COLLECTED WHIZBANGS
by Roy A. Sykes, Jr.

An Anthology Of Tutorials on APL Programming Techniques
Volume 1
NOTE TO READERS

In December 1974 Scientific Time Sharing Corporation held a seminar for its APL*PLUS Service Representatives. One outcome of that seminar was a "wish list" of goodies these marketing folks would like to have. On that list, they expressed a desire for some sort of "APL Whizbang" -- a column describing neat programming tricks that would illustrate some powerful, but perhaps not obvious, features of the language.

A year later, in delayed response to that request, the "Whizbang" was born in News, the APL*PLUS Service newsletter. The first "Whizbang" illustrated a programming technique for finding the current definition of a name. That was the first and last pure "Whizbang". In response to reader requests, the "Whizbang" evolved into a more general tutorial on APL programming techniques.

Over the past two and a half years, the reader response to the "Whizbang" has been gratifying. Today it remains one of the most popular features of News. For those who've never seen the "Whizbang" and for those who'd like to reminisce, we've collected past "Whizbangs" in this handy reference booklet.

Neither the "Whizbang" nor this booklet could exist without the devoted efforts of Karen Kromas and Beth Matsumune of STSC. Many thanks to them -- for patiently translating my barely legible scrawl into finished columns -- and to the other STSC people who review the drafts. And, most of all, thanks to the readers who make it all worthwhile.

Roy A. Sykes, Jr.
Los Angeles, California
August 1978

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WHAT'S IN A NAME?

Finding the current definition of a named object in the workspace is useful in programs that may or may not reference global objects. A common technique, using the APL*PLUS primitive \( \text{DSIZE} \), to find the storage required is:

\[
R+0<\text{DSIZE 'OBJECTNAMES'}
\]

\[
\text{DSIZE } \leftrightarrow \text{ STORAGE REQUIRED}
\]

Unfortunately, this algorithm returns a 1 indiscriminately for groups and labels, as well as for functions and variables. Using \( \text{DIDLOC} \) (object definition) is more appropriate, but has the disadvantage of producing too much information; we wish only to know what the current definition is, not that at every level of the state indicator.

Before the scan operator's existence, the technique for picking out the proper element of \( A+\text{DIDLOC 'OBJECTNAMES'} \) (in \( \text{ORIGIN} \ 1 \)) was cumbersome:

\[
R+((1+(1=\$A)\downarrow 1)\$A)[;1]
\]

With the advent of scan, the same fundamental technique was used, incrementally improved to:

\[
R+((+/\&\&A=\neg 1)\$A)[;1]
\]

But using scan in another way gives us a much more elegant solution:

\[
R+(,\neg A\neg 1)\,A
\]

The last solution is fast and succinct, and works in either origin.

The results of these three algorithms are the same:

- \( R \) object is currently
  - 0 undefined
  - 1 a function
  - 2 a variable
  - 4 a group
  - 8 a label

Observe that \( \langle \rangle \) is similar to \( \&\& \), but only the first 1 on each row is preserved. Because the global definition of an object cannot be \( \neg 1 \), we're assured of exactly a single 1 in each row of the result of \( \langle \rangle \).

One use of this technique is the emulation of subscripted or triadic APL functions \( A/B \) or \( A/[K]B \):

\[
\begin{align*}
\text{V} & R+A \text{ COMPRESS } B;C \\
[1] & C-,\text{IDLOC 'COORD'} \diamond +(2=((\neg C\neg 1)/C)\downarrow 4)\downarrow 4 \\
[2] & R+A/B \diamond +0 \\
[3] & d:=R+A/[COORD] B \diamond C+=\text{ERASE 'COORD'} \\
\text{V} & R+B \text{ SUB } C \\
[1] & \text{COORD}+C \diamond R+B \\
\text{V}
\end{align*}
\]
This article shows how one can use permutation vectors in APL to rearrange city names and population data from separate sources into a convenient report.

One common characteristic of the four expressions:

- `S ? S` ○ `\$` ○ `\$` ○ `\$` ○ `\$`

is that they each generate a permutation vector. A permutation vector of length \( N \) is an arbitrary arrangement of \( N \). A permutation vector may be recognized by the truth of either of the following expressions, which both assert whether \( PV \) contains exactly one of all its indices:

\[
\wedge / (1 \circ PV) \in PV \\
\wedge / PV[ PV] = 1 \circ PV
\]

One may also test whether a vector is a permutation vector by:

\[
\wedge / PV = \mathbb{A} \circ PV
\]

This statement depends on the fact that every permutation vector has a unique inverse permutation, expressed as \( \mathbb{A} PV \). If \( PV \) is indeed a permutation vector, then the inverse of its inverse should be identical to itself.

Because permutation vectors represent all indices of a vector with \( PV \) elements, they are commonly used in selection and reordering. For instance, \( GV \circ PV \) generates that permutation which, if applied as subscripts to \( V \), would arrange \( V \) in descending order:

\[
V + 71 \circ PV \circ PV \circ PV \circ PV \circ PV \circ PV \circ PV
\]

The particular permutation \( GV \) is called a descending grade vector. The inverse permutation of a grade vector is called a ranking vector, which expresses the ordinality of the vector:

\[
v, [1] \ GV, [0.5] \ \mathbb{A} GV
\]

\( \mathbb{A} PV \) is the descending ranking vector on \( V \) because it is the permutational inverse of the descending grade vector of \( V \). One might expect then that \( \mathbb{A} \circ \mathbb{A} PV \) is the ascending ranking vector on \( V \), and that is indeed the case.

Although grade vectors occur more commonly, ranking vectors have many uses in merging, rearranging, and reporting data. For example, suppose we have a matrix of city names, \( NAMBS \), arranged by state, an associated vector \( EW \) indicating
whether the cities are eastern (0) or western (1), and two vectors, EAST and WEST, containing the population of the eastern and western cities.

NAMES

LOS ANGELES, CA
SAN FRANCISCO, CA
DENVER, CO
WASHINGTON, DC
CHICAGO, IL
BOSTON, MA
NEW YORK, NY
PHILADELPHIA, PA
HOUSTON, TX

EW
1 1 1 0 0 0 0 0 1

EAST
757 3367 641 7868 1949
WEST
2816 716 515 1233

We wish to produce a single listing, sorted by both city name and population. This is almost impossible to do (unless, fortuitously, the order of cities and populations correspond), because objects (lines of the report) can only be arranged in one order at a time.

However, ordering can also be indicated by a ranking vector, so we decide to arrange the report by city name, and express the population relationships by a ranking vector. The function REPORT uses two ranking vectors and one independent grade vector.

V REPORT;RA;ALP;POP;RANK;GRADE;FORMAT
[2] ALP='ABCDEFGHIJKLMNOPQRSTUVWXYZ'
[3] RA+ALP = POP+(EAST,WEST)[!!EW]
[4] RANK+!VPOP+POP[GRADE+!RAiALP1~NAMESJ
[5] 'CITY NAME POP RANK'
[7] FORMAT !FMT(NAMES[GRADE;J;POP;RANK)

On line [3] of REPORT we use an ascending ranking vector, !!EW, to merge the elements of EAST and WEST:

EW ! EW ! EW
1 1 1 0 0 0 0 1
4 5 6 7 8 1 2 3 9
6 7 8 1 2 3 4 5 9

EAST,WEST ! POP+(EAST,WEST)[!!EW]
757 3367 641 7868 1949 2816 716 515 1233
2816 716 515 757 3367 641 7868 1949 1233

POP and NAMES now correspond; hence, we must reorder both by the same indices to maintain that relationship.

Line [4] of REPORT performs several operations. It generates an ascending grade vector by coding the city names into numbers and grading up those numbers; it reorders POP into ascending sequence by city name, saving GRADE so we can later reorder NAMES by the same permutation; and finally, it generates a descending ranking vector on POP to express the ordering of populations, although we will be using the ordering of city names to organize the report.

!CODED+RAiALP;NAMES
2.09E24 3.02E24 8.95E23 3.59E24 7.67E23
6.62E23 2.32E24 2.62E24 1.52E24

!GRADExCODED
6 5 3 9 1 7 8 2 4

!POPxPOP[GRADE]
641 3367 515 1233 2816 7868 1949 716 757

(POP),(0.5] RANK+!POP
6 2 5 7 4 9 8 1 3
8 2 9 5 3 1 4 7 6

Line [7] uses GRADE, which we computed on line [4], to sort by city name, to reorder NAMES in ascending sequence; it then uses !FMT to format the report.

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VOILA! -- Your very own almanac.
This article discusses the use of subscription for selecting and changing scattered elements of an APL array.

The APL indexing (or subscription) function provides a powerful facility for identifying elements of an array. Once identified, those elements may be selected (A[I]) or changed (I+DATA). An individual element is identified by one or more indices, depending on the rank of the left argument. Each set of indices sufficient to identify one element of an array is called an index-tuple. The right argument is a list of APL expressions representing the indices for each coordinate of the left argument. The expressions are separated by semicolons, and the entire list is enclosed in brackets.

**LEFTARG[R;I;G;H;T;...;A;R;G]**

If all indices of a coordinate are used, the expression (but not the semicolon) may be elided for that coordinate.

The elements that are identified represent the cross product (outer product) of all specified indices of each coordinate coupled to all specified indices of the other coordinates. For instance, each element of a three-dimensional (3-D) array,

```
      \(L \times R \times C\)
```

must be identified by three indices: layer, row, and column.

```
L\#2 \circ R\#1 \circ C\#4
```

If the result of any of the expressions is not a one-element array, each element is conceptually coupled with all elements of the other expressions to produce an array of index-tuples (in this case, each having three elements),

```
L\#2 \circ R\#3 \circ C\#1 \#2 \#5 \#2
```

which are then used to select the data:

```
T[L;R;G]
```

If we wish to select elements scattered throughout the array, the outer product index-coupling generally identifies more elements than we want. Essentially, we would like to disable the (outer product) cross-coupling, leaving only (scalar) parallel-coupling. The two techniques for doing this are:

- refine the result of the index function, and
- reduce the rank of the indexed array.

