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ModelWorks

An Interactive Simulation Environment for Personal Computers and Workstations

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ModelWorks 2.0

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ModelWorks

An Interactive Simulation Environment for Personal Computers and Workstations

by

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Abstract

ModelWorks is a modeling and simulation environment in Modula-2 specifically designed to be run interactively on modern personal computers and workstations. It supports modular modeling by featuring a coupling mechanism between submodels and unrestricted number of state variables, model parameters etc. up to the limits of the computer resources. It allows for the formulation of continuous time, discrete time as well as continuous and discrete time mixed models. Finally ModelWorks offers in its interactive simulation environment a handy user interface featuring efficient alterations of model and simulation run parameters.

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About ModelWorks and this Text

ModelWorks is a simulation environment to solve dynamic systems as they are used in biology, physics, chemistry, environmental and engineering sciences to model various processes. It is also particularly well suited to be used by university students during a modeling course. ModelWorks can be used for simple didactic models as well as for very complex research models.

ModelWorks allows to work with an arbitrary number of dynamic models described by differential or difference equation systems. A global model can be separated into, possibly hierarchically organized, submodels which exist as independent units communicating via output-input coupling. Modular and hierarchical modeling is supported, which is particularly useful if for instance one wishes to keep experimental results clearly separated from a theoretical, mathematical model by formulating them as a parallel model, or to enhance model clarity, or to build model libraries. Discrete and continuous models can be combined in one global model, with correct data exchange controlled by the simulation environment.

Simple mathematical models can be built with only minor programming knowledge, whereas programming experts have full access to a powerful programming language and may expand into any realm of sophisticated calculations still profiting from the simulation environment and numerical algorithms provided by ModelWorks. Hence in contrast to most existing simulation software ModelWorks fully supports the researcher during a model development process, which often starts with a first, crude model and ends with the most sophisticated, in every detail refined research model[1].

ModelWorks is based on a high-level programming language which has been selected considering the following criteria: It has been formally defined; it is general and powerful enough to support not only numerical computations, but also a window based, graphical user interface; on the other hand it is also simple enough to be comprehended and mastered by the non-computer scientist having learned programming in a basic computer science course, such as for instance taught in Pascal programming courses; on the other hand it also offers support for the development of large and complex models for the expert; finally and not the least, the language is available in efficient implementations on many machines as e.g. Apple® Macintosh®[2], IBM® personal computers[3], or Sun® workstations[4] . Therefore we have chosen Modula-2 as the programming language to be used for ModelWorks, currently meeting all the listed requirements closest (WIRTH, 1988)[5]. Due to this approach ModelWorks could be designed as a fully open system, which can be expanded or customized by the user to any purpose he desires.

[1] ModelWorks does not force the modeler to discard the simulation software together with all other investments in learning , implementation, and testing time, or any compatibility issues, when he reaches the limits of the simulation language; on the contrary, ModelWorks avoids the risk of having to restart with the model implementation all over again in a high-level programming language, since it does so from the very beginning. In contrast to a simulation language a well designed, general purpose, high-level programming language guarantees that anything which can be computed on a computer can be realized. It appears that one of the reasons why so many experienced researchers almost never use simulation software but use instead general-purpose high-level programming languages is that they avoid the risk to have to switch techniques in the middle of a project.

[2] Macintosh is a registered trademark of Apple® Computer, Inc.

[3] IBM is a registered trademark of International Business Machines Corporation.

[4] Sun is a registered trademark of Sun Microsystems, Inc.

[5] See the appendix for cited literature

ModelWorks consists of a set of library modules written in Modula-2, which contain the program parts common to any simulation, such as numerical integration algorithms, and the tabular plus graphical display of the simulation results, or the interactive changing of model or other simulation parameters. The variable portion, the model of interest, is to be supplied by the user in the form of a standard Modula-2 program. It describes the model's behavior and installs the model in the simulation environment by means of the elements provided by the so-called client interface of ModelWorks. Modeling and simulating with ModelWorks includes therefore three steps: a) Writing a Modula-2 program (the model definition), b) compilation, and c) execution of the program (running simulation experiments with the model within the simulation environment).

Interactive modeling and interactive simulations are supported in ModelWorks in several ways. The user interface of ModelWorks in the simulation environment allows to change interactively all settings, including any simulation parameters such as the integration method or the step length, model parameters and/or initial values of the state variables, plus selection of the display of simulation results. Simulation results are made visible to the user by the so-called system behavior monitoring concept: Values of any variable may be written onto a file for future reference, written into a table, or displayed as curves in line-charts. All data can be reset to a given default value. Further, the model's data structure are all stored dynamically. This allows the user to install an unlimited number of models of an arbitrary size, with an arbitrary number of variables each, up to the limits of the hardware.

ModelWorks simulation environment is based on the *Dialog Machine*[1], guaranteeing a consistent user interface and has originally been implemented using MacMETH[2], a fast and efficient Modula-2 language system for the Apple® Macintosh® computer (WIRTH *et al.*, 1988). ModelWorks simulation environment runs on any machine on which the *Dialog Machine* is available. If this is the case, an efficient and smooth port of ModelWorks in a few days work is possible. Currently ModelWorks is available for Macintosh computers with at least 512 KBytes of memory (RAM) plus at least two floppy drives and IBM® PCs which run under MS DOS and have 640 KBytes of memory (RAM) plus a hard disk. For more details on particular implementations and hard plus software requirements for specific versions, see the *Appendix*. This text serves as a manual for the ModelWorks software. Since all versions are very similar and differences are the exceptions, there exists only this one text. Differences between versions are minor and briefly mentioned wherever appropriate.

This text is subdivided into three parts: Part I is a *Tutorial* containing a little tour to be followed step by step. It suffices to learn all basic techniques, which are needed in order to model and simulate simple models with ModelWorks. Part II explains the *Theory* and concepts behind ModelWorks, in particular model formalisms and all functions of ModelWorks. Any advanced modeling, such as modular modeling, requires to study the theoretical part. Part III is a *Reference* manual containing a complete list and description of all features of ModelWorks. Finally the *Appendix* contains detailed instructions for the installation, model development cycle, and other technical details of interest during the daily work with ModelWorks. Included are also listings of ModelWorks' definition modules, several listings of sample models, convenient quick reference listings, and an index.

Reading Hint: Throughout this text *italics* are used to emphasize that the text is to be taken literally, in particular also case sensitive. E.g. in the citation of an identifier, such as a module name like *SimMaster* or if the user has to open a file or directory with a given name such as *Logistic.OBM* or *\MW\SAMPLES*. For easier orientation, the pages, figures and tables in Part I *Tutorial* and II *Theory* are prefixed with the letter T, in part III Reference with the letter R, and in the *Appendix* with the letter A. Within some parts figures and tables are numbered separately, starting e.g. with Fig. R1 respectively Tab. A1.

[1] See the appendix for availability and installation of the *Dialog Machine*

[2] See the appendix for availability and installation of MacMETH

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[1] Current address: Project-Centre IDA or Institute of Automatic Control and Industrial Electronics, Swiss Federal Institute of Technology Zürich (ETHZ), ETH-Zentrum, CH-8092 Zürich, Switzerland

Part I - Tutorial

This tutorial describes the elementary usage of ModelWorks, i.e. you learn how to develop and simulate models using ModelWorks.

The first chapter, *General Description*, describes the general, fundamental concepts of ModelWorks .

The second chapter, *Getting Started with the Simulation Environment*, contains a step by step explanation for running an existing model and getting familiar with the simulation environment of ModelWorks.

The third chapter, *Getting Started with Modeling*, teaches how to develop new models.

Having read this tutorial you will be able do develop and simulate your own, simple models. However, if you are interested in more complex models and more advanced techniques, this tutorial is not sufficient. In order to learn the more sophisticated features of ModelWorks you should read part II *ModelWorks Theory* and the second chapter, *Client interface*, of part III *Reference.* They contain a full and complete description of all possibilities ModelWorks offers.

This tutorial is best read while having access to a computer and the described steps are actually executed[1]. This requires that the reader is already familiar with his/her computer and the usage of its software, in particular the choosing of menu commands, clicking on objects (i.e. object selection), and the dragging of objects (e.g. moving the scroll box in a scroll bar). Moreover it is assumed that the user knows how to operate a simple programming editor (e.g. the desk accessory *MockWrite*), has a basic knowledge of the programming language Pascal or Modula-2 and is familiar with the mathematics involved with modeling and simulation of differential and difference equation systems. No particular information is provided on these topics. Please refer to other texts if you should have any difficulties with any of these subjects[2]. The appendix contains information on how to proceed in order to install the ModelWorks software.

Reading Hint: For easier orientation, the pages, figures and tables of Part I *Tutorial* are prefixed with the letter T.

[1] Note that the following text assumes that you will work with the original ModelWorks version as available on the Macintosh® computer. If you have no access to a Macintosh® computer, the instructions are to be executed similarly, but may look a bit differently or behave slightly differently, since the IBM® PC version of the *Dialog Machine* is only a subset of the Macintosh® version. A few hints: On the IBM® PC folders become directories, object files ending with the extension "OBM" become linked GEM applications with the extension "APP", and in contrast to the Macintosh MS DOS file names are truncated to 8 characters (extension excluded); note that the latter may also affect module names. For more details see the appendix. Wherever necessary, IBM® PC specific information has been added in form of footnotes. Please interpret the text accordingly and accept our apology for not being able to offer an IBM® PC text version; note that we are a research institution, not a commercial software company, and hence not able to maintain more than that version we use ourselves in our daily research work; however, you should have no difficulties in following the tutorial text, since all essential features of ModelWorks are available on the IBM® PC version as well.

[2] We recommend: Operation of the computer: Your owner's guide, e.g. *Macintosh owner's guide*. Modula-2: WIRTH, N. 1988. *Programming with Modula-2*. Springer-Verlag, Heidelberg, New York, 4th corrected ed. Modelling: LUENBERGER, D.G., 1979. *Introduction to dynamic systems - Theory, models, and applications*. Wiley, New York, 446pp.

1 General Description

ModelWorks is an interactive modeling and simulation environment to study the behavior of dynamic models, which are described by differential or difference equations. Any system described by a set of coupled, ordinary differential or difference equations can be modeled using ModelWorks. Since ModelWorks features modular modeling, it is also possible to mix models of different types and even simultaneously integrate them with different integration methods.

ModelWorks has two interfaces to communicate with the human user: the user interface of the simulation environment for the simulationist and the client interface for the modeler who builds models (Fig. T1).

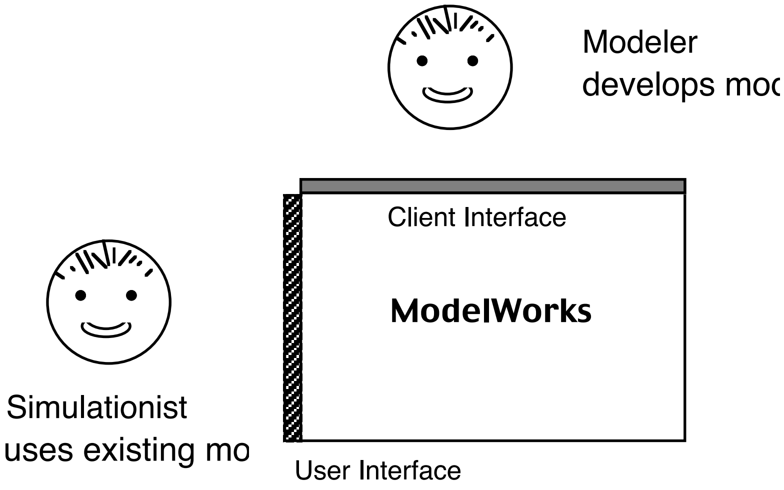


Fig. T1: The two interfaces of ModelWorks: The modeler uses the client interface for the model development, the simulationist uses the user interface of ModelWorks' simulation environment to perform simulation experiments with an already existing model. Typically the modeler and the simulationist are one and the same person changing just roles.

