

The actual choice of n and M for a given precision is left for the individual programmer. Programmed for the GE-225, accurate answers of $\tan^{-1} 1 = \pi/4$ were obtained for double precision in comparison with the known values. The semiiterative method can be programmed in a very short time for any multiple precision and is efficient in comparison with taking more terms of the Taylor's series, taking into account the divisions required for the square root process. Telescoped Taylor's series may be used if desired, but a shorter telescoped Taylor's series can be used if the semiiterative scheme is employed. Telescoping, however, is expected to take more storage for the coefficients than a simple truncated series. Telescoping also discards the advantage of flexibility and applicability to n -tuple precision programs.

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Algorithms

J. WEGSTEIN, Editor

ALGORITHM 202

GENERATION OF PERMUTATIONS IN LEXICOGRAPHICAL ORDER

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```

procedure PERLE (S, N, I, E);
integer array S; integer N; Boolean I; label E;
comment If the array S contains a certain permutation of the
  N digits 1, 2, ..., N before call, the procedure will replace
  this with the lexicographically next permutation. If initialization
  is required set the Boolean variable I equal true, which
  will be changed automatically to false through the first call,
  otherwise set I equal false. If no further permutation can be
  generated, exit will be made to E. For reference see BIT 2
  (1962), 228-231;
begin integer j, u, w;
if I then begin for j = 1 step 1 until N do S[j] := j;
  I := false; go to Rose
end;
w := N;
Lilie: if S[w] < S[w-1] then
  begin if w = 2 then go to E;
  w := w - 1; go to Lilie
end;
u := S[w-1];
for j := N step -1 until w do
begin if S[j] > u then
  begin S[w-1] := S[j];
  S[j] := u; go to Tulpe
end
end;
Tulpe: for j := 0 step 1 until (N-w-1)/2 + 0.1 do
  begin u := S[N-j];
  S[N-j] := S[w+j]; S[w+j] := u
end;
Rose:
end PERLE
  
```

ALGORITHM 203

STEEP1

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```

procedure STEEP1 (lb, xs, ub, dx, xmin, fmin, n, eps, relax, dxmax,
  eta, psi, pmax, zeta, FUNK);
value dx, n, eps, relax, dxmax, eta, psi, pmax, zeta;
integer n;
real fmin, eps, relax, dxmax, eta, psi, pmax, zeta;
array lb, xs, ub, dx, xmin; real procedure FUNK;
comment STEEP1 is a subroutine to find the minimum of a
  differentiable function of n variables, using the method of
  steepest descent. It mainly consists of three parts: (1) a sub-
  
```

routine *ATIVE*, for computing the partial derivatives, (2) a subroutine *STEP*, for computing the components of an array *xstep*[1:*n*], which is a new approximation of *xmin*[1:*n*], (3) the compound tail of the procedure body. Both subroutines are only called for once, but by writing the program in this way it is quite easy to change the flow of the program.

Significance of the parameters: *lb*(*i*), *ub*(*i*) are lower and upper bounds for the independent variables. *xs*(*i*) is the starting value for *xmin*(*i*). *xmin*(*i*) is the computed *i*th component of the minimum, *fmin* the value of the function in *xmin*. *n* is the number of variables. *eps* is a small number which is a measure of the desired accuracy—rather of *fmin* than of *xmin*(*i*). *FUNK* (*x*) is the function to be minimized. The other parameters are described in the comments on the three parts mentioned;

begin integer j; real alpha, p; array xstep, dfdx, dfpr[1:*n*];
procedure ATIVE;

begin real beta, gamma, lambda; Boolean A, B;

comment 1. A useful estimate for the derivative is $\frac{f(x+dx)-f(x-dx)}{2dx}$, where *dx* should be small, but not so small

that roundoff noise dominates. This may be achieved by taking *dx* such that $\eta < \left| \frac{f(x+dx)-f(x-dx)}{f(x)} \right| < 100 \eta$, where η is a measure for the relative roundoff error. When $|f(x)| < 1$ it is better to replace the denominator by a constant. In the program the parameter *psi* is used for this purpose. The components *dx*(*i*) are used as a first guess. When the derivative is 0, the program enlarges *dx* until *dx* > *dxmax*.

ATIVE computes *dfdx*[1:*n*] in *xmin*. The previously computed partial derivatives *dfpr*[1:*n*] as well as *relax* are used for relaxation purposes. See comment 3. The Boolean *A* is used when *x*+*dx* or *x*-*dx* crosses the boundary *ub* or *lb*. In that case *fmin* has to be recomputed afterwards. The Boolean *B* is of a somewhat complicated nature. It may be seen that *dx* has the character of an own array for *ATIVE*. In the neighborhood of the minimum this may have the following effect: A step in one variable is taken such that *f*(*x*+*dx*) becomes equal to *f*(*x*-*dx*). Then in the next call for *ATIVE* *dx* has to be doubled, etc. By using the Boolean *B* it is possible to keep *dx* constant near the minimum.