It is important to note that, for vectors, only one index is needed to identify each element. Hence, vector indexing already can do scattered-point selection because no index-coupling is performed.

```
V* 'BRUTE' \circ V[6 5 1 5 4]
```

However, for matrices, two indices are needed to identify each element. Indexing produces these two-element index-tuples by coupling all specified row and column indices:

```
M* 'SPADE' \circ M* 4 7 \circ M
```

Using transpose to refine the result

Suppose that what we really want in the above case is simply a pairwise coupling of the row and column indices, for example:

```
M[1;1],M[2;3],M[4;2],M[3;5],M[1;1]
```

This technique applies to selecting scattered elements out of any array, assuming the index expressions are vectors. For \(A[V_1;V_2;V_3;...;V_N]\) (where \(N=ppA\)), one would use

```
\(A(V_1;V_2;V_2;...;V_N)\)
```

and the result would be a vector of length

```
(pV1)(pV2)(pV3)...l(pV_N)
```
If we generalize the problem somewhat we find that we can primitively select:

scattered points (scalar elements) from vectors by \( V[C] \), and

scattered lines (row/column vectors) from matrices by \( M[R;] \) or \( M[;C] \), and

scattered planes (matrices) from 3-D arrays by \( T[L;;] \), \( T[;R;] \), or \( T[;;C] \).

(Elided coordinate indices may be replaced by any APL expression.)

Remember that we can select scattered points from a matrix, but only if they all fall on a single row or column. The same principle applies to scattered points or lines in a 3-D array. Essentially

\[ M[3; 5 1 2 3 5 2 4] \]

is really only selecting scattered points from the vector

\[ M[3;] \]

Conversely, we cannot select:

scattered scalars from matrices or higher-order arrays, or

scattered vectors from 3-D or higher-order arrays, or

scattered matrices from 4-D or higher-order arrays,

unless all the selected subarrays are identified by single indices along all other coordinates (thus effectively reducing the rank of the indexed array).

In general, if we wish to select more than one subarray (e.g., a scalar) from an array of rank greater than one higher than that subarray (e.g., a matrix), we must use a slicing transpose to obtain the result. The following table illustrates scattered-array indexing for common cases where \( L, R, \) and \( C \) are vectors:

<table>
<thead>
<tr>
<th>Select scat- from a vector a matrix a 3-D array</th>
<th>from</th>
<th>from</th>
<th>from</th>
</tr>
</thead>
<tbody>
<tr>
<td>points ( 1 V[C]* ) 1 1( W[R;C]) 1 1 ( 1 V[L;R;C])</td>
<td>1 1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>cols ( 1 V[C]* ) 1 2 ( V[C]* ) ( 2 1 2 V[L;;C])</td>
<td>1 1</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>rows ( 1 V[;]* ) 1 2 ( W[R;]) ( 1 1 2 V[L;R;])</td>
<td>1 1</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>planes ( 1 2 W[;;]* ) ( 1 2 3 W[L;;]*)</td>
<td>1 1</td>
<td>2</td>
<td>3</td>
</tr>
</tbody>
</table>

(*) The \( \text{;} \) may be elided from these expressions.

Here's an example of indexing scattered rows:

\[ \{ 8 7 \text{p} G \}[1 4 3 8 5 ;] \]

Reducing the rank of the indexed array

The transpose technique is concise, but it has several disadvantages:

- For large right arguments (the indices) it requires a great deal of temporary workspace storage and extra computer time to select all the superfluous data before the transpose is performed.

- Altering the shape of the result necessitates potentially confusing changes to both the indices and the left argument to transpose.

- It does not allow specification.

An alternative technique is to reduce the rank of the indexed array such that we can use primitive indexing. This requires that we somehow recalculate the indices to correctly identify the desired data. In the preceding example (selecting scattered rows):

\[ \{ 8 7 \text{p} G \}[1 4 3 8 5 ;] \]

The indices were actually calculated by:

\[ \text{IND}+ 1 1 1 2 2 , [0.5] 1 4 3 4 1 \]

Notice the dependence on the \( \text{ORIGIN} \) to offset the indices when working in \( \text{ORIGIN} \). Number systems (which is actually what 1 deals with) are based in \( \text{ORIGIN} \).

A more common case is selecting scattered points from an arbitrary array. Since only vector indexing primitively allows selection of scattered points, we must reduce the rank of the array to 1 (e.g., ravel it) and calculate the subscripts (assume \( \text{ORIGIN} \)):
The function $SPA$ might be used as follows:

\begin{verbatim}
DATA+3 3 4 5  
D+M+M
SPA
(4 4 pR),[2.5J
1 2 3 4 5 6 7
8 9 10 11 12
M SPS 2,[1.5J:5 m ROW 2; COLS 1-5
8 9 10 11 12
M SPS(15),[1.5J 2 m ROWS 1-5; COL 2
2 9 16 23 30
M SPS 5 1 p:5 m LAST COORD. EXTENDED
1 9 17 25 33
ROWS+1,[1.5J:5 m COLS+(15),[1.5J
5 0 2 0 m ROWS, COLS
1 6
2 12
3 18
4 24
5 30

The function $SPA$ might be used as follows:

\begin{verbatim}
DATA+2
D+M+M
SPA
1+(pRJ)\(L,1,1 R,0.5 C)\-1
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35

\end{verbatim}

Notice how the base value operation had the effect of multiplying by 28 (number of elements in each layer), by 7 (number of elements in each row), and by 1.

In fact, we can write a generalized scattered-point selection function as follows:

\begin{verbatim}
V R+A SPS B;C
[1] a SCATTERED-POINT SELECTION.
[2] a <A> IS THE ARRAY TO BE SUBSCRIPTED.
[4] a CONFORMABILITY: *(1,1,1),pA)
[5] a ORIGIN DEPENDENT. *(pR)\-1+pB
[6] a R+PA \& C\'=';1
[7] a R+(,A)[(R1(1\(1pB)\BQ)+C-R\C] V

A scattered-point assignment function, utilizing a global to hold the data, might be defined as:

\begin{verbatim}
V R+A SPA B;C
[1] a SCATTERED-POINT ASSIGNMENT.
[3] a THE GLOBAL <DATA>. *(pR)\-1+pB
[4] a R+A \& C\'=';1 \& A+pA

In both of these functions, the ORIGIN offset is calculated in a slightly different fashion to maximize efficiency for large index arrays.

A few examples should show the power of SPS:

\begin{verbatim}
M SPS 5 2 p:35
1 2 3 4 5 6 7
8 9 10 11 12 13 14
15 16 17 18 19 20 21
22 23 24 25 26 27 28
29 30 31 32 33 34 35

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-10-

-11-

-12-
SOME NOTES ON DATE STORAGE

The processing of calendar dates often involves fairly complex conversions between the stored representation and what is presented to the user. Typically, dates are stored in one of two formats, both designed to allow the representation of a date as a single number:

- **Ordinal Representation**
  Dates in this form are stored as integers indicating the number of days elapsed since a certain base date. In particular, the APL*PLUS File Subsystem stores DFRDCI timestamps as ordinal values relative to March 1, 1960. Given a file timestamp TS, the number of elapsed days can be calculated by LS5184000 (5184000 = the number of sixtieths of a second in one day).

- **Packed Representation**
  Dates in this form are stored as 100LYEAR~MONTH~DAY. The form is commonly abbreviated to YYMMDD, expressing only dates in the twentieth century. Today's date represented as a packed number can be calculated by 100oooo1100L760714 A BASTILLE DAY

Both representations allow qualitative analysis among dates. That is, dates stored in either format may be compared and ordered directly. However, quantitative analysis (e.g., "How many days between ...") is possible only with the ordinal representation.

Ordinal dates are not as commonly used as packed dates because they are significantly more expensive to process, particularly in the complex conversion necessary to display them in a meaningful format. Frequently, dates are stored in packed format, and occasionally converted to ordinal format for quantitative processing.

Dates also have a variety of display formats, such as:

7/4/76 SEPTEMBER 2, 1945 31 MAY 69

The standard format used in columnar reports is MM/DD/YY (although in Europe the accepted form is DD/MM/YY). Assuming our dates are in a vector DATES in YYMMDD form, how can we most efficiently display the standard format?

The most obvious approach is to unpack the dates into three numbers each, reorder them, and format each column:

D+100100 100 100 YDATES 'G2/3/99/99/99' OFMT D

We can reduce the number of format phrases, and speed up OFMT's operation, by the following:

'II2,2P/0/2I2' OFMT D

To really speed up the process, however, we should consider formatting only one number per date. This can be done by repackaging the dates in the desired order, and using the O format phrase to insert the slash (/) decorations:

D+100100 100 100 YDATES 'O9/29/99/99/99' OFMT D

The reordering can be speeded up even more by:

D+100100 0 100000 YDATES

which reduces the required number of internal arithmetic and data-movement operations.

A disadvantage of the above techniques is that they all require a large amount of intermediate storage; in fact, they may temporarily require up to six times the working area for each date! The solution is some clever algebraic manipulation of the digits within each date.

Here's a symbolic illustration of what we want:

\[
\begin{align*}
\text{YYMMDD} & \downarrow \\
\text{MMDDYY} & \\
\hline
1. \text{Let's start by picking off the month and day:} & 1000000|YYMMDD & \text{MMDD} \\
2. \text{Multiplying that by 1000000 (6 digits) produces:} & 1000000\times\text{MMDD} & \text{MMDD000000} \\
3. \text{To which we add the original dates:} & \text{YYMMDD}+\text{MMDD000000} & \text{MMDDYYMMDD} \\
4. \text{Now all we have to do is divide by 10000 (to eliminate the trailing four digits that represent MMDD):} & \text{MMDDYYMMDD}/10000 & \text{MMDDYYMMDD} \\
5. \text{and floor the result:} & \text{LMDDYY.MMDD} & \text{MMDDYY} \\
\hline
\end{align*}
\]

It could be written in one statement:

\[
\begin{align*}
\text{LMDDYY.MMDD} & \\
\hline
\end{align*}
\]

There's yet a further simplification that will eliminate the I, and allow the whole calculation to proceed in integer representation. The fractional part of step (4) is exactly \((10000|YYMMDD)/10000\). Given \(MD+1000000|YYMMDD\), the statement above becomes:

\[
\begin{align*}
\text{(YYMMDD+1000000×MD)}/10000 & \\
\hline
\end{align*}
\]

-12-
which is equivalent to:

\[
\frac{YYMMDD + (1000000 \times MD) \times MD}{1000000} - MD \times 10000
\]

because of the fraction in step (4). Now distribute the denominator (10000):

\[
\frac{YYMMDD + 1000000 \times MD}{1000000} - MD \times 10000
\]

Reassociate the numerator:

\[
\frac{YYMMDD + (1000000 \times MD) - MD}{1000000}
\]

Add common terms (distribute MD):

\[
\frac{YYMMDD + 999999 \times MD}{1000000}
\]

and expand MD:

\[
\frac{YYMMDD + 999999 \times 10000 \times YYMMDD}{1000000}
\]

This statement requires one-third the dynamic storage of its equivalent:

\[
100 \times 0 \times 10000 \times TDATES
\]

and executes up to three times faster!

