

Algorithms in the Nashlib set in various programming languages – Part 4

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Abstract

Algorithms 24 and 25 from the book Nash (1979) are implemented in a variety of programming languages including Fortran, BASIC, Pascal, Python and R. These routines concern the use of iterative methods, in particular conjugate gradients, to solve linear algebra problems.

Overview of this document

This section is repeated for each of the parts of Nashlib documentation.

A companion document **Overview of Nashlib and its Implementations** describes the process and computing environments for the implementation of Nashlib algorithms. This document gives comments and/or details relating to implementations of the algorithms themselves.

Note that some discussion of the reasoning behind certain choices in algorithms or implementations are given in the Overview document.

Algorithm 24 – conjugate gradients for linear equations and least squares

Fortran

Listing

```
      SUBROUTINE A24CG(N,B,C,TOL,G,IPR,APR,V,T,IMULT)
C  ALGORITHM 24 CONJUGATE GRADIENT SOLUTION OF LINEAR EQUATIONS
C  HAVING POSITIVE DEFINITE COEFFICIENT MATRIX
C  J.C. NASH    JULY 1978, FEBRUARY 1980, APRIL 1989
C  N          = ORDER OF PROBLEM AND LENGTH OF VECTORS B,C,G,V,T
C  B          = INITIAL GUESS FOR SOLUTION (INPUT) MAY BE NULL
C              = SOLUTION (OUTPUT)
C  C          = RIGHT HAND SIDE OF EQUATIONS
C  TOL        = CONVERGENCE TOLERANCE ON SIZE OF RESIDUAL SUM OF SQUARES
C  G          = VECTOR OF APPROXIMATE RESIDUALS (OUTPUT)
C  IPR        = PRINTER CHANNEL. IF IPR.GT.0 PRINT TO CHANNEL IPR
C  APR        = NAME OF SUBROUTINE TO PUT A*T IN V
C              CALLING SEQUENCE:  CALL APR(N,T,V)
C  V,T        = WORK ARRAYS OF N ELEMENTS EACH
C  IMULT      = NO. OF MATRIX MULTIPLICATIONS ALLOWED (INPUT) OR USED (OUT)
C  STEP 0
      INTEGER N,IPR,IMULT,LIMIT,I,ITN,COUNT
      REAL TOL,G2,G2L,K,T2,B(N),C(N),G(N),T(N),V(N)
      LIMIT=IMULT
      IMULT=0
C  STEP 1
      5  IMULT=IMULT+1
      IF(IMULT.GT.LIMIT)RETURN
      CALL APR(N,B,G)
      DO 10 I=1,N
        G(I)=G(I)-C(I)
      10 CONTINUE
C  STEP 2
      20  G2=0.0
      DO 25 I=1,N
        G2=G2+G(I)**2
        T(I)=-G(I)
      25 CONTINUE
      IF(IPR.GT.0)WRITE(IPR,950)IMULT,G2
      950 FORMAT(13H AFTER STEP 2,I4,15H PRODUCTS,  RSS=,1PE16.8)
C  STEP 3
      IF(G2.LT.TOL)RETURN
C  STEP 4
      DO 110 ITN=1,N
C  STEP 5
        IMULT=IMULT+1
        IF(IMULT.GT.LIMIT)RETURN
        CALL APR(N,T,V)
C  STEP 6
        T2=0.0
        DO 60 I=1,N
          T2=T2+T(I)*V(I)
```

```

60    CONTINUE
C  STEP 7
      K=G2/T2
      G2L=G2
C  STEP 8
      G2=0.0
      COUNT=0
      DO 80 I=1,N
        G(I)=G(I)+K*V(I)
        T2=B(I)
        B(I)=T2+K*T(I)
        IF(T2.EQ.B(I))COUNT=COUNT+1
        G2=G2+G(I)**2
80    CONTINUE
C  STEP 9
      IF(COUNT.EQ.N)GOTO 5
C      IF(COUNT.EQ.N)GOTO 20
C      IF(G2.LT.TOL)RETURN
C  USING ALTERNATIVE STEP 9 ROUTE
      IF(G2.LT.TOL)GOTO 5
      IF(IPR.GT.0)WRITE(IPR,951)IMULT,G2
951  FORMAT(13H AFTER STEP 9,I4,15H PRODUCTS, RSS=,1PE16.8)
C  STEP 10
      T2=G2/G2L
      DO 100 I=1,N
        T(I)=T2*T(I)-G(I)
100  CONTINUE
C  STEP 11
110  CONTINUE
C  STEP 12
      GOTO 5
C  NO STEP 13 SINCE RETURN USED
      END
      SUBROUTINE FRANK(N,T,V)
C  J.C. NASH    JULY 1978, APRIL 1989
      INTEGER N,I,J
      REAL T(N),V(N),S
      DO 10 I=1,N
        S=0.0
        DO 5 J=1,N
          S=S+AMINO(I,J)*T(J)
5    CONTINUE
        V(I)=S
10   CONTINUE
      RETURN
      END