A similar effect may occur in the large. When *f*(*x*) tends to a constant for *x* tending to $+\infty$ and $-\infty$, then for $|x|$ large *dx* has to be taken large. It is only possible to make *dx* smaller in the neighborhood of the minimum by reducing *dx* after each call of *ATIVE*.

From the last two remarks one may deduce that the first guess for *dx*(*i*) should be made with considerable care. Tabulating the function near the starting point may be very helpful;

begin ATIVE: lambda := 0;
for j := 1 step 1 until n do
begin
large: *A* := *B* := false; **if** *xmin*[*j*] + *dx*[*j*] > *ub*[*j*]
then begin *xmin*[*j*] := *ub*[*j*] - *dx*[*j*]; *A* := true **end**
else if *xmin*[*j*] - *dx*[*j*] < *lb*[*j*]
then begin *xmin*[*j*] := *lb*[*j*] + *dx*[*j*]; *A* := true **end;**
small: *xmin*[*j*] := *xmin*[*j*] + *dx*[*j*]; *alpha* := *FUNK* (*xmin*);
xmin[*j*] := *xmin*[*j*] - 2 × *dx*[*j*]; *beta* := *FUNK* (*xmin*);
xmin[*j*] := *xmin*[*j*] + *dx*[*j*]; **if** *A* **then** *fmin* := *FUNK* (*xmin*);
A := false;
if *alpha* - *fmin* > 0 ∧ *beta* - *fmin* > 0
then begin *B* := true; **go to comp end;**
gamma := abs((*alpha*-*beta*)/(if abs(*fmin*) < *psi* then *psi* else *fmin*));
if *gamma* > 100 × *eta* **then**
begin *dx*[*j*] := .2 × *dx*[*j*]; **go to small end;**
if *gamma* < *eta* **then**
begin *dx*[*j*] := 2 × *dx*[*j*]; **if** *dx*[*j*] < *dxmax* **then**

go to large else *dx*[*j*] := *dxmax* **end**
comp: *dfdx*[*j*] := (*alpha*-*beta*)/(2 × *dx*[*j*]);
lambda := *lambda* + *dfdx*[*j*] ↑ 2;
if ¬ *B* **then** *dx*[*j*] := .5 × *dx*[*j*]
end for; *lambda* := sqrt (*lambda*);
for j := 1 step 1 until n do
dfdx[*j*] := *dfdx*[*j*]/*lambda*
end procedure ATIVE;

procedure STEP;

comment 2. A step is taken in all variables at the same time.

The order of magnitude of the step in one variable should be of the order of magnitude of this variable. To accomplish this three weighting factors are given to the partial derivatives:

$$1) \lambda = \left(\sum_{i=1}^n \left(\frac{\partial f}{\partial x_i} \right)^2 \right)^{-1/2} \quad (\text{see subroutine ATIVE}),$$

2) $|x_i|$, or when small, *zeta*,

3) a number *p*, which is put equal to 1 at the beginning of the program and which tends to 0 at the minimum.

After a decrease of the function the step is accepted and *p* is multiplied by 1.5. After an increase *p* is divided by 2. *pmax* replaces *p* when *p* becomes greater than *pmax*;

begin for j := 1 step 1 until n do
begin *alpha* := (1-*relax*) × *dfdx*[*j*] + *relax* × *dfpr*[*j*];
xstep[*j*] := *xmin*[*j*] - *p* × *alpha* ×
(if abs(*xmin*[*j*]) < *zeta* **then** *zeta* **else** abs(*xmin*[*j*]));
dfpr[*j*] := *alpha*;
if *xstep*[*j*] > *ub*[*j*] **then** *xstep*[*j*] := *ub*[*j*]
else if *xstep*[*j*] < *lb*[*j*] **then** *xstep*[*j*] := *lb*[*j*]
end for
end STEP;

comment 3. In the next part—the compound tail—the calls for *ATIVE* and *STEP* are organized. The values 1.5 and .5 of the factors of *p* are not very important. During the iteration *p* gets an optimal value, which slowly varies. Only at the end *p* rapidly tends to 0. The programme was tested on the functions $\frac{y^2+1}{x^2+1}$

and $\frac{(x-y)^2-2}{(x+y)^2+2}$, the latter being the first one except for a rotation of the *xy*-plane over $\pi/4$ radians. In the first case a “gutter” coincides with the *x*-axis, while for $x > 0$ and $|y| \geq 1 \frac{\partial f}{\partial x} \leq 0$.

