE ARRANGED TO **ADD,** TO **STORE,** AND EVEN TO EMBODY **LOGICAL RELATIONSHIPS** (WHATEVER THAT MEANS). DETAILS LATER!

IF I INSERT FINGER AND FLIP THIS SWITCH, THEN I AM A DEAD ENGINEER!

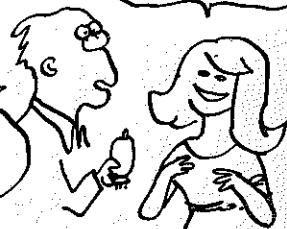
BY THE 1930'S, A NUMBER OF PEOPLE HAD SEEN HOW VERY RAPID COMPUTERS COULD BE BUILT FROM HARDWARE STRAIGHT OFF THE SHELF!!



DESPITE THE TUBES FANTASTIC SWITCHING SPEED, THE FIRST ELECTRONIC COMPUTING MACHINES USED ELECTROMECHANICAL SWITCHES LIKE RELAYS, BECAUSE THEY WERE MORE RELIABLE.

REMINDS ME OF MY EX-HUSBAND...

TUBES GET TOO HOT AND BURN OUT!



Who built THE FIRST ELECTROMECHANICAL COMPUTER? THE VERY FIRST WAS **KONRAD ZUSE** (1910-). HIS Z-1, BUILT IN 1936, CALCULATED WITH RELAYS AND READ INPUT FROM PUNCHED FILM.

ZUSE, A GERMAN, TRIED TO SELL THE Z-1 TO HIS GOVERNMENT FOR WAR WORK.

IT CAN PLAY "BATTLE OF BRITAIN"! "FRENCH INVADERS"! "STALINGRAD"!



THE NAZIS ASSUMED THEY HAD "ALL BUT" WON THE WAR, SO THEY TURNED HIM DOWN... AND POSSIBLY CHANGED HISTORY!!

Aha!



THE COMPUTER WAS REALLY BORN WITH

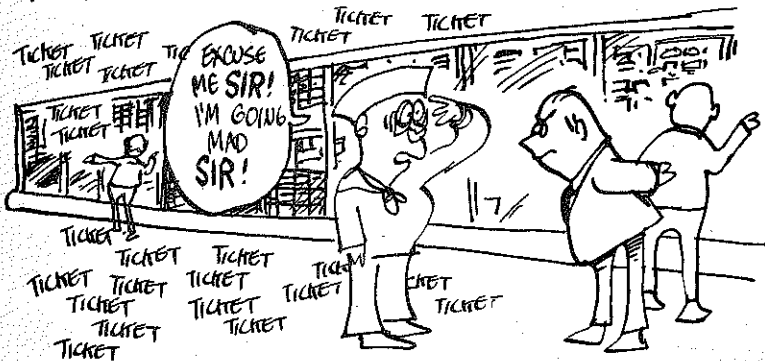
WORLD WAR II

(NOTE ROMAN NUMERAL!)

IN THE USA, THE NAVY COLLABORATED WITH HARVARD AND IBM TO CONSTRUCT THE MARK I, AN ELECTROMAGNETIC GIANT LAUNCHED IN 1944.



DESIGNED BY HARVARD PROF HOWARD AIKEN, WHO MODELED IT ON BABBAGE'S ANALYTICAL ENGINE, MARK I OCCUPIED SOME 1200 CUBIC FEET AND CONTAINED THOUSANDS OF RELAYS. WHEN IT CRANKED UP, THEY SAY IT SOUNDED LIKE A MILLION KNITTING NEEDLES!!



MARK I COULD MULTIPLY TWO 10-DIGIT NUMBERS (A CONVENIENT MEASURE OF COMPUTER SPEED) IN ABOUT

3 SECONDS.

AN UNMANNED OF SPEED!



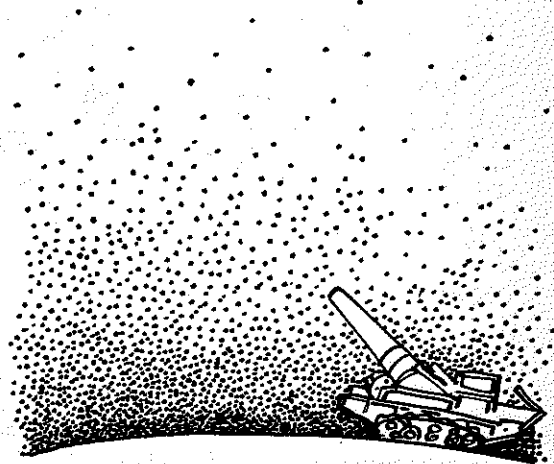
UNBEKNOWNST TO THE NAVY, THE ARMY WAS ALSO FUNDING A COMPUTER PROJECT—ONLY THEIRS WOULD USE TUBES!