```

Example output

We solve the linear equations problem

$$Ax = b$$

for A being the Frank matrix and b the vector that is all 1s, that is, A times a vector of ones. Different orders of problem are tried. This problem has an obvious solution, which is that

$$x_i = 1$$

and the elements of A are integers, so we can compute the error in the solution as well as the residual

$$b - Ax$$

```
A <- matrix(0, nrow=5, ncol=5)
b <- rep(1,5)

for (i in 1:5) {
  for (j in 1:5){
    A[i,j]=min(i,j)
  }
}
print(A)
```

```
##      [,1] [,2] [,3] [,4] [,5]
## [1,]    1    1    1    1    1
## [2,]    1    2    2    2    2
## [3,]    1    2    3    3    3
## [4,]    1    2    3    4    4
## [5,]    1    2    3    4    5
```

```
C <- A %*% b
print(C)
```

```
##      [,1]
## [1,]    5
## [2,]    9
## [3,]   12
## [4,]   14
## [5,]   15
```

Note that the program, as given, is single precision, so some of the results are not terribly accurate. Also the control IMULT is an upper limit on the number of matrix multiplications before the process is artificially halted. We still get an approximate solution at this stage, and the result accuracy in terms of residuals and error.

```
gfortran ../fortran/dr24.f
mv ./a.out ../fortran/dr24le.run
../fortran/dr24le.run < ../fortran/a24f.in
```

```
## ORDER=   10 IMULT=   50 TOLERANCE=  9.99999994E-09
## MEAN ABSOLUTE -- RESIDUAL=  2.67982487E-05 -- ERROR=  8.17596883E-05
## ORDER=   10 IMULT=   10 TOLERANCE=  9.99999994E-09
## MEAN ABSOLUTE -- RESIDUAL=  3.41129315E-04 -- ERROR=  4.34631103E-04
## ORDER=   10 IMULT=    5 TOLERANCE=  9.99999994E-09
## MEAN ABSOLUTE -- RESIDUAL=  1.70371048E-02 -- ERROR=  2.66596377E-02
## ORDER=   50 IMULT=   51 TOLERANCE=  9.99999994E-09
## MEAN ABSOLUTE -- RESIDUAL=  3.52401723E-04 -- ERROR=  4.98390182E-05
## ORDER=   50 IMULT=   10 TOLERANCE=  9.99999994E-09
## MEAN ABSOLUTE -- RESIDUAL=  9.57564563E-02 -- ERROR=  1.86094921E-02
## ORDER=   50 IMULT=  100 TOLERANCE=  9.99999975E-06
```

```
## MEAN ABSOLUTE -- RESIDUAL= 2.42843627E-04 -- ERROR= 2.69281853E-04
## ORDER= 0 IMULT= 0 TOLERANCE= 0.00000000E+00
```