As an exercise, try applying these principles to converting dates input in MMDDYY form to their YYMMDD representation.

August 1976

STRETCHING THE WORKSPACE

"... programs execute faster in less space." Those are sweet words to APL users. They mean functions will consume fewer CPU cycles, take less connect time, and require less workspace storage. The net effect is lower cost and increased utilization of the APL workspace.

That third benefit is important. Workspaces hold only a limited amount of information. They must accommodate functions, variables, groups, a symbol table (to store object names), execution stack information (the state indicator), and other internal directories. Moreover, during execution of expressions, the active workspace is continually allocating and freeing storage for temporary values.

By making efficient use of the free working area of the active workspace (measured by WVA), the APL*PLUS System reduces the incidence of WS FULL errors. The user can therefore store more programs or process more data than is otherwise possible, thus leading to additional benefits in programmer productivity, more efficient execution, and reduced internal overhead.

There are four fundamental, as well as several specialized, mechanisms currently employed by the APL*PLUS System to conserve available workspace storage resources. All are invoked automatically, and generally have no immediately apparent effect on running programs. Without them, however, usable working area would be drastically reduced, and WS FULL would be a recurring nightmare to programmers.

When executing a function, the APL System typically requires space for both the argument(s) and the result simultaneously. For example, during execution of

\[
R+(VEC\times 0) \times MAT[;2 3 4]
\]

the system will, at one instant, require space for the temporary value VEC\times 0, the other temporary value MAT[;2 3 4], and the result of the compression. Essentially,

\[
TEMP1=VEC\times 0 \times TEMP2=MAT[;2 3 4]
R=TEMP1/TEMP2 \times \text{ERASB 'TEMP1 TEMP2'}
\]

Of course, VEC and MAT are held in the workspace during the entire process. Given this general rule, let's see how the system tries to conserve space.

1. In-place storage

Often the system recognizes that the result of an operation fits into the space used by one of its temporary arguments, and is "smart" enough to use that same area to store the result. For instance,

\[
A++\set 100
\]

requires space only for 100; the +\ is subsequently stored over that temporary
value. This effect would not take place for \( A^+\backslash A \) because the argument to scan is not a temporary value.

Other examples of in-place storage are:

\[
R\leftarrow \Phi(50) \quad \text{both for } \Phi \text{ and } []
R\leftarrow 101p2+1100 \quad \text{both for } p \text{ and } +
\]

Some functions, like reversal and reshape, normally make copies if there is room in the workspace, and resort to in-place storage and slower algorithms only if necessary to avoid a WS FULL condition.

2. Chained variables

Chained variables can result in significant savings when using defined functions with named arguments. Most APL systems materialize often superfluous (wasteful) copies of named arguments; the APL*PLUS System defers copying until necessary -- sometimes not at all!

The following function returns an ascending grade vector on its numeric matrix argument:

\[
\begin{align*}
\text{V} & \leftarrow \text{GRADE MAP} ; 10 C \text{OL} \\
[1] & \text{IO} \leftarrow \text{''1} \circ \text{R} \leftarrow \left(\text{pMAT}\right)\left[\text{IO}\right] \\
[2] & \text{A} \leftarrow \left(\text{COL} \leftarrow \left(\text{pMAT}\right)\left[\text{IO}+1\right]\right) + 0 \circ \text{COL} \leftarrow \text{COL} \leftarrow \text{~IO} \\
[3] & \text{V} \leftarrow \text{A} \times \text{R} \leftarrow \text{MAT}\left[\text{R} ; \text{COL}\right] \circ \text{A} \times \text{IO} \leftarrow \text{COL} \leftarrow \text{~IO} + 1
\end{align*}
\]

Given \( M \leftarrow 100 20 \ p100 \), executing \( G V \leftarrow \text{GRADE } M \) requires OWA to be slightly more than 1400 bytes. The traditional function-calling mechanism would have required OWA to be more than 9400 bytes to avoid a WS FULL.

3. Datatype conservation

Numbers stored in binary, integer, or floating-point format require 1, 32, or 64 bits per number, respectively. Several enhancements in the APL*PLUS System deal with conserving storage by maintaining datatype wherever possible. For example,

\[
60:4:6 \quad \text{''2} \times 31 \quad \text{''1:12}
\]

all return 4-byte integer results, rather than the 8-byte floating-point results given by other APL systems. Similarly, dyadic +, *, /, \\, \text{i} and \text{!} operations on Boolean arguments preserve the binary datatype. Also, indexed assignment attempts to maintain the datatype of the target variable whenever possible. For example:

\[
A \leftarrow 100p0 \quad \text{A}[\text{]} \leftarrow 200 \quad \text{a COS OP 0 RADIANS}
\]

preserves \( A \) as binary, even though 200 is a floating-point 1.

4. Name referencing

Several identity operations perform no actual data movement in the workspace at all. Instead they pass internal pointers to the right argument. This occurs for both named and temporary arguments. For instance, the following expression takes almost no workspace storage beyond that required for \( CV \):

\[
\begin{align*}
\text{CV} & \leftarrow 800000p'\text{ABC'} \\
\text{CV} & \leftarrow \left(\text{pCV}\right)\circ \text{\text{~1} / . \text{C}'\text{CV}'} \\
\text{m} & \text{\text{~1} / . \text{C}} \quad \text{pass pointers}
\end{align*}
\]

A particularly common use is functions that ravel arguments which are predominantly vectors anyway.

5. Specialized mechanisms

Besides the techniques described above, several others are used when specific syntactic constructions are encountered. For instance

\[
'I80' \quad \text{FMT 10000p1}
\]

requires only 1500 bytes for execution, even though the "result" would seem to require 800,000 bytes. Similarly,

\[
\text{BV} \leftarrow \text{pBV}
\]

requires space only for the result. In the case where \( \text{BV} \leftarrow 5000000p1 \), OWA need be only 76 bytes to execute the expression, rather than the over 2 million bytes that might otherwise be necessary. Another special case is +\text{OLC}, which requires only 40 bytes for execution, regardless of the size of the state indicator. In fact, +\text{OLC} may work when \text{OLC} alone engenders a WS FULL error!

Of course, a large workspace always helps. As recently as 1972, an APL*PLUS workspace was limited to 32,000 bytes -- now it's over 100,000! Theoretically, we could allow even larger workspaces. But keeping workspaces reasonably-sized and making maximum use of that storage increases the throughput of the APL*PLUS System, and assures maximum machine utilization, economical operation, and the good response time which users depend on.

The ability to bring data and functions in from files, to dynamically expunge objects, and to automatically load other workspaces also helps the user avoid WS FULL errors. And, of course, there's always \text{ERASE}! But the automatic mechanisms used by the APL*PLUS System are the silent sentries in stretching storage.

October 1976
This article discusses some guidelines and techniques for branching and iteration in APL. Many people have asked me, "What's the fastest way to branch?" I hope to shed some light on this often-maligned subject.

Guidelines for Branching

The following three guidelines will simplify the maintenance of your code and improve its readability. The techniques you use are not as important as how consistently you use them.

1. Branch to labels, not line numbers. If your branch targets are line numbers rather than labels, simply inserting or deleting lines from a program can become a heinous task. Furthermore, minor benefits in storage and execution speed are gained by using label variables rather than constants.

2. Adopt a consistent notation for labels. Labels like LOOP, AGAIN, DO, MORE, and QOPS seldom add clarity to programs, especially large programs. Furthermore, they give the reader little or no clue as to where in the function they refer, or whether they are in fact labels. Common notations are (L1;L2;L3;...) and (L;L2;L3;...). More mnemonic conventions can help the reader recognize program segments (for example, L1 or ER2). The notation or convention that you choose is irrelevant as long as you adhere to it.

3. Adopt consistent techniques for branching and iteration. For instance, some people favor

\[ \text{LABEL} \times \text{condition} \]

while others use

\[ +\text{(condition)} \text{LABEL} \]

Again, it's not so important which techniques you use (except for trivial differences in execution speed), but that you use them consistently. Among my personal favorites are:

\[ +\text{(condition)} \text{LABEL} \]
\[ +(\text{xvector}) \text{LABEL} \]
\[ +(\text{vector}) \text{LABEL} \]
\[ +(\text{conditions}) \text{LABEL} \]
\[ +(\text{vector}) \text{LABEL} \]
\[ +(\text{vector}) \text{LABEL} \]
\[ +(\text{conditions}) \text{LABEL} \]
\[ +(\text{conditions}) \text{LABEL} \]
\[ +(\text{vector}) \text{LABEL} \]
\[ +(\text{vector}) \text{LABEL} \]

Some Useful Techniques

1. Subroutines to handle branching logic.

Programs can often be made more readable by using functions with mnemonic names for branch calculations. For instance,

\[ \ldots \Diamond +\text{THISL} \text{IF } M>C+C+1 \]

is certainly more understandable than

\[ \ldots \Diamond +\text{(M}C+C+1) \text{OILC} \]

or

\[ T: \ldots \Diamond +\text{(M}C+C+1) \text{OILC} \]

You can define the functions IF and THISL as:

\[
\begin{array}{ll}
V R+A IF B & [1] \\
V R+\text{THISL} & [1] \\
V & [1]
\end{array}
\]

\[ R+\text{IF condition} \]

IF can also be used for multiple conditions. For instance,

\[ +(L4,L5) \text{IF } -1 1=xA \]

will branch to L4 if A is negative, L5 if A is positive, and fall through if A is zero.

