

# Algorithms

J. H. WEGSTEIN, Editor

ALGORITHM 160  
COMBINATORIAL OF M THINGS  
TAKEN N AT A TIME  
M. L. WOLFSON AND H. V. WRIGHT  
United States Steel Corp., Monroeville, Penn.

```
integer procedure combination (m, n);
value n; integer m, n;
comment calculates the number of combinations of m things
taken n at a time. If n is less than half of m, then the program
calculates the combinations of m things taken m - n at a time
which is the exact equivalent of m things taken n at a time;
begin integer p, r, i;
p := m - n;
if n < p then begin p := n; n := m - p end;
if p = 0 then begin r := 1; go to exit end;
r := n + 1;
for i := 2 step 1 until p do r := (r * (n+i))/i;
exit: combination := r
end combination
```

ALGORITHM 161  
COMBINATORIAL OF M THINGS  
TAKEN ONE AT A TIME, TWO AT A TIME,  
UP TO N AT A TIME  
H. V. WRIGHT AND M. L. WOLFSON  
United States Steel Corp., Monroeville, Penn.

```
procedure combination vector (m, n, v);
integer m, n; integer array v;
comment calculates all combinations of m things taken from 1
to n at a time. The result is a vector, v, within which the first
element is the combination of m things taken 1 at a time, the
second element is the combinations of m things taken 2 at a time,
the third element taken 3 at a time, ..., and the nth element
taken n at a time.
begin integer i;
v[1] := m;
for i := 2 step 1 until n do
v[i] := (v[i-1] * (m-i+1))/i;
end combination vector
```

ALGORITHM 162  
XYMOVE PLOTTING  
FRED G. STOCKTON  
Shell Development Co., Emeryville, Calif.  
procedure xymove (XZ, YZ, XN, YN); value XZ, YZ, XN, YN;  
integer XZ, YZ, XN, YN;  
comment xymove computes the code string required to move the  
pen of a digital incremental X,Y-plotter from an initial point  
(XZ, YZ) to a terminal point (XN, YN) by the "best" approxi-

mation to the straight line between the points. The permitted  
elemental pen movement is to an adjacent point in a plane  
Cartesian point lattice, diagonal moves permitted. The eight  
permitted pen movements are coded

1 = +Y, 2 = +X+Y, 3 = +X, 4 = +X-Y,  
5 = -Y, 6 = -X-Y, 7 = -X, 8 = -X+Y.

The approximation is "best" in the sense that each point tra-  
versed is at least as near the true line as the other candidate  
point for the same move.

xymove does not use multiplication or division;  
begin integer A, B, D, E, F, T, I, move;  
comment code (J) is a procedure which returns a value of code  
according to the following table:

J	1	2	3	4	5	6	7	8
code	1	2	3	2	3	4	5	4
J	9	10	11	12	13	14	15	16
code	5	6	7	6	7	8	1	8

plot (move) is a procedure which sends move to the plotter as a  
plotter command;

```
if XZ = XN ^ YZ = YN then go to return;
A := XN - XZ; B := YN - YZ; D := A + B; T :=
B - A; I := 0;
if B ≥ 0 then I := 2;
if D ≥ 0 then I := I + 2;
if T ≥ 0 then I := I + 2;
if A ≥ 0 then I := 8 - I else I := I + 10;
A := abs(A); B := abs(B); F := A + B; D := B - A;
if D ≥ 0 then begin T := A; D := -D end else T := B;
E := 0;
repeat: A := D + E; B := T + E + A;
if B ≥ 0 then begin E := A; move := code(I);
F := F - 2 end
else begin E := E + T; F := F - 1;
move := code(I-1) end;
plot(move);
if F > 0 then go to repeat;
return:
end
```

ALGORITHM 163  
MODIFIED HANKEL FUNCTION  
HENRY E. FETTIS  
Aeronautical Research Laboratories, Wright-Patterson  
Air Force Base, Ohio

```
procedure EXPK (P, X, E); real P, X, E;
comment this procedure calculates the modified Hankel Func-
tion  $e^x K_p(x)$  to within a given accuracy E from the integral
representation:
```

$$e^x K_p(x) = \int_0^{\infty} e^{x(1-\cosh t)} \cosh(pt) dt;$$

```

begin real F, G, H, R, S, T, U, Y, Z, ZP;
  R := 0.0;
  H := 1.0;
  iteration: begin
    G := R;
    T := .5 × H;
    S := 0;
    Z := exp(T);
    U := Z × Z;
    integration: begin
      Y := X × (1 - .5 × (Z+1/Z));
      if P = 0 then ZP := 1
      else ZP := Z ↑ P;
      F := .5 × exp(Y) × (ZP+1/ZP);
      S := S + F;
      Z := Z × U;
    end;
    if F ≥ E then go to integration
    else R := H × S;
      H := .5 × H;
    end;
    if abs (R-G) ≥ E then go to iteration
    else EXPK := R
  end EXPK

```

### ALGORITHM 164 ORTHOGONAL POLYNOMIAL LEAST SQUARES SURFACE FIT

R. E. CLARK, R. N. KUBIK, L. P. PHILLIPS  
The Babcock & Wilcox Co., Atomic Energy Div.,  
Lynchburg, Va.

**procedure** *surfacefit* (*x, u, y, w, z, nmax, mmax, imax, jmax*)  
result: (*beta, phi, zcomp, minsqd, minsqdcomp, sumdifcomp, maxdifcomp*);

**real array** *x, u, y, w, z, phi, beta, zcomp*;

**integer** *nmax, mmax, imax, jmax*;

**real** *minsqd, minsqdcomp, sumdifcomp, maxdifcomp*;

**comment** this is a transliteration of an operating program written in Burroughs ALGOL for the B-220. It fits, in the least squares sense, a polynomial function of two independent variables to values of a dependent variable specified at points on a rectangular grid in the plane of the independent variables. The use of orthogonal polynomials leads to a particularly simple system of linear equations rather than the ill-conditioned system which arises from the usual normal equations. It also provides a measure of the improvements resulting from each new term included which further leads, in this algorithm, to an automatic selection of a "best" degree polynomial function as determined by Gauss' criterion. The initial normalization of the variables results in significant reduction of round off errors in many cases. This algorithm is developed more fully in BAW-182. For a very similar approach to this and related problems see Cadwell, J. H., "Least Squares Surface Fitting Program", *The Computer J.* 3 (1961), 266 and Cadwell, J. H., and Williams, D. E., "Some Orthogonal Methods of Curve and Surface Fitting," *The Computer J.* 4 (1961), 260. A further reference is Gauss, C. F., "Theoria Combinationis Observationum Erroribus Minimis Obnoxial," *Gauss Werke* 4 (Gottingen 1873), 3-93. *x[i]* and *y[j]* are the independent variables, *z[i, j]* is the dependent variable. *u[i]* and *w[j]* represent the weights corresponding to *x[i]* and *y[j]*, respectively. *nmax* is one more than the maximum degree of *x* to be considered. *mmax* is one more than the maximum degree of *y* to be considered. *imax* is the number of *x*'s, and *jmax* is the number of *y*'s. *beta[n, m]* is a measure of the improvement resulting from the inclusion of the  $x^ny^m$ th term. *phi[n, m]* is the poly-

nomial coefficient for the  $x^ny^m$ th term. Note the degree of the resulting polynomial may be less than the maximum degree specified as a result of the application of Gauss' criterion. *zcomp* is the computed dependent variable.