In the second case, where the gutter is along the line *x*=*y*, the relaxation is especially interesting, because with *relax* = 0 (and *pmax*=100) the iteration follows the gutter in an unstable way. With starting values *x*=-14 and *y*=21 from *x*=*y*=26 about 300 steps were taken along the gutter with *p* about .01. With *relax* = .35 and *pmax* = .5 we had about 150 steps from *x*=*y*=23. In the gutter itself *relax* = .85 gave the best results, but in that case the gutter was reached at *x*=*y*=63.

Other parameter values were: *zeta* = *psi* = 1, *dxmax*=100, *eta* = 10^{-7} with *eps* = 10^{-8} gave *fmin* in 10 figures correctly and *xmin*[*i*] in 4 to 6 figures for various starting values of *xs*[*i*];

p := 1;
for j := 1 step 1 until n do
begin *xmin*[*j*] := *xs*[*j*]; *dfpr*[*j*] := 0 **end;** *fmin* := *FUNK* (*xmin*);
deriv: *ATIVE*;
next: *STEP*;
alpha := *FUNK* (*xstep*);
if *alpha* < *fmin* **then**
begin *fmin* := *alpha*; *p* := 1.5 × *p*;
if *p* > *pmax* **then** *p* := *pmax*;
for j := 1 step 1 until n do *xmin*[*j*] := *xstep*[*j*];
go to deriv end;
p := .5 × *p*;
if *p* > *eps* **then go to next;**
comment As *p* has become smaller than *eps* this is the end of

STEEP1. The program *ACTIVE* takes up rather a lot of computer time by the way it chooses a value for $dx(i)$. A thorough simplification is obtained by taking $dx(i)$ as $10 \uparrow -3 \times \text{abs}(x_{\min}[i])$, where again $x_{\min}[i]$ may be replaced by $zeta$. Further, at the cost of some loss of accuracy, computing time is saved by taking $\frac{f(x+h)-f(x)}{h}$ as an estimate for the derivative. This program, as far as it differs from *STEEP1*, is described in algorithm 204, *STEEP2*. An interesting compromise between the two methods is obtained by interchanging the computation of dx and $dfdx$ in *ACTIVE* of *STEEP1* and omitting the iteration on dx . This routine *ACTIVE*, which has to be used in *STEEP1*, is given by J. G. A. Haubrich in algorithm 205;

end STEEP1

ALGORITHM 204

STEEP2

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procedure STEEP2 ($lb, xs, ub, dx, x_{\min}, f_{\min}, n, eps, relax$
 $dx_{\max}, p_{\max}, zeta, FUNK$);
value $dx, n, eps, relax, dx_{\max}, p_{\max}, zeta$;
integer n ;
real $dx, f_{\min}, eps, relax, dx_{\max}, p_{\max}, zeta$;
array lb, xs, ub, x_{\min} ; **real procedure** *FUNK*;
comment dx should now be taken about $10 \uparrow -3$, dx_{\max} could
be taken equal to 1. As the program is equal to *STEEP1* after
the declaration of the procedure *ACTIVE*, the ALGOL description
is cut off there;
begin integer j ; **real** $alpha, p$;
array $xstep, dfdx, dfpr$ [1:n];
procedure ACTIVE;
begin real $beta, lambda$; $lambda := 0$;
for $j := 1$ **step 1 until** n **do**
begin $alpha := dx \times (\text{if } \text{abs}(x_{\min}[j]) < dx_{\max}$
then dx_{\max} **else** $\text{abs}(x_{\min}[j])$);
if $x_{\min}[j] + alpha > ub[j]$ **then** $alpha := -alpha$;
 $x_{\min}[j] := x_{\min}[j] + alpha$; $beta := FUNK(x_{\min})$;
 $x_{\min}[j] := x_{\min}[j] - alpha$;
 $dfdx[j] := (beta - f_{\min})/alpha$;
 $lambda := lambda + dfdx[j] \uparrow 2$
end for; $lambda := \text{sqrt}(lambda)$;
for $j := 1$ **step 1 until** n **do** $dfdx[j] := dfdx[j]/lambda$;
end procedure ACTIVE

ALGORITHM 205

ACTIVE

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procedure ACTIVE;
begin real $beta, lambda$; **Boolean** A ;
comment This routine may replace *ACTIVE* in *STEEP1*. The
significance of eta has slightly changed;
 $lambda := 0$;
for $j := 1$ **step 1 until** n **do**
begin $A := \text{false}$; $alpha := dx[j]$;