Typically the modeler and the simulationist are one and the same person. However their roles are distinct and should be clearly separated: The modeler defines all properties of a simulation model, i.e. he specifies a model definition. This includes the specification of the model's mathematical properties and its objects, such as equations, state variables, and parameters, plus the objects' default values and ranges. It is also the modeler who implements the model by writing a ModelWorks model definition program.

The simulationist runs interactive simulation experiments, hereby using one or several models, which have been constructed by the modeler. He is restricted to use these models within certain limitations which have been specified by the modeler, but within that range, he may interactively define and execute with the model any kind of experiment he wishes. For instance he may observe its temporal behavior, sample points from particular trajectories, modify parameter values within a defined range, or run a sensitivity analysis. ModelWorks contains all elements and algorithms needed for computer simulations, such as numerical integration algorithms, the interactive changing of parameter values, and the display of simulation results. The only exception of course is the model itself, which has to be provided by the modeler.

Normally a ModelWorks model definition consists of several objects, which belong to various classes. First there must be present at least one model; but the model definition may consist of any number of models. Second, normally each model is associated with several objects like model equations, state variables, model parameters, auxiliary variables, and monitorable variables. Such objects are called model objects (Fig. T2).

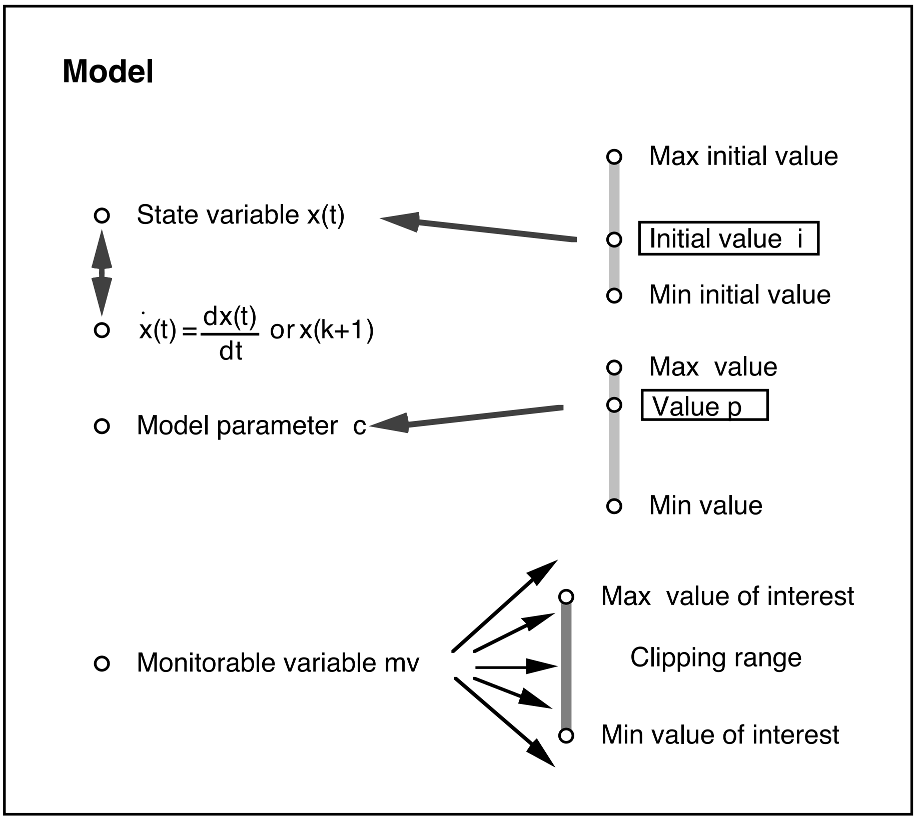


Fig. T2: Model objects (○) of a ModelWorks model: A ModelWorks model definition must consist of at least one model and every model usually contains state variables, model parameters, and monitorable variables. Any initial value, parameter value, minimum, or maximum value becomes mandatory, if the associated variable or parameter is declared within the model definition. ModelWorks maintains the actual values of state variables, parameters, and monitorable variables and even remembers their initially specified values (default values): ← : ModelWorks automatically assigns the initial value *i* to the state variable *x* at the begin of every simulation run, and the value *p* is assigned to the model parameter *c* at the beginning of the simulation session or after any interactive change. ↕ : ModelWorks uses the derivative or new value in order to compute and repeatedly assign newly obtained values to the state variable during the course of a simulation run (numerical integration). → : During simulation experiments the unknown values, which the monitorable variable *mv* may obtain, shall be drawn in graphs only if they fit within a particular range of interest; otherwise ModelWorks will clip them from the display.

A model is always of a particular type, i.e. either continuous time or discrete time. This type is given by the kind of equations which belong to the model: In the case of continuous time the model equations are ordinary differential equations, in the case of discrete time they are ordinary difference equations. Note however, that a ModelWorks model definition program may be structured, i.e. it consist of several models which may be of a differing type, i.e. some models may be continuous time other discrete time. In the latter case results a so-called mixed continuous and discrete time model definition.

A model may consist of any number of model equations. However, they must be given as explicit, either first order differential equations or first order difference equations. E.g. the following differential equation describing the van der Pol oscillator

$$\ddot{y} + \mu(y^2 - 1)\dot{y} + y = 0$$

is not in the proper form, since it is neither explicit nor is it first order. On the other hand, the same equation reformulated[1] as a system of explicit, coupled first order differential equations

$$\dot{x}_1 = x_2$$
$$\dot{x}_2 = \mu(1-x_1^2)x_2 - x_1$$

is now suitable to be used directly as a set of ModelWorks model equations. The second form is called the state variable form. Most differential or difference equations can be formulated in this form.

Usually each model uses a number of state variables. Each state variable must be associated with a second variable used as its first order derivative in the case of continuous time, or its new value in the case of a discrete time model. The model equations are formulated as expressions capable of defining the values of the derivative or new value. The expression may be an arbitrary function of any of the other model objects, such as state variables, auxiliary variables, or model parameters. Every state variable must be associated with a particular initial value and a range within which it may be changed interactively (Fig. T2).

Every model may have any number of model parameters, each associated with a particular value and a range within which it may be changed interactively. Typically model parameters are not or only rarely changed in the middle of simulation experiments (Fig. T2).

Intermediate results from an expression may be stored in a variable which will be later used in another expression. Such auxiliary variables are often used to compute complex expressions defining the value of a derivative of a state variable. In a ModelWorks model definition program the modeler may use any number of auxiliary variables. However in the current version, ModelWorks does neither especially recognize such variables nor does it hinder the modeler to use them in whichever way he wishes.

Finally models may have any number of monitorable variables. They are used to monitor the current values of any variable or otherwise accessible real numbers used in the ModelWorks model definition program. Each monitorable variable is associated with a clipping range used for the graphical display of the simulation results (Fig. T2).

All values specified by the modeler are remembered by ModelWorks as the so-called default values. The values currently in use by the simulation environment are called the current values. While starting the model definition program, ModelWorks assigns the default values to the current values. This is called a reset. Any time the simulationist wishes to do so, he may execute a further reset of a specific class of values, so that their current values are overwritten with their defaults. This mechanism is most useful if the simulationist wants to resume a well defined state before continuing with his work, especially after having made many and complex interactive changes.

[1] From the definitions $x_1 = y$ and $x_2 = \dot{y}$ follows $\dot{x}_2 = \ddot{y}$, i.e. the variable substitutions $\ddot{y} \rightarrow \dot{x}_2$, $\dot{y} \rightarrow x_2$, $y \rightarrow x_1$; rearrange resulting two equations to make the derivatives explicit.

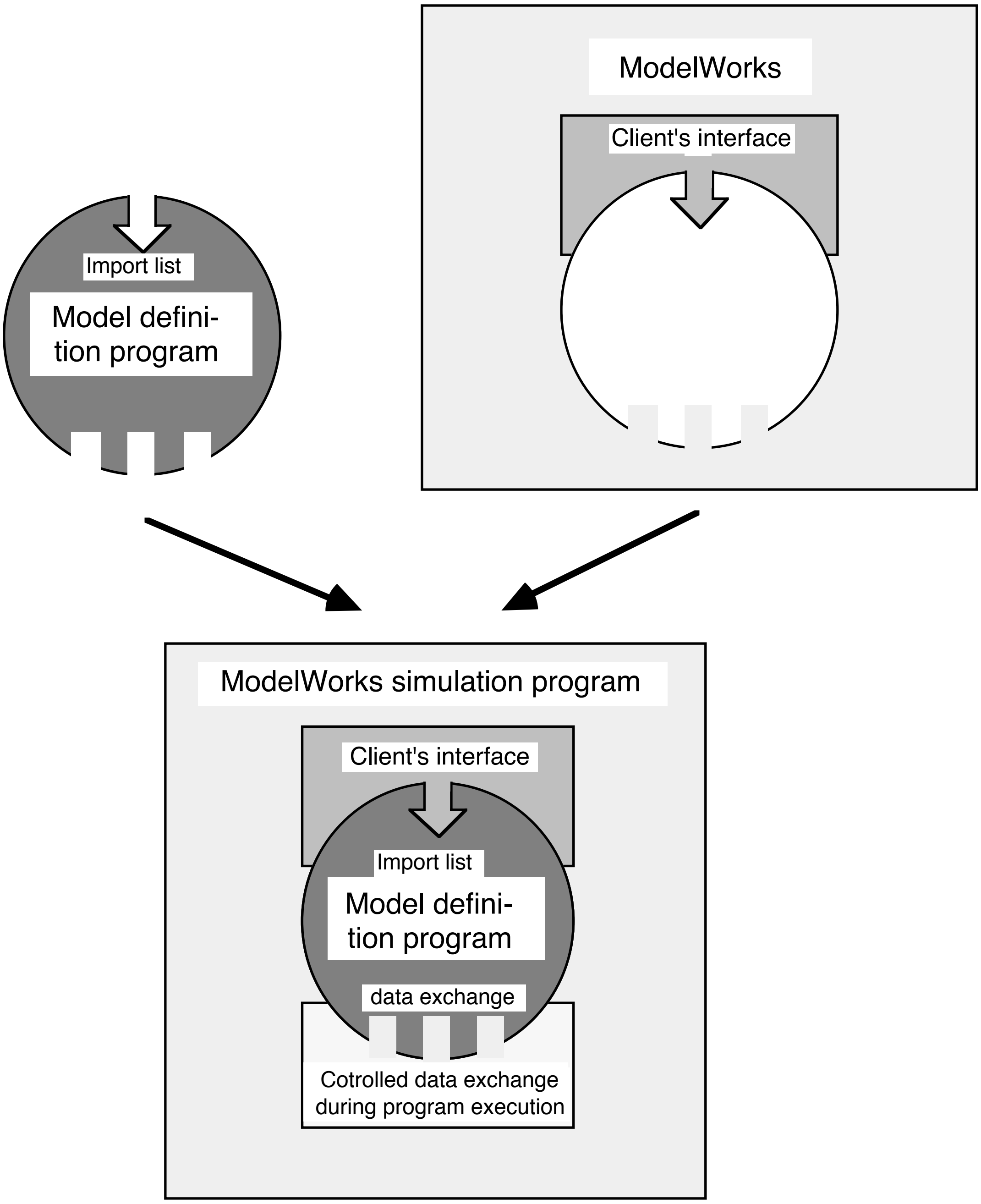


Fig. T3: Organization of ModelWorks: ModelWorks is the constant part common to any simulation program forming the simulation environment. The variable part, the model definition program, describes the actual model to be simulated. Both units form together the final simulation program. They are linked by procedures provided in the client interface and by mutual data exchange.

Ranges for initial values of state variables or model parameters are defined solely by the modeler. They become effective only in the simulation environment while the simulationist edits the current values of these model objects. ModelWorks guarantees that the simulationist assigns only values to an initial value of a state variable or a model parameter which lie within these ranges. Hence the modeler can use this mechanism to enforce limits within which the model equations are still valid in order to reduce the danger that the simulationist runs a meaningless simulation experiment or encounters a fatal error condition. However, the clipping ranges for monitorable variables behave differently and should not be confounded with range limits: The simulationist can change clipping ranges interactively anytime.