WE'LL SHOW THEM NAVY WIMPS!



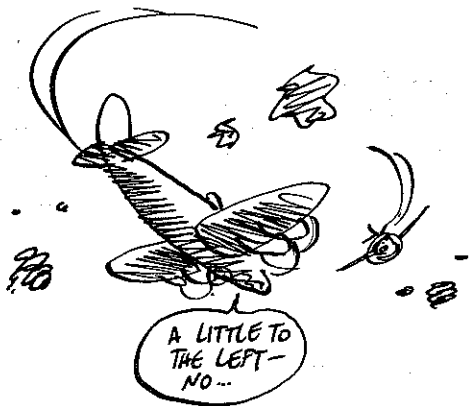
THEIR AIM WAS THE SAME AS TARTAGLIA'S IN THE 1500'S: TO COMPUTE **BALLISTICS** MORE ACCURATELY.

TARTAGLIA HAD ERRED IN SAYING THAT CANNON-BALLS FLY IN PARABOLIC PATHS. IN REALITY, AIR RESISTANCE ALTERS THEIR TRAJECTORY APPRECIABLY, AND IN A VERY COMPLEX WAY, BECAUSE AIR RESISTANCE DIMINISHES AT HIGHER ALTITUDES.



IN WORLD WAR I, THE GERMAN CANNON "BIG BERTHA" SHOT 94 MILES—TWICE AS FAR AS EXPECTED FROM OVERSIMPLIFIED CALCULATIONS!

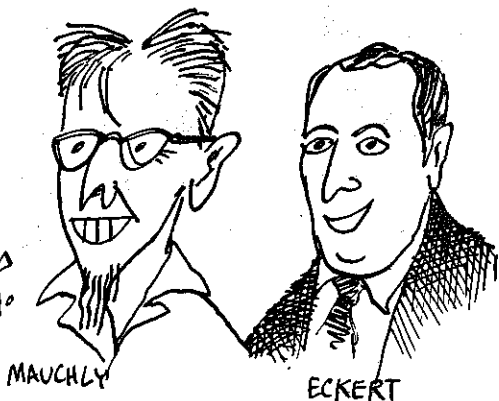
GUNNERS AND BOMBARDIERS THEREFORE NEEDED ACCURATE BALLISTIC TABLES TO AIM BY. THESE COULD HARDLY BE CALCULATED ON THE FLY!



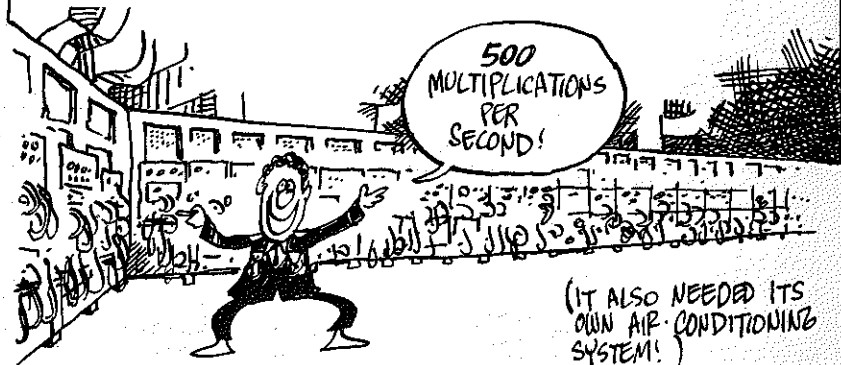
BALLISTIC TABLES USED TO BE CALCULATED BY ROOMFULS OF "GIRLS" WITH ADDING MACHINES — AND EVEN THIS WAS SLOW.



