

Algorithms

H. J. WEGSTEIN, Editor

ALGORITHM 88 EVALUATION OF ASYMPTOTIC EXPRESSION FOR THE FRESNEL SINE AND COSINE INTE- GRALS

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Technology, Atlanta, Ga.

real procedure FRESNEL (u) Result: (frcos, frsin); **value**
(u);

comment This procedure evaluates the Fresnel sine and cosine
integrals for large u by expanding the asymptotic series given
by

$$S(u) = \frac{1}{2} - \frac{\cos(x)}{\sqrt{2\pi x}} \left[1 - \frac{1 \cdot 3}{(2x)^2} + \frac{1 \cdot 3 \cdot 5 \cdot 7}{(2x)^4} - \dots \right] \\ - \frac{\sin(x)}{\sqrt{2\pi x}} \left[\frac{1}{2x} - \frac{1 \cdot 3 \cdot 5}{(2x)^3} + \frac{1 \cdot 3 \cdot 5 \cdot 7 \cdot 9}{(2x)^5} - \dots \right]$$

and

$$C(u) = \frac{1}{2} - \frac{\sin(x)}{\sqrt{2\pi x}} \left[1 - \frac{1 \cdot 3}{(2x)^2} + \frac{1 \cdot 3 \cdot 5 \cdot 7}{(2x)^4} - \dots \right] \\ - \frac{\cos(x)}{\sqrt{2\pi x}} \left[\frac{1}{2x} - \frac{1 \cdot 3 \cdot 5}{(2x)^3} + \frac{1 \cdot 3 \cdot 5 \cdot 7 \cdot 9}{(2x)^5} - \dots \right]$$

in which $x = \pi u^2/2$. Reference: PEARCEY, T. *Table of the Fresnel*

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Integral to Six Decimal Places. The Syndics of the Cambridge University Press, Melbourne, Australia (1956).;

```
begin pi := 3.14159265; arg := pi * (u ↑ 2)/2; temp := 1;
  argsq := 1/(4 * (arg ↑ 2)); term := -3 * argsq;
  series := 1 + term; N := 3;
first: if temp = series then go to second; temp := series;
  termi := term;
  term := -termi * (4 * N - 7) * (4 * N - 5) * (argsq);
  if abs(term) > abs(termi) then go to second;
  series := temp + term; N := N + 1; go to first;
second: series2 := 1/2 * arg; temp := 0; term := series2;
  N := 2;
loop: if series2 = temp then go to exit; termi := term;
  term := -termi * argsq * (4 * N - 5) * (4 * N - 3);
  if abs(term) > abs(termi) then go to exit;
  temp := series2; series2 := temp + term;
  N := N + 1; go to loop;
exit: if u < 0 then half := -1/2 else half := 1/2;
  frcos := half + (sin(arg) * series - cos(arg) + series2)/
    (pi * u);
  frsin := half - (cos(arg) * series2 + sin(arg) * series)/
    (pi * u)
end FRESNEL;
```

ALGORITHM 89 EVALUATION OF THE FRESNEL SINE INTEGRAL JOHN L. CUNDIFF

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Technology, Atlanta, Ga.

real procedure FRESNELSIN (u) Result: (frsin); **value** u;
comment This algorithm computes the Fresnel sine integral
defined by,

$$S(u) = \int_0^u \sin \pi t^2/2 dt,$$

by evaluating the series expansion

$$S(x) = \sqrt{\frac{2x}{\pi}} \left[\frac{x}{3} - \frac{x^3}{7 \cdot 3!} + \frac{x^5}{11 \cdot 5!} - \frac{x^7}{15 \cdot 7!} + \dots \right]$$

where $x = \pi u^2/2$. Reference: PEARCEY, T. *Table of the Fresnel Integral to Six Decimal Places*. The Syndics of the Cambridge University Press, Melbourne, Australia (1956).;

```
begin Pi2 := 1.5707963; x := Pi2 * x * (u ↑ 2); frsin := x/3;
  frsqr := x ↑ 2; N := 3; term := (-x * frsqr)/6;
  frsini := frsin + term/7;
Loop: if frsin = frsini then go to exit; frsin := frsini;
  term := -term * frsqr / ((2 * N - 1) * (2 * N - 2));
  frsini := frsin + term / (4 * N - 1); N := N + 1;
  go to Loop;
exit: frsin := frsini * u
end FRESNELSIN;
```