These functions are especially beneficial in programs with complex branching logic and many transfers of control. However, in simple iteration (see below) they exact a small but noticeable penalty in CPU resources.

2. Faster techniques for iteration.

The following techniques, while quite fast, generally detract from readability and should therefore be used judiciously.

Typically, loops involve a leading test as exemplified by ITERATE.

\[
\begin{array}{l}
\text{V ITERATE M:C} \\
\text{[1] SETUP } C+1 \\
\text{[2] } +0 \text{ IF } C>M \text{ PROCEED } C+C+1 \text{ } +\text{OILC} \\
\text{V}
\end{array}
\]

We can produce a speedier version of ITERATE by eliminating the IF subroutine and using a label.

\[
\begin{array}{l}
\text{V ITERATE2 M:C} \\
\text{[1] SETUP } C+1 \\
\text{[2] } A:=+(C>M)\text{O0 } \text{ PROCESS } C+C+1 \text{ } +A \\
\text{V}
\end{array}
\]

By employing a trailing test, the branch overhead can be reduced significantly. The once-executed leading test, \text{+M+0}, accommodates the zero case.

\[
\begin{array}{l}
\text{V ITERATE3 M:C} \\
\text{[1] SETUP } +M+0 \text{ C+1} \\
\text{[2] } A:=\text{PROCESS } +M+C+C+1\text{A} \\
\text{V}
\end{array}
\]

Further, by precalculating all branch points, we can avoid the serial iteration-by-iteration testing. APL permits (and even encourages) parallel processing on data -- why not parallel calculations, testing, and branch-point determination? ITERATE4 illustrates a simplified form of this technique.
Note that all of the above algorithms correctly handle the case where zero iterations are requested. They are also restartable; that is, if PROCESS produces a WS FULL or VALUE ERROR, the problem can be corrected, and +[]0 will resume execution normally. It is true that \texttt{ITERATE2} could have been shortened to

\begin{verbatim}
[1] SETUP C+1 +L+(M+pA),0
\end{verbatim}

However, resumption after a VALUE ERROR on \texttt{PROCESS} would have incremented \texttt{C} twice (once before the error, and once after the restart), thereby skipping one iteration.

The following table illustrates the relative CPU timings of the above techniques with varying numbers of iterations. The ratios are to \texttt{ITERATE4}; \texttt{SETUP} and \texttt{PROCESS} were set as empty matrices.

<table>
<thead>
<tr>
<th>Iterations (N)</th>
<th>0</th>
<th>1</th>
<th>10</th>
<th>100</th>
<th>1000</th>
</tr>
</thead>
<tbody>
<tr>
<td>\texttt{ITERATE}</td>
<td>1.11</td>
<td>1.60</td>
<td>2.47</td>
<td>2.89</td>
<td>2.97</td>
</tr>
<tr>
<td>\texttt{ITERATE2}</td>
<td>.90</td>
<td>1.08</td>
<td>1.45</td>
<td>1.67</td>
<td>1.68</td>
</tr>
<tr>
<td>\texttt{ITERATE3}</td>
<td>.65</td>
<td>.92</td>
<td>1.23</td>
<td>1.40</td>
<td>1.41</td>
</tr>
<tr>
<td>\texttt{ITERATE4}</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
</tr>
</tbody>
</table>

(Executed 11/29/76 at 7:27 P.M. EST on \texttt{APLPLUSC} with 20 users)

3. Recursed!

Did you know that you can use the execute function (\texttt{*}) to effect iteration in desk calculator mode? Assume \texttt{N} is the number of iterations (\texttt{N=1}), and \texttt{C} is the counter (initialized as \texttt{C+1}). Now compare the following two lines -- one in a function, the other in desk calculator mode:

\begin{verbatim}
[1] \texttt{L: PROCESS \texttt{*}(M2C+C+1)/L}
[2] \texttt{A: PROCESS \texttt{*}(M2C+C+1)/L}
\end{verbatim}

Both have the effect of executing \texttt{PROCESS} as many times as called for by \texttt{M}. Observe that whereas the first line uses branching to the label \texttt{L}, the second uses \texttt{*} to recursively execute the statement represented by \texttt{L}. Unpleasantly, the execute construction consumes significantly more CPU time and is far more extravagant in its use of workspace storage. It does, however, illustrate the interesting relationship between \texttt{-} and \texttt{*}.

January 1977

**STRING SEARCHING**

The ability to rapidly locate string occurrences in other strings is often useful. The many techniques applicable to the problem also provide enlightening examples of efficient problem-solving in \texttt{APL}. This article discusses several algorithms for string searching to illustrate efficiency of execution and some interesting techniques.

A string is a vector, typically character. String searching means locating the occurrences of one string, called the substring, in another string, called the target string. The result can be a Boolean vector of the same length as the target string with 1's denoting the leading element of each match. More commonly (see each function below), the result is the origin-sensitive indices of the 1's in the Boolean vector (i.e., \texttt{BV}/\texttt{pBV}). Overlapping matches are possible. In all functions, the left argument \texttt{A} is the target string and the right argument \texttt{B} is the substring for which we will search.

The most fundamental \texttt{APL} solution is quite straightforward:

\begin{verbatim}
[1] \texttt{R+A SS1 B;C;D;E}
[2] \texttt{R+(EtA=(D,C+1)pA)/lE}
[3] \texttt{R OR ALTERNATIVELY,}
[4] \texttt{R+(EtA=((D-1)D)0B;=A)iE}
\end{verbatim}

All characters in the target string are compared with all characters in the substring, the logical matrix is shifted to align each potential occurrence, and the indices of complete matches are selected. Notice that if the length of the substring \texttt{B} is greater than that of the target string \texttt{A}, then no matches are possible. Furthermore, if the substring is empty, all indices are returned. The number of potential matches, \texttt{B}, is normally 1 plus the difference in lengths of the strings, that is, \texttt{E+C-D} or \texttt{E+C-D-1}. The two \texttt{0}'s are to correctly handle empty or overlong substrings.

A somewhat more elegant solution employs inner product to detect matches:

\begin{verbatim}
[1] \texttt{R+4 SS2 B;C;D;E}
[2] \texttt{R+(EtB=+(D,C+1)pA)/iE}
[3] \texttt{R OR ALTERNATIVELY,}
[4] \texttt{R+(EtB-((D-1)D)0D;=A)iE}
\end{verbatim}

Rather than rotating a logical array, this technique builds a matrix of all possible matches and then uses \texttt{A= to select those that are complete. Observe the pleasant effect of the reshape on line \texttt{(2)} -- it both builds and shifts the matrix. \texttt{SS2} is somewhat faster than \texttt{SS1}, although it requires more workspace area (\texttt{[WA]}) in which to execute.
Unfortunately, both of these algorithms are inherently inefficient because they must compare all possible combinations of characters in the two strings; that is, they are "blind," and continue to process even if no matches are possible. A somewhat better approach is to determine the indices of the first character, and compare only the remaining candidates with the rest of the string:

\[
\begin{align*}
V &= \text{R+A SS3 } B;C;D;E \\
[1] &= C+pA*, A \odot D+pB*, B \odot +B|\text{A+D} \\
[2] &= R+I_C \odot +0 \text{ a EMPTY STRING} \\
[3] &= H+(AeB)/C \odot +0 \text{ a SINGLETON STRING} \\
[4] &= B+E0C-D-1 \odot -(pR+(E+Ac1+B)/B)+0 \\
V &= \text{V}
\end{align*}
\]

This function employs some new techniques worth discussing. Notice the unusual branch on line [1] which has the effect of trapping both the empty and one-element cases. If desired, line [2] could then be modified to return \( \theta \) in the empty case rather than all indices -- a more usable result.

Line [4] calculates the number of potential matches, and locates the occurrences of the first character. (For character arguments, \( \varepsilon \) is typically faster than \( \equiv \) because of the internal algorithm used.) If the first character is not found, the function exits immediately with an empty result. Otherwise, a matrix of all remaining candidates is built via outer product and subscription, and \( A,= \) is used to produce the compression vector which selects only complete matches. The \( -(\text{+1})+D \) construct cleverly accounts for the index origin while removing the index of the character already examined.

While SS3 is a considerable improvement over SS1 and SS2, it is still relatively naive. For instance, if the first character of the substring occurs frequently in the target string, little or no savings may accrue. Furthermore, the risk of a \( WS\ FULL \) is increased because of the larger space required by the matrix of indices. A more sophisticated algorithm employs basically the same technique, but attempts to minimize the number of initial "hits" by searching for the character in the substring that has the least number of expected occurrences:

\[
\begin{align*}
V &= \text{R+A SS4 } B;C;D;E;F;G \\
[1] &= C+pA*, A \odot D+pB*, B \odot +B|\text{A+D} \\
[2] &= R+I_C \odot +0 \text{ a EMPTY STRING} \\
[3] &= H+(AeB)/C \odot +0 \text{ a SINGLETON STRING} \\
[4] &= B+F* \text{ ETAISOMRLCPHUMDBWYGKVJQXZ...} \\
[5] &= B+0FC-D-1 \odot +(pR+(E+Ac1+B)/B)+0 \\
[6] &= G+G-F+IC+1 \\
[7] &= +\theta(pR+(E+GF)+(E+AcK)/B)+0 \\
[8] &= G+F*G \odot B+F*G \\
[9] &= G+(F*G/1+B)+0 \\
[10] &= \text{V}
\end{align*}
\]

Line [4] specifies a letter distribution vector arranged in descending order of expected frequency in normal text. By line [6], \( F \) has become the index in the substring of the letter with the fewest probable occurrences in the target string. This letter is used for the first comparison. Its index is then removed on line [7] for the outer product calculation of indices and \( A,= \) comparison on line [8].