if $x_{\min}[j] + alpha > ub[j]$ **then**
begin $x_{\min}[j] := ub[j] - alpha$; $A := \text{true}$ **end**
else if $x_{\min}[j] - alpha < lb[j]$ **then**
begin $x_{\min}[j] := lb[j] + alpha$; $A := \text{true}$ **end**;
 $x_{\min}[j] := x_{\min}[j] + dx[j]$; $alpha := FUNK(x_{\min})$;
 $x_{\min}[j] := x_{\min}[j] - 2 \times dx[j]$; $beta := FUNK(x_{\min})$;
 $x_{\min}[j] := x_{\min}[j] + dx[j]$; **if** A **then** $f_{\min} := FUNK$
 (x_{\min}) ;
 $dfdx[j] := (alpha - beta)/(2 \times dx[j])$;
 $lambda := lambda + dfdx[j] \uparrow 2$;
if $alpha - f_{\min} > 0 \wedge beta - f_{\min} > 0$ **then go to end**;
 $beta := \text{abs}((alpha - beta)/(\text{if } \text{abs}(f_{\min}) < psi \text{ then } psi \text{ else } f_{\min}))$;
if $beta > eta$ **then** $dx[j] := .3 \times dx[j]$ **else**
begin $dx[j] := \times d3x[j]$; **if** $dx[j] > dx_{\max}$ **then** $dx[j] := dx_{\max}$ **end**;
end; **end for**;
 $lambda := \text{sqrt}(lambda)$;
for $j := 1$ **step 1 until** n **do** $dfdx[j] := dfdx[j]/lambda$
end procedure ACTIVE

ALGORITHM 206

ARCCOSSIN

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procedure ARCCOSSIN(x) **Result**:(\arccos, \arcsin);
value x ;
real x, \arccos, \arcsin ;
comment This procedure computes $\arccos(x)$ and $\arcsin(x)$ for
 $-1 \leq x \leq 1$. The constant 2^{-27} depends on the word length and
relative machine precision, and may be replaced by a variable
identifier. *Alarm* is the procedure which messages that x is in-
valid.
The approximation formula used here was coded for MUSA-
SINO-1 in its own language at the Electrical Communication
Laboratory Tokyo. This algorithm was translated into FAP and
successfully ran on an IBM 7090;
begin real $A, x1, x2, a$; **integer** r ;
if $\text{abs}(x) > 1$
then go to Alarm
else if $\text{abs}(x) > 2 \uparrow (-27)$
then go to L1
else begin $\arccos := 1.5707963$; **go to L3**
end;
L1: if $x = 1$
then begin $\arccos := 0$; **go to L3**
end
else if $x = -1$
then begin $\arccos := 3.1415926$; **go to L3**
end
else begin $A := 0$; $x1 := x$;
for $r := 0$ **step 1 until** 26 **do**
begin if $x1 < 0$
then begin $a := 1$; $x2 := 1 - 2 \times x1 \uparrow 2$ **end**
else begin $a := 0$; $x2 := 2 \times x1 \uparrow 2 - 1$ **end**;
 $A := A + a \times 2 \uparrow (-r-1)$;
 $x1 := x2$
end;
 $\arccos := 3.1415926 \times A$;
end;
L3: arcsin := 1.570963 - arccos;
end ARCCOSSIN

CERTIFICATION OF ALGORITHM 41

EVALUATION OF DETERMINANT [Josef G. Solomon, RCA Digital Computation and Simulation Group, Moorestown, N. J.]

BRUCE H. FREED

Dartmouth College, Hanover, N. H.

When Algorithm 41 was translated into SCALP for running on the LGP-30, the following corrections were found necessary:

1. In the "y" loop after " $B[Count,y] := Temp$ " and before the "end" insert
 $Temp := C[Count+1,y];$
 $C[Count+1,y] := C[Count,y];$
 $C[Count,y] := Temp$
2. "Sign" is an ALGOL word when uncapitalized. However, many systems (if not all) do not recognize the difference between small and capital letters. For this reason "Sign" was changed to "ssign" for the LGP-30 run (and in the revision which follows later).

The following addition might be made in the specification as a concession to efficiency: " $value A,n;$ ".

The following changes might be made to make the Algorithm less wordy:

1. for " $Ssign := 1; Product := 1;$ "
put " $Ssign := Product := 1;$ "
2. for " $begin B[i,j] := A[i,j]; C[i,j] := A[i,j] end;$ "
put " $B[i,j] := C[i,j] := A[i,j];$ "
3. for " $begin B[i,j] := B[i,j] - Factor \times C[r,j] end end;$ "
put " $B[i,j] := B[i,j] - Factor \times C[r,j] end;$ "

The above corrections and changes were made and the program was run with the correct results, as follows:

$$A = \begin{pmatrix} 10.96597 & 35.10765 & 96.72356 \\ 2.35765 & -84.11256 & .87932 \\ 18.24689 & 22.13579 & 1.11123 \end{pmatrix}$$

Determinant = .1527313₁₀06

Hand calculation on a desk calculator gives the value of the determinant for the above matrix as 152,731.3600.

$$A = \begin{pmatrix} 1.0 & 3.0 & 3.0 & 1.0 \\ 1.0 & 4.0 & 6.0 & 4.0 \\ 1.0 & 5.0 & 10.0 & 10.0 \\ 1.0 & 6.0 & 15.0 & 20.0 \end{pmatrix} \quad \text{Determinant} = .9999999₁₀+00$$

The above matrix, being a finite segment of Pascal's triangle, has determinant equal to 1.000000000.

$$A = \begin{pmatrix} 0.0 & 0.0 & 0.0 \\ 5.0 & 9.0 & 2.0 \\ 7.0 & 5.0 & 4.0 \end{pmatrix} \quad \text{Determinant} = .0000000₁₀+00$$

This is, of course, exactly correct.

