A DYNAMIC MODELLING SYSTEM WITH CHINESE CHARACTER DYNAMO
AS THE KERNEL
--SOFRWARE TOOL FOR SYSTEM DYNAMICS

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ABSTRACT

This paper gives a brief account of the technical details of Chinese Character DYNAMO compiler, which follows the current DYNAMO grammar. The compiler is in the form of modules, which lays good foundation for further expansion. Taking DYNAMO as a kernel, reinforcing its internal function and statistical analysis of results, joining other programming languages, methods and modeles, adding verification of model and using advanced ideas of other branches of system science, we can build a Modelling System with Chinese Character DYNAMO as the kernel. This paper gives the logic design of the Modelling System .

THE MOTIVATIONS OF THE EXTENDED DYNAMO

As a useful tool of system dynamics, DYNAMO is a very succesful simulation language. It can easily represent complex systems which are of higher order, nonlinear and have many feedback loops. The syntax is simple and clear. This kind of language is very expressive and very easy to use. When the cause-effect relationships of the system are carefully analyzed, it is easy to transform them into a DYNAMO model. With the micro structure as building block and delineating the causal links of the neighbouring elements, one can get the picture of the macro nature of the systems. Moreover, The original data it requires need not to be very accurate and not to be many . Henceforth, it can build the system model by means of gradual refinement. As it has been known to all, the DYNAMO model has been very widely used in various fields.

However, in practical use, users have found its defects. Some of these defects are: its macro functions are not enough: table function can only delineate functions with equal distance of argument, but in actual usage, we need table functions with unequal distance of argument and table functions with two or more arguments. Furthermore, its time subscript are defined very rigidly. It has a syntax table stipulating the time subscript of all the variables in an equation. Actually all these time subscript can only help the user correctly use the concept of time. It does not offer any useful information to the computer.
Therefore, all these time subscripts can be omitted. It is more so as in the Chinese characters models. In actually used models, it is often required to calculate different values of one variable in different times. It can not be done with the

change of time subscript without the B equation. And if with BOX variable, it is not nesecery to use time subscript. For example, suppose that price is a auxiliary variable PRICE, market demand is a auxiliary variable DEMA too. We want to find the relationship between DEMA and PRICE. If DT represent one month, the (PRICE.K-PRICE.J)/ PRICE.K is the rate of price change. The DEMA.K is a function of this rate. Because we can't put time subscript J on right side of A equation, it is wrong to put this expression on the right side of A equation. We need B equation to preserve value of PRICE in the last month.So it is reasonable to preserve BOX variable and cancel time subscript.

In addition, many users need more features, The typical one is the continuous manipulation of the results. This need can not be met by the table and graph output techniques currently used. More calculations need to be done on the result data, for example, to comparing results, to getting sensitivity parameters and sensitivity variables. Some users want various inputs of the model, but not just in the form of equations. Some want to join other kind of models with a DYNAMO Model.

The Chinese Character DYNAMO Compiler had been completed by the end of 1984. It compiles traditional DYNAMO Model which have Chinese character identifier of every variable and may send Chinese error messages. Besides, the compliler is in the form of modules, which is easy to add new functions.

Now 1 put forward a scheme which extends the Chinese character DYNAMO compliler into a Dynamic Modelling System.

PRINCEPLE OF THE EXTENSION

1. Taking DYNAMO as a kernel, compatible with current DYANMO model

Because DYNAMO has been used so extensively that many people are familiar with it, many succesful models have been developed. All the succesful results of the research in this field should be taken into consideration and be incorporated into the proposed scheme.

When the new Modelling System deals with the traditional Model, we can get the results which include those obtained by the traditional DYNAMO.

2. User friendly

DYNAMO is user friendly. Althouhg the new system contains many new and strong functions, New Modelling System must preserve DYNAMO's useful features. For example, the indentifier of all the variables and error messages,are expressed in Chinese. User operation guides are in the form of men-machina dialogue in Chinese.

3. Open System

All of the known requirements of the users can not be met at once. And some new ones may come up as the time goes bv

Therefore we keep our system open for expansion of new functions, which will satisfy increasing demands. So everyone can accumulate their experience for further development to be used by himself or others.

4. Modular construction

Chinese Character DYNAMO is in the form of modules, It contains basic functions in its first version, and is being improved constantly with more functions added, and new version will be resulted.

The Modelling System must fully use the modules of the latest version of DYNAMO.

