SYSTEMS RESEARCH INSTITUTE
POLISH ACADEMY OF SCIENCES

INTERNATIONAL INSTITUTE FOR APPLIED SYSTEMS ANALYSIS

CONTRACTED STUDY AGREEMENT REG / POL / 1

"CONCEPTS AND TOOLS FOR STRATEGIC REGIONAL SOCIO-ECONOMIC CHANGE POLICY"

STUDY REPORT

PART 3

APPENDIX: SOFTWARE AVAILABLE

COORDINATOR, IIASA: A. KOCHETKOV
COORDINATOR, SRI PAS: A. STRASZAK

ZTS / ZPZC / ZTSW 1-36/85

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Consisting of 3 Parts

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II. PROGRAMS FOR THE ANALYSIS OF STRUCTURAL MODELS

by Tomasz Romanowicz

In complex problems which appear in many disciplines such as economics, sociology, information science, urban modelling and cybernetics the structural rather than the algebraic aspects are considered. With the growing recognition that complex problems cut across disciplines, a need arises of enabling people from different disciplines to share a common set of symbols, related to easily interpretable intellectual operations. The most important purpose is to make it possible to apply common analytic methodology to the structures that are generated as a step toward achieving better capability to deal with complex problems, Ganin and Solomatin (1984).

The term "structural modelling" is used to describe modelling techniques which are concerned with the relationships between the various elements of the problem.

In this communication problems which are modelled via transitive, binary relations are considered. Preliminary steps of structural modelling such as identifying of problem elements and relations, and construction of the model will be omitted here. Special attention will be devoted to methods meant for the analysis of structural models.

Problem elements in models considered are represented by nodes, relations among them by directed edges. For example: when the relation "depends on" is taken into account, directed edge from node i-th to node j-th means that j-th problem element depends on i-th problem element. These interrelations can also be described via binary nonsymmetric square matrix, called adjacency matrix, which is associated with the digraph. Much is known about properties of digraphs, see e.g. Harary, Norman and Cartwright (1965). From the point of view of the analysis of structural models however, the most important ones are: reachability and strong connectivity.

A reachability matrix is a square, binary, nonsymmetric (in general case) matrix $R^{[n \times n]}$. Such a matrix R satisfies the following conditions:

$$R^2 = R$$

$$R + I = R$$

Reachability matrix R may be obtained from an adjacency matrix A by raising matrix A+I to some power $k < n$. A more efficient methods for obtaining reachability matrix R have been proposed by Kevorkian, Kevorkian (1975), and by others, e.g. Dulmage and Mendelsohn (1963) or Warfield (1976).

There are many algorithms for partitioning of digraphs into a number of strongly connected components. Several partitioning algorithms here been formulated between 1962 and 1972, Dulmage and Mendelsohn (1963), Norman (1965), Steward (1962), Tarjan (1972). It is now accepted that the most efficient one is that of Tarjan, based on the depth-first search.

Two computer programs for the analysis of structural models have been developed.

Program REA creates reachability matrix R from adjacency matrix A by boolean addition of rows. This program operates according to the algorithm of Kevorkian.

Program STRONG determines the strongly connected components of a digraph according to the algorithm of Tarjan.