Since we have concluded that reducing the number of potential hits on one character is beneficial, why not do it on two or three? In fact, why not conclude the entire process by constantly refining the potential matches until none remain, or until we have exhausted the substring? SS5 does just that:

\[
\begin{align*}
V &= \text{R+A SS5 } B;C;D;E;F;G \\
[1] &= C+pA*, A \odot D+pB*, B \odot +B|\text{A+D} \\
[2] &= R+I_C \odot +0 \text{ a EMPTY STRING} \\
[3] &= H+(AeB)/C \odot +0 \text{ a SINGLETON STRING} \\
[4] &= B+0FC-D-1 \odot +(pR+(E+Ac1+B)/B)+0 \\
[5] &= B+(IC-1)+B \\
[6] &= G+(F*G/(E+AcK)/B)+0 \\
[7] &= C*D>C*C+1 \\
V &= \text{V}
\end{align*}
\]

Through line [4] the function is identical to SS3; that is, both empty and one-element strings are accommodated, and the first character of longer strings has been compared. Line [5] initializes the substring element counter, and modifies \( B \) so that the counter is appropriate in either origin. Lines [6] and [7] compose the loop; on line [6] the \( C \)th character beyond existing matches in the target string is compared with the \( C \)th character of the remaining substring. If no matches remain, the function terminates. Otherwise, the counter on line [7] is incremented and the function branches back to line [6] if there are more characters to compare in the substring.

In most cases, SS5 is highly efficient. It slows down somewhat if the substring is quite long because it must iterate on each element. On the other hand, its antecedents are all dangerously prone to \( WS\ FULL \) problems in similar situations, especially if the target string is also long. However, \( WS\ FULL \) errors are still possible in SS5, particularly if the first character of the substring occurs often in the target string. This situation can be remedied in much the same way as was illustrated in the progression from SS3 to SS4:

\[
\begin{align*}
V &= \text{R+A SS6 } B;C;D;E;F;G \\
[1] &= C+pA*, A \odot D+pB*, B \odot +B|\text{A+D} \\
[2] &= R+I_C \odot +0 \text{ a EMPTY STRING} \\
[3] &= H+(AeB)/C \odot +0 \text{ a SINGLETON STRING} \\
[4] &= B+F* \text{ ETAISOMRLCPHUMDBWYGKVJQXZ...} \\
[5] &= B+0FC-D-1 \odot +(pR+(E+Ac1+B)/B)+0 \\
[6] &= G+G-F+IC+1 \\
[7] &= +\theta(pR+(E+GF)+(E+AcK)/B)+0 \\
[8] &= G+F*G \odot B+F*G \\
[9] &= G+(F*G/1+B)+0 \\
[10] &= \text{V}
\end{align*}
\]

An expected letter distribution vector is used to rearrange the elements of the substring so that the fewest possible matches are likely for each iteration.
Besides reducing the expected storage requirements, this technique normally speeds up the search further because fewer comparisons need be performed.

Some conclusions can be drawn from the above discussion:

- the shortest solution is not necessarily the fastest;
- handling special cases as such is often beneficial;
- iteration can be faster than "closed-form" code; and
- intelligent analysis of an algorithm can yield substantial gains in CRU efficiency and workspace conservation.

In case you're dubious, the following timing comparisons should dispel any doubts. The target string is the variable `INSTRUCTIONS` (3683 characters) from workspace 1 `FILEAID` on the APL*PLUS System. The times are in CPU milliseconds; the origin is 1.

<table>
<thead>
<tr>
<th>SUBSTRING</th>
<th>dE</th>
<th>SS1</th>
<th>SS2</th>
<th>SS3</th>
<th>SS4</th>
<th>SS5</th>
<th>SS6</th>
</tr>
</thead>
<tbody>
<tr>
<td>''</td>
<td>3683</td>
<td>19</td>
<td>19</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>' '</td>
<td>783</td>
<td>85</td>
<td>60</td>
<td>8</td>
<td>8</td>
<td>8</td>
<td>8</td>
</tr>
<tr>
<td>'aw'</td>
<td>0</td>
<td>82</td>
<td>56</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>' '</td>
<td>342</td>
<td>164</td>
<td>105</td>
<td>27</td>
<td>28</td>
<td>14</td>
<td>14</td>
</tr>
<tr>
<td>'AN'</td>
<td>33</td>
<td>163</td>
<td>104</td>
<td>10</td>
<td>9</td>
<td>7</td>
<td>7</td>
</tr>
<tr>
<td>'aw'</td>
<td>0</td>
<td>162</td>
<td>103</td>
<td>3</td>
<td>4</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>'THE'</td>
<td>20</td>
<td>262</td>
<td>204</td>
<td>55</td>
<td>9</td>
<td>14</td>
<td>8</td>
</tr>
<tr>
<td>'THE '</td>
<td>16</td>
<td>261</td>
<td>203</td>
<td>14</td>
<td>9</td>
<td>9</td>
<td>9</td>
</tr>
<tr>
<td>'MATRIX'</td>
<td>5</td>
<td>357</td>
<td>300</td>
<td>15</td>
<td>5</td>
<td>10</td>
<td>9</td>
</tr>
<tr>
<td>'PERMITS'</td>
<td>15</td>
<td>456</td>
<td>403</td>
<td>113</td>
<td>17</td>
<td>18</td>
<td>13</td>
</tr>
<tr>
<td>'PERMITS'</td>
<td>15</td>
<td>455</td>
<td>401</td>
<td>16</td>
<td>17</td>
<td>12</td>
<td>13</td>
</tr>
<tr>
<td>'NOTFOUND'</td>
<td>0</td>
<td>454</td>
<td>399</td>
<td>22</td>
<td>19</td>
<td>7</td>
<td>7</td>
</tr>
<tr>
<td>'ac1oup~w'</td>
<td>0</td>
<td>455</td>
<td>399</td>
<td>3</td>
<td>4</td>
<td>4</td>
<td>4</td>
</tr>
</tbody>
</table>

(Executed 2/25/77 at 9:19 P.M. EST
On APLPLUSC/470-10011 with 8 users)

March 1977
Two problems are inherent in all measurements: (1) the accuracy of the measuring device, and (2) the impact of the measuring device on the process it is measuring. Observe that if we repeat the test above, the time may differ slightly.

This phenomenon is normal and reflects imprecise timing resolution within the computer. We can improve the statistical reliability of our measurement by performing the algorithm several times, and dividing the total time by the number of iterations.

If the algorithm takes a very small amount of computer time, as in the following example,

the coarse resolution of the timer makes it impossible to obtain reliable measurements. Thus it is essential to repeat the algorithm many times just to accumulate a measurable amount of time.

The first algorithm is faster for small vectors, but the second is substantially faster for large vectors.
USING BOOLEANS TO CONTROL COMPUTATION

One of APL's unique contributions to computing languages is its ability to generate and manipulate Boolean arrays (those containing only 1's and 0's). Although binary (or bit) datatype is available in many other languages, it is often clumsy to use, requiring conversion and indirect manipulation. APL, on the other hand, handles Boolean data directly and efficiently; the data is stored compactly (one value per bit) and processed rapidly.

Boolean values are most often generated by one of the six relational functions (< ≤ = ≥ > *) or by epsilon (`). Five other functions perform logical calculations: and (∧), or (∨), nand (*), nor (¬), and (−). Together, these provide all the nontrivial functions of logical calculus. For instance, exclusive-or is (− ∧) and logical implication is (− ·). The reduction and scan operators also gain new significance with Boolean arguments.

Most uses of Boolean values deal with representing logical true-false conditions. For instance,

\[ V[\neg V>8] \]

\[
\begin{array}{ccccccccccc}
11 & 9 & 12 & 14 & 13 & 8 & 7 & 5 & 8 & 3 & 6 & 1 & 5 & 7 \\
\end{array}
\]

Boolean values can also represent values in binary representation. The following expression gives the base-2 representation of 165 in 8 bits:

\[
\begin{array}{cccccccc}
2 & 2 & 2 & 2 & 2 & 2 & 2 & 1 \\
1 & 0 & 1 & 0 & 0 & 1 & 0 & 1 \\
\end{array}
\]

We can convert back to the base-10 value:

\[ 2110100101 \]

With some imagination, we can also use Boolean values to control other calculations. A common operation is multiplication by a bit vector. For instance, assume we have a matrix \( R\&G S \) of sales region names and an associated vector \( N A C C \) indicating how many new accounts each region has generated. We'd like to produce a new-account report.

\[ \text{DISP} \times N A C C > 0 \]

\[ \text{NA} + N A C C \times N A C C > 1 \]

\[ \text{DISP} \times R\&G S, ' R M (M O N A) B L I G' \times F M T N A \]

NEW ENGLAND (3)
MIDDLE ATLANTIC (10)
EAST NORTH CENTRAL (5)
EAST SOUTH CENTRAL
WEST SOUTH CENTRAL
PACIFIC (2)

\[ \neg \text{DISP} \times R\&G S \]

SOUTH ATLANTIC
WEST NORTH CENTRAL
MOUNTAIN

By using logical multiplication, we "zeroed out" \( N A \) for regions with only one new account, and used the \( B \) modifier to suppress display.

Another application is to return 0 rather than 1 for \( 0 \times 0 \):

\[ A + 6 7 0 5 3 0 5 0 0 7 \]
\[ B + 3 4 0 2 3 0 4 5 8 2 \]
\[ A \times B \diamond A \times B \times B = 0 \]
\[ 2 1.75 1.25 1 1.25 0 0 0 3.5 \]
\[ 2 1.75 0.25 1.25 0 0 0 3.5 \]

Here we used exponentiation by a logical vector to change 0's into 1's because 0\(^1\) will produce the desired 0. We could also have used \( A \times B \times B = 0 \) in this case.

The following table (the first two rows were illustrated above) shows the most useful manipulations and what they produce when \( \text{BOOLEAN} \) is 0 or 1.