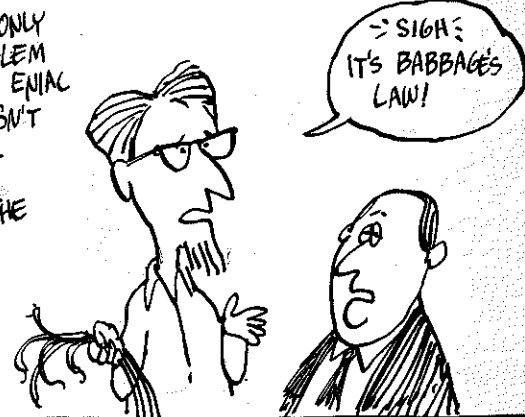
THE CHIEF ENGINEERS IN THE ARMY PROJECT WERE J. PERSPER ECKERT AND JOHN MAUCHLY.



THE RESULT OF THEIR LABORS WAS THE BARN-SIZED ENIAC: THE ELECTRONIC NUMERICAL INTEGRATOR AND CALCULATOR. WITH 18,000 TUBES, ENIAC WAS FAST:



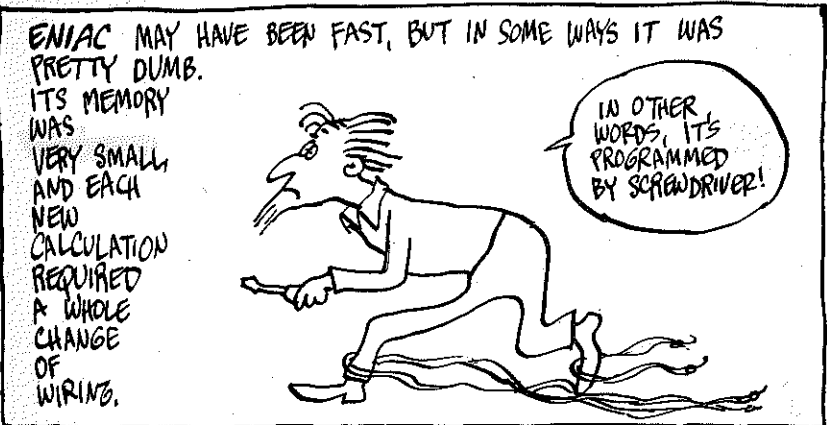
THE ONLY PROBLEM WITH ENIAC WAS THAT IT WASN'T COMPLETED UNTIL 1946, SEVERAL MONTHS AFTER THE WAR WAS OVER!





BEST THING ABOUT WAR IS THERE'S ALWAYS ANOTHER!

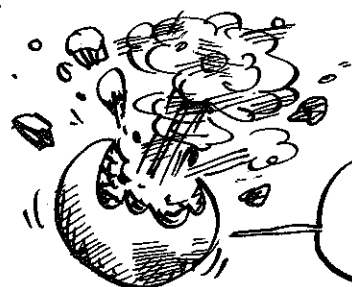
SO THE ARMY PUT ENIAC TO WORK ON THE NEXT WAR, DOING CALCULATIONS FOR THE NUCLEAR WEAPONS PROGRAM...



ENIAC MAY HAVE BEEN FAST, BUT IN SOME WAYS IT WAS PRETTY DUMB. ITS MEMORY WAS VERY SMALL AND EACH NEW CALCULATION REQUIRED A WHOLE CHANGE OF WIRING.

IN OTHER WORDS, ITS PROGRAMMED BY SCREWDRIVER!

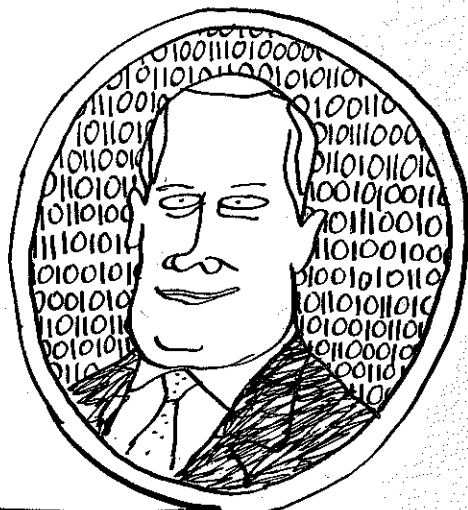
BUT STILL IMPRESSIVE: WITH 18,000 TUBES FLICKERING ON AND OFF 100,000 TIMES PER SECOND, ENIAC HAD TO PERFORM FAR MORE RELIABLY THAN ANY MACHINE EVER CONSTRUCTED.



MISCALCULATION COULD BE FATAL!

NOW ENTERS JOHN VON NEUMANN

(1903-1957), A PRINCETON MATH PROFESSOR WHO MORE THAN ANYONE GETS CREDIT FOR TURNING ELECTRONIC CALCULATORS INTO "ELECTRONIC BRAINS."