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APPENDIX. PROGRAM PRINTOUTS

```
LEVEL  21                    MAIN                DATE = 83264          02/
      COMMON /B3/A2(290,290),A1(290,290),IKS(300)
      COMMON/B4/NAM(290,2)
      COMMON/B5/Y,YES
      COMMON/B6/ RO(290,2)
      INTEGER RO,RON(2)
      INTEGER*2 A2,A1,IKS,Y(300),YES(300)
      INTEGER COL(3),ENDA(2),NAM
      INTEGER*2 RAI(300),RAJ(300)
      DATA ENDA(1)/'ENDA'/,ENDA(2)/'TA  '/
      DATA ILX/'XXXX'/
      DATA IUL/' UL '/
      MPSX=0
      MPSX=1
   20 L=-1
    1 READ(7,101)COL,RON
      IF(COL(1).EQ.ILL) GOTO 1
  101 FORMAT(3A4,2X,2A4)
      L=L+1
      IF(L.EQ.0)GOTO 6
      NAM(L,1)=COL(2)
      NAM(L,2)=COL(3)
      RO(L,1)=RON(1)
      RO(L,2)=RON(2)
    6 CONTINUE
      CALL COMP(2,COL,1,ENDA,1,LT)
      IF(LT.EQ.1)GOTO 1
      N=L-1
      WRITE(6,2)N
    2 FORMAT('  N= ',I3)
      IF(MPSX.EQ.1)GOTO 80
      READ(7,100)KANT
      IF(KANT.EQ.ILX) GOTO 3
  100 FORMAT(A4)
  292 FORMAT(' RO ',2A4)
   80 CALL BAZA(N)
      GOTO 9
    3 CONTINUE
      DO 5 I=1,N
      DO 5 J=1,N
      A2(I,J)=0
    5 CONTINUE
      LL=0
    7 READ(7,110)KANT,I,J
      IF(KANT.EQ.ILX) GOTO 109
  110 FORMAT(A4,2I4)
      A2(I,J)=1
      LL=LL+1
      GOTO 7
  109 CONTINUE
    9 CONTINUE
      DO 300 I=1,N
      RAI(I)=0
  300 RAJ(I)=0
      I=0
      LTL=0
  305 I=I+1
      IF(I.GT.N) GOTO 400
      LLX=0
```

```
FORTRAN IV G LEVEL  21                          MAIN

0059                DO 306 K=1,N
0060                IF(A2(I,K).EQ.0) GOTO 306
0061                LLX=LLX+1
0062                MI=I
0063                MJ=K
0064              306 CONTINUE
0065                IF(LLX.NE.1) GOTO 305
0066                RAI(MI)=1
0067                RAJ(MJ)=1
0068                LTL=LTL+1
0069                GOTO 305
0070              400 NO=N
0071                N=N-LTL
                  C COMPRESS
0072                I1=0
0073                DO 410 I=1,NO
0074                IF(RAI(I).NE.0) GOTO 410
0075                I1=I1+1
0076                J1=0
0077                DO 410 J=1,NO
0078                IF(RAJ(J).NE.0) GOTO 410
0079                J1=J1+1
0080                 A1(I1,J1)=A2(I,J)
0081              410 CONTINUE
0082                DO 411 I=1,N
0083                DO 411 J=1,N
0084              411 A2(I,J)=A1(I,J)
0085                DO 444 I=1,N
0086                DO 444 J=1,N
0087                IF(A2(I,J).EQ.0) GOTO 444
0088              444 CONTINUE
0089              445 FORMAT('      I=',I3,'    J=',I3)
0090                CALL PART(N)
                  C ZAPIS X,Y,YES
0091                DO 12 I=1,30
0092                K=(I-1)*10+1
0093                L=I*10
0094                WRITE(7,116)(IKS(J),J=K,L)
0095                WRITE(7,117)(Y(J),J=K,L)
0096                WRITE(7,118)(YES(J),J=K,L)
0097               12 CONTINUE
0098              116 FORMAT('XOUT',10I3)
0099              117 FORMAT('Y    ',10I3)
0100              118 FORMAT('YES ',10I3)
0101             1000 CONTINUE
0102                STOP
0103                END
```

```
FORTRAN IV G LEVEL  21                  BAZA                    DATE = 83264

0001                SUBROUTINE BAZA(N)
0002                COMMON/B3/A2(290,290)
0003                COMMON/B6/RO(290,2)
0004                INTEGER RO
0005                INTEGER ENDA(2),KOLB(2),KOL(3),IRO(2),IRO1(2)
0006                INTEGER*2 A2,GUL(1500,2)
0007                INTEGER IRO'(2),IRO1(2)
0008                REAL V(1500)
0009                DATA IW2/'    '/.
0010                DATA ILX/'XXXX'/
0011                DATA ENDA(1)/'ENDA'/,ENDA(2)/'TA  '/
0012                DATA IUL/' UL '/
0013                REWIND 7
0014                LL=0
0015                DO 30 I=1,N
0016                DO 30 J=1,N
0017             30 A2(I,J)=0
0018                LB=0
0019                LX=0
0020                READ(7,102)IEN,KOLB,IROB,VALU
0021            102 FORMAT(A4,2A4,2X,2A4,2X,F12.5)
0022             10 READ(7,102)IEN,KOLB,IROB,VALU
0023                IF(IEN.EQ.IUL) GOTO 10
0024                LB=LB+1
0025                IF(LB.GT.N) GOTO 999
0026             20 READ(8,100)KOL,IRO,VAL,IRO1,WAR
0027            100 FORMAT(3A4,2X,2A4,2X,F12.5,3X,2A4,2X,F12.5)
0028                CALL COMP(2,ENDA,1,KOL,1,LT)
0029                IF(LT.EQ.0)READ(7,103)IRO
0030            103 FORMAT(14X,2A4)
0031                IF(LT.EQ.0) GOTO 999
0032                CALL COMP(2,KOLB,1,KOL,2,LT)
0033                IF(LT.EQ.0) GOTO 25
0034             21 IF(LX.EQ.0)GOTO 20
0035                LX=0
0036                BACKSPACE 8
0037                GOTO 10
0038             25 LX=1
0039                LPAX=0
0040                LPAY=0
0041                DO 27 I=1,N
0042                IF(IRO(1).EQ.RO(I,1).AND.IRO(2).EQ.RO(I,2))LPAX=I
0043                IF(IRO1(1).EQ.RO(I,1).AND.IRO1(2).EQ.RO(I,2))LPAY=I
0044             27 CONTINUE
0045                IF(LPAX.EQ.0) GOTO 28
0046                A2(LPAX,LB)=1
0047                LL=LL+1
0048                GUL(LL,1)=LPAX
0049                GUL(LL,2)=LB
0050                V(LL)=VAL
0051             28 IF(LPAY.EQ.0)GOTO 29
0052                A2(LPAY,LB)=1
0053                LL=LL+1
0054                GUL(LL,1)=LPAY
0055                GUL(LL,2)=LB
0056                V(LL)=WAR
0057             29 CONTINUE
0058                GOTO 20
```