$$\text{minsqd} = \left( \frac{\sum_{i,j} u[i] \cdot w[j] \cdot z[i,j]^2 - \sum_{n,m} \text{beta}[n,m]}{\text{imax} \cdot \text{jmax}} \right)^{1/2}$$

$$\text{minsqdcomp} = \left( \frac{\sum_{i,j} u[i] \cdot w[j] \cdot (z[i,j] - \text{zcomp}[i,j])^2}{\text{imax} \cdot \text{jmax}} \right)^{1/2}$$

$$\text{sumdifcomp} = \frac{\sum_{i,j} |z[i,j] - \text{zcomp}[i,j]|}{\text{imax} \cdot \text{jmax}}$$

$$\text{maxdifcomp} = \max |z(i,j) - \text{zcomp}(i,j)|$$

*minsqd* and *minsqdcomp* are equal if computation is exact. In practice they will not be equal due to the imprecise nature of calculation. A wide discrepancy indicates excessive errors in calculation;

**begin**

**real array** *a, b, denpa[1:nmax], c, d, denqa[1:mmax], alpha[1:nmax, 1:mmax], p[1:nmax, 1:imax], q[1:mmax, 1:jmax], pc[1:nmax, 1:mmax], qc[1:mmax, 1:mmax]*;

**integer** *n, m, i, j, s, t, r*;

**real** *sumx, sumy, sumz, meanx, meany, meanz, numa, dena, denb, numc, denc, dend, alph, sumzsq, gausscrit, trialgausscrit, betasum, rescomp, poly*;

**comment** normalization of variables;

*sumx* := *sumy* := *sumz* := 0.0;

**for** *i* := 1 **step** 1 **until** *imax* **do**

*sumx* := *sumx* + *x[i]*;

*meanx* := *sumx*/*imax*;

**for** *i* := 1 **step** 1 **until** *imax* **do**

*x[i]* := *x[i]* - *meanx*;

**for** *j* := 1 **step** 1 **until** *jmax* **do**

*sumy* := *sumy* + *y[j]*;

*meany* := *sumy*/*jmax*;

**for** *j* := 1 **step** 1 **until** *jmax* **do**

*y[j]* := *y[j]* - *meany*;

**for** *i* := 1 **step** 1 **until** *imax* **do begin**

**for** *j* := 1 **step** 1 **until** *jmax* **do**

*sumz* := *sumz* + *z[i,j]* **end**;

*meanz* := *sumz*/(*imax* × *jmax*);

**for** *i* := 1 **step** 1 **until** *imax* **do begin**

**for** *j* := 1 **step** 1 **until** *jmax* **do**

*z[i, j]* := *z[i, j]* - *meanz* **end**;

**comment** evaluate orthogonal polynomials;

*numa* := *dena* := 0.0;

**for** *i* := 1 **step** 1 **until** *imax* **do begin**

*p*[1, *i*] := 1.0;

*numa* := *numa* + *u*[*i*] × *x*[*i*];

*dena* := *dena* + *u*[*i*] **end**;

*a*[2] := *numa*/*dena*;

**for** *i* := 1 **step** 1 **until** *imax* **do**

*p*[2, *i*] := *x*[*i*] - *a*[2];

**for** *n* := 3 **step** 1 **until** *nmax* **do begin**

*numa* := *dena* := *denb* := 0.0;

**for** *i* := 1 **step** 1 **until** *imax* **do begin**

*numa* := *numa* + *u*[*i*] × *x*[*i*] × *p*[*n*-1, *i*] ↑ 2;

*dena* := *dena* + *u*[*i*] × *p*[*n*-1, *i*] ↑ 2;

*denb* := *denb* + *u*[*i*] × *p*[*n*-2, *i*] ↑ 2 **end**;

*a*[*n*] := *numa*/*dena*; *b*[*n*] := *dena*/*denb*;

**for** *i* := 1 **step** 1 **until** *imax* **do**

*p*[*n*, *i*] := (*x*[*i*] - *a*[*n*]) × *p*[*n*-1, *i*] - *b*[*n*] × *p*[*n*-2, *i*] **end**;

*numc* := *denc* := 0.0;

**for** *j* := 1 **step** 1 **until** *jmax* **do begin**

*q*[1, *j*] := 1.0;

*numc* := *numc* + *w*[*j*] × *y*[*j*];

*denc* := *denc* + *w*[*j*] **end**;

```

c[2] := numc/denc;
for j := 1 step 1 until jmax do
  q[2, j] := y[j] - c[2];
for m := 3 step 1 until nmax do begin
  numc := denc := dend := 0.0;
  for j := 1 step 1 until jmax do begin
    numc := numc + w[j] × y[j] × q[m-1, j] ↑ 2;
    denc := denc + w[j] × q[m-1, j] ↑ 2;
    dend := dend + w[j] × q[m-2, j] ↑ 2 end;
  c[m] := numc/denc; d[m] := denc/dend;
  for j := 1 step 1 until jmax do
    q[m, j] := (y[j]-c[m]) × q[m-1, j] - d[m] × q[m-2, j] end;
  comment evaluate contribution of each orthogonal polynomial
  to the minimization of the residuals;
for n := 1 step 1 until nmax do begin
  denpa[n] := 0.0;
  for i := 1 step 1 until imax do
    denpa[n] := denpa[n] + u[i] × p[n, i] ↑ 2 end;
  for m := 1 step 1 until nmax do begin
    denqa[m] := 0.0;
    for j := 1 step 1 until jmax do
      denqa[m] := denqa[m] + w[j] × q[m, j] ↑ 2 end;
  for n := 1 step 1 until nmax do begin
    for m := 1 step 1 until nmax do begin
      alph := 0.0;
      for i := 1 step 1 until imax do begin
        for j := 1 step 1 until jmax do
          alph := alph + u[i] × w[j] × z[i, j] × p[n, i] × q[m, j]
          end;
        alpha[n, m] := alph/(denpa[n]×denqa[m]);
        beta[n, m] := alpha[n, m] × alph; end end;
  comment application of Gauss' criterion to determine the de-
  gree polynomial which yields the closest fit to the given data.
  Gauss' criterion is, strictly speaking, applicable only to cases
  where the weights u[i] and w[j] are unity;
  sumzsq := 0.0;
  for i := 1 step 1 until imax do begin
    for j := 1 step 1 until jmax do
      sumzsq := sumzsq + u[i] × w[j] × z[i, j] ↑ 2 end;
  s := t := 1;
  for n := 1 step 1 until nmax do begin
    betasum := 0.0;
    for m := 1 step 1 until nmax do begin
      for r := 1 step 1 until n do
        betasum := betasum + beta[r, m];
      if betasum > sumzsq then trialgausscrit := 0.0
      else
        trialgausscrit := (sumzsq-betasum)/(imax×jmax-n×m);
      if n = 1 ∧ m = 1 then gausscrit := trialgausscrit;
      if gausscrit = trialgausscrit then begin
        if n × m < s × t then begin
          s := n;
          t := m end end;
        if gausscrit > trialgausscrit then begin
          gausscrit := trialgausscrit;
          s := n;
          t := m end end end;
  nmax := s;
  nmax := t;
  minsqd := (gausscrit×(imax×jmax-nmax×nmax))/(imax×jmax)
  ↑ ½;
  comment evaluation of orthogonal polynomial coefficients;
  for n := 1 step 1 until nmax do begin
    pc[n, m] := 1.0;
    for s := 1 step 1 until n - 1 do begin
      pc[n, s] := -a[n] × pc[n-1, s];
      if s ≠ 1 then pc[n, s] := pc[n, s] + pc[n-1, s-1];
      if s ≠ n - 1 then pc[n, s] := pc[n, s] - b[n] × pc[n-2, s]
      end end;

