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ABSTRACT

A computer-assisted course was designed to provide students with an understanding of modeling and simulation techniques in quantitiative ecology. It deals with continuous systems and has two segments. One develops mathematical and computer tools, beginning with abstract systems and their relation to physical systems. Modeling principles are next presented, with emphasis on compartment-flow models, followed by discussion of simulation. The FORTRAN IV language and the IBM 360 Continous System Model Program are then described in detail, and equilibria and stability are treated. In part two, students were burdened by the math required and the amount of time spent on programing languages. The first difficulty was overcome by the introduction of compartment-flow models, the second by the development of an easy-to-use computer program. This Compartment Flow Model Simulation Program (COFLO) is an input language which takes a description of a compartment-flow model and simulates the behavior of the modelled system, converting the model system into a FORTRAN program for compilation and execution. COFLO has been implemented on the UNIVAC 1106 computer at the Southeast Regional Data Center of Florida Atlantic and Florida International Universities. (LB)

COFLO: A COMPUTER AID FOR TEACHING ECOLOGICAL SIMULATION

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In this paper the author describes his experiences teaching a course in modeling and simulation methods in ecology at Florida Atlantic University during the spring quarter of the 1971-1972 academic year. He also describes a new simulation language designed specifically for student use in ecological simulation which was developed as an outgrowth of the course.

The Course

The course was somewhat unusual in that it brought together a group of students with diverse backgrounds--mathematics, computer science, or biology--and attempted to give them an understanding of those modeling and simulation techniques which are most relevant to quantitative ecology. The need for such a course is obvious on several grounds. (a) Systems ecology is an emergent discipline whose full development will require contributions from mathematicians and computer scientists as well as ecologists. (b) Rapid development of systems ecology must be encouraged to facilitate long range planning to protect the environment. (c) The problems of systems ecology are sufficiently different from those encountered in modeling and simulation in business and engineering that a separate course is required for modeling and simulation methods in ecology.

The course was concerned primarily with modeling continuous systems with only slight attention to discrete and probabilistic systems. It was divided into two segments. The first dealt primarily with the development of the mathematical and computer tools required for continuous system simulation, and the second segment consisted of an examination of several papers in systems ecology to permit observation of applications of the tools which had been developed. The principal source of material for the first segment of the course was part I of Systems Analysis and Simulation in Ecology, volume I, edited by Bernard C. Patten [3]. Papers for the second segment of the course were selected primarily from the remainder of Patten and from Heinmets [1].

The first segment essentially followed the form of part I of Patten [3]. The notion of an abstract system was introduced, and the features of such systems and their relation to physical systems was discussed. The principles of modeling were discussed next with emphasis on compartment-flow models. This having been done, the notion of simulation was introduced. First, analog computation was discussed, and then digital computation. Since the class did not have access to an analog computer, the IBM 1130 Continuous System Modeling Program, which provides a digital computer simulation of an analog computer, based on input containing a description of the analog computer circuit, was used. The FORTRAN IV programming language was briefly described, and then the IBM System/360 Continuous System Modeling Program was presented in detail. The first segment of the course concluded with a brief discussion of equilibria and stability.

In the second segment each student was given the task of providing a brief oral presentation of a published paper in systems ecology for the rest of the class.

The most striking impression of the material of the course was that the non-mathematicians were heavily burdened by the mathematics--particularly differential equations--and that an extremely large amount of time was spent on programming languages at the expense of other material. Further analysis of the material in the course revealed that the use of compartment-flow models, which are quite natural for many ecological systems, could permit a reasonably full development of simulation concepts without the explicit introduction of differential equations, provided that a mechanism was available for the direct simulation of a model expressed in compartment-flow form. Furthermore, the development of an easy to use computer program to handle this problem would substantially reduce the amount of time spent on programming languages.

COFLO

The Compartment-Flow Model Simulation Program (COFLO) was designed to meet the requirement set forth above, while allowing for the greatest possible variety of applications. COFLO is an input language which takes as its input a description of a compartment-flow model and simulates the behavior of the modeled system for a given time period, printing the results at prescribed time intervals. It functions by converting the model description into a FORTRAN program which it then causes to be compiled and executed.