Finally, one major change can be made which does away with several instructions and reduces variable storage requirements by n^2 . This change is the complete removal of matrix C from the program. It is extraneous.

The revised Algorithm was translated into SCALP and run on the LGP-30 with exactly the same results as above.

The revised Algorithm 41 follows.

ALGORITHM 41, REVISION

EVALUATION OF DETERMINANT [Josef G. Solomon, RCA Digital Computation and Simulation Group, Moorestown, N. J.]

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real procedure determinant (a,n);

real array a; integer n; value a,n;

comment This procedure evaluates a determinant by triangularization;

begin real product, factor, temp;

array b[1:n,1:n];

integer count, ssign, i, j, r, y;

ssign := product := 1;

for i := 1 step 1 until n do

for j := 1 step 1 until n do

b[i,j] := a[i,j];

for r := 1 step 1 until n-1 do

begin count := r-1;

zerocheck: if b[r,r] \neq 0 then go to resume;

if count < n-1 then count := count + 1 else go to zero;

for y := r step 1 until n do

begin temp := b[count+1,y];

b[count+1,y] := b[count,y];

b[count,y] := temp end;

ssign := -ssign;

go to zerocheck;

zero: determinant := 0; go to return;

resume: for i := r+1 step 1 until n do

begin factor := b[i,r]/b[r,r];

for j := r+1 step 1 until n do

b[i,j] := b[i,j] - factor \times b[r,j] end end;

for i := 1 step 1 until n do

product := product \times b[i,i];

determinant := ssign \times product;

return: end

CERTIFICATION OF ALGORITHM 45

INTEREST [Peter Z. Ingerman, *Comm. ACM* Apr. 1961 and Oct. 1960]

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INTEREST was translated into Dartmouth College Computation Center's "Self Contained ALGOL Processor" for the Royal-McBee LGP-30. When using SCALP, memory capacity is severely limited and thus it was necessary to run this program in two blocks. Block I ended with the computation of I, and Block II started with the "newm" loop. After making the changes listed below, test problems using up to three interest rates and up to 18 time periods were used with the following results:

Loan	Periods	Interest Rates	Payments	Final Balance*	Tolerance
\$100.00	1	0.05	\$105.00	\$0.00	\$0.25
1800.00	10	0.03	211.01	0.05	4.50
875.65	8	0.08 to 500.00			
		0.05 over 500.00	139.78	-1.49	2.19
14750.00	18	0.06 to 5000.00			
		0.05 to 10,000.00			
		0.04 over 10,000.00	1201.70	10.35	36.88

* Hand calculation.

It is noted that in each case the final balance is within the prescribed tolerance (0.0025 of the loan).

In the following corrections bracketed subscripts replace ordinary subscripts and exponentiation is represented by \uparrow rather than superscript.

The following corrections should be made in the Note on Interest in the October, 1960, issue of *Comm. ACM*:

1. Definition of $B[n]$: Replace "minimum" by "maximum". Replace " $j[n]$ " by " $j[n-1]$ ".

2. Define $B[k+1] \equiv L$.

3. Definition of $K[n]$: Replace " $B[n]$ " by " $B[n+1]$ ".

The following corrections were found necessary in the procedure:

1. The upper limit of the vector B is $k+1$, not k . It is not necessary to change the upper limit of the I -vector. (See correction 4 below.)

2. D, E, F, u, v were not declared and must be declared as **real**.

3. In the **array** declaration replace " $M[1:k]$ " by " $M[1:k+1]$ ".

4. As j approaches 0, i approaches 1 and $\lim (h/S) = 1/t$. Thus for $j[k+1] = 0$, $i[k+1] = 1$, and $M[k+1] = L/t$. Thus after

$M[p] := L \times (h[p,t]/S[p,t])$ end;

insert

$M[k+1] := L/t; B[k+1] := L;$

5. In the conditional statement following computation of $b[p]$, replace " $>$ " by " \geq ".

6. In same conditional statement, next line, " $mb := bp$ " should read " $mb := b[p]$ ".

7. $D := 1; E := F := 0;$

$newm: \text{ for } p := 1 \text{ step } 1 \text{ until } k \text{ do}$

should be changed to

$newm: D := 1; E := F := 0;$

for $p := 1 \text{ step } 1 \text{ until } k \text{ do}$

8. **begin** get $F: F := (D+m-E)/(1+i[q]);$

if $B[q+1] \geq F$ **then** $D := F$ **else** $q := q + 1;$

if $D \neq F$ **go to** get F **end;**

should be changed to read as follows:

begin get $F: F := (D+m)/i[q];$

if $B[q+1] \geq F$ **then** $D := F$ **else**

begin **if** $q < k$ **then** $q := q + 1$ **else** $D := F$ **end;**

if $D \neq F$ **then** **go to** get F **end;**

Note that the "then" in the last line was omitted from the original procedure.