```

```

for m := 1 step 1 until nmax do begin
  qc[m, m] := 1.0;
  for t := 1 step 1 until m - 1 do begin
    qc[m, t] := -c[m] × qc[m-1, t];
    if t ≠ then qc[m, t] := qc[m, t] + qc[m-1, t-1];
    if t ≠ m - 1 then qc[m, t] := qc[m, t] - d[m] × qc[m-2, t]
    end end;
  comment evaluation of approximating polynomial coefficients;
  for s := 1 step 1 until nmax do begin
    for t := 1 step 1 until nmax do begin
      phi[s, t] := 0.0;
      for n := s step 1 until nmax do begin
        for m := t step 1 until nmax do
          phi[s, t] := phi[s, t] + alpha[n, m] × pc[n, s] × qc[m, t]
          end end;
  comment evaluation of dependent variables using the approxi-
  mating polynomial;
  minsqcomp := sumdifcomp := maxdifcomp := 0.0;
  for i := 1 step 1 until imax do begin
    for j := 1 step 1 until jmax do begin
      zcomp[i, j] := 0.0;
      for s := nmax step - 1 until 1 do begin
        poly := phi[s, nmax];
        for t := nmax - 1 step 1 until 1 do
          poly := poly × y[t] + phi[s, t];
          zcomp[i, j] := zcomp[i, j] × x[i] + poly end;
        rescomp := z[i, j] - zcomp[i, j];
        zcomp[i, j] := zcomp[i, j] + meanz;
        minsqcomp := minsqcomp + u[i] × w[j] × rescomp ↑ 2;
        sumdifcomp := sumdifcomp + abs(rescomp);
        if abs(rescomp) > maxdifcomp then
          maxdifcomp := abs(rescomp) end end;
  minsqcomp := (minsqcomp/(imax × jmax)) ↑ ½;
  sumdifcomp := sumdifcomp/(imax × jmax);
  end surfacefit

```

## ALGORITHM 165

### COMPLETE ELLIPTIC INTEGRALS

HENRY C. THACHER, JR.\*

Reactor Eng. Div., Argonne National Lab., Argonne, Ill.

\* Work supported by the U.S. Atomic Energy Commission.

**procedure** KANDE(*m1, K, E, tol, alarm*);

**value** *m1, tol*;

**real** *m1, K, E, tol*;

**label** *alarm*;

**comment** this procedure computes the complete elliptic integrals  $K(m1) = \int_0^{\pi/2} (1 - (1 - m1) \sin^2 v)^{-1/2} dv$  and  $E(m1) = \int_0^{\pi/2} (1 - (1 - m1) \sin^2 v)^{1/2} dv$  by the arithmetic-geometric-mean process. The accuracy is limited only by the accuracy of the arithmetic.

Except for the provision of tests for pathological values of the parameter, the calculation of  $K$  is only a slight modification of the second procedure of Algorithm No. 149 (*Comm. ACM.* 5 (Dec. 1962), 605). These integrals may also be approximated to limited (6D) accuracy by Algorithms 55 and 56 (*Comm. ACM.* 4 (Apr. 1961), 180). Unless the square-root is exceptionally fast, the latter algorithms are probably more efficient for 6D-accuracy.

The complementary parameter,  $m1$ , is chosen as the independent variable, rather than the parameter,  $m$ , the modulus,  $k$  or the modular angle  $\alpha$ , because of the possibility of serious loss of significance in generating  $m1$  from the other possible independent variables when  $m1$  is small and  $dK/dm1$  is very large. These variables are related by  $m1 = 1 - m = 1 - k^2 = \cos^2 \alpha$ .

The formal parameter, *tol*, determines the relative accuracy of the result. To prevent entering a nonterminating loop, *tol* should not be less than twice the relative error in the square root routine. If  $m1 \leq 0$  or if  $m1 > 1$ , the procedure exits to alarm.  $K(0) = \infty$  while  $E(0) = 1.00000000$ .

The body of this procedure has been tested using the Dartmouth SCALP processor for the LGP-30. With  $tol = 5_{10} - 7$ , results agreed with tabulated values to within 3 in the seventh significant digit;

```

begin real a, b, c, sum, temp;
integer fact;
if  $m1 > 1 \vee m1 \leq 0$  then go to alarm;
a := fact := 1;
b := sqrt(m1);
temp := 1 - m1;
sum := 0;
iter: sum := sum + temp;
c := (a - b)/2;
fact := fact + fact;
temp := (a + b)/2;
b := sqrt(a × b);
a := temp;
temp := fact × c × c;
if  $abs(c) \geq tol \times a \vee temp > tol \times sum$  then go to iter;
sum := sum + temp;
K := 3.141592654/(a + b);
comment pi must be given to the full accuracy desired;
E := K × (1 - sum/2)
end