ALGORITHM 90
EVALUATION OF THE FRESNEL COSINE INTEGRAL

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real procedure FRESNELCOS (u) result: (frcos); **value** (u);
comment This algorithm computes the Fresnel cosine integral defined by

$$C(u) = \int_0^u \cos \frac{\pi t^2}{2} dt,$$

by evaluating the series expansion

$$C(u) = \sqrt{\frac{2x}{\pi}} \left[1 - \frac{x^2}{5 \cdot 2!} + \frac{x^4}{9 \cdot 4!} - \frac{x^6}{13 \cdot 6!} + \dots \right],$$

where $x = \pi u^2/2$. Reference: PEARCEY, T. *Table of the Fresnel Integral to Six Decimal Places*. The Syndics of the Cambridge University Press, Melbourne, Australia (1956).;

```
begin pi2 := 1.5707963; x := pi2 × (u ↑ 2); frcos := 1;
xsqr := x ↑ 2; N := 3; term := -xsqr/2;
frcoi := 1 + (term/5);
loop: if frcoi = frcos then go to exit; term := -term ×
xsqr/((2×N-2) × (2×N-3)); frcos := frcoi; frcoi :=
frcos + term/(4×N-3); N := N + 1; go to loop;
exits: frcos := u × frcos
end FRESNELCOS;
```

ALGORITHM 91
CHEBYSHEV CURVE-FIT

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procedure CHEBFIT(m, n, X, Y); **integer** m, n; **array** X, Y;
comment This procedure fits the tabular function $Y(X)$ (given

as m points (X, Y)) by a polynomial $P = \sum_{i=0}^n A_i X^i$. This polynomial is the best polynomial approximation of $Y(X)$ in the Chebyshev sense. Reference: STIEFEL, E. *Numerical Methods of Tchebycheff Approximation*, U. of Wisc. Press (1959), 217-232;

```
begin array X[1:m], Y[1:m], T[1:m], A[0:m], AX[1:m+2],
AY[1:m+2], AH[1:m+2], BY[1:m+2], BH[1:m+2];
integer array IN [1:m+2]; real TMAX, H; integer i,
j, k, imax;
comment Initialize;
k := (m-1)/(n+1);
for l := 1 step 1 until n+1 do IN [l] := (l-1)×k + 1;
IN[n+2] := m;
START: comment Iteration begins;
for i := 1 step 1 until n+2 do
begin AX[i] := X[IN[i]];
AY[i] := Y[IN[i]];
AH[i] := (-1) ↑ (i-1)
end i;
DIFFERENCE: comment divided differences;
for i := 2 step 1 until n+2 do
begin
for j := i-1 step 1 until n+2 do
begin BY[j] := AY[j];
BH[j] := AH[j]
end j;
end i;
```

```
for j := i step 1 until n+2 do
begin AY[j] := (BY[j] - BY[j-1])/
(AX[j] - AX[j-i+1]);
AH[j] := (BH[j] - BH[j-1])/
(AX[j] - AX[j-i+1])
end j;
```

```
end i;
H := -AY[n+2]/AH[n+2];
POLY: comment polynomial coefficients;
for i := 0 step 1 until n do
begin A[i] := AY[i] + AH[i] × H;
BY[i] := 0
end i;
BY[1] := 1; TMAX := abs(H); imax := IN[1];
for i := 1 step 1 until n do
begin
for j := 0 step 1 until i-1 do
begin
BY[i+1-j] := BY[i+1-j] - BY[i-j] × X[IN[i]];
A[j] := A[j] + A[i] × BY[i+1-j]
end j;
end i;
ERROR: comment compute deviations;
for i := 1 step 1 until m do
begin T[i] := A[n];
for j := 0 step 1 until n do T[i] := T[i] X[i] + A[n-j];
T[i] := T[i] - Y[i];
if abs(T[i]) ≤ TMAX then go to L1;
TMAX := abs(T[i]);
imax := i
end i;
L1:
for i := 1 step 1 until n+2 do
begin
if imax < IN[i] then go to L2;
if imax = IN[i] then go to FIT end
end i;
L2: if T[imax] × T[IN[i]] < 0 then go to L3;
IN[i] := imax;
go to START;
L3: if IN[1] < imax then go to L4;
for i := 1 step 1 until n+1 do IN[n+3-i] := IN[n+2-i];
IN[i] := imax;
go to START;
L4: if IN[n+2] ≤ imax then go to L5;
IN[i-2] := imax;
go to START;
L5: for i := 1 step 1 until n+1 do IN[i] := IN[i+1];
IN[n+2] := imax;
go to START;
FIT: end CHEBFIT
```

CERTIFICATION OF ALGORITHM 60

ROMBERG INTEGRATION (F. L. Bauer, *Comm. ACM*, June 1961)

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Since August 1961, the Romberg Integration has been successfully applied in FORTRAN language to various problems on an IBM 1620. Due to its elegant method and the memory saving features, the Romberg Integration has succeeded other methods in our program library, e.g., the Newton-Cotes integration of order 10.

Reference is made to Stiefel, *Numerische Mathematik* (Teubner Verlag, Stuttgart). Stiefel discusses in his book various methods of numerical integration including the Romberg algorithm.