Pascal

Listing of Algorithm 24

Example output for linear equations

Algorithm 24 solves linear equations, so no extra code is presented.

```
fpc ../Pascal2021/dr24le.pas
mv ../Pascal2021/dr24le ../Pascal2021/dr24le.run
../Pascal2021/dr24le.run <../Pascal2021/dr24le.in

## Free Pascal Compiler version 3.0.4+dfsg-23 [2019/11/25] for x86_64
## Copyright (c) 1993-2017 by Florian Klaempfl and others
## Target OS: Linux for x86-64
## Compiling ../Pascal2021/dr24le.pas
## dr24le.pas(204,8) Note: Local variable "s" is assigned but never used
## Linking ../Pascal2021/dr24le
## /usr/bin/ld.bfd: warning: link.res contains output sections; did you forget -T?
## 227 lines compiled, 0.1 sec
## 1 note(s) issued
## Order of problem = 4
## Coefficient matrix
## Solution after 4 iterations. Est. sumsquares 5.9124722517891191E-031
## 1.00000 0.00000 0.00000 0.00000
## Residuals
## -5.59E-016 -1.18E-016 2.15E-016 4.25E-016
## Sum of squared residuals = 5.5289991579958899E-031
```

Example output for least squares

```
fpc ../Pascal2021/dr24ls.pas
mv ../Pascal2021/dr24ls ../Pascal2021/dr24ls.run
../Pascal2021/dr24ls.run <../Pascal2021/dr24ls.in

## Free Pascal Compiler version 3.0.4+dfsg-23 [2019/11/25] for x86_64
## Copyright (c) 1993-2017 by Florian Klaempfl and others
## Target OS: Linux for x86-64
## Compiling ../Pascal2021/dr24ls.pas
## Linking ../Pascal2021/dr24ls
## /usr/bin/ld.bfd: warning: link.res contains output sections; did you forget -T?
## 248 lines compiled, 0.0 sec
## Number of rows in coefficient matrix = 5
## Number of columns in coefficient matrix = 3
## Coefficient matrix
## RHS vector and initial guess all 1s
## Normal equations -- coefficient matrix
## 5.00000 10.00000 15.00000
## 10.00000 20.00000 30.00000
## 15.00000 30.00000 45.00000
## Normal equations - RHS
## 5.00000 10.00000 15.00000
## Solution after 1 iterations. Est. normal eqn. sumsquares 0.0000000000000000E+000
```

```
##      0.64286      0.28571      -0.07143
## For original least squares problem -- Residuals
##      0.00E+000      0.00E+000      0.00E+000      0.00E+000      0.00E+000
## Sum of squared residuals = 0.0000000000000000E+000
```

Example output for inverse iteration for eigensolutions

We need extra code ?? Algorithm 24 solves linear equations, so no extra code is presented.