This new complier is named the Dynamic Modelling System with Chinese Character DYNAMO as the Kernel (or MSC-DYNAMO).

THE CONCEPTS OF MSC-DYNAMO

From the point view of SD, a system is composed of elements. Interrelationships and interaction among the elemens determine the laws of system change. The DYNAMO language describes the state of the system by a set of L variables. Rate of change of L is described by R variables, which are determined by some L and external variables. Another set of A variabes are introduced in order to represent complex relationship clearly. Essentially in DYNAMO the change of system state is represented by a set of differential equations. Then the evaluation of these equations is done by simple numerical integration in computer, and the state of the system at every time point is then yielded. General procedure of modelling is to define the system bound first, then finding system elements and causal relationships between them, transform these into flow diagram and finally writing the equations of DYNAMO.

The concepts of tranditional DYNAMO and the new Modelling System are illustruted by the following example, in which the data and causal relationship may not be very reasonable. This is an ecologic system which is composed of tigers and deers. In a large jungle these deers have plenty of food, they are in turn delicious food for the tigers. Birth rate of tiger depends on the number of deers shared by a tiger. This can be expressed as a table function (X):

tiger's birth rate per annum   0,0.2,0.3,0.31
number of deers shared by a tiger   0, 2 , 4 , 6

This means that the more food that can be eaten by a tiger the higher the birth rate.

The length of life of a tiger can be similarly expressed as a table function (Z):

tiger's length of life (year)   0, 20, 30, 31
number of deers shared by a tiger   0, 2 , 4 , 6

This means that the more food taken, the longer the tiger's life.

Deer's birth rate is a sine curve with a period of ten years. This means that natural environment influences periodically the birth of deers.

Deer's death rate depends on two factors. They may be eaten by the tigers. This is the table function(Y).

number of deers eaten by a tiger   0 , 1, 1.5, 1.6
number of deers shared by a tiger   0 , 2 , 4 . 6

On the other hand, when deers are not eaten by the tigers, they get old and will die naturally. Suppose that the deer's average length of life is a constant.

The Figure 1 describes this model.

DYNAMO equations of this system are

```
A DEERBR.K=0.01*SIN(6.28*TIME.K/10)+C1
C C1=0.03
R DEERB.KL=DEER.K*DEERBR.K
L DEER.K=DEER.J+DT*(DEERB.JK-DEERD.JK-DBYTE.JK)
R DEERD.KL=(DEER.K-Y.K*TIGER.K)/DEERDR.K
A DEERDR.K=DEERDRV
C DEERDRV=10
R DBYTE.KL=Y.K*TIGER.K
A Y.K=TABHL(TY,DPERT.K,0,6,2)
T TY=0,1,1.5,1.6
R TIGERB.KL=X.K*TIGER.K
A DPERT.K=DEER.K/TIGER.K
A X.K=TABHL(TX,DPERT.K,0,6,2)
T TX=0,0.2,0.3,0.31
R TIGERD.KL=TIGER.J/Z.K
L TIGER.K=TIGER.J+DT*(TIGERB.JK-TIGERD.JK)
A Z.K=TABHL(TZ,DPERT.K,0,6,2)
T TZ=0,20,30,31
N TIGER=TIGERN
C TIGERN=1000
N DEER=DEERN
C DEERN=10000
```

These equations are in fact a set of differential equations they can be expressed as:

$$\binom{R}{A} = F\binom{L}{A}$$
$$L(t_o)=L_o$$
$$L=PL$$

Here F is a vector function, $R, \dot{A}, L, L_o$ are column vectors respectivelly. P is a integral matrix named transfer matrix in which the elements are 0,1 or -1. $L(t_o)$ denotes the value of varaible L at the instant t. Let us see the meaning of F, P, R, A, L, L_o in terms of the above example:

$$R = \begin{pmatrix} \text{DEERB} \\ \text{DEERD} \\ \text{DBYTE} \\ \text{TIGERB} \\ \text{TIGERD} \end{pmatrix} \qquad A = \begin{pmatrix} \text{DEERBR} \\ \text{DEERDR} \\ \text{DPERT} \\ X \\ Y \\ Z \end{pmatrix}$$

$$L = \begin{pmatrix} \text{DEER} \\ \text{TIGER} \end{pmatrix} \qquad L_o = \begin{pmatrix} 1000 \\ 10000 \end{pmatrix}$$

The vector function F indicates that R and intermediate variable A are a function of L and A. Let us look at the first element of the vector function:

DEERB.KL=DEER.K*DEERBR.K

This means that the first element of R --DEERB is a function of DEER and DEERBR, the concrete functinal form is the multiplication of two arguments.