<table>
<thead>
<tr>
<th>Operation</th>
<th>BOOLEAN+0</th>
<th>BOOLEAN+1</th>
</tr>
</thead>
<tbody>
<tr>
<td>( A \times \text{BOOLEAN} )</td>
<td>0</td>
<td>( A )</td>
</tr>
<tr>
<td>( A \times \text{BOOLEAN} \times \text{BOOLEAN} )</td>
<td>1</td>
<td>( A )</td>
</tr>
<tr>
<td>( \text{BOOLEAN} )</td>
<td>1</td>
<td>( \text{BOOLEAN} )</td>
</tr>
<tr>
<td>( \text{BOOLEAN} \times \text{BOOLEAN} )</td>
<td>0</td>
<td>( \text{BOOLEAN} )</td>
</tr>
<tr>
<td>( A \times \text{BOOLEAN} \times \text{BOOLEAN} )</td>
<td>0</td>
<td>( \text{BOOLEAN} )</td>
</tr>
<tr>
<td>( A \times \text{BOOLEAN} \times \text{BOOLEAN} )</td>
<td>1</td>
<td>( \text{BOOLEAN} )</td>
</tr>
</tbody>
</table>

| (#) Only for integer \( A \). |

\[
\begin{array}{ccccccccccc}
11 & 9 & 12 & 14 & 13 & 8 & 7 & 5 & 8 & 3 & 6 & 1 & 5 & 7 \\
\end{array}
\]

\[ V[\neg V>8] \]

\[
\begin{array}{ccccccccccc}
2 & 2 & 2 & 2 & 2 & 2 & 2 & 1 \\
1 & 0 & 1 & 0 & 0 & 1 & 0 & 1 \\
\end{array}
\]

The entry \( V[\neg V>8] \) moves all elements greater than 8 to the front of the vector:
Often when dealing with arrays, we wish to process part of the array while leaving the rest untouched. For instance, add 3 percent to only those bills over 30 days old:

\[ \text{BILLS} + \text{BILLS} \times 1.03 \times \text{DAYSOLD} > 30 \]

Other times, we may wish to alter the order of the arguments of the computation itself based on a conditional array (e.g., \( A-B \) or \( B-A \)). For functions with an inverse, we may wish to conditionally alter the function used in a computation (e.g., \( A+B \) or \( A-B \)). If a function has an inverse, we can use \( -1 \) and one of \(*!\) on the conditional array to give us the proper answer. Or, as shown above, we can use the conditional array to control whether the operation is done or not. In the table below, \( C \) is the conditional array. \( C \) controls the function used in the first two lines, the order of the function's arguments in the next two lines, and whether or not the function is performed in the last three lines.

<table>
<thead>
<tr>
<th>If ( C = 0 )</th>
<th>If ( C = 1 )</th>
<th>By Using This Expression</th>
</tr>
</thead>
<tbody>
<tr>
<td>( A+B )</td>
<td>( A-B )</td>
<td>( A+B \times -1 \times C )</td>
</tr>
<tr>
<td>( A \times B )</td>
<td>( A \times B \times -1 \times C )</td>
<td></td>
</tr>
<tr>
<td>( A-B )</td>
<td>( (A-B) \times -1 \times C )</td>
<td></td>
</tr>
<tr>
<td>( A \times A )</td>
<td>( (A B) \times -1 \times C )</td>
<td></td>
</tr>
<tr>
<td>( A \times )</td>
<td>( A \times B \times C )</td>
<td></td>
</tr>
<tr>
<td>( A \times )</td>
<td>( A \times B \times C )</td>
<td></td>
</tr>
</tbody>
</table>

A more general way to interchange scalar function arguments conditionally is by reducing a two-row array that has been rotated by a conditional vector. For example, the following performs \( A \times B \) if \( C = 0 \) and \( B \times A \) if \( C = 1 \):

\[
\begin{pmatrix}
A, & [1] B, & [0.5] C \\
5 & 1 & 7 & 1 & 9 & 2 & 5 & 1 & 2 & 7 & 3 & 3 \\
1 & 6 & 1 & 8 & 1 & 4 & 2 & 27 & 5 & 6 & 2 & 4 & 4 \\
0 & 1 & 0 & 1 & 0 & 1 & 0 & 1 & 0 & 1 & 0 & 0 \\
\end{pmatrix}
\]

\[
(1, p A) \times f c e A, [0.5] B \\
5 & 6 & 7 & 8 & 9 & 16 & 25 & 27 & 32 & 36 & 49 & 64 & 81 \\
\]

Booleans can also be used to select one of two values via subscription. (Note that if the index origin is 0, the Boolean values can serve directly as indices, obviating the need for the \( *! \).)

\[
B+0101110011 \\
711[B+1] \quad \text{(or 7+B\times4} \text{ or 7+B\times4)} \\
7117111111771177 \\
\]

This capability allows simple plotting:

\[
[\times F R E Q \times 8 \times 42] \\
10 \times 24 \times 15 \times 31 \times 35 \times 5 \times 18 \\
'[\times 1] \times F R E Q \times 8 [\times 42] \\
\]

\[
\text{\textbf{July 1977}} \\
\]

Another way to use Booleans is to control the merge order of two vectors:

\[
\begin{align*}
\text{VOWELS} & \Rightarrow 'AEIOUY' \\
\text{CONS} & \Rightarrow 'FCTSL' \\
\text{MERGE} & \Rightarrow 1 \times 0 \times 1 \times 0 \times 0 \times 1 \times 0 \times \\
\end{align*}
\]

\[
(p \times \text{VOWELS}) = +/ \times \text{MERGE} \\
1 \times (p \times \text{CONS}) = +/ \times \text{MERGE} \\
1 \times \text{MERGE}[\times \text{MERGE}] \\
\]

\text{VOWELS} \text{ controls the selection of data from VOWELS (MERGE=0) or CONS (MERGE=1).}

Booleans can be used to control computations in many other ways. Bob Smith, known as the "Boolean Bomber" at Scientific Time Sharing Corporation, has done significant work in this area. His paper, "Boolean Functions and Techniques" is available from STSC as Working Memorandum No. 106.
(Note: All examples are in origin 1.)

Did you know that ... ?

'pA selects the first element of A as a scalar. What happens if A is empty?

3 5 +SCALAR is acceptable, and creates a matrix with all zeros or blanks except for position $[1;1]$ which is the same value as SCALAR.

($Np0)+SCALAR$ has the same effect as ($Np1)+pSCALAR$ or ($Np1)+tSCALAR$ -- it creates a singleton of rank $N$.

A scalar is allowed as the right argument to compression and expansion. In each case, the scalar is first replicated to the appropriate length. Thus, $B/SCALAR$ is identical to $B/((+/B)pSCALAR)$.

$A+.1/A$ changes $A$ into a one-element vector if $A$ was a scalar, but leaves all other arrays unchanged.

$0=.10pA$ returns 1 if $A$ is numeric, 0 if $A$ is character.

$N/.B=B=1$ returns 1 if $B$ is Boolean valued, 0 otherwise. $N/.B<0$ 1 can also be used but is somewhat slower.

You can denote a numeric array $R$ to its most compact internal representation with the following expression:

$$A+pR \phi L+(x/A)pO \phi L[r]+,R \phi R+ApL$$

Note particularly the third statement, a syntactic construction not often seen in APL programs.

Applying reversal ($p[K]A$) or rotation ($p[K+p]A$) along a nonexistent coordinate (that is, where $K+p$ is acceptable and has no effect. This can be useful. For instance, $V[p[K]V]$ sorts $V$ in ascending order if $K$ is 1, and in descending order otherwise.

The expression $+/[2]$ 3 0 4 p5 returns a 3 by 4 matrix of zeros, thereby actually increasing the storage requirements. Can you guess what $/[/230[p6$ returns, and why?

Relational scans ($\leq \leq \geq \geq \neq \neq \neq$) do not always return Boolean values. For example,

$$0 \ 0.5 \ 0.5 \ 0.5$$

Any outer product can be rewritten as an inner product. For instance, $A+.B$ can be restated as $(x(\kappa[x:pA]pA(x(1, pB)pB$ where $O$ can be any scalar dyadic function.

Any reduction on numeric data can likewise be written as an inner product. For instance, $x/[K]A$ can be restated as $0*+(x(\kappa[x:pA]pA.$

Base value (1) can be written as a matrix product. Thus $A_1B$ (without scalar or unitary coordinate extension on the left argument) can be restated as $(x(\kappa[pA+1, pA])*B$.

$A+A$ is faster than $A*2$, and $A*A$ is faster than $A*2$. Generally the simplest function is fastest; but the speed difference is small, so use the most natural construct.

The expression $((pA)\alpha A$ selects the major diagonal of any array.

'0' or '00' or '000' can be used with $\text{DFMT}$ to suppress display of unwanted columns. For example:

'I0,I2,A0,I4,3G8.3' $\text{DFMT}$ 4 8 p132

2 4 8.000
10 12 16.000
18 20 24.000
26 28 32.000

Many experienced APL programmers cannot name all APL primitive scalar dyadic functions. Can you? (Hint: + is one of them, and there are twenty more.)

September 1977
DATA SELECTION

Selecting data from an array is one of the most common operations in APL. There are three primary facilities for APL data selection:

- positional, using subscription \( A[B] \)
- conditional, using compression \( B[K]A \)
- bounded, using take \( B \+ A \) or drop \( B \+ A \)

There are also several specialized techniques for frontal and diagonal selection using reshape \( B \times A \) or transpose \( B \times A \). Besides selecting data, some of these functions can replicate data (subscription, compression of a scalar, and reshape), extend data (take), or reorganize data (subscription, reshape, and transpose). This article discusses these techniques as applied to the matrix \( A \) in origin 1:

\[
\begin{array}{cccccccc}
10 & 13 & 14 & 15 & 16 & 17 & 18 & 19 \\
20 & 23 & 24 & 25 & 26 & 27 & 28 & 29 \\
30 & 32 & 33 & 34 & 35 & 36 & 37 & 39 \\
40 & 42 & 43 & 44 & 45 & 46 & 47 & 49 \\
50 & 52 & 53 & 54 & 55 & 56 & 57 & 59
\end{array}
\]

Subscription is the most generalized selection function. It can be used to select, reorder, and replicate data.

\( A[2 \ 5 \ 1 \ ; \ 9 \ 1 \ 5 \ 7 \ 5 \ 5] \)

\[
\begin{array}{cccccccc}
29 & 21 & 25 & 27 & 25 & 29 \\
59 & 51 & 55 & 57 & 55 & 55 \\
19 & 11 & 15 & 17 & 15 & 15
\end{array}
\]

Because of its flexibility, subscription is typically the slowest of all selection functions applied to a matrix. However, it alone can reorder or selectively replicate data, and it can be used to the left of assignment (\(+\)). In the absence of these requirements, subscription is best used only to select single rows or columns, or small subarrays. Subscription is somewhat faster on vectors than it is on matrices.