ModelWorks has been designed to make modeling as easy as possible, yet as powerful and flexible as possible. Hence, for ModelWorks a model is a variable, not predefined portion of a simulation program, which has been left out so that the modeler may define it at a later time (Fig. T3). A user of ModelWorks wishes to define freely this open portion according to his current needs, for instance by specifying a new set of coupled differential equations. The modeler does it by writing simple Modula-2 statements, which are to be filled in and linked to the remaining, constant parts of ModelWorks. This is similar to a key which fits into a matching hole of a lock, only the two together rendering the lock into a fully functional unit.

With the model definition program the modeler provides the missing key. The key must conform to certain rules in order to fit into the hole. However, in all other aspects this analogy breaks down, since a key is not constructed before each use anew, or must not be extended, or has not his own particular functionality; the latter are all typical properties of ModelWorks model definition programs.

The remaining parts of the simulation environment, i.e. the actual ModelWorks, can not be modified and constitute the preprogrammed ModelWorks software. They are general and hence common to any simulation program and resemble the lock with a hole for the key. When the simulationist starts a model definition program containing a model definition, the latter is inserted automatically into the hole of ModelWorks and what results is a fully functional simulation program (Fig. T3).

Technically a model definition program is a simple Modula-2 program module. Its main purpose is to define (declare) your model and its model objects, thus preparing the data exchange needed for simulation sessions. ModelWorks does not care how the modeler organizes the structure of the model definition program and actually knows almost nothing about anything the modeler does in his program. The only objects ModelWorks cares about are: models, state variables to be integrated numerically, model parameters to be changed interactively during a simulation session, and monitorable variables for the monitoring of the simulation results. Hence, they are the only objects which have to be made known, i.e. declared, to ModelWorks.

The link of models and their model objects to ModelWorks is achieved via the client interface. In its essence it consists of two library modules: *SimBase* and *SimMaster*. These modules provide all Modula-2 objects (types and procedures) needed to describe a model in the model definition program.

Executing a ModelWorks model definition program means to start first the simulation environment. Running the simulation environment is called a simulation session. At the begin of a simulation session ModelWorks initializes the simulation environment and normally executes all model and model object declarations as programmed by the modeler. It then performs a reset of all current values using all the defaults specified during the declarations. Subsequently ModelWorks is ready to execute commands entered by the simulationist, such as a simulation run, the execution of a simulation experiment, or the editing of the current values, e.g. of a model parameter or an initial value.

ModelWorks is not just another simulation language, since a model definition program is written as a plain Modula-2 program text. As a consequence ModelWorks can not automatically sort the statements which compute derivatives. Compared with other simulation software, e.g. ACSL®[1], this may be considered to be a draw-back. However, experience shows that automatic sorting of statements is error prone, if one models

[1] ACSL® is a proprietary simulation software program that is leased with restricted rights according to license agreement and terms and conditions by Mitchell and Gauthier Associates, Inc. (USA), Concord, MA, respectively by Rapid Data Ltd. (Europe), Worthing, Sussex, UK.

complex and ill-defined systems. Moreover, the greater flexibility offered by the host language Modula-2, a modern, powerful, and formally defined programming language, often outweighs the lack of automatic sorting, which is mostly not much more than a little inconvenience if the model definition has been carefully worked out before its implementation.

Most models maintain tight relationships among their objects such as state variables, parameters, and auxiliary variables etc. The modeler may keep logically connected objects close together, by defining related objects local to the model boundary. The latter normally coincides with the boundary of the scope of a Modula-2 module. Moreover, the modeler is free to use any Modula-2 feature he wishes: For instance model objects may be part of a complex data structure or the model definition may be spread over any number of modules, thus supporting modular modeling. This extensibility is one of the strongest features of ModelWorks.

Even if one is not familiar with the programming language Modula-2 but knows Pascal, it is feasible to use ModelWorks. On the other hand, ModelWorks is powerful and flexible enough to allow also the advanced modeler to develop sophisticated models.

Note that with ModelWorks the modeler has not only full access to all features of Modula-2, but also to those of the *Dialog Machine*[1]. The *Dialog Machine* is a generally applicable software layer between an application program such as ModelWorks and the system software respectively hardware. In this situation the user interacts via the the latter (mouse, keyboard, screen) only indirectly with the application; the *Dialog Machine* intercepts all user interaction and filters it according to a simple user interface. The *Dialog Machine* substantially facilitates the writing of interactive programs. Not only does it simplify the programming of sophisticated dialogs, but also does it ensure automatically a consistent man-machine interface. Hence it allows the modeler to extend the standard, predefined ModelWorks simulation environment easily, efficiently, and without forcing him or her first to become a computer scientist; yet it supports an easy programming of windows, menus, bitmapped graphics, plus mouse input. Moreover, the resulting program will be user-friendly: Thanks to the *Dialog Machine*'s dialog capabilities, the simulationist will be able to enjoy the use of a simulation program, which automatically conforms to a robust man-machine interface. This offers the advanced modeler to concentrate on the modeling process, instead of being distracted by the cumbersome and complex implementation details of user-interface problems. The easy access to the *Dialog Machine* is another strength of ModelWorks.

For instance the modeler may wish to extend the simulation environment by programming his own graphical monitoring in an additional, separate window or by adding further, customized functions to the simulation environment, i.e. by installing more menus offering additional menu commands. To give an example: ModelWorks and the *Dialog Machine* have been successfully used to program an interactive modeling environment, which allows to enter differential equations and model objects at run time, without having to resort to any programming at all.

Despite the many features ModelWorks offers, typical model definition programs are written in a simple, standard format. Hence, as long as one develops models without any sophisticated extras, even the beginning programmer can quickly learn to use ModelWorks successfully. Finally, as a simulationist only, there is no need to know anything about the more advanced features of ModelWorks, since ModelWorks itself has been implemented by means of the *Dialog Machine.* For instance, under-graduate students at the ETHZ have been able to work successfully with ModelWorks model definition programs within a learning time of only a few minutes.

[1] The *Dialog Machine* has been designed by Andreas Fischlin, implemented by Andreas Fischlin, Klara Vancso, and Alex Itten during the pilot project CELTIA under the auspices of Walter Schaufelberger from the Swiss Federal Institute of Technology ETHZ, Zürich, Switzerland.

2 Getting Started with the Simulation Environment

When you read this chapter and follow the instructions given, you learn step by step, how to run simulation experiments with ModelWorks. In particular you learn how to produce behavior trajectories of a sample model and how to change a model's initial and parameter values using the ModelWorks simulation environment.

It is assumed that you know how to operate the computer you are using, its operating system, and typical application software, and that you have ModelWorks installed[1] and are ready in order to actually perform the described procedures on your computer while reading this chapter.

2.1 The Sample Model

The sample model is a simple growth model for grass. It models in a crude way the growth of real grass by assuming logistic growth. In the first phase, the plants grow exponentially under optimal conditions. Within a given, constant time interval (doubling time), the density doubles. With increasing density, limiting factors, such as nutrients, light energy, or competition by the neighboring plants, become more important. This results in a decrease of the growth rate, expressed as a self-inhibition of the plants. Finally, the grass density reaches a maximum, the so-called carrying capacity determined by the plant's environment.

The following nonlinear differential equation describes the model:

$$dG(t)/dt = c_1G(t) - c_2G(t)^2 \tag{1}$$

where

State variable:

grass (g dry weight per m^2):	$G(t)$
Initial amount of grass/initial value:	$G(0) = 1.0$ g/m^2

Model parameters:

grass growth rate (day^{-1}):	$c_1 = 0.7$ day^{-1}
Self-inhibition coefficient(m^2 g^{-1} day^{-1}):	$c_2 = 0.001$ m^2 g^{-1} day^{-1}

Let us have a closer look at the model and its equation. The model has one state variable, the grass density G(t), which is a function of time. Further, it has two constant model parameters, c_1 and c_2. The first term of the differential equation, $c_1G(t)$, describes the exponential growth phase of the plants; the second, $- c_2G(t)^2$, is responsible for the self-inhibition.

The unknown element in Eq. (1) is the function G(t). During a simulation, this function is approximated by calculating a sequence of values $G(t_o)$, $G(t_1)$, $G(t_2)$... given the initial value $G(t_o)$. Since G(t) is defined by a differential equation these computations correspond to a particular solution of Eq. (1). In other words: By numerical integration ModelWorks produces the trajectory going through the point $G(t_o)$, i.e. solves an initial

[1] An exact description on how to install ModelWorks is given in the appendix. Please follow these instructions exactly, otherwise you may have difficulties while executing the described steps.

value problem. The sample model with the differential equation (1) has already been programmed, compiled and is ready for execution[1].

2.2 Simulating the Sample Model

To run the sample model, you have first to start the MacMETH Modula-2 development shell[2]. Start it with a double click on its icon, as you start any other Macintosh application. By the way, although there are other methods possible, it is generally recommended to develop and simulate ModelWorks models only by working with the MacMETH shell in the here described way[3]. To simulate the logistic grass model, choose the menu command *Execute* under the menu *File*. A dialog box is displayed where you can select and open the object file of the model *Logistic.OBM* contained in the folder *Work* or the folder *Sample Models* on one of the ModelWorks diskettes[4].

Upon opening this object file, you will start the ModelWorks simulation environment linked together with the sample model. Technically speaking, this simulation program is an ordinary MacMETH Modula-2 program running as a subprogram under the MacMETH shell. Once fully started, you see the initial screen of the ModelWorks simulation environment with its menu bar, and the four windows for models, state variables, model parameters, and monitorable variables (Fig. T4).

The menu-bar has five ModelWorks menus, each with several commands: *File* lets you print graphs, set preferences and quit the program; *Edit* allows you to access the clipboard to transfer graphs of simulation results to other programs or to desk accessories; *Settings* offers commands to set current values of the global simulation parameters or the so-called project description plus the resetting of current values to their defaults; *Windows* opens or activates the six windows of ModelWorks; and *Simulation* is used to execute and control simulations. In the visible windows, the model objects of the activated model, the grass growth model, are displayed. Throughout this manual read instructions as e.g. "choose menu command *File/Execute*" as "choose menu command *Execute* under menu *File*".

The windows initially displayed serve two purposes: First they are used to display current values such as initial values or parameter values and secondly they are used to enter values or settings. Hence they are called IO-windows (input-output windows). Here are the common characteristics of the four IO-windows:

All IO-windows display a button field in the upper left corner, a list of objects in the middle, and a scroll bar on the right side. Any model object can be selected by a simple mouse click. All subsequent clicks on the buttons refer to the currently selected object. Selection of the bold model title is interpreted as selection of all elements belonging to

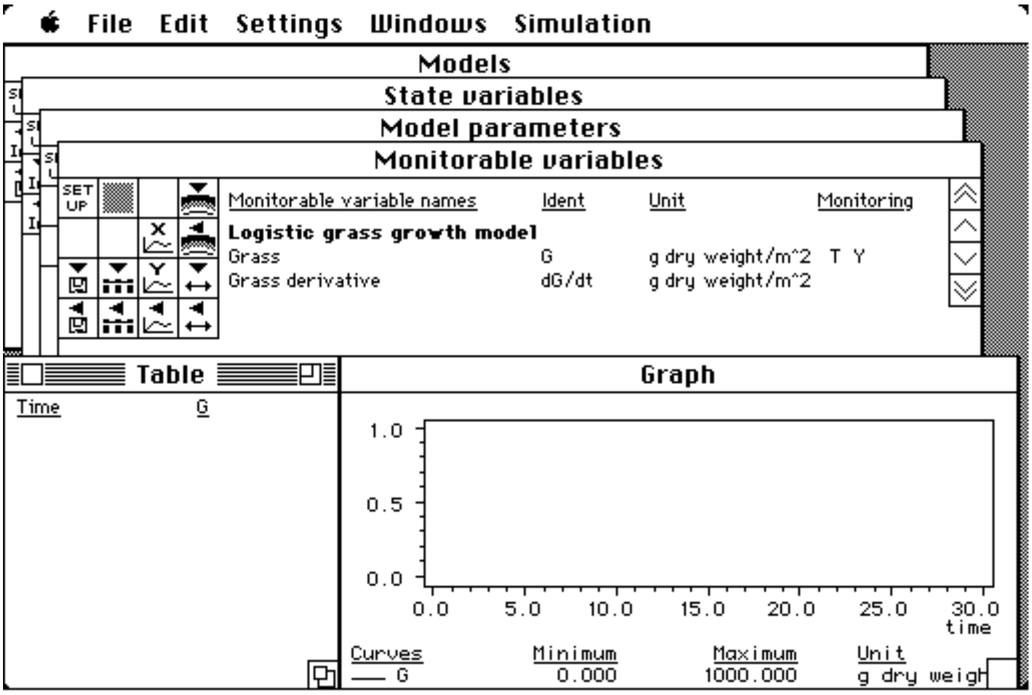
[1] On the Macintosh no preparations are necessary to follow this tutorial except that you should be using a working copy of the software (Working through the tutorial will change the contents of your diskettes, so don't use your originals!). On the IBM PC you are ready only if you have followed exactly the installation procedures described in the *Appendix*, in particular those for the installation of the ModelWorks software. You should have an executable GEM application made from the sample model *LOGISTIC.MOD* which is now called *LOGISTIC.APP*.