Algorithm 25 – Rayleigh quotient minimization

Fortran

Listing

```
C&&& A25
C TEST ALG 25 USING GRID (5 POINT)
C J.C. NASH JULY 1978, APRIL 1989
  LOGICAL IFR
  INTEGER N,M,NOUT,NIN,KPR,LIMIT,I
  EXTERNAL APR,BPR
C REAL EPS,PO,X(N),S(N),T(N),U(N),V(N),W(N),Y(N),RNORM
  COMMON /GSZ/ M,IFR,R(1600)
  REAL EPS,PO,RNORM,VNORM,RNV
  REAL S(1600),T(1600),U(1600),V(1600),W(1600),X(1600),Y(1600)
C I/O CHANNELS
  NIN=5
  NOUT=6
  1 READ(NIN,900)M,LIMIT
900 FORMAT(2I4)
  N=M*M
  WRITE(NOUT,950)M,N,LIMIT
950 FORMAT(' GRID ORDER',I4,' EQNS ORDER',I5,' LIMIT=',I4)
  IF(M.LE.0)STOP
  IFR=.FALSE.
C IBM MACHINE PRECISION
  EPS=16.0**(-5)
  KPR=LIMIT
  RNORM=1.0/SQRT(FLOAT(N))
  DO 10 I=1,N
    X(I)=RNORM
  10 CONTINUE
  CALL A25RQM(N,X,EPS,KPR,S,T,U,V,W,Y,PO,NOUT,APR,BPR)
  WRITE(NOUT,951)KPR,PO
951 FORMAT(' RETURNED AFTER',I4,' PRODUCTS WITH EV=',1PE16.8)
  DO 20 I=1,N
    R(I)=-PO*X(I)
  20 CONTINUE
  CALL APR(N,X,V)
  RNORM=0.0
  VNORM=0.0
  DO 30 I=1,N
    RNORM=RNORM+(V(I)+R(I))**2
    VNORM=VNORM+X(I)**2
  30 CONTINUE
  RNORM=SQRT(RNORM/N)
  VNORM=SQRT(VNORM/N)
  RNV=RNORM/VNORM
  WRITE(NOUT,952)RNORM,VNORM,RNV
952 FORMAT(' RESIDUAL NORM=',1PE16.8,' /','E16.8','=' ,E16.8)
  GOTO 1
  END
  SUBROUTINE BPR(N,X,V)
```



```

C J.C. NASH JULY 1978, APRIL 1989
C UNITM MATRIX * X INTO V
      INTEGER N,I
      REAL X(N),V(N)
      DO 100 I=1,N
        V(I)=X(I)
100 CONTINUE
      RETURN
      END
      SUBROUTINE APR(N,X,V)
C J.C. NASH JULY 1978, APRIL 1989
      LOGICAL IFR
      INTEGER N,I,J,M
      DOUBLE PRECISION S
      REAL X(N),V(N),D,Q
C M BY M GRID OF A GEORGE M=SQRT(N)
      COMMON /GSZ/ M,IFR,R(1600)
C COMMON /GSZ/M
      D=4.0
      Q=-1.0
      DO 100 I=1,N
C NOTE ALL INTEGERS
        J=I/M
        J=M*J
        S=D*X(I)
C SUBTRACT RHS FOR RESIDUAL
        IF(IFR)S=S-R(I)
C LEFT EDGE
        IF(I-J.EQ.1)GOTO 20
        S=S+Q*X(I-1)
C RIGHT EDGE
20 IF(I.GT.J)S=S+Q*X(I+1)
C TOP EDGE
        IF(I.GT.M)S=S+Q*X(I-M)
C BOTTOM EDGE
        IF(I.LE.N-M)S=S+Q*X(I+M)
        V(I)=S
100 CONTINUE
      RETURN
      END
      SUBROUTINE A25RQM(N,X,EPS,KPR,Y,Z,T,G,A,B,PO,IPR,APR,BPR)
C ALGORITHM 25 RAYLEIGH QUOTIENT MINIMIZATION BY CONJUGATE GRADIENTS
C J.C. NASH JULY 1978, FEBRUARY 1980, APRIL 1989
C N = ORDER OF PROBLEM
C X = INITIAL (APPROXIMATE?) EIGENVECTOR
C EPS = MACHINE PRECISION
C&&& for Microsoft test replace with actual names
C APR,BPR ARE NAMES OF SUBROUTINES WHICH FORM THE PRODUCTS
C V= A*X VIA CALL APR(N,X,V)
C T= B*X VIA CALL BPR(N,X,T)
C KPR = LIMIT ON THE NUMBER OF PRODUCTS (INPUT) (TAKES ROLE OF IPR)
C = PRODUCTS USED (OUTPUT)
C Y,Z,T,G,A,B RE WORKING VECTORS IN AT LEAST N ELEMENTS