Compression is less flexible than subscription; it can select only along a single coordinate, and it cannot replicate or reorder data. However, it can select non-contiguous rows or columns in the same order they occur in the array.

\( 1 \ 0 \ 0 \ 0 \ 1 \ /A \)

\[
\begin{array}{cccccccc}
11 & 12 & 13 & 14 & 15 & 16 & 17 & 18 \\
21 & 22 & 23 & 24 & 25 & 26 & 27 & 28 \\
31 & 32 & 33 & 34 & 35 & 36 & 37 & 39 \\
41 & 42 & 43 & 44 & 45 & 46 & 47 & 49 \\
51 & 52 & 53 & 54 & 55 & 56 & 57 & 59
\end{array}
\]

Because of its more limited capability, compression is typically faster than subscription. Of course, it is ideal when selecting on the basis of a Boolean vector from epsilon \( (\varepsilon) \) or one of the relational \( (\leq, \geq, \neq, \equiv, \lor, \forall) \) or logical \( (\land, \lor, \neg) \) functions. As noted, compression can select along only one coordinate. Thus the matrix must be compressed twice in order to select both rows and columns.

\[
\begin{array}{cccccc}
0 & 1 & 1 & 0 & 0 & 0 \\
24 & 25 & 26 & 27 \\
34 & 35 & 36 & 37
\end{array}
\]

If indices are already provided for one coordinate, it is usually faster to use \( B/\times B \) and subscription. For instance, \( A[B/\times B; 5 \ 4 \ 7 \ 6] \) should be used rather than \( BfA[; 5 \ 4 \ 7 \ 6] \).

Take and drop are the most restrictive selection functions. They allow only contiguous blocks of data to be selected, and they cannot replicate or reorder. They are quite fast, however, at selecting large blocks of data. One application of either function is sufficient to select any corner subarray.

\[
\begin{array}{cccccc}
3 & 5 & A & m^2 & 4 & A \\
11 & 12 & 13 & 14 & 15 & 16 & 17 & 18 & 19 \\
21 & 22 & 23 & 24 & 25 & 26 & 27 & 28 & 29 \\
31 & 32 & 33 & 34 & 35 & 36 & 37 & 38 & 39
\end{array}
\]

Any contiguous block of data can be selected by two applications of either function. The subarray

\( A[2 \ 3 \ ; \ 4 \ 5 \ 6 \ 7] \)

\[
\begin{array}{cccccccc}
24 & 25 & 26 & 27 \\
34 & 35 & 36 & 37 \\
\end{array}
\]

can be selected by each of 16 expressions:

\[
\begin{array}{cccccc}
2 & 4 & 3 & 7 & A & -2 & 4 & 3 & 6 & 4 & A \\
2 & 4 & 2 & 2 & A & -2 & 4 & 2 & 3 & 4 & A \\
1 & 3 & 3 & 7 & A & -1 & 2 & 3 & 6 & 4 & A \\
1 & 3 & 2 & 2 & A & -1 & 2 & 2 & 3 & 4 & A \\
2 & 4 & 4 & 7 & A & 2 & 4 & 4 & 6 & 4 & A \\
2 & 4 & 1 & 2 & A & 2 & 4 & 1 & 3 & 4 & A \\
-2 & 3 & 4 & 7 & A & -2 & 2 & 4 & 6 & 4 & A \\
-2 & 3 & 1 & 2 & A & -2 & 2 & 1 & 3 & 4 & A \\
\end{array}
\]

Unless extension (padding with zeros or blanks) is needed, convenience should determine whether to use take or drop.

Reshape and transpose are normally considered structural functions, but are often used for specialized selection. Reshape can select data from the front of an array. For instance, the following expression selects the first element as a scalar:
The next expression selects the first row as a vector:

\[ \text{pA} \]

11 12 13 14 15 16 17 18 19

Transpose can select the major diagonal, or the other diagonals if used with reversal.

\[ \text{pA} \]

1 1 11 22 33 44 55
1 1 19 28 37 46 55
1 1 51 42 33 24 15
59 48 37 26 15

Both reshape and transpose are very fast.

In general, the speed of all selection functions depends on the amount of data being selected, not on the size of the original array. As more data is selected, more CRUs will be consumed. By avoiding superfluous data selection and by using the most specialized function appropriate to your needs, you can increase the efficiency of your programs.

November 1977

Most APL systems are implemented as interpreters. This allows users great flexibility in creating and modifying programs. There is no need for compilation, and errors can be diagnosed and corrected during execution.

The major penalty of an interpreter is the cost of syntax analysis and dynamic data checking. Fortunately, APL functions tend to be quite short relative to programs in other languages, and therefore the interpretive overhead is minimized.

On the other hand, when looping is performed in APL, the interpretive overhead skyrockets because the same code must be reanalyzed for each iteration. The general rule, therefore, is to try to minimize looping in APL.

As anyone familiar with APL will attest, most programs can be written with no loops at all. APL's rich set of primitive functions and operators allows "closed form" (nonlooping) solutions to many complex problems. The control structures that must be written explicitly in other languages (e.g., DO loops) are performed implicitly in APL primitives (e.g., scan). But difficulties can arise when people who have been schooled in languages like FORTRAN, BASIC, and COBOL try to move their looping programs intact into APL.

For example, the following portion of a FORTRAN program calculates cash flow for a series of 360 investments using variable interest rates. DEP is N+1 deposits, the first being the initial amount; RATE is N interest rates between 0 and 1; CF is the result.

```
DIMENSION CF(361)
DIMENSION DEP(361)
DIMENSION RATE(360)

CF(1)=DEP(1)
DO 20 I=1,360
20 CF(I+1)=DEP(I+1)+CF(I)*(RATE(I)+1.)
```

This segment can be translated almost directly into the following APL program:

```
V CF+RATE CASHFLOW DEP;I;N
[1]
CF+DEP
[2] N+PRATE
[3] ->N+0 ○ I+1
[5] +L20×N+I+1
```

and will run successfully, albeit slowly:

```
(\text{pDEP}, \text{pRATE}) \text{ a 30-YEAR MONTHLY LOAN}
361 360
T+\text{IOAI} ○ CF+RATE CASHFLOW DEP ○ \text{IOAI-T}
0 2070 483 0 (0.\text{MILLICRUS}, \text{MILLISECONDS}, 0)
```

-36-
More than 2 computer resource units are required to run CASHFLOW -- not a very cost-effective solution!

Rather than entirely rethinking the problem, some users will take great pains to optimize the existing algorithm. This approach is fine if no alternative algorithms are considered, but it often results in a more obscure program:

\[ \sqrt{CF+R \text{ CASHFLOO } D;I;J;N;T} \]

[1] \[ T-D[I+1] O D+1+CF+D \]

[2] \[ R+R+1 \]

[3] \[ +N*((pR)pL),0 \]


The techniques used in CASHFLOO all serve to reduce interpretive overhead in the loop on line [4]. Interest rates \( R \) and branch targets \( N \) are calculated in advance, and subscript calculations are simplified. (Note that the use of one-letter variable names does not affect the cost of running the program.)

\[ T=DAI O CF+RATE CASHFLOO DEP O DAI-T \]

0 1301 330 0

We've reduced the cost by one third -- a significant savings, but still not enough to be cost effective.

By far the most effective approach is to reformulate the problem into an APL solution, rather than a warmed-over FORTRAN solution. Consider the following:

\[ \sqrt{CF+RATE FASTFLOW DEP} \]

[1] \[ CF=1, \times \text{RATE}+1 O CF+CF+\text{DEP}+CF \]

\[ \]

\( CF \) is set first to the cumulative present-value discount factors for future deposits. The deposits are divided by those factors, summed, and then multiplied by the factors to produce the result. A good exercise is to derive this algorithm from the looping algorithm; the key is that multiplication and division are both distributive with respect to addition (division is only right distributive).

FASTFLOW is indeed an elegant and inexpensive solution to the problem:

\[ T=DAI O CF+RATE FASTFLOW DEP O DAI-T \]

0 26 7 0

It performs 50 times faster than even the optimized looping solution, and illustrates the benefits that can be derived from writing nonlooping APL code.

January 1978

With the recent introduction of the system function \( \text{DSS} \) for character string searching, and the major speedups to character \( \lambda= \) and \( \nu \overline{2} \), a variety of new techniques are now practical. Although these techniques were usable before the enhancements, they were often infeasible because of WS FULL conditions or the large number of computer resource units needed to accomplish them. Frequently, obscure or clumsy code was written to circumvent the previous snailish pace of \( \lambda= \).

For example, a typical table lookup

\[ \text{MATRIX} \times \text{VECTOR} \]

was occasionally coded as

\[ \times / \text{MATRIX}=(p \text{MATRIX}) \text{VECTOR} \]

to reduce cost (at the risk of WS FULL). Now, the first expression is many times faster.

The improvements to \( \lambda= \) also dramatically altered the relative speeds of the six different string-searching algorithms presented in "String Searching" beginning on page 21. In particular, \( \text{SS2} \), \( \text{SS3} \), and \( \text{SS4} \) all use \( \lambda= \) for part or all of the search. Below is a table comparing their performance on 25 February 1977 with their current performance and with that of their \( \text{DSS} \)-equivalent \( (R+(A \text{ DSS} B))/pA) \). The times are in milliseconds.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>'A'</td>
<td>3683</td>
<td>19</td>
<td>2</td>
</tr>
<tr>
<td>'B'</td>
<td>783</td>
<td>60</td>
<td>8</td>
</tr>
<tr>
<td>'W'</td>
<td>0</td>
<td>56</td>
<td>2</td>
</tr>
<tr>
<td>'a'</td>
<td>342</td>
<td>105</td>
<td>27</td>
</tr>
<tr>
<td>'AN'</td>
<td>33</td>
<td>104</td>
<td>10</td>
</tr>
<tr>
<td>'aw'</td>
<td>0</td>
<td>103</td>
<td>3</td>
</tr>
<tr>
<td>'THE'</td>
<td>20</td>
<td>204</td>
<td>55</td>
</tr>
<tr>
<td>'THE'</td>
<td>16</td>
<td>203</td>
<td>14</td>
</tr>
<tr>
<td>'MATRIX'</td>
<td>5</td>
<td>300</td>
<td>15</td>
</tr>
<tr>
<td>'RATMIX'</td>
<td>0</td>
<td>301</td>
<td>23</td>
</tr>
<tr>
<td>'PERMITS'</td>
<td>15</td>
<td>403</td>
<td>113</td>
</tr>
<tr>
<td>'PERMITS'</td>
<td>15</td>
<td>401</td>
<td>16</td>
</tr>
<tr>
<td>'NOTFOUND'</td>
<td>0</td>
<td>399</td>
<td>22</td>
</tr>
<tr>
<td>'abc1Oupw'</td>
<td>0</td>
<td>399</td>
<td>3</td>
</tr>
</tbody>
</table>

(Executed 24 Feb 78 at 6:46 PM EST on APLPLUSC/470-10011 with 34 users)

Although they still suffer a propensity for WS FULLs with large arguments, it's nice to know their cost has dropped so dramatically!