The program requires that the model have the following form. The non-conservative compartment is labeled 0, and each of the other compartments is labeled with some integer between 1 and 99. The compartment labeled i is associated with the variable Xi. The independent variable may be referred to either as T or TIME.

There are five control statements: *NAMES, *FLOWS, *INITIALIZE, *TIMER, and *RUN. The control statements appear in the input in the order indicated above. The first four are each followed by model description statements.

*NAMES is used to indicate that the following statements describe names with a form other than Xi which are to be used for the variables associated with certain compartments. The statements have the form

```
Xi = name
```

or

```
T = name.
```

The *NAMES section is optional and is only present if non-standard names are used.

*FLOWS precedes the actual description of the model in terms of the individual flow equations. The equation for the flow from compartment i to compartment j is entered in the form

```
F(i,j) = expression.
```

The expression is written using the usual FORTRAN conventions.

*INITIALIZE indicates that the following statements provide initial values for compartment variables or values for computational constants. These statements have the form

```
variable = expression.
```

Any variable which is not otherwise initialized is initialized to zero, and if all variables are to be initialized to zero the section may be omitted.

The *TIMER section is used to set START and STOP values for the timer, and DELTA which determines the interval at which results are printed. The values are entered in the form

```
name = value,
```

and if value is zero the entry may be omitted.

The *RUN card indicates the end of the model description and starts the simulation run.

COFLO has been implemented on the UNIVAC 1106 computer at the Southeast Regional Data Center of Florida Atlantic and Florida International Universities. It may be used either from cards in the batch mode or from the interactive terminals in demand mode. In the later case the user receives immediate diagnostics if errors are made in entering the model and receives the results of the simulation without the delays inherent in batch utilization.

The operation of COFLO is best illustrated by example. In Appendix I we have a COFLO run for a partially forced non-linear version of Odum's food chain model for Silver Springs, Florida [2],[3]. The compartments are numbered as follows:

1 - producers (plants)

2 - herbivores

3 - carnivore

4 - top carnivores

5 - decomposers

The parameters Tij are feeding rates, Ri are respiration rates, Mi are natural mortality rates, and Li are losses downstream.

The program may also be used for models which do not fit the compartment-flow model form as illustrated by the example in Appendix II which uses the Lotka-Volterra equations.

Several improvements are planned for COFLO in the near future. In particular a ploting capability is planned and a library of special functions will be added. Copies of the COFLO code and users guide will be made available in the near future.