```

```

C  PO  =  APPROXIMATE EIGENVALUE (OUTPUT)
C  IPR  =  PRINT CHANNEL   PRINTING IF IPR.GT.0
C  STEP 0
      INTEGER N,LP,IPR,ITN,I,LIM,COUNT
      REAL X(N),T(N),G(N),Y(N),Z(N),PN,A(N),B(N)
      REAL EPS,TOL,PO,PA,XAX,GBX,XAT,GBT,TAT,TBT,W,K,D,V,GG,BETA,TABT,U
C  IBM VALUE - APPROX. LARGEST NUMBER REPRESENTABLE.
C&&& PA=R1MACH(2)
      PA=1E+35
      LIM=KPR
      KPR=0
      TOL=N*N*EPS*EPS
C  STEP 1
10  KPR=KPR+1
      IF(KPR.GT.LIM)RETURN
C  FIND LIMIT IN ORIGINAL PROGRAMS
      CALL APR(N,X,A)
      CALL BPR(N,X,B)
C  STEP 2
      XAX=0.0
      GBX=0.0
      DO 25 I=1,N
          XAX=XAX+X(I)*A(I)
          GBX=GBX+X(I)*B(I)
25  CONTINUE
C  STEP 3
      IF(GBX.LT.TOL)STOP
C  STEP 4
      PO=XAX/GBX
      IF(PO.GE.PA)RETURN
      IF(IPR.GT.0)WRITE(IPR,963)KPR,PO
963  FORMAT( 1H ,I4, ' PRODUCTS, EST. EIGENVALUE=',1PE16.8)
C  STEP 5
      PA=PO
C  STEP 6
      GG=0.0
      DO 65 I=1,N
          G(I)=2.0*(A(I)-PO*B(I))/GBX
          GG=GG+G(I)**2
65  CONTINUE
C  STEP 7
      IF(IPR.GT.0)WRITE(IPR,964)GG
964  FORMAT(' GRADIENT NORM SQUARED=',1PE16.8)
      IF(GG.LT.TOL)RETURN
C  STEP 8
      DO 85 I=1,N
          T(I)=-G(I)
85  CONTINUE
C  STEP 9
      DO 240 ITN=1,N
C  STEP 10
          KPR=KPR+1
          IF(KPR.GT.LIM)RETURN

```

```

        CALL APR(N,T,Y)
        CALL BPR(N,T,Z)
C   STEP 11
        TAT=0.0
        TBT=0.0
        XAT=0.0
        XBT=0.0
        DO 115 I=1,N
            TAT=TAT+T(I)*Y(I)
            XAT=XAT+X(I)*Y(I)
            TBT=TBT+T(I)*Z(I)
            XBT=XBT+X(I)*Z(I)
115    CONTINUE
C   STEP 12
        U=TAT*XBT-XAT*TBT
        V=TAT*XBX-XAX*TBT
        W=XAT*XBX-XAX*XBT
        D=V*V-4.0*U*W
C   STEP 13
        IF(D.LT.0)STOP
C   MAY NOT WISH TO STOP
C   STEP 14
        D=SQRT(D)
        IF(V.GT.0.0)GOTO 145
        K=0.5*(D-V)/U
        GOTO 150
145    K=-2.0*W/(D+V)
150    COUNT=0
C   STEP 15
        XAX=0.0
        XBX=0.0
        DO 155 I=1,N
            A(I)=A(I)+K*Y(I)
            B(I)=B(I)+K*Z(I)
            W=X(I)
            X(I)=W+K*T(I)
            IF(W.EQ.X(I))COUNT=COUNT+1
            XAX=XAX+X(I)*A(I)
            XBX=XBX+X(I)*B(I)
155    CONTINUE
C   STEP 16
        IF(XBX.LT.TOL)STOP
        PN=XAX/XBX
C   STEP 17
        IF(COUNT.LT.N)GOTO 180
        IF(ITN.EQ.1)RETURN
        GOTO 10
C   STEP 18
180    IF(PN.LT.P0)GOTO 190
        IF(ITN.EQ.1)RETURN
        GOTO 10
C   STEP 19
190    P0=PN

```

```

        GG=0.0
        DO 195 I=1,N
          G(I)=2.0*(A(I)-PN*B(I))/XBX
          GG=GG+G(I)**2
195     CONTINUE
C  STEP 20
        IF(GG.LT.TOL)GOTO 10
C  STEP 21
        XBT=0.0
        DO 215 I=1,N
          XBT=XBT+X(I)*Z(I)
215     CONTINUE
C  STEP 22
        TABT=0.0
        BETA=0.0
        DO 225 I=1,N
          W=Y(I)-PN*Z(I)
          TABT=TABT+T(I)*W
          BETA=BETA+G(I)*(W-G(I)*XBT)
225     CONTINUE
C  STEP 23
        BETA=BETA/TABT
        DO 235 I=1,N
          T(I)=BETA*T(I)-G(I)
235     CONTINUE
C  STEP 24
240    CONTINUE
C  STEP 25
        GOTO 10
C  NO STEP 26 - HAVE USED RETURN INSTEAD
        END