```

#### ALGORITHM 166

##### MONTECARLO

R. D. RODMAN

Burroughs Corp., Pasadena, Calif.

```

procedure montecarlo (n, a, row, tol, mxm, inv, test, count);
value n, row, tol, mxm; integer n, row, mxm, count;
real tol; real array a, inv, test;
comment this procedure will compute a single row of the
inverse of a given matrix using a monte carlo technique.
n is the size of the matrix, array a is the matrix, row indicates
which inverse row is to be computed, tol is a tolerance factor
and thus a criterion for terminating the process, mxm is 1000
times the maximum number of random walks to be taken,
after which the process is terminated, array inv contains the
inverse row, array test contains the innerproduct of inv with
the rowth column of a, count is the number of random walks
executed upon termination. real procedure RANDOM must
be declared in the blockhead of procedure MONTE CARLO
and generates a single random number between 0 and 1. If
a is the matrix to be inverted, the absolute value of the largest
eigenvalue of the matrix  $I - a$  ( $I$  is the unit matrix) must be
less than one to assure convergence. This procedure is easily
adapted to finding a single unknown from a set of simultaneous
linear equations;
begin integer i, j, k, nwk, lastwalk, walk; real res, p, g;
real array sum[1:n], v[1:n, 1:n];
start: p := (n-1)/n × n;
for i := 1 step 1 until n do for j := 1 step 1 until n do
v[i,j] := if i ≠ j then -a[i,j]/p else (1-a[i,j])/p;
nwk := 1000;
count := res := 0;
for k := 1 step 1 until n do test [k] := sum [k] := 0;

```

```

start1: lastwalk := row; g := 1;
start2: walk := (RANDOM/p) + 1;
if walk > n then go to stop;
g := v[lastwalk,walk] × g; lastwalk := walk;
go to start2;
stop: count := count + 1; sum[lastwalk] := sum[lastwalk] + g;
if count < nwk then go to start1;
for k := 1 step 1 until n do inv[k] := n × sum[k]/count;
for i := 1 step 1 until n do for k := 1 step 1 until n do
test[i] := inv[k] × a[k, i] + test[i];
for i := 1 step 1 until row-1, row+1 step 1 until n do
res := abs(test[i]) + res; res := abs(test[row]-1) + res;
if res < tol then go to exit;
if count ≥ 1000 × mxm then go to exit;
nwk := nwk + 1000; res := 0;
for k := 1 step 1 until n do test [k] := 0;
go to start1;
exit: end of monte carlo inversion procedure

```

#### ALGORITHM 167

##### CALCULATION OF CONFLUENT DIVIDED DIFFERENCES

W. KAHAN AND I. FARKAS

Institute of Computer Science, University of Toronto,  
Canada

```

real procedure DVDFC(n, X, V, B, W); integer n;
real array X, V, B, W;
comment DVDFC calculates the forward divided difference
 $\Delta f(X_1, X_2, \dots, X_n)$ . n is an integer which takes the values
n = 1, 2, 3, \dots in turn. X is a real array of dimension at least
n in which  $X[i] = X_i$  for  $i = 1, 2, \dots, n$ . The values  $X_i$  need
not be distinct nor in any special order, but once the array X
is chosen it will fix the interpretation of the arrays B and V.
If  $X[1], X[2], \dots, X[n]$  are in monotonic order, then the effect
of roundoff upon any nth divided difference is no more than
would be caused by perturbing each  $f(X[i])$  by n units at most
in its last significant place. But if the  $X$ 's are not in mono-
tonic order, the error can be catastrophic if some of the divided
differences are relatively large. V is a real array of dimension
at least n containing the values of the function  $f(X)$  and per-
haps its derivatives at the point  $X_i$ .  $V[i] = f^m(X_i)/m!$  and
m = mi for  $i = 1, 2, 3, \dots, n$ . mi is the number of times that
the value of  $X_i$  has previously appeared in the array X. B is
a real array of dimension at least n containing backward divided
differences. Before a reference to DVDFC is executed one should
have  $B[i] = \Delta f(X_i, X_{i+1}, \dots, X_{n-1})$  for  $i = 1, 2, \dots, n-1$ .
After that reference to DVDFC is executed one will find  $B[i] =$ 
 $\Delta f(X_i, X_{i+1}, \dots, X_{n-1}, X_n)$  for  $i = 1, 2, \dots, n-1, n$ . When
n = 1 the initial state of B is irrelevant. W is a real array of
dimension  $(2 + \bar{m})$  at least, where  $\bar{m}$  is the maximum value of
mi for  $i = 1, 2, \dots, n$ . W is used for work space;
begin real DENOM; integer i, j, NK, NIN;
if n = 1 then go to L1;
NK := 1;
for i := 1 step 1 until n do
begin
if  $X[i] = X[n]$  then begin NK := NK + 1;
W[NK] := V[i] end
end i;
for i := n step -1 until 2 do
begin W[1] := B[i - 1]; B[i] := W[2];
NIN := if n - i + 2 < NK then n - i + 2 else NK;
for j := NIN step -1 until 2 do
begin
DENOM := X[n] - X[i + j - 3];
if DENOM ≠ 0 then go to L2;

```

```

W[j] := W[j + 1];
if NK - j - 1 ≠ 0 then go Cont;
NK := NK - 1;
go to Cont;
L2: W[j] := (W[j] - W[j - 1])/DENOM;
Cont: end j;
end i;
B[1] := W[2];
go to L3;
L1: B[1] := V[1];
L3: DVDFC := B[1];
end DVDFC

```

The following program segment is an example of how *DVDFC* can be used to construct a table of forward or backward differences.

```

for n := 1 step 1 until N do
begin
X[n] := ...; V[n] := ...; F[n] := DVDFC(n, X, V, B, W)
end;

```

The array *F* can be used in *FNEWT*(*z*, *N*, *X*, *F*, *R*, *D*, *E*) or the array *B* in *BNEWT*(*z*, *N*, *X*, *B*, *P*, *D*, *E*). See algorithms "Newton interpolation with forward (backward) divided differences." *DVDFC* has been written as a FORTRAN II function and is available from I.C.S., University of Toronto;

#### ALGORITHM 168 NEWTON INTERPOLATION WITH BACKWARD DIVIDED DIFFERENCES

W. KAHAN AND I. FARKAS

Institute of Computer Science, University of Toronto,  
Canada

```

procedure BNEWT(z, N, X, B, P, D, E); value z, N;
real z, P, D, E; integer N; real array X, B;
comment X is a real array of dimension at least N in which
X[i] = Xi for i = 1, 2, 3, ..., N. The values Xi need not be
distinct nor in any special order, but once the array X is chosen
it will fix the interpretation of the array B. B is a real array of
dimension at least N and contains the backward divided differ-
ences B[i] = Δf(Xi, Xi+1, ..., XN) i = 1, 2, ..., N. If two
or more of the values Xi are equal then some of the B's must
be confluent divided differences, see algorithm: "Calculation of
confluent divided differences." P is the value of the following
polynomial in z of degree N-1 at most, B(N) + (z-XN)·
{B(N-1) + (z-XN-1){B(N-2) + ... + (z-X2)B(1)} ... }.
This polynomial is an interpolation polynomial which would,
but for rounding errors, match values of the function f(x) and
any of its derivatives that DVDFC might have been given. D
is the value of the derivative of P. E is the maximum error in
P caused by roundoff during the execution of BNEWT. The
error estimate is based upon the assumption that the result of
each floating point arithmetic operation is truncated to 27 sig-
nificant binary digits as is the case in FORTRAN programs on
the 7090. BNEWT has been written as a FORTRAN II subroutine
and is available from I.C.S., University of Toronto;