Pleasantly, the discussion of string-search techniques is now moot because we have \( \text{DSS} \). In fact, even if \( \text{DSS} \) weren't available, the following simple function would perform the same task:

\[ \text{MATRIX} \times \text{VECTOR} \]
The function \texttt{DSS} takes roughly twice as long as \texttt{SS} to perform a given search. Moreover, \texttt{DSS} has the advantage of requiring no additional or intermediate workspace storage.

Not only does \texttt{DSS} provide cost and storage advantages, but it also allows novel or simpler approaches to problems. Below are a few examples.

Determine if function \texttt{DSPELL} is currently suspended or pendent; that is, whether it's in the state indicator.

\begin{verbatim}
OLD \texttt{v/(1+p0SI,1+p,FN)+0SI}A.='FN,'[f'
\texttt{v/(1+p0SI,7)+0SI}A.='DSPELL'
NEW \texttt{v/,'}[f'
\texttt{v/,'}[f'
\end{verbatim}

Mark the line-ending carriage returns in a function.

\begin{verbatim}
OLD \texttt{v}[OIOIFVR]+'FNNAME' \texttt{OR}[0IO-6-pVR]+'[
OLD \texttt{VR[OFTCNL}]A1'VR='[
NEW \texttt{VR} \texttt{DSS} \texttt{TCNL} '='
\end{verbatim}

And finally, here's a function that locates a string in any row of a matrix:

\begin{verbatim}
\texttt{v R=M ROWSS V}
\end{verbatim}

\texttt{ROWSS} locates all occurrences in the ravelled matrix, and its result is reshaped to the shape of the matrix. Then, those columns that might identify matches spanning more than one row are dropped. Finally, the \texttt{v} singles out the proper rows. \texttt{ROWSS} will locate matches in a character matrix:

\begin{verbatim}
\texttt{pSTATES}
50 14 (STATES ROWSS 'NIA')/STATES CALIFORNIA PENNSYLVANIA VIRGINIA WEST VIRGINIA (STATES ROWSS 'LIN')/STATES ILLINOIS NORTH CAROLINA SOUTH CAROLINA
March 1978
\end{verbatim}

\begin{verbatim}
\texttt{BACK TO BASICS}
\end{verbatim}

One of the beauties of APL is the ability to get useful results while using only a small subset of the language. Gradually, through curiosity and experimentation, users discover more advanced features which they can apply to their problems. In the interest of hastening that discovery, I'd like to introduce you to a powerful function in APL called base value. I'll discuss its performance on scalars and vectors only, leaving you to experiment with matrices if you wish.

Base value, also called decode, is represented by the \texttt{i} symbol (shift \texttt{B}). It is dyadic and accepts only numeric arguments. Let's see what happens in a simple case.

\begin{verbatim}
10i 8 2 9 5
8295
\end{verbatim}

The effect of "putting numbers together" is actually the result of evaluating the polynomial expression

\begin{verbatim}
8x^3 + 2x^2 + 9x + 5
\end{verbatim}

for \(x=10\), or, for you APL'ers out there:

\begin{verbatim}
X=10
(8X*3)+(2X*2)+(9X)+5
8295
\end{verbatim}

or

\begin{verbatim}
5+X*9+X*2+X*8
8295
\end{verbatim}

Notice that the coefficients are on the right and the independent variable is on the left. Thus, base value evaluates polynomials. This may seem esoteric, but it actually proves quite useful. For example, you can use it to combine month, day, and year into one number, or to determine the number of seconds in 2 hours, 10 minutes, and 38 seconds.

\begin{verbatim}
1001 6 5 77 m (10000x6)+(100x5)+1x77 60577
\end{verbatim}

or

\begin{verbatim}
601 2 10 38 s (3600x2)+(60x10)+1x38 7838
\end{verbatim}

Note that the following three expressions are equal:

\begin{verbatim}
2+3x4 0 3i 4 2 0 4i 3 2
14
14
14
\end{verbatim}

From what you've seen so far, can you explain why \texttt{1iVEC} is the same as \texttt{+/VEC}, and why \texttt{0iVEC} is the same as \texttt{-1+VEC}? For scalars and vectors, \texttt{A*B} is equivalent to \texttt{+/W*B} (or \texttt{W+,x*B}), where \texttt{W} is a vector of weights derived from \texttt{A}. As we've seen above, if the left argument is
a scalar, then (assuming \[10+1\]) \( W \) is calculated as follows:

\[
W = A \cdot (pB)^{-1} pB
\]

\[
60 \cdot 3 -1 2 3
60 \cdot 2 1 0
3600 60 1
\]

More generally, if the left argument is a vector,

\[
A \cdot B
\]

base value is evaluating a mixed radix polynomial. In the example above we're calculating the number of milliseconds in 1 week, 2 days, 3 hours, 4 minutes, 5 seconds, and 6 milliseconds. In this case the left argument represents:

- (placeholder)
- 7 days per week
- 24 hours per day
- 60 minutes per hour
- 60 seconds per minute
- 1000 milliseconds per second

The weighting vector is computed by performing a multiplication scan from right-to-left on all but the first element of the left argument, and catenating a 1 to that result:

\[
W = \phi_1 \cdot x \cdot \phi_1 + A
\]

\[
W = \phi_1 \cdot x \cdot \phi_1 \cdot 0 7 24 60 60 1000
\]

\[
W = \phi_1 \cdot x \cdot \phi_1 \cdot 24 60 60 1000
\]

\[
W = \phi_1 \cdot x \cdot \phi_1 \cdot 60 60 24 7
\]

\[
W = \phi_1 \cdot x \cdot \phi_1 \cdot 60000 3600000 864000000 6048000000
\]

\[
W = \phi_1 \cdot x \cdot \phi_1 \cdot 60000 3600000 864000000 6048000000
\]

\[
W = \phi_1 \cdot x \cdot \phi_1 \cdot 1 000 60 000 1000 1
\]

Hence we multiply the number of milliseconds in a week by the number of weeks, add it to the number of milliseconds in a day multiplied by the number of days, and so on, to produce the result:

\[
+/W \cdot x \cdot B
\]

If either argument is scalar, it is extended to the length of the other argument, and the same weighting vector calculation is used. Thus the following expressions are equivalent:

\[
12 12 12 12 2
314 12 12 12 2
314 12 12 12 2
314 12 12 12 2
36120 60 10 0 120
36120 60 60 10 0 120
36120 0 60 60 10 0 120
36120 743 60 60 10 0 120
36120

As illustrated, the first element of the left argument does not affect the result, but serves only as a placeholder. If either argument is not a scalar or one-element vector, the lengths of the arguments must match.

\[
60 60 \cdot 10 0 120
60 60 \cdot 10 0 120
\]

This rule is identical to that used by inner product (for example, \( + \cdot x \)) although in inner product the first element of the left argument does affect the result.

**SOME USEFUL APPLICATIONS**

Right justify a character vector \( V \):

\[
(1 - (V = ' ') \cdot 1) \cdot V
\]

Actually, this expression will right justify an array of any rank. It uses the "reverse multiplication scan" weighting vector calculation as an and-scan \((\&)\), and the \( (+/ \cdot x)\) to calculate \((+)\) the number of contiguous ending spaces.

"Why Not to Loop" beginning on page 37 contains the function \( \text{FASTFLOW} \) to compute a cash flow series for a starting balance \((SB)\) and \( N \) subsequent deposits \((DP)\), all compounded at varying interest rates \((IR)\).

\[
V \cdot CF \cdot RATE \cdot \text{FASTFLOW} \cdot DP
\]

\[ SB \cdot 100 \]
\[ DP \cdot 0 50 100 \cdot 0 123.26 \]
\[ IR \cdot 0.2 0.25 0.08 0 0.05 0.06 \]
\[ \text{FASTFLOW} \cdot SB, DP \]

\[
100 \cdot 120 \cdot 200 \cdot 316 \cdot 100 \cdot 105 \cdot 234.56
\]

If you don't need the intermediate values and only wish to know the ending balance, the following expression will suffice:

\[
(0, IR + 1) \cdot SB, DP
\]

Given an array \( YM \) containing months packed as \( YYMM \) or \( YYYYMM \), add \( A \) months and return the dates in the same format:

\[
V \cdot R \cdot A \cdot MONTHADD \cdot YM
\]

\[ R \cdot 100 100000 12TA + 12100000 100 T Y M - 1 \]

\[
7 \cdot \text{MONTHADD} \cdot 197805 \cdot 197806 \cdot 197812
\]
\[ 197812 \cdot 197901 \cdot 198007 \]
\[ 0.5 \cdot 11 \cdot 16 \cdot \text{MONTHADD} \cdot 197804 \]
\[ 197711 \cdot 197705 \cdot 197612 \]
\[ 16 \cdot \text{MONTHADD} \cdot 197806 + 16 \]
\[ 197808 \cdot 197810 \cdot 197812 \cdot 197902 \cdot 197904 \cdot 197906 \]

This is a lovely illustration of the relationship between decode \((J.)\) and encode \((T.)\). It uses both to convert back and forth between decimal and base-12 representation.

May 1978