= 83

```
FORTRAN IV G LEVEL  21                    BAZA                    DATE = 8326
0059          999 CONTINUE
0060          107 FORMAT(' X= ',16F7.3)
0061              WRITE(7,112)ILX
0062              DO 75 LP=1,LL
0063              I=GUL(LP,1)
0064              J=GUL(LP,2)
0065              WRITE(7,111)I,J,V(LP)
0066          111 FORMAT(4X,2I4,F20.6)
0067           75 CONTINUE
0068              WRITE(7,112)ILX
0069          112 FORMAT(A4,23X)
0070              WRITE(6,700)LC
0071          700 FORMAT('  LICZBA NIEZER.ELEMENTOW MAC.SAZ.=',I6)
0072              RETURN
0073              END
```

```
      SUBROUTINE PART(N)
      COMMON/B3/A2,A1,X
      COMMON /B4/NAM(290,2)
      COMMON/B5/Y,YES
      INTEGER*2 A1(290,290),A2(290,290),X(300),Y(300),Z(300),YY(300
      INTEGER*2 ZZ(300),YES(300)
      DO 4000 I=1,300
      X(I)=0
      YES(I)=0
 4000 Y(I)=0
      IY=0
      CALL OUTSET(N)
   40 CONTINUE
C  TWORZENIE MACIERZY OSIAGALNOSCI
      DO 42 K=1,N
   42 A1(K,K)=1
      DO 43 J=1,N
      DO 43 I=1,N
      IF(A1(I,J).EQ.0) GOTO 43
      IF(I.EQ.J) GOTO 43
      DO 44 K=1,N
      IF(A1(I,K).NE.0) GOTO 44
      IF(A1(J,K).EQ.0) GOTO 44
      A1(I,K)=1
   44 CONTINUE
   43 CONTINUE
      DO 45 I=1,N
      Z(I)=0
      Y(I)=0
      YES(I)=0
      DO 45 J=1,N
      IF(A1(I,J).NE.0)A1(I,J)=1
   45 CONTINUE
C  PARTITIONING
      LPO=0
      DO 39 I=1,N
      KC=X(I)
      ZZ(KC)=I
   39 YY(I)=X(I)
   41 CONTINUE
      LPO1=LPO+1
      DO 48 I=LPO1,N
      DO 47 J=LPO1,N
      IF(A1(I,J).EQ.0) GOTO 47
      IF(A1(J,I).NE.0) GOTO 47
      GOTO 48
   47 CONTINUE
      LO=LPO
      IY=IY+1
      LAND=0
      DO 49 K=LPO1,N
      IF(A1(I,K).EQ.0) GOTO 49
      LO=LO+1
      Y(LO)=YY(K)
      LHAD=YY(K)
      Z(LHAD)=1
      LAND=LAND+1
   49 CONTINUE
```

```
FORTRAN IV G LEVEL  21                    PART                    DAT

0057                  YES(IY)=LAND
0058                  LPQ=LQ
0059                  GOTO 55
0060               48 CONTINUE
0061               55 LZ=0
0062                  DO 52 I=1,N
0063                  KUX=YY(I)
0064                  IF(Z(KUX).NE.0) GOTO 52
0065                  LZ=1
0066                  LQ=LQ+1
0067                  Y(LQ)=YY(I)
0068               52 CONTINUE
0069                  DO 53 I=1,N
0070                  KC=YY(I)
0071               53 ZZ(KC)=I
                C PERMUTACJA RZEDOW I KOLUMN MACIERZY
0072                  DO 56 I=LPQ1,N
0073                  MI=Y(I)
0074                  KL=ZZ(MI)
0075                  DO 56 J=1,N
0076                  MJ=Y(J)
0077                  KK=ZZ(MJ)
0078               56 A2(I,J)=A1(KL,KK)
0079                  DO 57 I=1,N
0080                  DO 57 J=1,N
0081               57 A1(I,J)=A2(I,J)
0082                  IF(LZ.EQ.0) GOTO 99
0083                  DO 58 I=1,N
0084               58 YY(I)=Y(I)
0085                  GOTO 41
0086               99 CONTINUE
0087                  DO 59 I=1,N
0088                  KC=X(I)
0089               59 ZZ(KC)=I
0090                  DO 60 I=1,N
0091                  MI=Y(I)
0092                  KL=ZZ(MI)
0093                  DO 60 J=1,N
0094                  KK=Y(J)
0095               60 CONTINUE
0096              606 CONTINUE
0097                  RETURN