```

```

begin real z1; integer i;
P := D := E := 0;
for i := 1 step 1 until N do
begin
z1 := z - X[i];
D := P + z1 × D;
P := B[i] + z1 × P;
E := abs(P) + E × abs(z1)
end;
E := (1.5×E - abs(P))×310 - 8
end BNEWT

```

#### ALGORITHM 169 NEWTON INTERPOLATION WITH FORWARD DIVIDED DIFFERENCES

W. KAHAN AND I. FARKAS

Institute of Computer Science, University of Toronto,  
Canada

```

procedure FNEWT(z, N, X, F, R, D, E); value z, N;
real z, R, D, E; integer N; real array X, F;
comment X is a real array of dimension at least N in which
X[i] = Xi for i = 1, 2, ..., N. The values Xi need not be dis-
tinct nor in any special order, but once the array X is chosen
it will fix the interpretation of the array F. F is a real array
of dimension at least N and contains the forward divided
differences F[i] = Δf(X1, X2, ..., Xi) i = 1, 2, ..., N. If
two or more of the values Xi are equal then some of the F's
must be confluent divided differences, see algorithm: "Calcula-
tion of confluent divided differences." R is the value of the fol-
lowing polynomial in z of degree N-1 at most, F(1) + (z-X1)·
{F(2) + (z-X2){F(3) + ... + (z-XN-1)F(N)} ... }. This
polynomial is an interpolation polynomial which would, but
for rounding errors, match values of the function f(x) and any
of its derivatives that DVDFC might have been given. D is the
value of the derivative of R. E is the maximum error in R
caused by roundoff during the execution of FNEWT. The
error estimate is based upon the assumption that the result of
each floating-point arithmetic operation is truncated to 27
significant binary digits as is the case in FORTRAN programs
on the 7090. FNEWT has been written as a FORTRAN II sub-
routine and is available from I.C.S., University of Toronto;

```

```

begin real z1; integer i;
R := D := E := 0;
for i := N step -1 until 1 do
begin
z1 := z - X[i];
D := R + z1 × D;
R := F[i] + z1×R;
E := abs(R) + abs(z1)×E
end;
E := (1.5×E - abs(R))×310 - 8
end FNEWT

```

#### ALGORITHM 170 REDUCTION OF A MATRIX CONTAINING POLYNOMIAL ELEMENTS

PAUL E. HENNION

Giannini Controls Corp., Astromechanics Res. Div.,  
Berwyn, Penn.

```

real procedure POLYMATRIX (A, NCOL, N, COE, NP1);
value A, NCOL, N; real array A; integer NCOL, N;
comment this procedure will expand a general determinant,
where each of the elements are polynomials in the Laplace com-
plex variable. This program is useful for the investigation of
dynamic stability problems when using the transfer function
approach. The process is one of triangularization of a poly-
nomial matrix with real coefficients whereupon multiplication
of the diagonal elements the determinant polynomial is formed.
The polynomial matrix as defined herein is a matrix whose
elements are polynomials of the form  $\sum_{i=0}^N a_i x^i$ . When such a
matrix is triangularized, all elements below the main diagonal
are nulled. Then upon expanding, the nonvanishing terms are
those formed by the product of these diagonal elements. Hence
stability criteria may be checked by evaluating the roots of the
characteristic equation thus formed using some suitable root
extracting routine.

```

Consider the polynomial matrix with quadratic elements ( $N = 2$ ). In this case the three-dimensional input matrix  $A$  is size  $A[1:NCOL, 1:NCOL, 1:M]$ , where  $NCOL$  is the order of the matrix and  $M = N \times NCOL + 1$ . Here the first subscript of  $A$  refers to the row, the second to the column, and the third to the polynomial coefficient. Therefore, prior to entry the constant term of a general polynomial element is contained in  $A[i, j, 1]$ , the linear term is contained in  $A[i, j, 2]$ , and the quadratic term in  $A[i, j, 3]$ . Upon completion of the routine, the coefficients of the determinant polynomial are contained in  $COE[1:M]$ . The constant coefficient being in  $COE[1]$ , the linear coefficient in  $COE[2]$ , the quadratic coefficient in  $COE[3]$ , etc. The variable  $NP1$  will specify the number of coefficients of the determinant polynomial. In general  $NP1 \neq M$  since some terms may vanish during the expansion.

If the polynomials comprising the matrix elements are not all of equal degree, set  $N$  prior to entry equal to the degree of the highest ordered polynomial;

```

begin real  $sa, sb$ ; integer  $i, j, k, j1, j2, j3, j4, j5, j6, j7, j8, j9, j10,$ 
 $j11, NP1, M$ ; array  $C1[1:M], C2[1:M], COE[1:M]$ ;
integer array  $MAT[1:NCOL, 1:NCOL]$ ;
start:  $M := N \times NCOL + 1$ ; for  $i := 1$  step 1 until  $NCOL$  do
  begin for  $j := 1$  step 1 until  $NCOL$  do begin  $MAT[i, j] := 0$ ;
    for  $k := 1$  step 1 until  $M$  do begin
      if  $A[i, j, k] \neq 0$  then  $MAT[i, j] := k$ ; end end end;  $j1 := 1$ ;
L0:  $j9 := 0$ ; for  $i := j1$  step 1 until  $NCOL$  do begin
  if  $MAT[i, j1] < 0$  then go to exit;
  else if  $MAT[i, j1] = 0$  then go to L1
  else  $j9 := j9 + 1$ ;  $j3 := i$ ;
L1: end; if  $(j9 - 1) < 0$  then go to exit
  else if  $(j9 - 1) > 0$  then go to L2
  else if  $(j3 - j1) < 0$  then go to exit
  else if  $(j3 - j1) = 0$  then go to L12
  else for  $j := j1$  step 1 until  $NCOL$  do
    begin  $j2 := MAX(MAT[j3, j], MAT[j1, j])$ ;  $j4 := MAT[j3, j]$ ;
     $MAT[j3, j] := MAT[j1, j]$ ;  $MAT[j1, j] := j4$ ;
    for  $k := 1$  step 1 until  $j2$  do
      begin  $sa := A[j3, j, k]$ ;  $A[j3, j, k] := A[j1, j, k]$ ;
       $A[j1, j, k] := -sa$ ; end end; go to L12;
L2:  $j3 := j1 + 1$ ; for  $i := j3$  step 1 until  $NCOL$  do begin
L3: if  $(MAT[i, j1] < 0)$  then go to exit
  else if  $(MAT[i, j1] = 0)$  then go to L11
  else if  $(MAT[j1, j1] < 0)$  then go to exit
  else if  $(MAT[j1, j1] = 0)$  then go to L4
  else if  $(MAT[i, j1] - MAT[j1, j1]) \geq 0$  then go to L5 else
L4: for  $j := j1$  step 1 until  $NCOL$  do begin
   $j2 := MAX(MAT[j1, j], MAT[i, j])$ ;  $j4 := MAT[j1, j]$ ;
   $MAT[j1, j] := MAT[i, j]$ ;  $MAT[i, j] := j4$ ;
  for  $k := 1$  step 1 until  $j2$  do begin  $sa := A[i, j, k]$ ;
   $A[i, j, k] := A[j1, j, k]$ ;  $A[j1, j, k] := -sa$ ;
  end end; go to L3;
  comment Interchange row  $i$  with  $j1$ ;
L5:  $j7 := MAT[i, j1]$ ;  $j5 := MAT[j1, j1]$ ;  $j6 := j7 - j5$ ;
   $sb := A[i, j1, j7] / A[j1, j1, j5]$ ;
  if  $(abs(sb) - 4) < 0$  then go to L6
  else if  $(j6) < 0$  then go to exit
  else if  $(j6) = 0$  then go to L4 else
L6: for  $j := j1$  step 1 until  $NCOL$  do begin  $j5 := MAT[j1, j]$ ;
  for  $k := 1$  step 1 until  $j5$  do begin  $j7 := k + j6$ ;
  if  $(j7 - M) > 0$  then go to L10 else
L7: if  $(abs(A[i, j, j7] - sb \times A[j1, j, k]) - 2_{10} - 8) \leq 0$  then go to L8
  else  $A[i, j, j7] := A[i, j, j7] - sb \times A[j1, j, k]$ ;
  go to L9;
L8:  $A[i, j, j7] := 0$ ;
L9: end end;
L10: for  $j := j1$  step 1 until  $NCOL$  do begin
   $j7 := MAX(MAT[i, j], MAT[j1, j] + j6)$ ;  $MAT[i, j] := 0$ ;
  for  $k := 1$  step 1 until  $M$  do begin if  $(A[i, j, k]) \neq 0$  then
   $MAT[i, j] := k$  end end;