Sometimes it is not necessary for us to describe in greater details these concrete relationships. Instead of the function we can use the matrix D. The elements of D are only 0 or 1, which indicates which elements of R, A are related to the elements of L, A.
Then,

$$\begin{pmatrix} R \\ A \end{pmatrix} \triangleq D \begin{pmatrix} L \\ A \end{pmatrix}$$

Here $\triangleq$ do not nean that the left side is equal to the right side. It means that D can express relationship between the elements of left side and the elements of right side.
Obviously first row of D is (10100000). D is called the relation matrix. P in our sample is

$$\begin{pmatrix} 1 & -1 & -1 & 0 & 0 \\ 0 & 0 & 0 & 1 & -1 \end{pmatrix}$$

Although causal-loop diagrams and flow diagrams are visually intuitive and easy for communication with others, but for the manipulation in a computer these diagrams can be more conveniently shown as a graph.
It is

G=(Q,E)
Q=(L,R,A,C)
E=(M,I)

Here G is a graph. Q is a set of nodes which include L nodes, R nodes, A nodes and C nodes, representing the arguments L, R, A, C . E denotes arcs which are directed line segments. M is the physical flow whose direction is similar to real physical flow, that is if R causes L to increase, then the arc represents the flow from R to L, if R causes L to decrease, then it is directed from L to R. I is the information chain. So (DEERB,DEER) is a element of M and (DEER,DEERB) is a information chain.

In order to understand and manipulate the model we must find
all the longest path or loop of the physical flows which are
stream of one R followed by one L, possibly some delay links
which are actually again a series of one R followed by one L
may appear in the path. There are three paths in the above
example.

    (DEERB,DEER,DEERD)
    (DEERB,DEER,DBYTE)
    (TIGERB,TIGER,TIGERRD)

There are also subgraphs constructed with one L as a center.
These subgraphs can be expressed as a set, for example:

a DEER centered subgraph is (+DEERB,-DEERD,-DBYTE),
a TIGER centered subgraph is (+TIGERB,-TIGERD)

Here + means that R causes L to increase, - means that R causes
L to decrease.

According to the information chains we can trace back to all
the variables which are related to one R varaible, for example,

(X,DPERT,DEER)
(X,DPERT,TIGER)
(TIGER)

these three cause-effect chains are related to TIGERB.

In DYNAMO model intermediete variable A can be cancelled by
substitution of functions. In our example if intermediete A is
cancelled then only (DEER,TIGER) are L,A variables related to
TIGERB.

The variable A which affects other elements but is not affected
by others is named external variable, that is, A is the
starting point and therefore is a external variable. Other A's
are named internal variable. Only DEERBR and DEERD are
external variables in above example. For a correct DYNAMO
model it is possible to cancel all of internal variable by
substitution of functions. In this way, the relation matrix
can be transformed into the following form

$$R \stackrel{\triangle}{=} B \begin{pmatrix} L \\ A \end{pmatrix}$$

Here A is external variable only, elements of B can only be 0
or 1 which indicate which elements of R are related to the
elements of L,A. We can call B as a pure relation matrix. Then
our model becomes the flow daigram as the Figure 2 .

In Figure 2

$$A = \begin{pmatrix} DEERBR \\ DEERDR \end{pmatrix}$$

$$B = \begin{pmatrix} 1 & 1 & 1 & 0 \\ 1 & 1 & 0 & 1 \\ 1 & 1 & 0 & 0 \\ 1 & 1 & 0 & 0 \\ 1 & 1 & 0 & 0 \end{pmatrix}$$

The first two columns express which L is related to R. The last two columns express which A is related to R.

Generally if L part or A part of B can be transposed to a block diagonal matrix with exchange of columns, it is possible to partition the system into absolutely isolated subsystems. If they can be transposed to a nearly block diagonal matrix, it is possible to partition the system into nearly isolated subsystem. To transpose a complex system automaticly by computer would be helpful to understand the structure of the system. There are some important concepts in the manipulation of the results. If the values of the variable oscillate in time with respect to a set of values of some parameter, then we can find average period of the variable. The variable with short period is called the fast variable and the variable with long period is called the slow variable. Slow variable may become the order variable. The interval between the crest and the next crest is defined as period. Note that step of calculation must be much smaller than the period.