0098                  END
```

```
FRAN IV G LEVEL 21          , OUTSET          DATE = 83264

      SUBROUTINE OUTSET(N)
      COMMON/B3/A,R,X
      INTEGER*2 R(290,290),COL(300),ROW(300),X(300),A(290,290)
      INTEGER*2 KOL(300),RO(300)
      DO 3 I=1,N
      RO(I)=0
    3 KOL(I)=0
      DO 609 I=1,J
      IF(A(I,I).EQ.0) GOTO 609
      A(I,I)=-1
      KOL(I)=1
      RO(I)=1
  609 CONTINUE
    7 CONTINUE
      DO 1 I =1,N
      ROW(I)=0
    1 COL(I)=0
      DO 2 J =1,N
      IF(KOL(J).NE.0) GOTO 2
      GOTO 4
    2 CONTINUE
    4 ICOL=J
    8 L=0
      DO 5 I=1,N
      IF(A(I,ICOL).NE.1.OR.ROW(I).NE.0) GOTO 5
      L=I
      IF(RO(I).NE.0) GOTO 5
       GOTO 10
    5 CONTINUE
      IF(L.EQ.0) GOTO 6
      I=L
      GOTO 10
    6 COL(ICOL)=1
   35 CONTINUE
      DO 36 J=1,N
      IF(COL(J).EQ.0) GOTO 36
      DO 37 I =1,N
      IF(A(I,J).NE.1.OR.ROW(I).NE.0) GOTO 37
  373 FORMAT(' -------------------------')
      GOTO 40
   37 CONTINUE
   36 CONTINUE
      WRITE(6,105)
  105 FORMAT('  FEWER VARIABLES THAN EQUATIONS - SORRY')
      DO 450 I=1,30
      K=(I-1)*10+1
      L=I*10
      WRITE(6,455)(COL(J),J=K,L)
  450 WRITE(6,456)(ROW(J),J=K,L)
      PAUSE ' PROSZE PRZERWAC LICZENIE'
  455 FORMAT(' COL ',10I4)
  456 FORMAT(' ROW ',10I4)
      GOTO 99
   40 DO 42 K=1,N
      IF(A(K,J).NE.-1) GOTO 42
      A(K,J)=1
      KOL(J)=0
       RO(K)=0
```

```
FORTRAN IV G LEVEL  21                    OUTSET                    DATE = 832

0059                    GOTO 43
0060                42  CONTINUE
0061                43  A(I,J)=-1
0062                    ICOL=J
0063                    KOL(ICOL)=1
0064                    RO(I)=1
0065                47  ROW(I)=1
0066                    IRO=I
0067                    GOTO 12
0068                10  CONTINUE
0069                    A(I,ICOL)=-1
0070                    KOL(ICOL)=1
0071                    RO(I)=1
0072                    COL(ICOL)=1
0073                    ROW(I)=1
0074                    IRO=I
0075                12  CONTINUE
0076                    DO 14 J=1,N
0077                    IF(A(IRO,J).EQ.-1.AND.J.NE.ICOL) GOTO 16
0078                14  CONTINUE
0079                    GOTO 20
0080                16  A(IRO,J)=1
0081                    KOL(J)=0
0082                    RO(IRO)=0
0083                    ICOL=J
0084                    GOTO 8
0085                20  CONTINUE
0086                    DO 21 I=1,N
0087                    IF(KOL(I).EQ.0) GOTO 7
0088                21  CONTINUE
0089                    DO 25 I=1,N
0090                    DO 25 J=1,N
0091                    IF(A(I,J).NE.-1) GOTO 25
0092                    X(I)=J
0093                    A(I,J)=0
0094                25  CONTINUE
0095                    DO 470 I2=1,30
0096                    K=(I2-1)*10+1
0097                    L=I2*10
0098               470  WRITE(6,90)(X(J),J=K,L)
0099                90  FORMAT(' XOUTSET  ',20I4)
0100                    DO 26 I=1,N
0101                    DO 26 J=1,N
0102                    KK=X(J)
0103                26  R(I,J)=A(I,KK)
0104                99  RETURN
0105                    END
```

STUDY REPORT

PART 1: BACKGROUND METHODOLOGIES

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