```

Example output

?? explanation needed

```

gfortran ../fortran/a25.f
mv ./a.out ../fortran/a25.run
../fortran/a25.run < ../fortran/a25.in

```

```

## GRID ORDER 3 EQNS ORDER 9 LIMIT= 100
## 1 PRODUCTS, EST. EIGENVALUE= 1.33333337E+00
## GRADIENT NORM SQUARED= 1.77777791E+00
## 5 PRODUCTS, EST. EIGENVALUE= 1.17157304E+00
## GRADIENT NORM SQUARED= 5.56937471E-13
## RETURNED AFTER 5 PRODUCTS WITH EV= 1.17157304E+00
## RESIDUAL NORM= 1.31790827E-07 / 3.43119442E-01= 3.84096069E-07
## GRID ORDER 10 EQNS ORDER 100 LIMIT= 400
## 1 PRODUCTS, EST. EIGENVALUE= 4.00000244E-01
## GRADIENT NORM SQUARED= 1.28000033E+00
## 15 PRODUCTS, EST. EIGENVALUE= 1.62028164E-01
## GRADIENT NORM SQUARED= 7.54772778E-09
## RETURNED AFTER 15 PRODUCTS WITH EV= 1.62028164E-01
## RESIDUAL NORM= 5.59246428E-06 / 1.13465175E-01= 4.92879371E-05
## GRID ORDER -1 EQNS ORDER 1 LIMIT= 0

```

Pascal

Listing

```
procedure rqmcg( n : integer;
                A, B : rmatrix;
                var X : rvector;
                var ipr : integer;
                var rq : real);

var
  count, i, itn, itlimit : integer;
  avec, bvec, yvec, zvec, g, t : rvector;
  beta, d, eps, gg, pa, pn, step : real;
  ta, tabt, tat, tbt, tol, u, v, w, xat, xax, xbt, xbx : real;
  conv: boolean;

begin
  writeln('alg25.pas -- Rayleigh quotient minimisation');
  itlimit := ipr;
  conv := false;
  ipr := 0;
  eps := calceps;
  tol := n*n*eps*eps;

  pa := big;
  while (ipr<=itlimit) and (not conv) do
    begin
      matmul(n, A, X, avec);
      matmul(n, B, X, bvec);
      ipr := ipr+1;

      xax := 0.0; xbx := 0.0;
      for i := 1 to n do
        begin
          xax := xax+X[i]*avec[i]; xbx := xbx+X[i]*bvec[i];
        end;
      if xbx<=tol then halt;
      rq := xax/xbx;
      write(ipr, ' products -- ev approx. =',rq:18);
      if rq<pa then
        begin
          pa := rq;
          gg := 0.0;
          for i := 1 to n do
            begin
              g[i] := 2.0*(avec[i]-rq*bvec[i])/xbx; gg := gg+g[i]*g[i];
            end;
          writeln(' squared gradient norm =',gg:8);
          if gg>tol then

            begin

              for i := 1 to n do t[i] := -g[i];
```

```

itn := 0;
repeat
  itn := itn+1;
  matmul(n, A, t, yvec);
  matmul(n, B, t, zvec); ipr := ipr+1;
  tat := 0.0; tbt := 0.0; xat := 0.0; xbt := 0.0;
  for i := 1 to n do
    begin
      xat := xat+X[i]*yvec[i]; tat := tat+t[i]*yvec[i];
      xbt := xbt+X[i]*zvec[i]; tbt := tbt+t[i]*zvec[i];
    end;

  u := tat*xbt-xat*tbt; v := tat*xbx-xax*tbt;
  w := xat*xbx-xax*xbt; d := v*v-4.0*u*w;
  if d<0.0 then halt;

  d := sqrt(d);
  if v>0.0 then step := -2.0*w/(v+d) else step := 0.5*(d-v)/u;

  count := 0;
  xax := 0.0; xbx := 0.0;
  for i := 1 to n do
    begin
      avec[i] := avec[i]+step*yvec[i];
      bvec[i] := bvec[i]+step*zvec[i];
      w := X[i]; X[i] := w+step*t[i];
      if (reltest+w)=(reltest+X[i]) then count := count+1;
      xax := xax+X[i]*avec[i]; xbx := xbx+X[i]*bvec[i];
    end;
  if xbx<=tol then halt
    else pn := xax/xbx;
  if (count<n) and (pn<rq) then
    begin
      rq := pn; gg := 0.0;
      for i := 1 to n do
        begin
          g[i] := 2.0*(avec[i]-pn*bvec[i])/xbx; gg := gg+g[i]*g[i];
        end;
      if gg>tol then
        begin
          xbt := 0.0; for i := 1 to n do xbt := xbt+X[i]*zvec[i];

          tabt := 0.0; beta := 0.0;
          for i := 1 to n do
            begin
              w := yvec[i]-pn*zvec[i]; tabt := tabt+t[i]*w;
              beta := beta+g[i]*(w-g[i]*xbt);
            end;
          beta := beta/tabt;

          for i := 1 to n do t[i] := beta*t[i]-g[i];
        end;
    end
end