9. In the "redo" loop insert a semicolon after the statement

$T[ib] := T[ib] + T[p] - b[p];$

10. In the "redo" loop, next line, omit the second "end".

11. In the "redo" loop,

$p := k$ **end;**

should be changed to

$p := k$ **end end;**

REMARK ON ALGORITHM 129 MINIFUN

MINIFUN [V. W. Whitley, *Comm. ACM*, Nov. 1962]

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Some errors found in Algorithm 129 MINIFUN [*Comm. ACM*, Nov. 1962] are given below.

In addition, the way "steepest descent" is used to compute the minimum of a function of n variables is not entirely satisfactory. The method for computing first derivatives may be improved in two ways:

1. Instead of computing $\frac{f(x+h)-f(x)}{h}$ it is better to take $\frac{f(x+h)-f(x-h)}{2h}$. As $f(x-h)$ has been computed by MINIFUN this does not give rise to extra computations.

2. In MINIFUN the choice of h seems rather deliberate. Indeed, h is taken as $.2 \times (xub - xlb)$, where xub and $xl b$ are variable bounds of x . In the beginning of the program these bounds are put equal to the fixed bounds $b1$ and ub ; afterwards in the iteration process they should tend towards each other, and in the limit they provide the minimum. So especially when a good approximation to the minimum is unknown, $b1$ and ub have to be taken well apart from each other, which means that h is rather large. At the limit, however, h is very small. It is better to take h in such a way that the nominator $f(x+h)-f(x-h)$ attains an appropriate value.

As the method used by MINIFUN is the Newton-Raphson method applied to the first derivatives, convergence is not always secured—especially since first and second partial derivatives are estimated with numerical methods.

It should be noted that the test on end of program is not correct. For a further possible decrease of the function one has not to look in the direction of the coordinate axes but in the direction of the steepest descent.

ALGOL descriptions of some "steepest descent" programs which were written in the symbolic code of the Philips computer Pascal [cf. H. J. Heijn and J. C. Selman, *IRE Trans. EC10* (June 1961), 175-183] are given in Algorithms 203, 204 and 205.

CORRECTIONS OF MINIFUN:

Printing errors: The line below label *nustep* should read:

begin **if** $abs(dmax) < abs(dxmin[j])$ **then**

The label 1 *bdkk* should be *lbdchk*

In **comment** MINIFUN: $k1=2$: a new minimum has not been found.

The label *nustep* should be placed before the statement: $dmax := dxmin[j]$; The declaration of $xmin$ should be removed from the blockhead of the procedure body. The 2-dimensional arrays $x[1:n, 1:4]$ and $g[1:n, 1:4]$ can be replaced by a **real** x and a 1-dimensional **array** $g[1:4]$ respectively.

An improvement could be the insertion of the statement

$k1 := 1;$

just before the label *nustep*.

I am having considerable trouble with the obviously important part played by the **array** *wnew*, although it does not change after being set in the first statement of the program. Furthermore it seems to me that *wnew* plays a double rôle: first the component *wnew[k]* is the value of *xt[k]* before an iteration on *xt[k]*. But then one should insert another statement after label *nustep*: $wnew[k] := xt[k]$; Secondly *wnew[k]* is to be understood as half the distance between upper and lower bound $t1[k]$ and $b1[k]$, which is only true when $b1[k] = 0$.

Convergence of $delx[j]$ to 0 is only achieved when $xlb[k]$ and $xub[k]$ are tending towards each other. This indicates that *wnew[k]* should go to 0 too. (See statements after label *stnubds*.)

The following modifications could remove these objections (starting with the line above label *restart*):

if $ft < fmin$ **then** **go to** check **else** $xt[k] := wnew[k];$

restart: **if** $xt[k] < wnew[k]$ **then** **go to** *lbdchk*;

if $xt[k] = wnew[k]$ **then** **go to** *stnubds*;

if $xt[k] < t1[k]$ **then** **go to** *nupbds*;

$xt[k] := 0.5 \times (wnew[k] + t1[k]);$

nupbds: $xub[k] := t1[k]; xlb[k] := 2 \times xt[k] - t1[k];$ **go to** *newdel*;

stnubds: $xlb[k] := xt[k] - 0.5 \times (wnew[k] - xlb[k]);$

$xub[k] := xt[k] + 0.5 \times (wnew[k] - xub[k]);$ (etc.)

lbdchk: **if** $xt[k] = b1[k]$ **then** $xt[k] := 0.5 \times (wnew[k] + b1[k]);$
 $xlb[k] := b1[k]; xub[k] := 2 \times xt[k] - b1[k];$ **go to** *newdel*; (etc.)