```

```

L11: end; go to L0;
L12:  $j1 := j1 + 1$ ; if  $(j1 - NCOL) < 0$  then go to L0 else
  for  $j := 1$  step 1 until  $NCOL$  do begin
     $j2 := MAT[j, j]$ ;
    for  $k := 1$  step 1 until  $j2$  do  $C1[k] := A[j, j, k]$ ;
L13: if  $(j - 1) < 0$  then go to exit
  else if  $(j - 1) = 0$  then go to L14
  else for  $k := 1$  step 1 until  $NP1$  do  $C2[k] := COE[k]$ ;
  for  $k := 1$  step 1 until  $M$  do  $COE[k] := 0$ ;
  if  $(j2) < 0$  then go to exit
  else if  $(j2) = 0$  then go to L15
  else for  $k := 1$  step 1 until  $j2$  do begin
    for  $j10 := 1$  step 1 until  $NP1$  do begin
       $j11 := k + j10 - 1$ ;
       $COE[j11] := COE[j11] + C1[k] \times C2[j10]$ ;
    end end;  $NP1 := j11$ ; go to L15;
L14: for  $k := 1$  step 1 until  $j2$  do  $COE[k] := C1[k]$ ;
   $NP1 := j2$ ;
L15: end;
exit: end POLYMATRIX

```

CERTIFICATION OF ALGORITHM 55  
 COMPLETE ELLIPTIC INTEGRAL OF THE FIRST  
 KIND [John R. Herndon, *Comm. ACM*, Apr. 1961]  
 and

CERTIFICATION OF ALGORITHM 149  
 COMPLETE ELLIPTIC INTEGRAL [J. N. Merner,  
*Comm. ACM*, Dec. 1962]

HENRY C. THACHER, JR.\*  
 Reactor Eng. Div., Argonne National Laboratory,  
 Argonne, Ill.

\* Work supported by the U.S. Atomic Energy Commission.

The bodies of Algorithm 55 and of the second procedure of Algorithm 149 were tested on the LGP-30 computer using SCALP, the Dartmouth "LOAD-AND-GO" translator for a substantial subset of ALGOL 60. The floating-point arithmetic for this translator carries 7+ significant digits.

In addition to modifications required because of the limitations of the SCALP subset, the following need correction:

In Algorithm 55:

1. The constant 0.054555509 should be 0.054544409.
2. The function  $\log$  should be  $\ln$ .

In procedure ELIP 2 of Algorithm 149, the statement  $a := c$  should be  $a := C$ .

The parameters of Algorithm 149 are related to the complete elliptic integral of the first kind by:  $K = a \times ELIP(a, b)$  where the parameter  $m = k^2 = 1 - b/a$ .

The maximum approximation error in Algorithm 55 is given by Hastings as about  $0.6_{10} - 6$ . In addition there is the possibility of serious cancellation error in forming the complementary parameter  $t = 1 - k \times k$ . For  $k$  near 1, errors as great as 4 significant digits were sustained. In these regions, the complementary parameter itself is a far more satisfactory parameter.

The accuracy obtainable with Algorithm 149 is limited only by the arithmetic accuracy and the amount of effort which it is desired to expend. Six-figure accuracy was obtained with 5 applications of the arithmetic-geometric mean for  $a = 1000$ ,  $b = 2$ , and with one application for  $a = 500$ ,  $b = 500$ .

Neither algorithm is satisfactory for  $k = 1$ . The behavior for Algorithm 55 will be governed by the error exit from the logarithm procedure. Under these circumstances, Algorithm 149 goes into an endless loop. Algorithm 149 may also go into an endless loop of the terminating constant ( $10 - 8$  in the published algorithm) is too small for the arithmetic being used. For the SCALP arithmetic it was found necessary to increase this tolerance to  $5.0_{10} - 7$ . The

resulting values of the elliptic integrals were, however, accurate to within 2 in the 7th significant digit (6th decimal).

The relative efficiency of the two algorithms will depend strongly on the efficiency of the square-root and logarithm subroutines. With most systems, Algorithm 55 will provide sufficient accuracy, and will be more efficient. If a square-root operation or a highly efficient square-root subroutine is available, Algorithm 149 may well be the better method.

**CERTIFICATION OF ALGORITHM 73  
INCOMPLETE ELLIPTIC INTEGRALS** [David K  
Jefferson, *Comm. ACM* Dec. 1961]

R. P. VAN DE RIET  
Mathematical Centre, Amsterdam

The algorithm contained three misprints:  
The 26th line of the procedure

$$E := (2 \times n - 1) / (2 \times N);$$

should read

$$E := (2 \times n - 1) / (2 \times n);$$

The 46th line of the procedure

$$\uparrow 2) \uparrow ((2 \times n - 1) / (2 \times n));$$

should read

$$\uparrow 2) \uparrow ((2 \times n - 1) / (2 \times n));$$

The 49th line of the procedure

$$L [2] := L [4] + 1 / (n \times 2 \times n - 1);$$

should read

$$L [2] := L [1] + 1 / (n \times (2 \times n - 1));$$

The program was run on the X1 computer of the Mathematical Centre. For  $\phi = 45^\circ$ ,  $k = \sin(10^\circ(10^\circ)180^\circ)$ ,  $E$  and  $F$  were calculated. The result contained 12 significant digits.