VON NEUMANN PONDERED THE COMPUTER'S LOGICAL STRUCTURE IN THE ABSTRACT: HOW IT CONTROLS ITSELF, HOW MUCH MEMORY IT NEEDS AND WHAT FOR, ETC... AND HE ASKED HIMSELF HOW COMPUTERS COULD BE MADE MORE LIKE HUMAN "WIRING," I.E., THE CENTRAL NERVOUS SYSTEM.



OH, THE INPUT BONE CONNECTED TO THE MEMORY BONE...

CONSIDER HOW A HUMAN BEING "RUNS A PROGRAM":

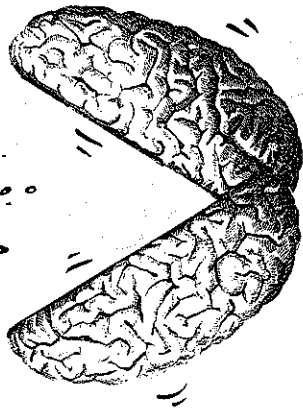
WHEN A SURGEON STARTS TO CUT, IT SHOULDN'T BE NECESSARY TO KEEP REFERRING BACK TO THE TEXTBOOK FOR INSTRUCTIONS.



No... FIRST THE SURGEON GOES TO MEDICAL SCHOOL, READS THE PROCEDURES, AND COMMITS THEM TO MEMORY.



THIS SPEEDS UP SURGERY CONSIDERABLY!

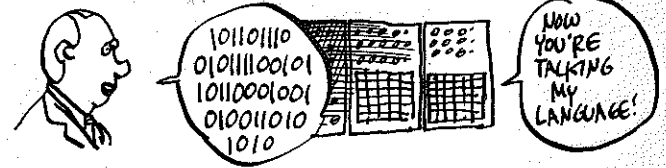


YOUR BRAIN IS FULL OF THESE "STORED PROGRAMS":

YOU KNOW HOW TO TIE YOUR SHOELACES, HOW TO FEED YOURSELF, HOW TO MULTIPLY 94 TIMES 16, HOW TO TALK, HOW TO WALK...

VON NEUMANN PROPOSED TO MAKE COMPUTERS DO LIKEWISE:

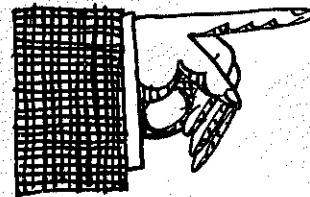
1. FIND A WAY TO ENCODE THE INSTRUCTIONS INTO A FORM WHICH COULD BE STORED IN THE COMPUTER'S MEMORY. VON NEUMANN SUGGESTED USING STRINGS OF ONES AND ZEROS.



2. STORE THE INSTRUCTIONS IN MEMORY, ALONG WITH WHATEVER OTHER INFORMATION (NUMBERS, ETC) IS NEEDED TO DO THE PARTICULAR JOB.



3. WHEN RUNNING THE PROGRAM, FETCH THE INSTRUCTIONS STRAIGHT FROM MEMORY, RATHER THAN READING A NEW PUNCHCARD AT EACH STEP.



THIS IS THE CONCEPT OF THE
STORED PROGRAM.

The advantages?



SPEED ○ LIKE THE SURGEON,
THE COMPUTER FINDS IT
MUCH FASTER TO WHIZ
INSTRUCTIONS FROM "BRAIN"
TO "FINGERS" THAN TO
"RETURN TO THE TEXTBOOK"
AFTER EXECUTING EACH STEP.



VERSATILITY:

WITH SEVERAL PROGRAMS
STORED AT ONCE, THEY CAN
REFER TO ONE ANOTHER
RUNNING IN COMBINATION.
SURGERY IS ACTUALLY
SUCH A COMBINATION.



SELF-MODIFICATION:

IF STORED ELECTRONICALLY,
PROGRAMS MAY EASILY BE
WRITTEN WHICH CAN MODIFY
OR ADJUST THEMSELVES.
THIS TURNS OUT TO BE
CRITICALLY IMPORTANT!



TO MAKE HIS POINT, VON NEUMANN WROTE SOME CODE FOR A PROGRAM CALLED:

SORT AND MERGE



IT'S A SIMPLE JOB TO DESCRIBE:

GIVEN TWO LISTS
OF NAMES (FOR
EXAMPLE):

ALABAMA, S.
ANTEATER, J.
ANTEATER, B.
AARDVARK, A.