REFERENCES

1. F. Heinmets (Ed.), Concepts and Models of Biomathematics. New York: Marcel Dekker, 1969.

2. H. T. Odum, Trophic structure and productivity of Silver Springs, Florida Ecological Monographs, 1957, 55-112.

3. B. C. Patten (Ed), Systems Analysis and Simulation in Ecology vol. I New York: Academic Press, 1971.

APPENDIX I

```
*XOT *COFLO      * SILVER SPRINGS MODEL

          COMPARTMENT - FLOW MODEL SIMULATION PROGRAM

*FLOWS
F(0,1)=F1
F(0,2)=F2
F(1,2)=T12*X1*X2
F(2,3)=T23*X2*X3
F(3,4)=T34*X3*X4
F(1,5)=M1*X1
F(2,5)=M2*X2
F(3,5)=M3*X3
F(4,5)=M4*X4
F(1,0)=LR1*X1
F(2,0)=R2*X2
F(3,0)=R3*X3
F(4,0)=R4*X4
F(5,0)=R5*X5
*INITIALIZE
X1=3421.26
X2=213.44
X3=62.06
X4=9.87
X5=24.38
F1=0.
F2=486.
T12=2074./(X1*X2)
T23=392./(X2*X3)
T34=21./(X3*X4)
M1=3455./X1
M2=1005./X2
M3=46./X3
M4=6./X4
R1=11974./X1
L1=2498./X1
RL1=R1+L1
R2=1891./X2
R3=317./X3
R4=13./X4
R5=4599./X5
*TIMER
STOP=10.
DELTA=0.5
*RUN
                         TABLE OF INCLUDED FLOWS
       0  1  2  3  4  5
     0    X  X
     1 X     X        X
     2 X        X     X
     3 X           X  X
     4 X              X
     5 X
                         END OF PREPARATION PHASE
```

```
READY

 T=    .00 X(I)=   .3421+04   .2134+03   .6206+02   .3870+01   .2438+02
 T=    .50 X(I)=   .1577+04   .7233+02   .2038+02   .72[illegible]1+01   .1059+02
 T=   1.00 X(I)=   .8520+03   .4735+02   .2242+01   .2909+01   .4446+01
 T=   1.50 X(I)=   .4720+03   .4072+02   .2173+00   .1013+01   .3257+01
 T=   2.00 X(I)=   .2638+03   .3783+02   .2031-01   .3477+00   .1860+01
 T=   2.50 X(I)=   .1480+03   .3640+02   .1853-02   .1192+00   .1673+01
 T=   3.00 X(I)=   .8323+02   .3565+02   .1669-03   .4083-01   .1779+00
 T=   3.50 X(I)=   .4095+02   .3525+02   .1493-04   .1399-01   .1164+01
 T=   4.00 X(I)=   .2039+02   .3502+02   .1330-05   .4705-02   .5923+00
 T=   4.50 X(I)=   .1497+02   .3490+02   .1182-06   .1643-02   .1010+01
 T=   5.00 X(I)=   .8378+01   .3483+02   .1049-07   .5629-03   .9919+00
 T=   5.50 X(I)=   .4722+01   .3479+02   .9300-09   .1929-03   .9718+00
 T=   6.00 X(I)=   .2661+01   .3477+02   .8244-10   .6610-04   .9593+00
 T=   6.50 X(I)=   .1500+01   .3476+02   .7326-11   .2265-04   .9535+00
 T=   7.00 X(I)=   .8455+00   .3475+02   .6474-12   .7761-05   .9191+00
 T=   7.50 X(I)=   .4766+00   .3474+02   .5736-13   .2659-05   .6187+00
 T=   8.00 X(I)=   .2686+00   .3474+02   .5082-14   .9112-06   .9340+00
 T=   8.50 X(I)=   .1514+00   .3474+02   .4503-15   .3122-06   .9454+00
 T=   9.00 X(I)=   .8535-01   .3474+02   .3989-16   .1070-06   .9455+00
 T=   9.50 X(I)=   .4811-01   .3474+02   .3535-17   .3666-07   .9451+00
 T=  10.00 X(I)=   .2712-01   .3474+02   .3131-18   .1256-07   .9451+00

                  END OF SIMULATION
```

APPENDIX II

```
@XQT .COFLO          . LOTKA - VOLTERRA EQUATIONS

          COMPARTMENT - FLOW MODEL SIMULATION PROGRAM

*NAMES
X1=POP1
X2=POP2
*FLOWS
F(0,1)=R1*POP1*(1.-POP1/K1-ALPHA*POP2/K2)
F(0,2)=R2*POP2*(1.-POP2/K2-BETA*POP1/K1)
*INITIALIZE
POP1=10.
POP2=90.
K1=50.
K2=120.
ALPHA=-2.
BETA=.6
R1=.5
R2=.6
*TIMER
STOP=15.
DELTA=1.
*RUN
                         TABLE OF INCLUDED FLOWS
      0  1  2
   0     X  X
   1
   2
                         END OF PREPARATION PHASE
READY

T=    .00 X(I)=   .1000+02   .9000+02

T=   1.00 X(I)=   .3263+02   .8404+02

T=   2.00 X(I)=   .6933+02   .6712+02

T=   3.00 X(I)=   .8958+02   .4818+02

T=   4.00 X(I)=   .9007+02   .3563+02

T=   5.00 X(I)=   .8494+02   .2855+02

T=   6.00 X(I)=   .7999+02   .2455+02

T=   7.00 X(I)=   .7626+02   .2218+02

T=   8.00 X(I)=   .7365+02   .2073+02

T=   9.00 X(I)=   .7180+02   .1982+02

T=  10.00 X(I)=   .7065+02   .1924+02

T=  11.00 X(I)=   .6982+02   .1886+02

T=  12.00 X(I)=   .6927+02   .1862+02

T=  13.00 X(I)=   .6890+02   .1846+02

T=  14.00 X(I)=   .6865+02   .1836+02

T=  15.00 X(I)=   .6849+02   .1829+02

                       END OF SIMULATION
```