Comparison with a 12-decimal table of Legendre-Emde (1931) showed that the 12th digit was affected with an error, at most 4 units large. After about 10 minutes of calculation (i.e. more than 100 cycles) no results were obtained for  $k = \sin 89^\circ$ ,  $\phi = 1^\circ$  and the calculation was discontinued.

**REMARKS.** As  $\phi$  is unchanged during the calculation, we placed the statement  $\cos \phi := \cos (\phi)$  in the beginning of the program, to be certain that the cosine was not calculated 30 or more times. Moreover, in the expression for  $T[1]$  and  $T[2]$ ,  $\text{sqrt}(1 - \sin \phi \uparrow 2)$  was replaced by  $\cos \phi$ , so that loss of significant figures does not occur.

The expression  $2 \times n$  was changed in a new variable, to obtain a more rapid program.

**CERTIFICATION OF ALGORITHM 91  
CHEBYSHEV CURVEFIT** [A. Newhouse, *Comm.*  
*ACM*, May 1962]

ROBERT P. HALE  
University of Adelaide, Adelaide, South Australia

The CHEBFIT algorithm was translated into FORTRAN and successfully run on an IBM 1620 when the following alterations were made:

- (a) 2nd line after  
**comment** Initialize;  
should read  
**for**  $i := 1$  **step** 1 **until**  $n+1$  **do**  $IN[i] := (i-1) \times k + 1$ ;
- (b) 2nd and 3rd lines after  
*Poly*: **comment** polynomial coefficients;  
should read  
**begin**  $A[i] := AY[i+1] + AH[i+1] \times H$ ;  $BY[i+1] := 0$

- (c) 3rd line after  
*ERROR*: **comment** compute deviations;  
should read  
**for**  $j := 1$  **step** 1 **until**  $n$  **do**  $T[i] := T[i] \times X[i] + A[n-j]$ ;
- (d) Immediately before statement  $L2$  insert  $i := n + 2$ ; (as **for** list may be exhausted and  $i$  no longer defined).
- (e) 2nd line after statement  $L3$  should read  $IN[1] := imax$ ;
- (f) 1st line after statement  $L4$  should read  $IN[i-1] := imax$ ;

**CERTIFICATION OF ALGORITHM 133  
RANDOM** [Peter G. Behrenz, *Comm. ACM*, Nov. 1962]  
JESSE H. POORE, JR.  
Louisiana Polytechnic Institute, Ruston, La.

Algorithm 133 was transliterated into FORTRAN II for the IBM 1620 computer. A monitor program performed the test indicated in Algorithm 133 on the generated numbers.

Results of the test are shown in the following chart. The notation used is identical to that used in the algorithm.

$X_0$	$\frac{1}{N} \sum X_n$	$\frac{1}{N} \sum X_n^2$	
13543288579	.4986480931	.3280561242	$N = 500$
	.4840396640	.3141520616	$N = 1000$
	.4996829627	.3321160892	$N = 5000$
24376589411	.4971414796	.3297990588	$N = 500$
	.4997720126	.3326801987	$N = 1000$
	.4986380784	.3319949173	$N = 5000$
34359738367	.4962408228	.3339214302	$N = 500$
	.4974837457	.3335720239	$N = 1000$
	.4929612237	.3253421270	$N = 5000$
11324679915	.5313808305	.3691599122	$N = 500$
	.5167083685	.3498558251	$N = 1000$
	.5043814637	.3383429327	$N = 5000$

**CERTIFICATION OF ALGORITHM 145  
ADAPTIVE NUMERICAL INTEGRATION BY  
SIMPSON'S RULE** [W. McKeeman, *Comm. ACM*,  
Dec. 1962]

WM. M. MCKEEMAN  
Stanford University, Stanford, Calif.

Suggested changes in the code:

1. Replace all occurrences of  $\text{eps}/3.0$  by  $\text{eps}/1.7$ .
2. Replace level  $\geq 7$  by level  $\geq 20$ .
3. The second parameter  $a$  in the final call of Simpson was omitted; insert it.

With the above changes, a BALGOL translation of *Integral* has been tested successfully on a large number of functions. An example of its behavior is given below:

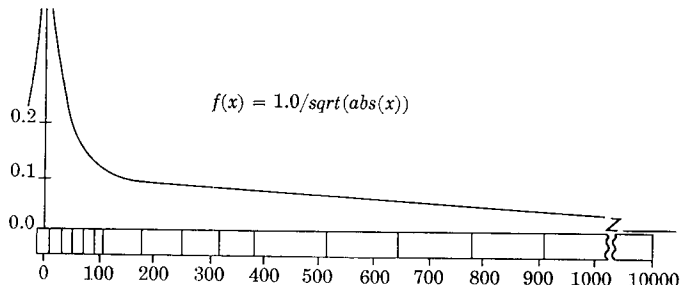
Machine: Burroughs 220, 8 decimal digit floating-point mantissa.  
 $f(x) = 1.0/\text{sqrt}(\text{abs}(x))$ ; which has a pole at the origin.  
 $a = -9.0$ ;  $b = 1000.0$ ; correct answer = 206.0;

$\text{eps}$	computer answer	relative error
0.1	200.22251	0.028
0.01	206.00226	0.0000107
0.001	206.00092	0.0000045
0.0001	205.99985	0.0000007

If the recursion was allowed to go thirty levels deep we found:

0.0001    206.00005    0.0000002

The graph below shows the adaptive clustering of the points of evaluation around the pole of the function (taken from the first example above).



Each vertical line represents a point of evaluation for the function during the execution of the call:

**integral**(f, -9.0, 10000.0, 0.1);

#### CERTIFICATION OF ALGORITHM 147

PSIF [D. Amit, *Comm. ACM.*, Dec. 62]

HENRY C. THACHER, JR.\*

Reactor Eng. Div., Argonne National Lab., Argonne, Ill.

\* Work supported by the U. S. Atomic Energy Commission.

The following minor errors were noted in this algorithm:

- (3) in the comment should read  $\epsilon < 1/240 x^8$ .
- The function *tan* is not a standard ALGOL function. It should be declared, or replaced by  $\sin(\ )/\cos(\ )$ .
- The block labelled *large* should be closed by inserting **end** immediately after 252.

The efficiency of the program would be improved by the following modifications:

- Let the statement

**if**  $x = 0$  **then begin** . . . **end**;

be the first statement of the procedure body.

- Delete the condition  $x \neq 0$  from the if clause,

**if**  $x > -1 \wedge x \neq 0$  **then** . . .

- Delete the declaration of *pei*, and the assignment of the value of 3.141592654 to *pei* in the statement

$psi := pei \times \sin(pei \times (x+0.5))/\cos(pei \times (x+0.5));$   
replace *pei* by the value 3.141592654.