TARDIGRADE, C.
BEAVER, M.
OWL, H.
ALLIGATOR, A.



AARDVARK, A.
ALABAMA, S.
ALLIGATOR, A.
ANTEATER, B.
ANTEATER, J.
BEAVER, M.
OWL, H.
TARDIGRADE, C.

MAKE ONE LIST IN ALPHABETICAL ORDER.

THIS SEEMINGLY SIMPLE PROCESS BECOMES HORRIBLY TIME-CONSUMING WHEN THE LISTS ARE LONG.

SO:

HERE'S ANOTHER
IDEAL COMPUTER JOB
THAT CONTAINS
ESSENTIALLY NO
MATH. YOU CAN
SEE HOW THIS ONE
MIGHT APPEAL TO
SOMEONE COMPILING
A TELEPHONE
DIRECTORY OR A
MAILING LIST!!



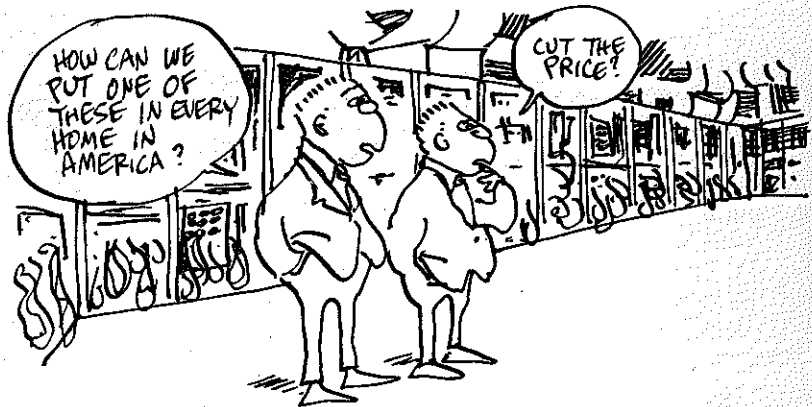
ACTUALLY, THERE'S SOME ARGUMENT OVER WHO INVENTED THE STORED PROGRAM. ECKERT AND MAUCHLY CLAIMED CREDIT, TOO... AND THE ENIAC PROJECT DISSOLVED IN A WELTER OF LAWSUITS OVER WHO OWNED WHAT IDEA...



WELCOME TO THE COMPUTER AGE...



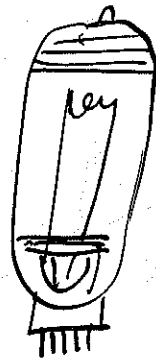
STORED PROGRAMS ARE WHAT SEPARATE TRUE COMPUTERS FROM EVERYTHING PRE-ENIAC.



IF COMPUTERS HAD REMAINED AS BULKY AS ENIAC, THEY WOULDN'T BE WHAT THEY ARE TODAY... BUT THEY DIDN'T, AND THEY ARE...

IN 1947, THE YEAR AFTER ENIAC WAS FINISHED, A TEAM AT STANFORD INVENTED THE **TRANSISTOR**, USING ELEMENTS CALLED SEMICONDUCTORS.

LIKE TUBES, TRANSISTORS CAN ACT AS SWITCHES, BUT THEY'RE SMALLER, FASTER, COOLER, AND LONGER-LIVED AND THEY DRAW FAR LESS ELECTRIC POWER.



TIME TO RETIRE, FATSO!



THE FIRST TRANSISTORIZED COMPUTERS WERE ROOM-SIZED, NOT BARN-SIZED, AND THEIR COST (A COUPLE OF MILLION DOLLARS) WAS AFFORDABLE BY LARGE BUSINESSES AND UNIVERSITIES.

AND SO "COMPUTER ERROR" ENTERED EVERYDAY LIFE!

PHONE BILL
10056/00



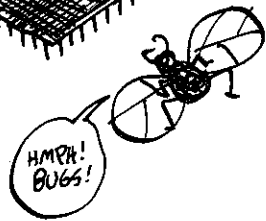
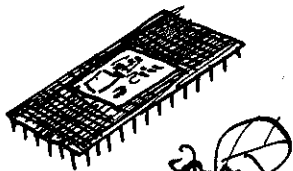
THEN THE TRANSISTOR BEGAN TO SHOW AN INCREDIBLE ABILITY TO SHRINK IN SIZE AND PRICE.