[2] On the IBM PC you have to start first the GEM desktop and then to start the application *LOGISTIC.APP*. In case you should encounter difficulties up to this point, please refer to the GEM documentation and/or check your installation (s. a. the *Appendix*). Ignore this and the next paragraph to which this footnote belongs, they contain Macintosh specific information only.

[3] Please refer to the *Appendix* for more details on the exact organization of the ModelWorks diskettes and how to work with MacMETH.

[4] In case you should have any difficulties up to this point executing the described steps on your computer, please refer to the MacMETH documentation and/or check your installation (see also the Appendix for detailed instructions how to install ModelWorks and a brief introduction how to work with MacMETH).

this model. Selection of *all* objects of a list is possible by clicking the button ▨ . All buttons with a down arrow ▼ are used to *set* a current value, whereas buttons with a left arrow ◀ are used to *reset* a value to its default as defined by the modeler. The button SET UP serves to specify which columns, i.e. current values of the model objects, are to be shown in the list.



Monitorable variable names	Ident	Unit	Monitoring
Logistic grass growth model			
Grass	G	g dry weight/m^2	T Y
Grass derivative	dG/dt	g dry weight/m^2	

Time	G

Curves	Minimum	Maximum	Unit
—— G	0.000	1000.000	g dry weigh

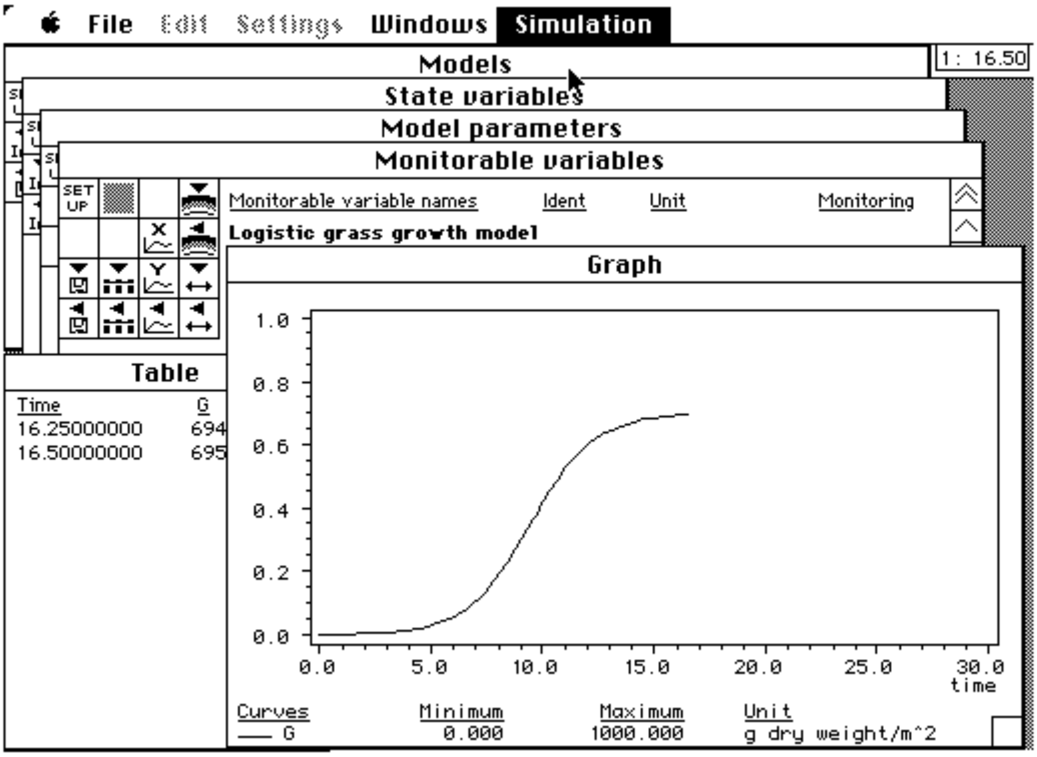
Fig. T4: Initial screen of the ModelWorks simulation environment obtained immediately after starting the model definition program, i.e. the module which contains the definition of the logistic grass growth sample model. All four IO-windows for the models, the state variables, the model parameters, the monitorable variables, plus the graph and the table window are open. The latter two windows have been slightly rearranged from their default size and position in order to give a better view onto the IO-windows.

The menu command *Settings/ All above* resets the program to its original state as it was at the beginning of the simulation session. If you should loose the orientation during a complex series of interactive changes, this command allows you always to resume a well defined state.

If you should have changed already any settings up to this point, reset it first with the menu command *Settings/Reset All above* before continuing with this guided tour.

2.2.1 DEFAULT SIMULATION

You can immediately start a simulation experiment (run), because ModelWorks ensures that any valid model definition program contains all necessary data for the so-called default simulation run. Choose the menu command *Simulation/Start run* to actually start the simulation. The graph and the table windows are automatically opened, and a small time display window appears in the upper right corner. Now, ModelWorks integrates the differential equation and displays simultaneously the results in the graph and table windows. In the graph window, you see how the grass grows at the beginning exponentially and how it reaches finally its equilibrium density (Fig. T5).



```
Time              G
16.25000000       694
16.50000000       695
```

```
Curves    Minimum    Maximum     Unit
—— G        0.000    1000.000    g dry weight/m^2
```

Fig. T5: ModelWorks simulation environment during a simulation run of the logistic grass growth sample model. In addition to the IO-windows the table plus graph windows are currently open. The current time is displayed in the upper right corner. The graph window shows the growth curve of the grass (g/m^2).

2.2.2 Changing initial values

Initial values can be changed in the window for state variables: bring the state variable window to the front (click on it or choose the command *Windows/State variables*), and select the state variable *Grass*. Click on the button ▼Init and change in the appearing entry form the initial value to 4.0. This means, that the grass starts growing at a higher density. Verify this in another simulation run; the maximal density remains the same. Use other initial values to explore the model's behavior (e.g. 200; 0.1). If you want to enter a initial value out of the allowed range [0,10'000], the program will refuse to accept it. For instance try to enter 10001 or -1 and see what happens.

After your explorations, reset the initial value with the menu command *Settings/Reset All model's initial values*, or with the button ◀Init.

2.2.3 Changing parameters

Model parameter values can be changed in the window for model parameters in the same manner as described for initial values. Clear the graph with the menu command *Windows/Clear graph* and perform a simulation run for reference purposes. What will happen if you increase the growth rate c_1 of the grass? Faster growth, or higher maximal density? Increase the growth rate from 0.7 to 1.2, and perform a simulation run. Now, the population grows faster, and reaches a higher equilibrium value. In the table output you can see the maximum value the grass density reached (≈1200 g/m^2).

2.2.4 CHANGING SCALING

As the grass curve exceeds the maximum value of 1000, ModelWorks clips these values. In order to avoid this clipping and to have also a look at the clipped portions of the curve, you should rescale the monitorable variable *Grass*. You may achieve this by increasing the upper limit of interest for the grass. This can be done in the window for monitorable variables. Bring it to the front, select *Grass*, and click on the button ↕. In the appearing entry form, you can enter the new scaling value for the upper limit of interest, type 1200 and click into the OK button; ModelWorks writes the values automatically into the legend in the graph window. Perform another simulation run. This time, the curve should be fully visible and no longer be clipped.

2.2.5 CHANGING MONITORING

ModelWorks uses the expression *monitoring* for any kind of display of simulation results. Any variable which can be monitored is called a *monitorable variable.* Every monitoring definition is done in the window for monitorable variables. ModelWorks uses one window for numerical display (tabulated), and one window for the graphical display (line charts) of results, called the table window respectively the graph window. Storage of numerical results is also supported on the so-called stash file for the use of the data by other programs, e.g. a spread sheet program like Microsoft Excel™ or a program for statistical analysis or just to document a simulation run. At a time ModelWorks uses just one stash file only.

The model definition program of the sample model declares a second monitorable variable beside the state variable *Grass*. This is the derivative of grass listed in the IO-window *Monitorable variables* with the name *Grass derivative*. However, the defaults specified by the modeler for this variable are such that it is not displayed unless the simulationist activates it for actual monitoring. To see what the curve of the derivative looks like, bring the window for monitorable variables to the front, select *Grass derivative*, and click on the button Y (Toggle function). In the column *Monitoring* appears a "Y" in the row for the monitorable variable *Grass derivative* and the legend of the graph is accordingly updated[1]. The values of the variable *Grass derivative* will be drawn as another curve in the line chart of the window *Graph* during the next simulation run. Running another simulation displays the two curves *Grass* respectively *Grass derivative*.

You may generate also other graphs, e.g. *Grass derivative* versus *Grass*. Select the monitorable variable *Grass* in the window for the monitorable variables window and click onto the buttons Y and then X. In the column *Monitoring* disappears first the "Y" and then appears a "X" in the row for the monitorable variable *Grass*. This means that the values of the variable *Grass* will no longer be shown on the y-axis (ordinate) (toggle function) but will be used as x-values on the abscissa. The values of the variable *Grass derivative* should still be displayed as y-values (check the "Y" in the column *Monitoring* and the legends for the curves and the abscissa in the graph window). Run another simulation run and you should see a dome-shaped curve of *Grass derivative* vs *Grass.*

Before you proceed, please select the command *Reset: All model's graphing* under menu *Settings*.

[1] This may depend on the currently set preferences, i.e. the immediate update of the graph takes place only if the option «Once changed, immediately redraw graph» available under menu command *File/Preferences* is currently checked; otherwise the redrawing of the graph will be deferred till the begin of the next simulation run.

During the steps described in the previous two paragraphs you may have noticed that ModelWorks uses different colors[1] and line patterns if you have activated several monitoring variables at once. For instance the "Y" in the window *Monitoring variables* is drawn in the same color as the corresponding curve, and curves are drawn using different patterns (important on monochrome screens and laser printers) in order to assist you in telling the curves apart. These characteristics of a monitoring variable are called curve attributes and they consist of first the line style (*LineStyle* - the pattern with which a line connecting two points is drawn), second the color of a curve (*stain*), and thirdly the *symbol* with which points of a curve are marked. Unless explicitly specified, ModelWorks assigns curve attributes automatically, which is therefore called the automatic curve attribute definition strategy. For instance following this strategy ModelWorks assigns automatically the *stain coal* (black) to the first and *ruby* (red) to the second variable being activated for monitoring[2]. This helps the user to tell curves optimally apart under many circumstances.