The change of some parameters influences the state of the system. For example, a parameter C1 is shown by a list of values: X1,X2,......Xm, then the values of the state variable L simultaneously changes. Suppose that simulation interval is [0,nDT], total n+1 points. The relationship between parameter C1 and LAB in the interval is showen as follows.

	0	DT	2DT	3DT	....	nDT
X1	LAB10	LAB11	LAB12	LAB13	....	LAB1n
X2	LAB20	LAB21	LAB22	LAB23	....	LAB2n
...						
Xm	LABm0	LABm1	LABm2	LABm3	....	LABmn

From these m curves we can obtain an average curve, a top envelope and a bottom envelope.

We can define many kinds of sensitivity coefficients of LAB to C1 for Xi. For example, by taking the average relative difference the sensitivity conefficient is:

$$\frac{\sum_{j=1}^{N} \left| \frac{LAB_{i-1,j} - LAB_{i,j}}{LAB_{i,j}} \right|}{N} \Bigg/ \left| \frac{X_{i-1} - X_{i}}{X_{i}} \right|$$

By taking the maximum relative difference the sensitivity conefficient is:

$$\underset{j \leq N}{MAX} \left| \frac{LAB_{i-1\,j} - LAB_{i\,j}}{LAB_{i\,j}} \right| \Bigg/ \left| \frac{X_{i-1} - X_i}{X_i} \right|$$

We can find most sensitive variable when the variable has the largest sensitive coneffcient compared with other variables for the same parameters. Also we can find most sensitive parameter when the parameter has the largest sensitive coneffcient compared with other parameters for the same variables. This means that some parameter has strong effect on the system.

Joining other models with a DYNAMO model is another new concept. It means that values of some variables of the DYNAMO model are obtained from other external model. These variables are defined to the external variables which includs A, L, R.

EXTENTED FUNCTIONS AND USER'S INTERFACE

I will simply list some new commands, which instruct computer to do new jobs for the users.

1. internal macro functions

   a. table function with unequal distance of argument TABLEN

These two statments indicate that Y is a function of X:

A Y.K=TABLEN(YT,X.K)
T YT=3,5/4,9/4.5,7/5.7,10

that is
        when X=3   ,   Y=5,
             X=4   ,   Y=9,
             X=4.5 ,   Y=7,
             X=5.7 ,   Y=10

here the values of X is incrmented. When X is not equal to above number, we may calculate Y with linear interpolation.

   b. table function with two arguments TABLDE

These two statments indicate that Y is a function of X1 and X2:

A Y.K=TABLDE(YT,X1.K,0,4,2,X2.K,2,14,4)
T YT=3,5,4/9,7,1/1,7,6/3,6,1

this means

X2 \\ X1	0	2	4
2	3	5	4
6	9	7	1
10	1	7	6
14	3	6	1

c. table function with unequal distance of two arguments TABLDN.

These two statments indicate that Y is a function of X1 and X2:

```
A Y=TABLDN(YT,X1.K,X2.K)
T YT=3,4,1/3,5,6/4,4,3/4,5,8
```

that is
$$\text{when } X1=3, \quad X2=4; \quad Y=1.$$
$$X1=3, \quad X2=5; \quad Y=6.$$
$$X1=4, \quad X2=4; \quad Y=3,$$
$$X1=4, \quad X2=5; \quad Y=8$$

2. library of the external macro functions

Some typical structures composed of several elements often occur in the model. MSC-DYNAMO has an open library of external macro. The user writes a macro function for substitution for the structure. Macro compiler compiles it and puts its object codes into the library of macro functions for further use.

In order to help other users to use the external macro functions specifications in Chinese can be written and stored in the library.

For example, cusp in Catastrophe Theory is typical process, it can be written as a macro function :

```
MACRO      CUSP(X,U,V,C)
L CUSP.K=CUSP.J+DT*$R1.JK
R $R1.KL=4*X.K*X.K*X.K+2*U*X.K+V
N CUSP=C
MEND
```

External macro is written by EDLIN, compiled by MCOM and saved in MACRO.LIB. If the user uses external macro in his model, he must link all object modules by MLINK before running the object codes. The form of external macro is as same as general macro.

3. manipulation of time subscript

MSC-DYNAMO can accept model whithout time subscript. For example, this is a correct equation in MSC-DYNAMO:

```
L L1=L1+DT*(R1-R2)
```

If the user writes wrong subscript, the MSC-DYNAMO just sends a warning message, then substitutes it for the correct one and replace the old statements (original version is kept in the backup file).