REMARK ON ALGORITHM 157

FOURIER SERIES APPROXIMATION [C. J. Mifsud, *Comm ACM*, Mar. 1963]

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This algorithm was written in FAP language for the 32-K IBM 704. It was tested on a sawtooth curve, and the sawtooth was recreated by summing the expansion up through the $2N + 1$ constants, with excellent results.

* Work supported by the United States Atomic Energy Commission.

The arrays S , C and u are never referenced with a variable subscript. For a saving of time, I suggest that simple variables be used instead.

By declaring one additional real variable, one can bring the phrase

$$2/(2 \times N + 1)$$

outside of the **for** loops, because N does not change through the procedure. This results in a saving of $4N+2$ mult-ops.

CERTIFICATION OF ALGORITHM 158 EXPONENTIATION OF SERIES [H. E. Fettis, *Comm. ACM*, Mar. 1963]

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This procedure was translated into FORTRAN and run on the Remington-Rand LARC Computer. Three changes are necessary.

- (1) The last line of the comment should read
for the natural logarithm of $f(x)$;
- (2) The third line from the end should read

$$S := S + (P \times (i-k) - k) \times B[k] \times A[i-k];$$

(This line was given correctly in algorithm 134.)

- (3) The second line from the end apparently should read

$$B[i] := A[i] := (S/i);$$

for the case $P = 0$ only. Probably the best way to incorporate this is by making two changes:

- (a) Change the **if** clause to read
if $P = 0$ **then** $R := 1$ **else** $R := P$; $B[1] := R \times A[1]$;
- (b) Change the second line from the end to read

$$B[i] := R \times A[i] + (S/i);$$

A large number of examples were run quite successfully; the following give representative samples.

- (1) $(1+2x+3x^2+0.5x^3)^2 = 1+4x+10x^2+13x^3+11x^4+3x^5+0.25x^6$
(using $A[4] := A[5] := A[6] := 0$).
- (2) Setting $P := 1$ gives $B[i] := A[i]$.
- (3) Let $f(x) = e^x = 1 + \sum_{i=1}^n \frac{1}{i!} x^i$ and let $P = \ln 2 = .693147181$.

Then $g(x) = 2^x = 1 + \sum_{i=1}^n \frac{(\ln 2)^i}{i!} x^i$. (See Table 1.)

- (4) Let $f(x) = e^x$ and $P = -1$. Then $g(x) = e^{-x}$. For $P=0$, apparently the constant term of $g(x)$ should be zero instead of one.

TABLE 1

	$A[i]$	$B[i]$
1	1.000000000	0.693147181
2	0.500000000	0.240226507
3	0.166666667	0.055504109
4	0.041666667	0.009618129
5	0.008333333	0.001333356
6	0.001388889	0.000154035
7	0.000198413	0.000015253
8	0.000024802	0.000001322
9	0.000002756	0.000000102
10	0.000000276	0.000000007

- (5) Let $f(x) = e^x$ and $P=0$. Then $g(x) = x$.

- (6) Let $f(x) = \sum_{i=0}^n x^i$ and $P=0$. Then $g(x) = \ln(1-x^n) - \ln(1-x) =$

$$\sum_{i=1}^n \frac{1}{i} x^i. \text{ (See Table 2.)}$$

TABLE 2

	$A[i]$	$B[i]$
1	1.0	1.000000000
2	1.0	0.500000000
3	1.0	0.333333340
4	1.0	0.250000000
5	1.0	0.200000000
6	1.0	0.166666670
7	1.0	0.142857140
8	1.0	0.125000000
9	1.0	0.111111110
10	1.0	0.100000000
11	1.0	0.090909100
12	1.0	0.083333330
13	1.0	0.076923080
14	1.0	0.071428580
15	1.0	0.066666660

CERTIFICATION OF ALGORITHM 163 MODIFIED HANKEL FUNCTION [Henry E. Fettis, *Comm. ACM*, Apr. 1963]

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Since this algorithm is a function declaration, the procedure declaration should be:

real procedure $EXPK(D, X, E); \dots$

Otherwise, no syntactical errors were noticed.

The body of the procedure was translated and run on the LGP-30 computer, using the Dartmouth SCALP system. Results for $E = 0.0001$, $X = 0.1(0.1)1.0$, $P = 0$, 0.3333333, 0.6666667 and 1.0000000 agreed with values tabulated in Jahnke-Emde-Losch to the 3-4D given in the tables, except for errors discovered in the table of $2/\pi K_{2/3}(x)$.