However, the automatic curve attributes definition strategy has also its disadvantages, in particular the attributes may change all the time. For instance in one graph the *Grass* is black, in the other it is red but *Grass derivative* becomes black etc. The actual color will depend only on the exact chronological sequence in which a monitorable variable has been activated for monitoring with the button 📈. To try this out click on *Grass derivative* in the *Monitorable variables* window and toggle it with button 📈 so that it becomes activated (Y). Run a simulation, e.g. this time by pressing the command key (clover-leaf key) simultaneously with key 'R'. Note that curve *Grass* is drawn in black (unbroken) and Grass *derivative* in red (broken). Then click on *Grass* in the *Monitoring variable* window and toggle it with the button 📈 twice. Again both monitoring variables are activated (Y). Now rerun the simulation and note that this time colors are reversed, i.e. *Grass* is drawn in red (broken) and *Grass derivative* in black (unbroken). This is only because *Grass* has been activated for monitoring as the second curve after *Grass derivative* which has remained untouched during the toggling of *Grass*.

The convenient the automatic curve attributes definition strategy may be, the confusing it may become in complicated situations where the simulationist wishes to run may simulations and to compare the same monitoring variables. ModelWorks allows you to gain complete or partial control over the assignment of curve attributes, i.e. you can adopt your own curve attributes assignment strategy.. You may achieve this by assigning explicitly to monitoring variables their particular curve attributes. For instance change the color, of the curve *Grass*, to green and draw it with the symbol 'v' which may remind you of real grass tuft. Click on *Grass* in the window for monitorable variables, and click on the button ▤ (rainbow toggle function). Choose the attributes *unbroken* as line style[3], the *stain emerald* (green), and type 'v' in the symbol field; then click the "OK" push button. Finally select the command *Set: Global simulation parameters...* under the menu *Settings* and change the *monitoring interval* to 0.5; then click the "OK" push button. Now run another simulation run and you should see this time a green curve displaying the symbol 'v' at times 0, 0.5,1, 1.5,2 etc.

Note that from now on the curve *Grass* will always be drawn with exactly these curve attributes, i.e. in green regardless when and with how many other curves you currently display it. To see this behavior click on *Grass* in the *Monitoring variable* window and toggle it with the button 📈 twice. Run a simulation and note that *Grass* will be drawn

[1] On IBM PCs there are no colors available. Sorry, but the memory limitations of MS DOS have forced us to sacrifice them.

[2] the third becomes *emerald* (green), and the fourth *sapphire* (blue). For more details see part *Reference*.

[3] Note that specifying a line style is crucial; if you should omit it, automatic definition of curve attributes would still remain active regardless of the settings of stains or plotting symbols.

in green (unbroken,'v') and *Grass derivative* in black (unbroken)[1]. then click on *Grass derivative* and toggle it with the button 📈 once, so that it will no longer be activated for monitoring. Rerun the simulation and note that this time *Grass* is still drawn in green (unbroken,'v').

Once again there is a disadvantage to this method if all your monitoring variables adopt it: you will run more often than you may first think into a situation where several curves currently in display happen to be all of the same color or line style (may be important on a no-color only laser printer or a publication). For instance click on *Grass* in the *Monitoring variable* window and click on the button ▤, then select the line style broken, press the space bar to clear the symbol and hit return. Now click on *Grass* and activate it with button 📈. Rerun the simulation and note that you can no longer separate the two curves on a printer or a monochrome screen. Of course it is also possible to switch back to the automatic assignment strategy: Select *Grass* and click the button ▤; in the appearing entry form click into the top-most radio button *automatic definition of curve attributes* and close it by pressing the enter key, or alternatively, reset the curve attributes of variable *Grass* with the button ▤ or with the command *Reset: All model's curve attributes* under menu *Settings.*

Finally you can learn how to monitor the values of the variable *Grass derivative* in tabular form. Bring the window for monitorable variables to the front, select *Grass derivative*, and click on the button ▦ (Toggle function). In the column *Monitoring* appears a "T" in the row for the monitorable variable *Grass derivative*. This means that the values of the variable *Grass derivative* will be written into a column of the table in the window *Table* during the next simulation run. Bring the table window to the front, enlarge it till you see all columns and rerun the simulation.

Before continuing reset this time the table and graph monitoring plus all curve attributes to their defaults with the following method: Bring first the window *Models* to the front, select the row containing the model title (*Logistic grass growth model*) and click on the buttons ▦, 📈, and ▤. Note that the effect of this method is exactly the same as if you would have clicked on the buttons with the same pictures in the window *Monitorable variables* after having selected the model title (bold face *Logistic grass growth model*)in the latter window.

2.2.6 CHANGING PARAMETERS DURING SIMULATION

Now, you will learn, how you can change model parameters even in the middle of a simulation run. We let the model simulate the grass growth as before; but, when the density has reached its maximal value, we increase the self-inhibition of the plants, the parameter c_2 (this signifies, that the carrying capacity of the environment $K = c_1/c_2$ decreases, for instance due to a sudden nutrient depletion or an unknown toxic substance). After this change, the grass density will tend to a lower equilibrium value.

To do this, start a simulation with the same settings as before. When the population has reached its maximal value (this happens approximately at time 15.0, watch the time window), interrupt the simulation with the menu command *Simulation/Halt run (Pause).* In the parameter window, you can now increase the value of the self-inhibition coefficient c_2 from 0.001 to 0.002. continue the simulation with *Simulation/Resume run*, and observe the reaction of the system.

[1] Note that on a monochrome screen or a non-color printer such as a laser printer both curves are drawn with the same line style, i.e. unbroken, and can only be separated by their different symbols 'v' resp. none.

2.2.7 CHANGING INTEGRATION METHODS

To start with this section, reset the program to its initial state with *Settings/Reset All above*.

The numerical integration of the differential equation has to be done with special integration algorithms. ModelWorks offers several different methods for numerical integration. Each has its particular advantages and disadvantages. The default algorithm used in this example is *Euler,* which is shown in the model window. We shall compare two integration methods and record the results on the stash file.

First, we have to define the stash file output. Bring the window for monitorable variables to the front, select the variable *Grass*, and click on (Toggle function). In the column *Monitoring* appears the letter "F" for stash filing (this is in addition to the "T" and "Y", which signify that this variable is written already into the table and drawn in the graph). Now, during a simulation run the values of the variable *Grass* will be written also onto the stash file. Note, by default every new simulation will overwrite the stash file's content.

Differences between integration methods become more obvious with large integration step sizes (this is the step which is internally used for numerical integrations). Therefore, we change this step to a higher value. Select the menu command *Settings/Global simulation parameters*, and change in the entry form the value for the integration step *and* the monitoring interval to 1.0. (The monitoring interval is the interval at which simulation results are displayed. If this is smaller than the integration step, the former is automatically reduced to generate the requested result display).

With these settings you can perform a simulation run. The integration method *Euler* is the simplest integration algorithm; therefore it is fast, but not very precise. After the integration, the stash file *ModelWorks.DAT*[1], contained in the same folder as the MacMETH shell resides, is ready for inspection and you can open it with any text editor you have available, e.g. the desk accessory *MockWrite*[2]. It should contain the same simulation results as the table window (look for look for *DATA-BEGIN of Run 1 ...*).

For the next simulation choose another algorithm: Bring the model window to the front, select the model, and click ∫dt. Choose the more precise algorithm *Runge Kutta 4*: To prevent overwriting of the stash file, we change its name. Therefore, before starting the next simulation run, choose first the menu command *Settings/Select stash file*, and give the stash file a new name, e. g. *ModelWorks.DAT2*[3]. Only now start the simulation by choosing the menu command *Simulation/Start run.*

The new run will give different results, as you can easily verify in the graph. For a more detailed, numerical analysis, you could use the values on the two stash files. ModelWorks would even allow to write the two time series onto the same stash file[4].

[1] On the IBM PC the name of this file is truncated to 8 characters and hence becomes *MODELWOR.DAT*. The file resides in the same directory as *LOGISTIC.APP*.

[2] On the IBM PC use e.g. the editor of the JPI TopSpeed Modula-2 development environment.

[3] On the IBM PC use e.g. *MODELWOR.DA2*

[4] This a more advanced technique, requiring multiple model declarations. For more details on this subject, please refer to the reference manual.

2.2.8 Program termination

The program can be terminated with the menu command *File/Quit.* After that, the MacMETH environment becomes active again, ready to accept your next command, for instance the execution of another model[1]. To return to the desktop of the Finder, use the menu command *File/Quit* of the MacMETH shell.

[1] On the IBM PC you will return to the GEM desktop.

3 Getting Started with Modeling

In this chapter you will get a closer look at the way ModelWorks models are defined. First it is explained, how the Modula-2 program defining the logistic grass growth sample model was written. Then you learn how to define a new model by modifying an existing program text by using the MacMETH programming environment[1]. Finally, the new model is made ready to be executed, i.e. simulated, using ModelWorks to start another simulation session.

Again it is assumed that you know how to operate the computer and its software, and that you have ModelWorks installed and ready in order to actually perform the described steps on your computer while reading this chapter.

3.1 The Model Definition Program of the Sample Model

In the last chapter you worked with the grass growth model in the ModelWorks simulation environment as a simulationist. Now, we shall have a closer look at the used simulation program as a modeler. This program defines (declares) a logistic growth model and is called a model definition program. Step by step, we shall now go through this sample program contained in the file *Logistic.MOD*, and have a closer look at all its elements. The complete listings of the program *Logistic*, and of the definition modules *SimMaster* and *SimBase*, which form the client interface, are given in the appendix. Many ModelWorks model definition programs have the same structure as *Logistic.MOD*.

The import list contains all the items (types, constants, variables, and procedures) used within the program module. They are exported by the modules which form the client interface of ModelWorks:

```
FROM SimBase IMPORT
  Model, IntegrationMethod, DeclM, DeclSV, DeclP, RTCType,
  StashFiling, Tabulation, Graphing, DeclMV, SetSimTime,
  NoInitialize, NoInput, NoOutput, NoTerminate, NoAbout;

FROM SimMaster IMPORT RunSimMaster;
```

RunSimMaster is the procedure, which will start the simulation environment of ModelWorks. *DeclM, DeclSV, DeclMV* and *DeclP* are the procedures used to declare the models and their objects. The types *Model, IntegrationMethod, StashFiling, Tabulation, Graphing, RTCType* are needed in order to declare the model objects. All these objects, i.e. models, state variables, model parameters, monitorable variables, auxiliary variables and all associated variables, like derivatives, initial values and default values, are typically declared locally to the program module boundaries:

```
VAR
  m:  Model;
  grass, grassDot, c1, c2:  REAL;
```

m is a variable of the opaque type *Model*. It allows to reference the whole model. The logistic growth model has one state variable, and two parameters. ModelWorks requires that state variables, monitorable variables, and model parameters are variables of the elementary Modula-2 data type REAL. For every state variable of a ModelWorks model, we also have to define an associated second variable of type REAL. It either corresponds to the derivative ($\dot{x}(t) = dx/dt$ - continuous time) or the

[1] On the IBM PC you have to use the JPI TopSpeed Modula-2 development environment. For more information on how to operate it, consult the *Appendix* section installation or your JPI TopSpeed Modula-2 documentation.

new value (x(k+1) - discrete time) of the state variable (x(t) respectively x(k)). For the sample model, which is continuous time, this is the variable *grassDot.*

The procedure *Dynamic* is the heart of a ModelWorks model definition program. It contains the Modula-2 translation of the mathematical equations describing the model's dynamics, here Eq. (1); for a proper functioning of ModelWorks, it is very important, that this procedure computes the exact values of the derivatives or new values of all state variables as required by the given equation(s):

```
PROCEDURE Dynamic;
BEGIN
  grassDot:=  c1*grass - c2*grass*grass;
END Dynamic;
```

The procedure *Objects* contains the declarations of all model objects. For each of the four model objects, models, state variables, parameters, and monitorable variables, there exists a special declaration procedure. Once such a procedure has been called, ModelWorks knows the variable, defaults, plus ranges corresponding to the model object, and can access it to maintain its values, or can show it in a window, or use it to display its current value in a graph. It is mandatory to declare a model if you wish to declare model objects (see below). The declaration of model objects, i.e. state variables, model parameters, or monitorable variables is optional and depends only on the current needs[1].