4. joining other models.

If the user wants to join other models with our DYNAMO model, the user must declare first the external variables.

The form is :

EXVA <list of external variables>

For example,

EXVA A1,A2,A3

means that A1,A2 and A3 are three external variables. Accordingly, values of these variables are saved in the data base of exearnal variables. The values are sent by the other model, which may be a DYNAMO model or directly entered by EDLIN. MSC-DYNAMO automatically checks whether the intervals and steps of the two models are equal.

5. forms of input

In addition to the DYNAMO equation input, many other forms of model input can be accepted by MSC-DYNAMO.

Relation matrix and transfer matrix are some of the input forms. However some concrete relationships have not been given yet. Computer can inquire and accept answer from the user. For example, we give relation matrix of the above example as input, then the computer inquires:

"WHAT IS THE RELATIONSHIP BETWEEN DEERB AND DEERBR, DEER ?"

then displays half of the statment like this:

R DEERB=

The user completes whole statment like this:

R DEERB=DEERBR*DEER

and so on

If some rules of modelling are stored in the computer, MSC-DYNAMO automatically assists in modelling. For examlpe, we have a rule that relationship between function and arguments is F=C*A1*A2*A3....., here C means adjustable parameter. A1,A2,A3..... are arguments. Depending on the difference between the data of the real world and the calculated values, C is adjusted until the difference is small enough.

6. variable parameter input

MSC-DYNAMO can accept external parameter by using the specification statment like this

EXPA C1,C2

This means that values of external parameters C1, C2 can be retrieved from the data base of external parameter. These values are sent by EDLIN directly or by external algorithms writen by the user.

7. further manipulation of the results

  a. save results in the data base.

For further manipulation of results, we must first save our results in a data base by the statment

SAVE ⟨identifier of data base, list of variables⟩

This statment saves values of the variables indicated by the above statment in the data base. The first record in the data base contains the information about the name of the model, values of the parameters, identifiers of the variables, interval and step. This data base is vary important. The data in it will be retrieved and manipulated many times.

Other results can be saved too. Because of namy data and data bases,a subsystem to be manage them is required. The subsystem can retrieve data and sort data by some special key, etc.

  b. calculation of top evelope, bottom evelope and average curve.

The statments are like this

EVELOPE T L1,C1,2,3,6
EVELOPE B L1,C1,5,7,10
AVERAGE L1,C1,2.4,3.6,7.1

The first one means that when C1=2, C1=3, C1=6, we print top evalope of L1.

The second one means that when C1=5, C1=7, C1=10 we print bottom evelope of L1.

The third one means that when C1=2.4, C1=3.6, C1=7.1 we print average curve of L1.

  c. sensitivity coefficient

SEN L1,C1,5

means to print out sensitivity coefficient of L1 to C1 when C1 is 5.

  d. sensitivity parameter

SENPA L1

means to print out sensituvity paremeter for variable L1.

  e. sensitivity variable

SENVA C1

means to print out sensitivity variable for parameter C1.

f. direct enter other software package

CONNECT SPSS< list of variables>

means that results of the model direct output to SPSS (statistical package for the social sciences).

8. verification of the model

If we know values of some variables, we can store them in the data base of the known variables. Compare with the values calculated for verification.

THE MAIN MODULES AND THEIR FUNCTION

The figure 3 clearly illustrate relationships between all of the modules and their data.

The main modules and their functions are listed below.

1. calculation of the parameters

It accepts a set of known samples and calculates the statistical parameters, using some mathematical and statistical methods. For example, when the relationship between two variables shown by a set of a pair of numbers is known, calculate by the least squares method the slope and intercept of the line which expresses the relationship between those two variables.

According to the dynamical behavior of the system elements, calculate delay coeffecient of the system variables.

This module is open to the users. They can easily add varirous algorithms to the system to calculate parameter.

2. edidor of equation

First input form of this module is a file built by the EDLIN, which consists of the DYNAMO statments (equations). The file is then decomposed into separate statments and their order number.

This module also accepts the quasi-equations from the converter. It can erase old equations and just retain the latest ones.

3. compiler

This is the largest module and is composed of many submodules. It has been implemented and works normally. It accepts a single statment one by one and checks syntex and produces object codes.

The figure 4 shows its main functions.