[ALGORITHMS ARE CONTINUED ON PAGE 286]

Observations and Conclusions

The following observations and inferences are based on the initial experiences with a multiprogramming system:

1. It has been possible to make a significant improvement in the utilization of the main-frame time of the computer with large classes of real problems running at Lewis Research Center.

2. The interrupt feature is the basic tool that permits the automatic time sharing of independently coded and unrelated problems.

3. A clock that interrupts periodically would be a highly desirable tool to be used in the management of more general multiprogramming systems. Such a clock would be useful in preventing a "looping" problem from "hogging" the computer, as well as for running-time accounting.

4. Multiprogramming provides the incentive for more efficient problem and system codes by removing the output barrier. Previously, there was little motivation to prepare efficient codes in output-limited problems, since there was little advantage to be gained. The multiprogramming system has provided a method of exploiting such gains and has produced pressure for more efficient codes.

5. Operator attention to the input-output devices, such as a tape change, no longer need delay the computer. The computer can push ahead any problem that is not using the device undergoing the change.

6. Multiprogramming seems to develop a trend towards splintering of problems and their input-output tasks. This appears to have two advantages for multiprogramming in computers of limited store and input devices. First, it provides a much better opportunity to obtain a feasible mix of problems in the high-speed memory. Splintering of problems or data-reduction tasks will increase the possibility of getting compatible problems for a parallel-operation schedule.

7. Scheduling of parallel problems could be facilitated by an inexpensive procedure for code relocation. It would be desirable to relocate the codes of a current problem in the high-speed memory without more than a nominal delay in computation.

8. On-line debugging of problems is costly of computer time and an inefficient use of computer capabilities. However, from an individual problem standpoint, it is often an effective method of debugging. Parallel operation during on-line debugging, if it could be made safe, may reduce the cost of on-line debugging to a point where it is feasible.

REFERENCE

1. TURNER, L. R., AND RAWLINGS, J. H. Realization of randomly timed computer input and output by means of an interrupt feature. *IRE Trans. EC-7*, no. 2 (June 1958), 141-149.

ALGORITHMS—Continued

ALGORITHM 92 SIMULTANEOUS SYSTEM OF EQUATIONS AND MATRIX INVERSION ROUTINE

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procedure SIMULTANEOUS (U, W, C, X, B, n, kount, eps,
absf) ;

array U, W, C, X, B ; **integer** n, kount ;

real eps; **real procedure** absf;

comment This procedure solves the problem $Ux := b$ for the vector x . It assumes the problem written in the form $x'U' := b'$, where $'$ denotes transpose. The procedure is completed in n cycles and may be iterated *kount* times ($kount \leq 6$). The transpose of U is in $U[i, j]$ and the row vector b' is in B . The integer n is the dimension of U , and the solution row vector x' is in X . The matrix C is a check of accuracy. It should have b' in its first row, the first element b_1 of b' along its main diagonal, and zeros elsewhere. The real number *eps* checks to see how close the actual result is to this theoretical one. Also if we let $b' := (1, 0, \dots, 0)$, then this procedure finds the inverse $W[i, j]$ of U . The function *absf* finds the absolute value of its argument. The procedure chooses the column vectors of U as the row vectors of W in the 0th cycle of the first iteration. For all subsequent iterations, the row vectors of W , computed at the n th cycle of the last iteration, are the row vectors of W in the 0th cycle ;

begin integer i, j, k, p ; **real** bh, b1, Z ;

for j := 1 step 1 until n do

for i := 1 step 1 until n do W[j, i] := U[i, j];

S1: **for j := 1 step 1 until n do**

for i := 1 step 1 until n do C[i, j] := 0 ;

for j := 1 step 1 until n do

begin for k := 1 step 1 until n do

begin C[j, j] := C[j, j] + W[j, k] × U[k, j] **end**;

if j = 1 then Z := B[j]/C[j, j] **else** Z := 1/C[j, j];

for k := 1 step 1 until n do

begin X[k] := Z × W[j, k];

W[j, k] := X[k]

end k;

for k := 1 step 1 until n do

begin if k = j then go to S2 else

for p := 1 step 1 until n do

C[k, j] := C[k, j] + U[p, j] × W[k, p];

if j = 1 then bh := B[j] **else** bh := 1;

if k = 1 then b1 := B[j] **else** b1 := 0;

for p := 1 step 1 until n do

begin X[p] := bh × W[k, p] + (b1 - C[k, j]) × W[j, p];

W[k, p] := X[p]

end p;

S2: **if k = j ∧ j = n then go to S3**

end k;

end j;

S3: **for j := step 1 until n do**

if absf(absf(C[j, j]) - absf(B[1])) > eps **then go to S4**;

go to S6;

S4: **if** kount > 0 **then go to S5 else go to S6**;

S5: kount := kount - 1;

go to S1;

S6: **for j := step 1 until n do**

X[j] := W[1, j];

S7: **end** SIMULTANEOUS