The procedure *DeclSV* declares the state variable *grass*:

```
DeclSV(grass, grassDot, 1.0, 0.0, 10000.0,
       "Grass", "G", "g dry weight/m^2");
```

The actual parameters are the two real variables for the state variable itself *grass*, and its derivative *grassDot*. Next, there are three real constants: the default initial value, and the upper and lower limit of the range of initial values.There is no such thing as negative grass, hence the lower limit has been set to 0.0, the upper to a value beyond which values are no longer plausible. The three strings are the name, an abbreviated name, and the unit of the state variable. These strings, and the initial value, will be displayed in the IO-windows for state variables. The limits for the initial value will be used during interactive changes: attempts by the simulationist to enter initial values out of the allowed range will be refused. With this mechanism the modeler can prevent the simulationist from entering values which would result in illegal simulation experiments for which the model is not defined or which could cause some other fatal run-time errors.

The procedure *DeclMV* declares the variables *grass* and *grassDot* as monitorable variables. This is necessary if we want to monitor the values of these variables on the stash file, in the table, or in a graph. Typically state variables, auxiliary variables, and output variables (used to couple submodels) are the model objects which are declared as monitorable variables. Our calls of DeclMV:

```
DeclMV(grass, 0.0, 1000.0,
       "Grass", "G", "g dry weight/m^2",
       notOnFile, writeInTable, isY);
DeclMV(grassDot, 0.0, 500.0,
       "Grass derivative", "dG/dt", "g dry weight/m^2/time",
       notOnFile, notInTable, notInGraph);
```

[1] For instance, you could use ModelWorks also for the plotting of a function, e.g. a time series measured during an experiment (parallel model to compare measured with simulated behavior). In this case you would need to declare only a monitorable but not a state variable.

The first parameter denotes the real variable, which will be monitored. Next, there are two real constants: the default values for the scaling of the graphics output. The three strings are the same as for the state variables: the name, abbreviated name and the unit of the monitorable variables. The next three elements are default settings for file, table and graph output (e.g. isY means, that by default the variable *grass* will be plotted on the y-axis (ordinate) of the graph). These elements are imported with the enumeration types *StashFiling, Tabulation, Graphing*.

DeclP is the procedure for the declaration of model parameters. Since we have two model parameters, c_1 and c_2, it is called twice:

```
DeclP(c1, 0.7, 0.0, 10.0, rtc,
      "c1 (growth rate of grass)",
      "c1", "day^-1");
DeclP(c2, 0.001, 0.0, 1.0, rtc,
      "c2 (self inhibition coefficient of grass)",
      "c2", "m^2/g dw/day");
```

The parameter list contains first the real variable of the parameter. Next, there are three reals: the default value of the parameter, and the upper and lower limit of its range within which the simulationist may enter a new parameter value. A parameter declared as *rtc* (*RTCType*) means that its value may be changed even in the middle of a simulation, not only before or after a run. The three strings are again: the name, the abbreviated name, and the unit of the parameter. Note that model parameters must not be implemented as constants; since they can be changed interactively during a simulation session, they must be Modula-2 variables.

The next procedure *ModelDefinitions* declares the model. It contains the following call to procedure *DeclM*:

```
DeclM(m, Euler, NoInitialize, NoInput, NoOutput, Dynamic,
      NoTerminate, Objects, "Logistic grass growth model",
      "LogGrowth", NoAbout);
```

This declares the logistic grass growth model within ModelWorks. The first actual parameter is the model variable *m* . Then, *Euler* (type *IntegrationMethod*) defines the default integration method for this model. The next six parameters are all procedures; Modula-2 supports procedure types and therefore it is possible to use procedures as actual parameters when calling a procedure. This mechanism has to be used to install in ModelWorks all procedures, which describe the model dynamics and perform the model object declarations. It is then left to ModelWorks to actually call any of these procedures. The procedures *(No)Input, (No)Output, Dynamic* describe the model's dynamics, and the procedures *(No)Initialize, (No)Terminate* describe actions to be taken at the begin and end of every simulation run (more details on the purpose and usage of these procedures is given in the reference manual and in the definition of module *SimBase*). Some of these procedure identifiers have the prefix *No*, which means that these procedures have actually just empty bodies and are needed here only to call *DeclM* properly. The next procedure, *Objects*, declares all model objects as explained above. The next two elements are strings for the name and an abbreviated name of the model. The last procedure, in our case *(No)About,* could be used to write information about the model in the help window of ModelWorks (this window is activated by clicking on the button ? in the model window).

The procedure *SetSimTime* sets the default values for the simulation start and stop time.

Finally, we come to the short body of the program module:

```
BEGIN
  RunSimMaster(ModelDefinitions);
END Logistic.
```

The only action performed by this program is to call the procedure *RunSimMaster*. This starts the ModelWorks simulation environment, and passes the program control to ModelWorks. Its parameter, the procedure *ModelDefinitions*, contains the complete definition of the sample model. Note, how the procedures are nested: First ModelWorks will activate the simulation environment and call the procedure *ModelDefinitions*. Later on it will call the procedure *Objects*; which will result again in calls to the procedures *DeclSV*, *DeclMV*, and *DeclP*. This mechanism ensures that it is clear which objects belong to which model. Note also that while declaring an object, this object will also be immediately initialized with the given values. E.g. returning from procedure *DeclP(c,p,...* will imply that the default value *p* for the model parameter is assigned to the variable *c*.

3.2 Developing a New Model

Instead of just reading an existing model definition program we will develop a new model. However, the new model will not be written completely anew, that would be too cumbersome. Instead we will simply modify a copy of the sample model definition program to develop the new model. This is an easy, hence generally recommended way to develop ModelWorks model definition programs.

3.2.1 THE NEW MODEL

The new model does not only include grass, but also herbivores as the second state variable *aphids*. Aphids feed on the grass and establish an ecological relationship, for the sake of simplicity, we assume somehow similar to other predator-prey relationships. The new model will consist of two coupled differential equations, each describing the dynamics of the two species, according to the Lotka-Volterra predator-prey model[1]: the grass is the prey, and the aphids are the predators.

The model is described with the following nonlinear second order differential equation system; note that the parameter and initial values are not the same as in the former model[2]:

$$\begin{aligned} dG(t)/dt &= c_1\, G(t) \;-\; c_2\, G^2(t) \;-\; c_3\, G(t)\, A(t) \\ dC(t)/dt &= c_3\, c_4\, G(t)\, A(t) \;-\; c_5\, A(t) \end{aligned} \tag{2}$$

where

State variables:

Grass (g dry weight [dw] per m^2):	$G(t)$
Initial amount of grass/initial value:	$G(0) = 200$ g/m^2
Aphids (g dry weight [dw] per m^2):	$A(t)$
Initial number of aphids:	$A(0) = 20$ g/m^2

Model parameters:

Grass growth rate (day^{-1}):	$c_1 = 0.4$ day^{-1}
Self-inhibition coefficient(m^2 g^{-1} day^{-1}):	$c_2 = 8 * 10^{-5}$ m^2 g^{-1} day^{-1}
Grass consumption rate by aphids(m^2 g^{-1} day^{-1}):	$c_3 = 1.5 * 10^{-3}$ m^2 g^1 day^{-1}
Aphids birth rate per grass consumption (g g^{-1}):	$c_4 = 0.1$ g g^{-1}
Death rate of aphids (day^{-1}):	$c_5 = 0.2$ day^{-1}

[1] Early this century these models have first been formulated by LOTKA (1925) and VOLTERRA (1926). Their purpose is to describe the population dynamics of a prey and a predator species.

[2] The new parameter and initial values are not necessarily realistic, since the sole purpose of the model is to help to learn ModelWorks.

Let us have a closer look at the new model and its equations: The first equation is the same as before, except that the term $- c_3$ G(t) A(t) has been added. This term is responsible for a decrease of the net grass growth, due to grass consumption by aphids. The second equation describes the dynamics of the aphids: They can grow by feeding on the grass, which is expressed with the term c_3 c_4 G(t) A(t). The second term, $- c_5$ A(t), accounts for the natural mortality of the aphids.

In the next section it will be explained how to alter step by step a copy of the logistic grass growth, sample program to implement this new grass-aphids model; then the program will be compiled and finally be simulated.

It is assumed that you know how to edit a program text, and that you are familiar with the following terms and concepts: program text or source code, compilation, and the execution of programs.

3.2.2 MODEL DEFINITION PROGRAM FOR THE NEW MODEL

The ModelWorks distribution diskettes contain an editor[1], it is the shareware[2] desk accessory *MockWrite*, a simple, straight-forward text editor. To program the new model choose *MockWrite* in the Apple-menu[3] and open the file *Logistic.MOD* in the folder *Sample Models*. We create a copy of this file with the same content by choosing the menu command *MockWrite/Save As*[4]. Give the new file the name *GrassAphids.MOD*[5], and save it in the folder *Work*. This is the copy we shall use to develop the new model, thus avoiding to destroy the program text of the logistic grass growth sample model.

First change the module name. It is recommended to use the same name for the module name as you have used to name the file containing the module, i.e. *GrassAphids*. Throughout the following explanations the affected program text is shown together with its context. The text portions actually having been altered or added are shown underlined. At the beginning of the file

```
MODULE GrassAphids; (*My name, today's date*)

  (**********************************)
  (* Lotka-Volterra Grass and Aphids *)
  (**********************************)
```

and at the end of the file:

```
  RunSimMaster(ModelDefinitions);
END GrassAphids.
```

There is no need to change the import list. All objects required are already imported from the modules *SimMaster* respectively *SimBase*.

[1] On the IBM PC an editor is part of the JPI TopSpeed Modula-2 development environment.

[2] Please note that shareware does not mean it is free, but you owe the author a payment in case you use the software on a regular basis.

[3] On the IBM PC use the editor of the JPI TopSpeed Modula-2 development environment.

[4] On the IBM PC use the command *write to ...* under the *Editor Menu* of the JPI TopSpeed Modula-2 development environment.

[5] On the IBM PC name the file e.g. *GRASSAPH.MOD*.

Next declare the new state variable *aphids*, its derivative *aphidsDot*, and the three new parameters *c3*, *c4,* and *c5*:

```
VAR
  m:  Model;
  grass, grassDot, c1, c2:  REAL;
  aphids, aphidsDot, c3, c4, c5:  REAL;
```

Change the procedure *Dynamic* by adding the consumption term into the first statement plus inserting a second statement corresponding to the second differential equation:

```
PROCEDURE Dynamic;
BEGIN
  grassDot:=  c1*grass - c2*grass*grass - c3*grass*aphids;
  aphidsDot:= c3*c4*grass*aphids - c5*aphids;
END Dynamic;
```

Now edit the procedure *Objects* . Since several default values will be different from the ones of the old model, first change the parameters of the declaration procedures already present. The behavior of the state variable *grass* is different. It needs another initial value:

```
  DeclSV(grass,  grassDot, 200.0, 0.0, 10000.0,
    "Grass",  "G", "g dry weight/m^2");
```

The monitorable variable *grass* needs a new upper limit for its clipping range:

```
  DeclMV(grass, 0.0, 10000.0,
    "Grass", "G", "g dry weight/m^2",
    notOnFile, writeInTable, isY);
```

The model parameters *c1* and *c2* need new default values:

```
    DeclP(c1, 0.4, 0.0, 10.0, rtc,
      "c1 (growth rate of grass)",
      "c1", "day^-1");
    DeclP(c2, 8.0E-5, 0.0, 1.0, rtc,
      "c2 (self inhibition coefficient of grass)",
      "c2", "m^2/g dw/day");
```

Secondly, insert the procedures declaring the variable *aphids* as a state and as a monitorable variable, plus call the procedures declaring the new parameters:

```
    DeclSV(aphids, aphidsDot,20.0,  0.0, 1000.0,
      "Aphids", "A", "g dry weight/m^2");

    DeclMV(aphids, 0.0, 1500.0,"Aphids", "A","g dry weight/m^2",
      notOnFile, writeInTable, isY);

    DeclP(c3, 1.5E-3, 0.0, 1.0, rtc,
      "c3 (coupling parameter)",  "c3", "m^2/g dw/day");
    DeclP(c4, 0.1, 0.0, 10.0, rtc,
      "c4 (ratio of grass net use by aphids)",  "c4", "-");
    DeclP(c5, 0.2, 0.0, 10.0, rtc,
      "c5 (death rate of aphids)",  "c5", "day^-1");
```

You could call these procedures in any order, mix declarations of state variables with those of monitorable variables or parameter declarations. However, consider that the sequence of declarations corresponds to the order in which they are listed in the I/O-windows of ModelWorks simulation environment.