The main techeniques are:

1) translate the user's Chinese identifier into system's identifiers,
2) use different matrices to express various relationships of the variables.

4. external macro handling

It records and handles the macro defined by the user and produces the macro object codes, then send them to the macro library. It is open to the user. Everybody can define macros for commom use.

5. link

It links together the main object codes from the compiler, the macro object codes from the macro library, the external parameter value from the data base of external parameters and

the values of the external variables from the data base of external variable into the excutable object codes.

The other modules are easy to understand from the figure 3. which will not be explained here.

PROSPECT

The logical design of MSC-DYNAMO has been completed. The kernal part works normally. The whole system will be operative in July of this year.

MSC-DYNAMO is a good tool for modelling. Various forms of model represantion can be used to show the different essential aspects of the model. We can input various forms and get outputs in various forms. Automatic comparison between the results of calculation and the data from the real world data stored in the data base of known variables can be used to verify the model. Depending on those discrepancy, you can gradually improve your model until a satisfactory result is obtained. We can build some rules to help the computer build and improve the model automatically. MSC-DYNAMO includes almost the whole simulation process --- calculation of model parameter from original data, run of the model, verification and validation of the model, improvement of the model. It can absorb good experience from others and accumulate knowledge of modelling too. It is basically automatic and intelligent. Hence we can expect that it will become really strong tool for system research and that the system can be used to simulate self-organization, catastrophe and other complex phenomena without physical experimentation. It is can also used to simulate more complex social-economic and ecologic phenomena.
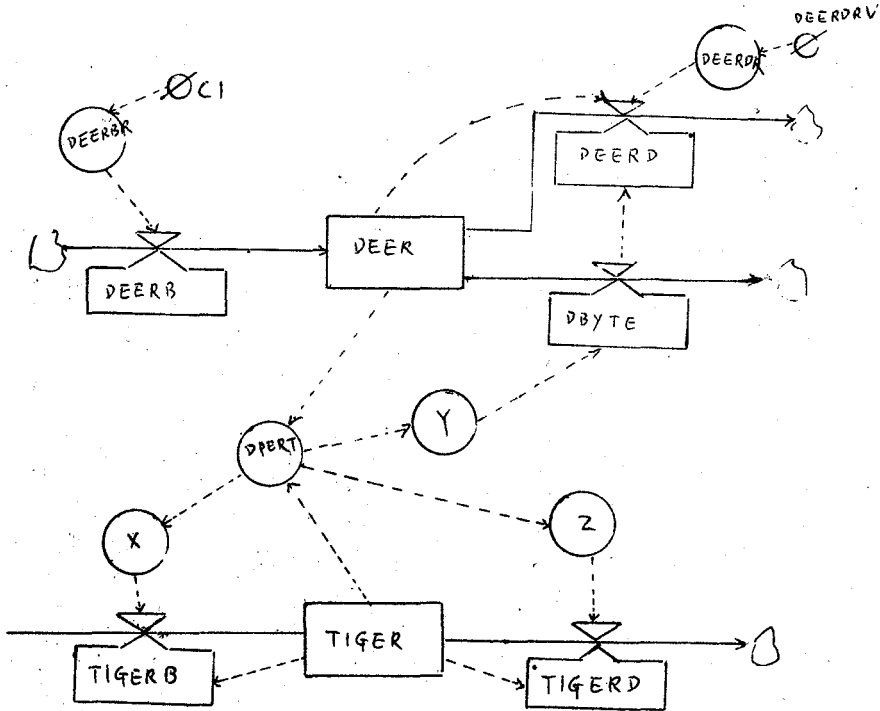
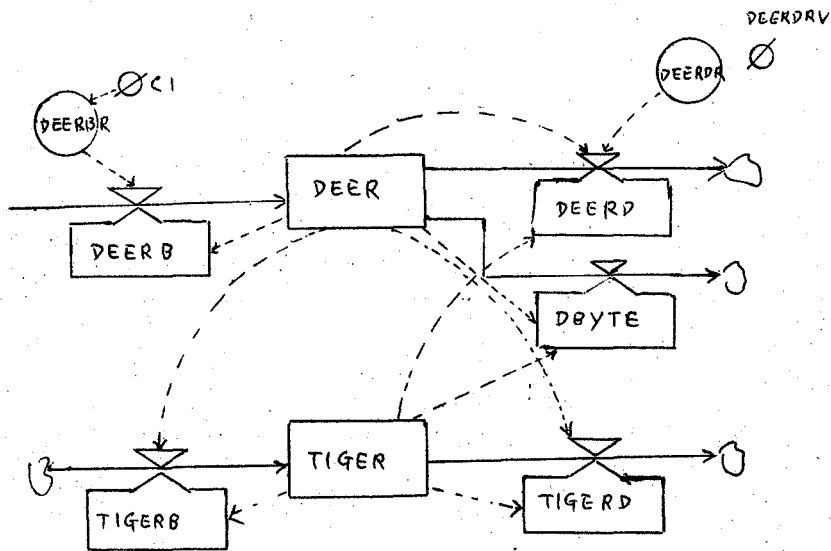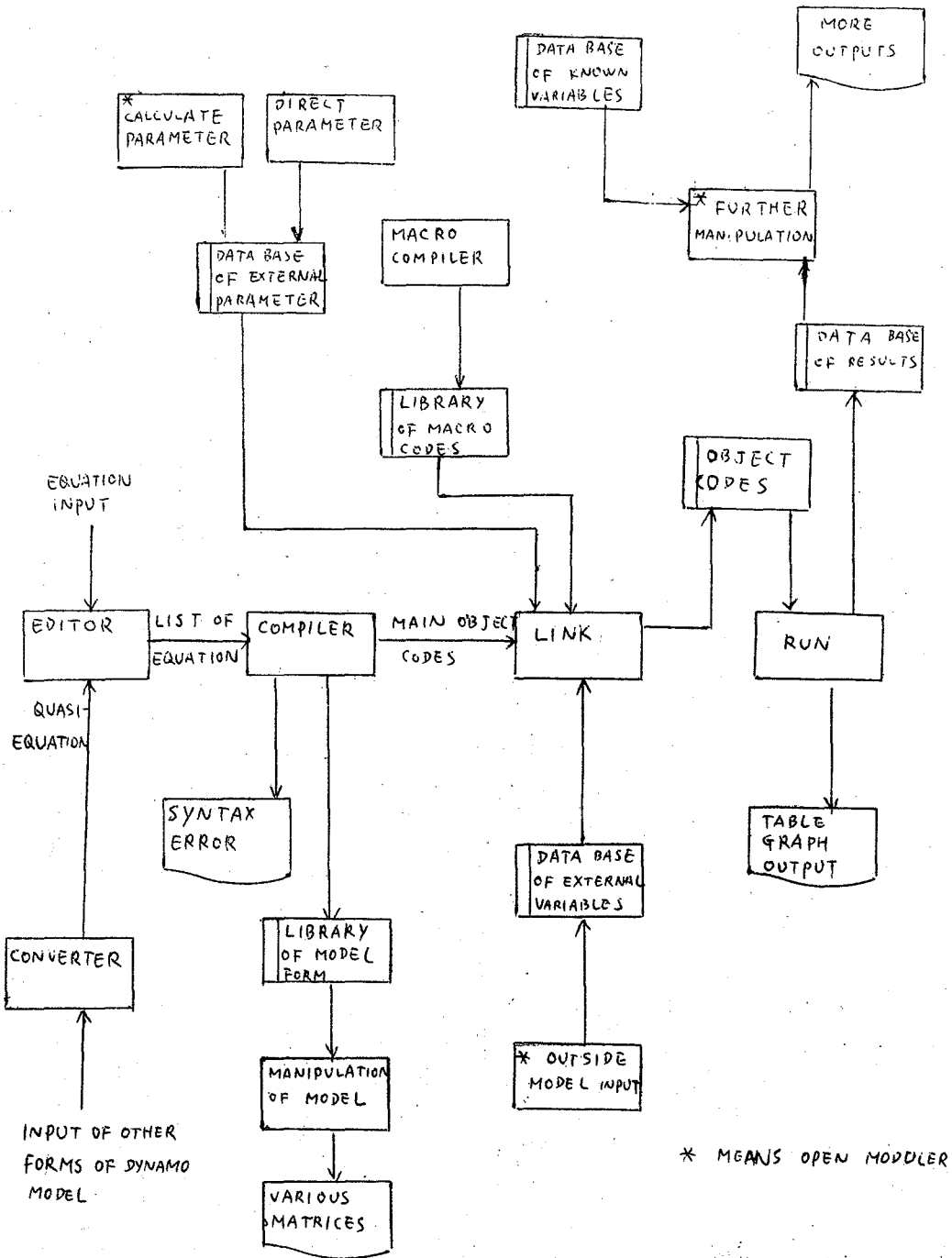FIGURE I   FLOW DIAGRAM OF EXAMPLE SYSTEM