With $X = 0$, the program ended in floating-point overflow. The algorithm itself, or the call of the procedure, should include a test to insure that the variable is greater than eps , where eps is chosen to prevent exceeding machine capacity.

The algorithm was found to be excessively slow. Times on the LGP-30 were of the order of 6 minutes. A considerable saving in time could be realized by improving the quadrature formula, currently the simple midpoint formula, repeated completely for each iteration. A more effective method would be a modified Romberg algorithm. A procedure based on the latter approach is being developed in this division.

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

TABLE A

n	$X[n]$	$V[n]$	$B[n]$	$B[n-1]$	$B[n-2]$	$B[n-3]$	$B[n-4]$	$B[n-5]$
1	5.0	148.4132	148.4132					
2	5.0	148.4132	148.4132	148.4132				
3	6.0	403.4288	403.4287	255.0155	106.6023			
4	6.0	403.4288	403.4287	403.4287	148.4132	41.81091		
5	5.0	74.20658	148.4132	255.0155	148.4132	41.81091	9.415191	
6	6.0	201.7144	403.4287	255.0155	148.4132	53.30115	11.49023	2.075043

The forward differences lie along the top diagonal.

Use of these results with B_{NEWT} and with F_{NEWT} gave the following results, for $N = 6$.

z	B_{NEWT}			F_{NEWT}		
	P	D	E	R	D	E
5.000000	148.4132	148.4132	$.4567298 \times 10^{-4}$	148.4132	148.4132	$.7420658 \times 10^{-5}$
5.500000	244.6973	244.6924	$.4173722 \times 10^{-4}$	244.6973	244.6924	$.3078276 \times 10^{-4}$
6.000000	403.4287	403.4287	$.2017143 \times 10^{-4}$	403.4287	403.4287	$.7441404 \times 10^{-4}$

CERTIFICATION OF ALGORITHM 167

CALCULATION OF CONFLUENT DIVIDED DIFFERENCES [W. Kahan and I. Farkas, *Comm. ACM*, Apr. 1963]

CERTIFICATION OF ALGORITHM 168

NEWTON INTERPOLATION WITH BACKWARD DIVIDED DIFFERENCES [W. Kahan and I. Farkas, *Comm. ACM*, Apr. 1963]

CERTIFICATION OF ALGORITHM 169

NEWTON INTERPOLATION WITH FORWARD DIVIDED DIFFERENCES [W. Kahan and I. Farkas, *Comm. ACM*, Apr. 1963.]

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The bodies of these procedures were tested on the LGP-30 computer using the Dartmouth SCALP compiler. Compilation and execution revealed no syntactical or mathematical errors.

It is to be noted that, although with Algorithm 169, reducing the value of N from that used to generate F leads to an interpolation polynomial based on fewer points, this is not true for Algorithm 168. This flexibility could be supplied by adding an additional formal parameter, *deg*, say, to the procedure, and by making the **for** statement read:

“**for** $i := N - \text{deg}$ **step** 1 **until** N **do** ... ”

The logic of the error estimate in Algorithms 168 and 169 is not entirely clear. However, it appears that the estimate can be adjusted for different precision of arithmetic by adjusting the constant $3_{10}-8$ appropriately. For the SCALP arithmetic, this constant was changed to $1_{10}-7$.

The algorithms were tested on the examples given by Milne-Thomson [*The Calculus of Finite Differences*, p. 4, Macmillan, 1951] and by Milne [*Numerical Calculus*, p. 204, Princeton, 1949]. In both examples, Algorithm 167 reproduced the divided difference table, and both Algorithms 168 and 169 reproduced the input values. As a check of the calculation of confluent divided differences, values of the exponential function of its first two derivatives at $x = 5.0$ and 6.0 were used. The difference table shown in Table A was obtained.

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

REMARK ON ALGORITHM 166

MONTECARLO INVERSE [R. D. Rodman, *Comm. ACM*, Apr. 1963]

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The algorithm contained two errors:

(1) The line which reads

start: $p := (n-1)/n \times n$;

should read

start: $p := (n-1)/n \uparrow 2$;

(2) The line which reads

start2: $\text{walk} := (\text{random}/p) + 1$;

should read

start2: $\text{walk} := \text{entier}((\text{random}/p) + 1)$;

After making the preceding corrections, procedure *montecarlo* was transliterated into EXTENDED ALGOL and run successfully on the Burroughs B-5000. Convergence occurred in all cases where the matrix satisfied the conditions set down in the comment statement of the algorithm. It was found that convergence was quickest and the routine most practical for matrices with eigenvalues small relative to one.

DATES TO REMEMBER

FJCC	Las Vegas	Nov. 12-14, 1963
SJCC	Washington	Apr. 21-23, 1964
ACM	Philadelphia	Aug. 25-28, 1964
IFIP	New York	May 22-24, 1965