The model declaration procedure *ModelDefinitions*, remains the same; except for minor changes in the actual parameters of the call to procedure *DeclM*. As the new model requires a better integration algorithm, we change the default method from *Euler* to *Heun*; further we change the model name strings:

```
DeclM(m, Heun, NoInitialize, NoInput, NoOutput, Dynamic,
      NoTerminate, Objects, "Aphid-grass model (Lotka-Volterra)",
      "GrassAphids", NoAbout);
```

Change the defaults for the simulation start and stop time as follows:

```
SetSimTime(0.0,100.0).
```

The main program needs no changes.[1]

Once you have finished editing the new model, save it with the command *Save* in the *MockWrite* menu, and close the *MockWrite* window[2].

3.2.3 Compilation of the new model

Use the MacMETH shell for the compilation and execution of ModelWorks models[3]. If you are not already in the MacMETH shell, start it now the same way as you have done before, when you have started the simulation environment. Select the command *File/Compile* and type the name of your just written source program: *GrassAphids.MOD* (or hit the TAB-key to choose the file with the ordinary Macintosh file opening dialog box). Press return or click the mouse to start the compilation (or click into the *Open* button).

Should you encounter any problems, e.g. the message *File not found*, check your installation[4]. If the compiler finds no errors in your program, the compilation will end with the message *+ :Work:GrassAphids.OBM size*; else you will see the message *+ :Work:GrassAphids.RFM errors detected*. In both cases, quit the compiler by pressing the return key or clicking the mouse.

In case compiler errors have been detected, you must first correct them before you can continue. You can ask the MacMETH shell to insert the error messages at the violating locations in your model definition source file by following this method: Select the menu command *Merge* under menu *File* of the MacMETH shell immediately after the compilation. Then use the text editor to correct your errors in the model definition program by searching for comments containing 4 hash marks ("####"); these comments contain the compiler error messages pointing with a little arrow "†" to the

[1] A complete listing of the new model is contained in the Appendix.

[2] On the IBM PC use the command *save file* under the *Editor Menu* of the JPI TopSpeed Modula-2 development environment.

[3] On the IBM PC use the JPI TopSpeed Modula-2 development environment. For more information on how to edit, compile, and correct programs with it, consult the *Appendix* section installation or your JPI TopSpeed Modula-2 documentation. Except for the last sentence ignore the whole section to which this footnote belongs, it contains Macintosh specific information only. However, in contrast to the Macintosh version you will have to add an extra step: link the compiled module and rename the resulting application to *GRASSAPH.EXE to GRASSAPH.APP.*

[4] Please refer to the Appendix for the installation of the ModelWorks software and the working with MacMETH.

position the error has been detected[1]. E.g. if your model definition program is missing the declaration of the parameter c_3, then your file may look similar to this:

```
       PROCEDURE Dynamic;
       BEGIN
         grassDot:=  c1*grass - c2*grass*grass - c3*grass*aphids;
     (* #### identifier not declared or not       † visible    *)
     (* #### incompatible operand types                     † *)
         aphidsDot:= c3*c4*grass*aphids - c5*aphids;
```

Insert your corrections and recompile your program. Execute the *Merge* command also after a successful compilation in order to have the old error-messages automatically removed (*Merge* always removes old error messages before it inserts any new ones). If needed, repeat the edit-compile-merge cycle until the compiler finds no more errors.

3.2.3 Simulation of the new model

Choose from within the MacMETH shell the menu command *File/Execute*[2]. A dialog box is displayed where you can select and open the just compiled object file *GrassAphids.OBM*. Note, the name of the OBM-file is defined by the name of the module, and **not** by the name of the file containing the source program. To avoid confusion it is recommended to use always the same names for files and modules.

After a while, you see the initial start-up screen of the ModelWorks simulation environment with the new variables displayed in the I/O-windows. Execute the following steps to explore the new model:

- Run a simulation with the default settings (Choose *Simulation/Start run*)

- Define a graph where the predator is plotted versus the prey (state space curve): Select the prey, and toggle its curve definition by clicking on the button . Click the button to define a plot which uses the x-axis (abscissa) to plot the prey values. Start a new simulation run. The resulting curve shows nicely how the grass and the aphids reach an equilibrium point.

- Set $c_2 = 0.0$ (no self-inhibition of the prey population). This results in a different stability behavior of the system: The oscillations of the population are no longer damped, but persist in a marginally stable limit cycle. In the state space you may observe closed trajectories, each corresponding to such a limit cycle. You should have obtained a graph similar to the one shown in Fig. T6.

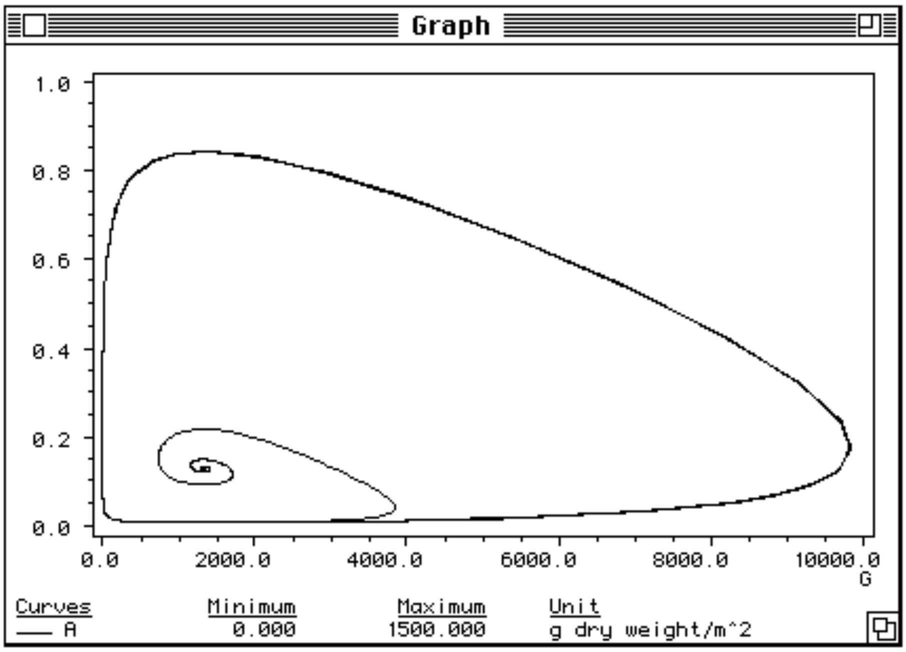
  Marginally stable limit cycles can be easily perturbed; verify this by changing the integration method to *Euler*, or while using the method *Heun* by increasing the integration step and the monitoring interval up to 0.5 . How accurate is the numerical integration algorithm?

Congratulations! You have reached the end of the introductory tour through ModelWorks. You should have learned to develop and simulate simple models using ModelWorks.

[1] In case of difficulties with Modula-2 please refer to WIRTH, N. 1988. *Programming with Modula-2*. Springer-Verlag, Heidelberg, New York, 4th corrected ed. or the MacMETH documentation (WIRTH *et al.*, 1988) for details on the specific MacMETH Modula-2 implementation.

[2] On the IBM PC you have to start first the GEM desktop and then to start the application *GRASSAPH.APP*.

In addition to the basic techniques you have just learned, ModelWorks features many more advanced modeling and simulation techniques. Among the more important features are modular, hierarchical modeling, including the coupling of several models and the mixing of discrete time with continuous time models. With ModelWorks it is easy to analyze results of complex simulation studies by means of a sensitivity analysis or a parameter identification. Moreover, thanks to its architecture open for extensions it allows for an unlimited number of possibilities. For a complete, full, and detailed description of all of ModelWorks features, please refer to the parts *Theory* and *Reference* of this text.



Curves	Minimum	Maximum	Unit
—— A	0.000	1500.000	g dry weight/m^2

Fig. T6: Graph of the simulation results produced with ModelWorks simulating the new, developed sample model . The graph shows a state space representation of a Lotka-Volterra like grass-aphids model system.

In case you would like to continue with the introductory example, here some suggestions how you could possibly explore it further on your own:

- introduce an auxiliary variable for the total biomass b(t):

  $$b(t) = G(t) + A(t) \qquad (3)$$

  Declare b(t) as a monitorable variable and compute its values within the procedure *Output*.

Part II: Theory

This part of the ModelWorks manual contains a description and functional specification of every feature ModelWorks offers. However, it contains only little information on the elementary and typical usage of ModelWorks. In case you should not be familiar with the basic concepts of ModelWorks, please read first the ModelWorks tutorial. In particular you should read the first chapter of the tutorial: *General Description*. Neither does this part of the manual contain technical information on the actual use.

This part of the manual explains the principles behind ModelWorks, not the details on the actual implementation and version of ModelWorks. Implementation dependent details are listed and explained in Part III *Reference* of this manual. The latter has been written to support you during your daily work with ModelWorks; this part is typically studied once, at the begin of any serious work with ModelWorks.

This part of the ModelWorks manual contains two chapters:

The chapter *Model Formalisms* presents the mathematical formalisms in which ModelWorks models are to be formulated. The first section of this chapter treats elementary models, the second structured models, which are built from several elementary, coupled submodels.

The chapter *ModelWorks Functions* describes all basic functions of ModelWorks: First it describes the functionality of the simulation environment and secondly general aspects of the model development process.

Any serious modeling with ModelWorks requires to read at least this part of the manual and the section on the client interface of the manual Part III *Reference*.

Reading Hint: For easier orientation, the pages, figures and tables of Part II *Theory* are prefixed with the letter T. Within this part the numbers of figures and tables follow those used in Part I *Tutorial*.

4 Model Formalisms

This chapter deals with theoretical aspects of modeling which are used in addition to the standard knowledge when developing models with ModelWorks. Please refer to a textbook for a general introduction to the modeling and simulation of dynamic systems[1]. In particular this chapter explains the mathematical formalisms in which the modeler should describe ModelWorks models. ModelWorks distinguishes between two model types: Elementary models and structured models. Structured models are composed of several coupled, elementary submodels.

4.1 Elementary Models

The elementary models which are used in ModelWorks are discrete or continuous time dynamic systems. They are formally described by a set of ordinary first order differential or difference equations. Generally model parameters are considered to be time invariant, but ModelWorks supports time variant parameters too. However it is recommended to treat them either as auxiliary variables (becoming part of the differential or difference equations) or to treat them as an input. A graphical representation is given in Fig. T7. A more detailed representation is given in Fig. T8.

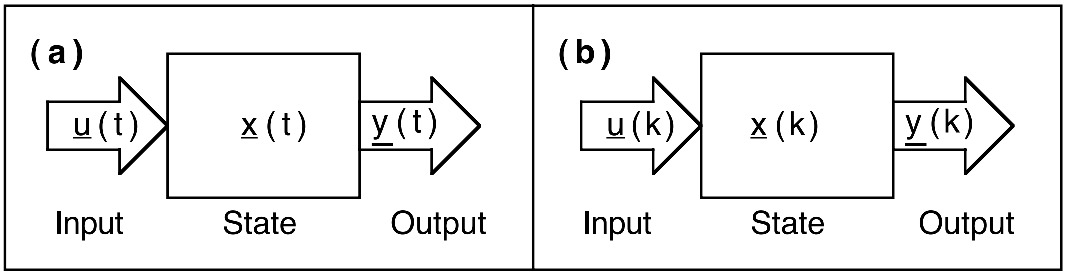


Fig. T7: Graphical representation of a dynamic system: (**a**) continuous time; (**b**) discrete time. These systems constitute the basic types used in ModelWorks to describe models.