```

```

        else
        begin
            if itn=1 then conv := true;
            itn := n+1;
        end;
        until (itn>=n) or (count=n) or (gg<=tol) or conv;
    end
    else conv := true;
end
else
begin
    conv := true;
end;
ta := 0.0;
for i := 1 to n do ta := ta+sqr(X[i]); ta := 1.0/sqrt(ta);
for i := 1 to n do X[i] := ta*X[i];
end;
if ipr>itlimit then ipr := -ipr;
writeln;
end;
end;

```

Example output

We use the same example as for Algorithm 15, with A the unit matrix and B the Frank matrix, here of order 5.

Note that we could modify the program to work with $-A$ to get the negative of the largest eigenvalue. Various shifting strategies might be used to get other solutions, but they are rather inconvenient and not recommended.

```

fpc ../Pascal2021/dr25.pas
# copy to run file
mv ../Pascal2021/dr25 ../Pascal2021/dr25.run
../Pascal2021/dr25.run <../Pascal2021/dr25p.in >../Pascal2021/dr25p.out

```

```

## Free Pascal Compiler version 3.0.4+dfsg-23 [2019/11/25] for x86_64
## Copyright (c) 1993-2017 by Florian Klaempfl and others
## Target OS: Linux for x86-64
## Compiling ../Pascal2021/dr25.pas
## dr25.pas(184,3) Note: Local variable "avec" not used
## dr25.pas(186,10) Note: Local variable "s" is assigned but never used
## Linking ../Pascal2021/dr25
## /usr/bin/ld.bfd: warning: link.res contains output sections; did you forget -T?
## 346 lines compiled, 0.1 sec
## 2 note(s) issued

```

```

Order of problem =5
Matrix A (unit)
Metric matrix B (frank)
Initial eigenvector approximation is all 1s
alg25.pas -- Rayleigh quotient minimisation
1 products -- ev approx. = 9.0909090909E-002 squared gradient norm = 7.2E-004
7 products -- ev approx. = 8.1014052771E-002 squared gradient norm = 3.2E-019
10 products -- ev approx. = 8.1014052771E-002 squared gradient norm = 1.6E-025

```

```
Solution after 11 products. Est. eigenvalue = 8.1014052771005207E-002
0.1698911 0.3260187 0.4557341 0.5485287 0.5968848
Residuals
5.61E-015 4.59E-014 7.77E-015 -1.24E-014 -2.09E-014
Sum of squared residuals = 2.7845218395467097E-027
```

Cleanup of working files

```
## /m21z/m21store/versioned/Nash-Compact-Numerical-Methods/fortran
## rm: cannot remove '*.o': No such file or directory
## rm: cannot remove '*.out': No such file or directory
## /m21z/m21store/versioned/Nash-Compact-Numerical-Methods/Pascal2021
## /m21z/m21store/versioned/Nash-Compact-Numerical-Methods/BASIC
## rm: cannot remove '*.out': No such file or directory
```

References

Nash, John C. 1979. *Compact Numerical Methods for Computers : Linear Algebra and Function Minimisation*. Book. Hilger: Bristol.