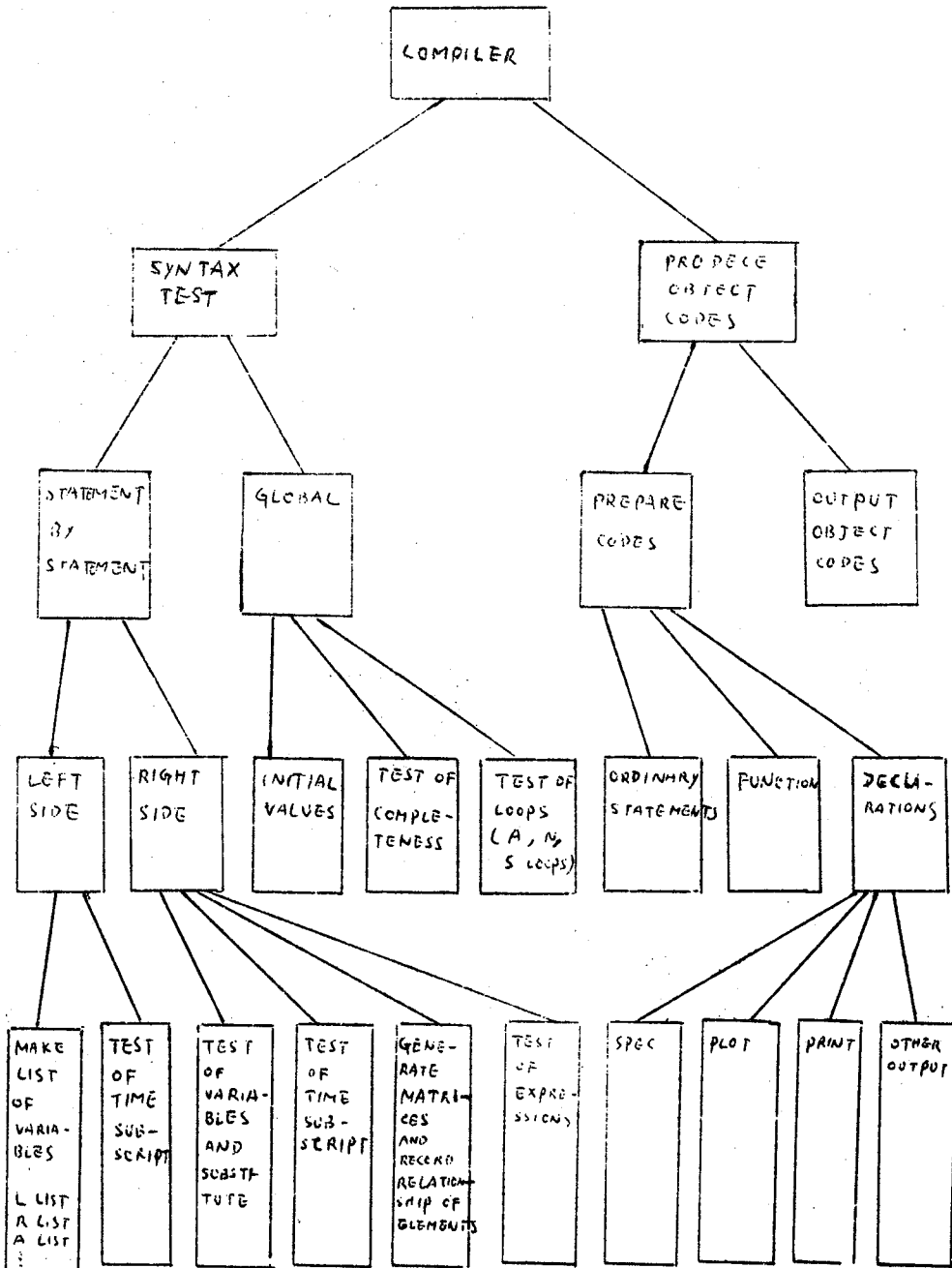FIGURE 2   SIMPLE FLOW DIAGRAM OF EXAMPLE SYSTEM

FIGURE 3   DATA FLOW CHART OF MSC-DYNAMO

FIGURE 4 MODULAR STRUCTURE OF THE COMPILER