- Replace the block labelled *large* by:

*large*: **begin real** *y*;  $x := 1/x$ ;  $y := x \times x$ ;  
 $psi := psi - \ln(x) + x/2 - ((y/252 - 0.008333333333) \times y + 0.08333333333) \times y$  **end**;

With these changes, the body of the procedure was translated and run on the LGP-30 computer using the Dartmouth SCALP processor. The program was used to tabulate *psif*(*x*) for  $x = -1$

(0.5)0(0.005)1.250. With  $a = 3.0$  the results agreed with tabulated values to within 3 in the 6th decimal place. This is considered satisfactory, since one decimal place is lost in applying the recurrence. Running time, including output on the Flexowriter and computation of new values of the independent variable, averaged about 30 seconds per value.

It should be observed that *psif*(*x*) is  $\Psi(x+1)$  as tabulated, for example, by Jahnke-Emde-Losch.

#### CERTIFICATION OF ALGORITHM 148

TERM OF MAGIC SQUARE [D. M. Collinson, *Comm.*

*ACM*, Dec. 1962]

J. N. R. BARNECUT

University of Alberta, Calgary; Calgary, Alberta, Canada

*MAGICTERM* was translated into FORTRAN for the IBM 1620. The procedure was tested for terms of squares up to order 13. Correct results were obtained. For determination of complete squares operating time was not significantly different from Algorithm 118.

#### CERTIFICATION OF ALGORITHM 148

TERM OF MAGIC SQUARE [D. M. Collison, *Comm.*

*ACM*, Dec. 62]

DMITRI THORO

San Jose State College, San Jose, Calif.

This algorithm was translated into FORTRAN and FORGO for the IBM 1620. No changes in the program were necessary. The elements of magic squares of odd orders up to 15 were generated satisfactorily.

A contribution to this department must be in the form of an Algorithm, a Certification, or a Remark. Contributions should be sent in duplicate to the Editor and should be written in a style patterned after recent contributions appearing in this department. An algorithm must be written in ALGOL 60 (see *Communications of the ACM*, January 1963) and accompanied by a statement to the Editor indicating that it has been tested and indicating which computer and programming language was used. For the convenience of the printer, contributors are requested to double space material and underline delimiters and logical values that are to appear in boldface type. Whenever feasible, Certifications should include numerical values.

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# A Suggested Method of Making Fuller Use of Strings in ALGOL 60

MIRIAM G. SHOFFNER AND PETER J. BROWN  
*University of North Carolina, Chapel Hill, N. C.*

*Notation.* Throughout this paper string quotes ( ' ') are used only as basic ALGOL symbols, whereas double quotes ( " ") have no significance other than as punctuation marks in the English language.

It seems to us that while ALGOL 60 cannot be made into a good symbol manipulation language without many additions two simple extensions would make a considerable difference, making ALGOL an adequate language for some symbol manipulation problems and also improving it in other ways. For a suggested way for incorporating full symbol manipulation features into ALGOL, see "A String Language for Symbol Manipulation Based on ALGOL 60" by J. H. Wegstein and W. W. Youden [*Comm. ACM*, Jan. 1962]. We propose two extensions to the use of strings which, we think, could be added into an existing translator with virtually no effort. As ALGOL stands, strings can be used only as actual parameters of procedures, presumably output procedures; nested strings are allowed but it would need some ingenuity to find a use for them. In our discussion we take "string" to mean a non-nested string. Our proposed additions (henceforward referred to here as "the additions") are:

- (i) Strings can be assigned as values of variables.
- (ii) Strings can be used as operands of the relational operators: "=" and "≠".

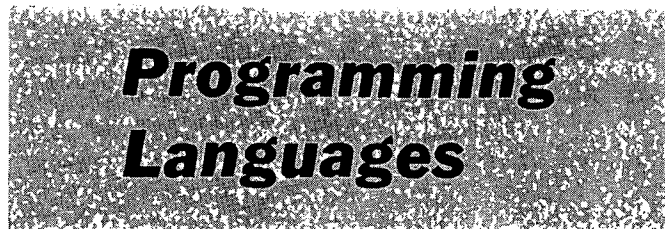
*Examples:*

```
color := 'black';  
if color = 'black' then ...;
```

A description of the exact syntactical changes necessary in the language is given at the end of this paper. The equivalent of the additions is already built into such algebraic languages as IT and GAT.

Variables having strings as value would be declared as being of type "string", and string arrays and string procedures (i.e. function designators of type string) would be allowed. It would be natural to have input procedures to assign strings as values of variables and output procedures to print string variables.

It might be a practical necessity for fixed-word-length machines to restrict the length of strings to one word-length. Restrictions somehow do not seem to be in the spirit of the ALGOL 60 report (to the exasperation of translator writers) but, of course, there are implicit restrictions on the size of integers and real numbers; so a restriction on the length of strings is not too unreasonable.



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Note that the additions do not provide for a way to decompose strings within the language. However, "packing" and "unpacking" routines could be added to a system which would respectively break a string down and store it symbol by symbol in a string array, and perform the reverse operation. A large class of symbol manipulation problems can be performed efficiently by splitting input strings into a number of strings consisting of one symbol each and storing these in an array.

The following advantages would be gained by incorporating the additions.

(i) Simple string manipulation programs could be written in ALGOL. Programs have been written in GAT, which is a subset of ALGOL as extended, to formally differentiate, prove theorems, transpose music, and perform other such functions. ALGOL could be a very powerful language for writing such nonnumeric programs.

(ii) It would be possible to output variable alphabetic information, for instance information input as data. This is not possible in ALGOL as it stands.

(iii) Algorithms involving multiple branching and sentinels could be better expressed. Consider the situation when a variable or its value can be in three or more possible states (for instance, the value of an integer variable being prime of form  $4n+1$ , prime of form  $4n-1$ , or non-prime, or, to take an example from an algorithm to be used in our ALGOL translator, the type of a variable being **real**, **integer** (or **string**) or **Boolean**). At one point in the program the state is found and later the program branches according to this state. At present a numerical indicator must be used for the state, for example, taking the values 0, 1 or 2. A branching statement might read in present notation:

```
if type = 0 then ... else if type = 1 then ... else ...;
```

The meaning of this statement could be appreciated much more readily if it were written using the additions:

```
if type = 'real' then ... else if type = 'integer' then ... else ...;
```

In addition, anywhere a sentinel (i.e. a numerical variable whose value is meaningless as a number but is used to convey information) is used, it would be useful to make it a string variable. When a sentinel has only two values a boolean variable (e.g. one named "number is prime") can be used. This is primarily an improvement to ALGOL in its role as a publication language for algorithms.

We think it would cost virtually nothing to build our additions into a translator. Presumably, on encountering a string a translator encodes it into the internal alpha-