FIRST CAME INTEGRATED CIRCUITS —

A WHOLE BOARDFUL OF TRANSISTORS MANUFACTURED AS A SINGLE UNIT... THEN

LARGE-SCALE AND VERY LARGE-SCALE INTEGRATION

(LSI AND VLSI), WHICH PACKED HUNDREDS OF THOUSANDS OF TRANSISTORS ON A TINY CHIP!

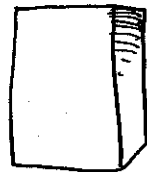


AS COMPONENTS SHRANK, THE INDUSTRY EXPLODED!

IN THE '60's, THE **MINICOMPUTER** APPEARED. IT WAS THE SIZE OF A DESK!



MAKES IT LESS MYSTERIOUS SOMEHOW!



IN THE '70's CAME THE **MICRO**, WHICH CAN BE AS SMALL AS YOU LIKE.



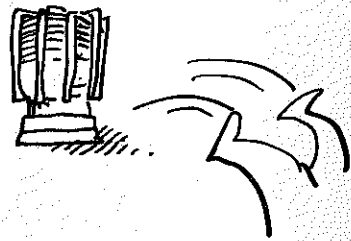
WHAT'S NEXT? THE DISPOSABLE?

BY THIS TIME, BIG COMPUTERS, ALSO KNOWN AS **MAINFRAMES**, HAD BECOME IMMENSELY POWERFUL.



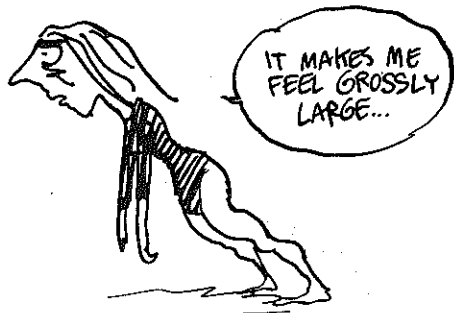
100,000 TRANSISTORS PER CHIP...
100,000 CHIPS PER MACHINE...

AND FINALLY THE EXOTIC **SUPERCOMPUTERS**, WHICH CALCULATE AT RATES UP TO 500 MEGAFLOPS* — A MILLION TIMES FASTER THAN ENIAC!

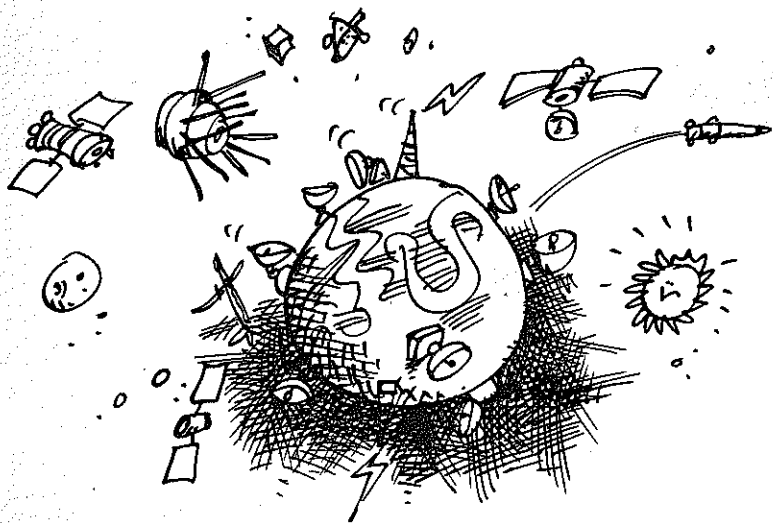


* MILLION FLOATING POINT OPERATIONS PER SECOND.

THERE'S NO END IN SIGHT... NOW WE HAVE MICROS WITH THE POWER OF MINIS, "SUPERMINIS" THAT RIVAL MAINFRAMES, MINIS ON A CHIP... AND THERE'S TALK OF REDUCING COMPONENTS TO MOLECULAR SIZE USING RECOMBINANT DNA TECHNOLOGY...



THERE SEEMS TO BE NO SUCH THING AS A COMPUTER WITH TOO MUCH COMPUTING POWER. NO MATTER THE SPEED OR CAPACITY, COMPUTERS ALWAYS FIND JOBS TO DO... AND NO WONDER: THIS IS THE AGE OF EXCESS INFORMATION!



PART I

LOGICAL SPAGHETTI