A continuous time system is given by the following equations:

Dynamic equations: $\underline{dx}(t) = \underline{f}(\underline{x}(t), \underline{u}(t), \underline{p}_f(t), t);$ $t \in [t_o,t_{end}]$ $t \in \Re$ (4.1)

Output equations: $\underline{y}(t) = \underline{g}(\underline{x}(t), \underline{p}_g(t), t);$ $t \in [t_o,t_{end}]$ $t \in \Re$ (4.2)

Initial conditions: $\underline{x}(t_o) = \underline{x}_o$ (4.3)

Input function: $\underline{u}(t);$ $t \in [t_o,t_{end}]$ $t \in \Re$ (4.4)

Parameter set: $\underline{p}(t)$ $t \in [t_o,t_{end}]$ $t \in \Re$ (4.5)

[1] E.g. LUENBERGER, D.G., 1979. *Introduction to dynamic systems - Theory, models, and applications.* Wiley, New York, 446pp.

A discrete time system is described by the following equations:

Dynamic equations: $\underline{x}(k+1) = \underline{f}(\underline{x}(k), \underline{u}(k), \underline{p}_f(k), k); \quad k=k_o,..., k_{f-1} \quad k \in \Im$ (5.1)

Output equations: $\underline{y}(k) = \underline{g}(\underline{x}(k), \underline{p}_g(k), k); \quad k=k_o,..., k_f \quad k \in \Im$ (5.2)

Initial conditions: $\underline{x}(k_o) = \underline{x}_o$ (5.3)

Input sequence: $\underline{u}(k) = \underline{u}(k_o), \underline{u}(k_1),... \underline{u}(k_f) \quad k=k_o,..., k_f \quad k \in \Im$ (5.4)

Parameter set: $\underline{p}(k) = \underline{p}(k_o), \underline{p}(k_1),... \underline{p}(k_f) \quad k=k_o,..., k_f \quad k \in \Im$ (5.5)

where:

t:	Continuous time
k:	Discrete time
$\Re$:	Set of real numbers
$\Im$:	Set of integer numbers
$\underline{x}$:	State vector
$\underline{dx}$:	Derivative vector (for continuous time systems only)
$\underline{u}$:	Input vector
$\underline{y}$:	Output vector
$\underline{p}$:	Parameter vector, composed of the elements of $\underline{p}_f$ and $\underline{p}_g$

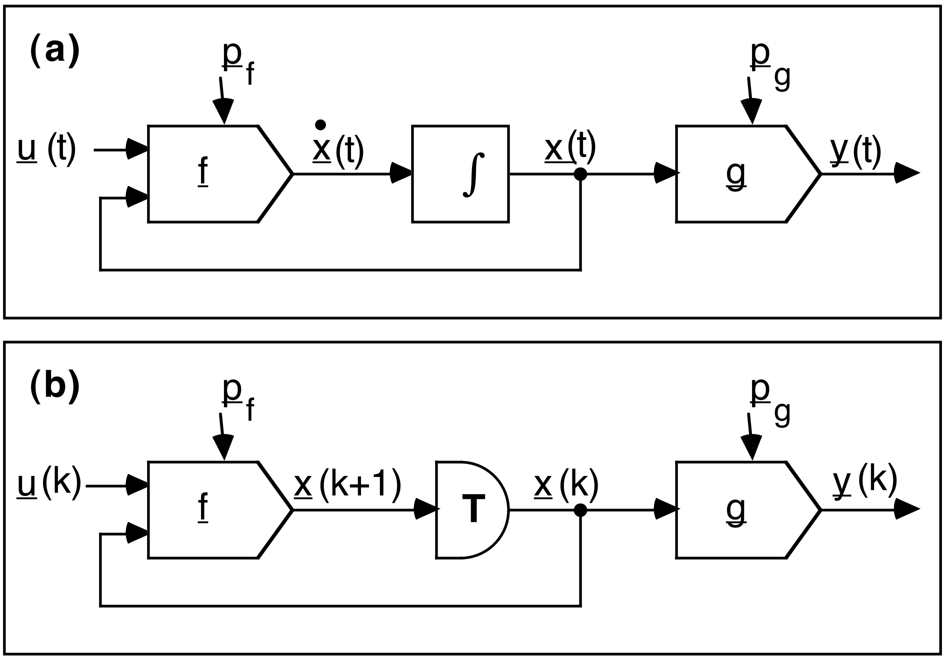


Fig. T8: Schematic representation of a dynamic (**a**) continuous time or (**b**) discrete time system. These systems constitute the basic types used in ModelWorks to describe elementary and structured models.

Note that the output $\underline{y}$ defined by Eq. (4.2), resp. (5.2) does not depend on the input $\underline{u}$. This restriction guarantees the correct calculation of structured models. Structured models are explained below.

In the context of ModelWorks the term *output* is used in a different than the usual meaning. It is reserved to the output produced by a submodel to be connected with the input of another submodel (coupling of submodels). It should not be confounded with the display of simulation results for the simulationist. The latter is called monitoring.

4.2 Structured Models (Coupling of Submodels)

Any number of elementary models, in this context called submodels, may be coupled to form complex, structured models. Any number of hierarchical levels may be introduced. Elementary models are defined exactly the same way as described in the previous chapter. The coupling is realized by connecting a submodel's output to another submodel's input. There are three cases to be distinguished: **(A)** all submodels are continuous time systems only, **(B)** all submodels are discrete time systems only, **(C)** and there are some continuous as well as discrete time submodels.

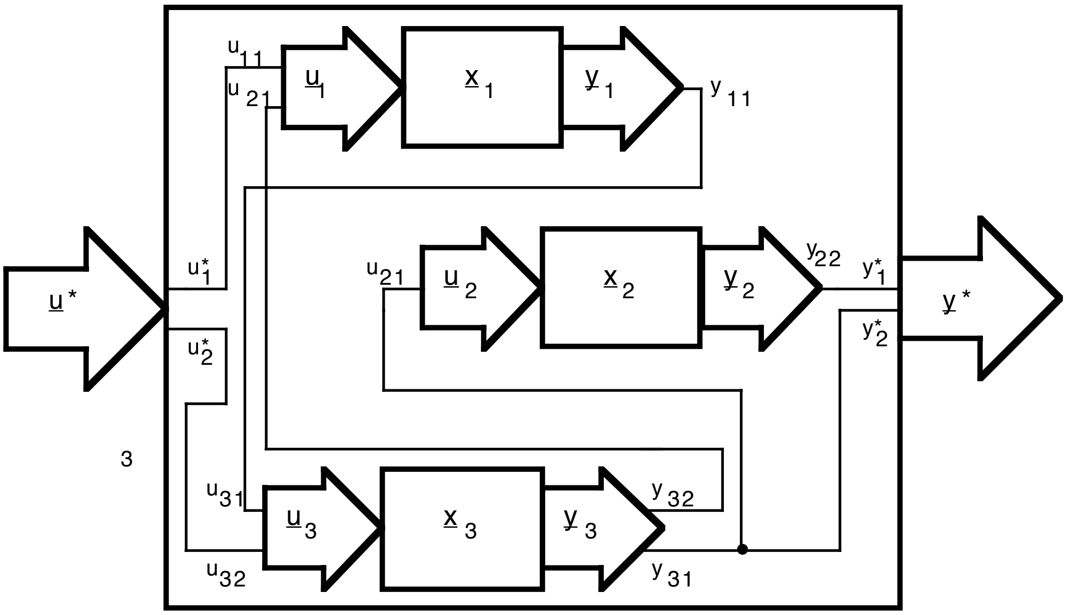


Fig. T9: Example of a structured model system composed of three elementary, coupled submodel systems. The global input $\underline{u}^*$ is defined by Eq. (6a, b, or c), the inputs of the subsystems u_{ij} by Eq. (7a, b, or c), the outputs of the subsystems y_{ij} by Eq. (9a, b, or c), and the global output $\underline{y}^*$ by Eq. (10a, b, or c).

(A) A structured model composed of n elementary, coupled submodels, each continuous time and defined according to Eq. (4.x) is defined as follows (for an example see also Fig. T9):

The input of the global system is given by

$$\underline{u}^* = \underline{u}^*(t) \qquad \text{(global input)} \qquad (6a)$$

The input to the submodel i depends on the global input $\underline{u}^*$, and on the output $\underline{y}_i(t)$ of the n submodels (output-input coupling):

$$\underline{u}_i(t) = \underline{h}_i\left(\underline{u}^*(t) , \underline{y}_1(t),... \ \underline{y}_n(t)\right) \qquad \text{(input of submodel i)} \qquad (7a)$$

The dynamic equations for obtaining the derivatives of the state variables of the submodel i:

$$d\underline{x}_i(t)/dt \;=\; \underline{f}_i\left(\underline{x}_i(t),\; \underline{u}_i(t), \underline{p}_{fi}(t), t\right) \qquad \text{(dynamic equations of submodel i)} \qquad (8a)$$

The output of the submodel i depends on the states and the parameter set of the submodel i. An output variable must not depend directly on an input variable (no direct output-input coupling). Since the input variables may depend directly on the output variables, a direct output-input coupling would lead to a circularity which could not be resolved generally.

$$\underline{y}_i(t) \;=\; \underline{g}_i\left(\underline{x}_i(t), \underline{p}_{gi}(t), t\right) \qquad \text{(output of submodel i)} \qquad (9a)$$

Some of these outputs are not connected to other submodels but are global outputs. These elements from $\underline{y}_i(t)$ form for each submodel the global output vectors $\underline{y}_i^*(t)$.

The output of the global system is given by combining the global output vectors $\underline{y}^*_i$ of the n submodels i:

$$\underline{y}^*(t) = \begin{bmatrix} \underline{y}_1^*(t) \\ \cdot \\ \cdot \\ \underline{y}_n^*(t) \end{bmatrix} \qquad \text{(global output)} \qquad (10a)$$

(B) A structured model composed of n elementary, coupled submodels, each discrete time and defined according to Eq. (5.x) is defined as follows (for an example see also Fig. T9):

$$\underline{u}^* \;=\; \underline{u}^*(k) \qquad \text{(global input)} \qquad (6b)$$

$$\underline{u}_i(k) \;=\; \underline{h}_i\left(\underline{u}^*(k)\;, \underline{y}_1(k),\ldots\; \underline{y}_n(k)\right) \qquad \text{(input of submodel i)} \qquad (7b)$$

$$\underline{x}_i(k+1) \;=\; \underline{f}_i\left(\underline{x}_i(k), \underline{u}_i(k), \underline{p}_{fi}(k), k\right) \qquad \text{(dynamic equations of submodel i)} \qquad (8b)$$

$$\underline{y}_i(k) \;=\; \underline{g}_i\left(\underline{x}_i(k), \underline{p}_{gi}(k), k\right) \qquad \text{(output of submodel i)} \qquad (9b)$$

$$\underline{y}^*(k) = \begin{bmatrix} \underline{y}_1^*(k) \\ \cdot \\ \cdot \\ \underline{y}_n^*(k) \end{bmatrix} \qquad \text{(global output)} \qquad (10b)$$

(C) A general structured model composed of n elementary, coupled submodels, each either continuous or discrete time and each defined according to Eq. (4.x) resp. Eq. (5.x) is defined as follows (for an example see also Fig. T9):

There are two different independent variables: the continuous time $t \in \Re$ and the discrete time $k \in \Im$. The constant time step 1 of the discrete time submodel(s) is interpreted as a real time interval, the *coincidence interval* c, on the time axis t. The discrete time submodels are only known at the endpoints of these intervals, the *coincidence time points* (or *coincidence points*). The continuous time submodel(s) describe continuous (or faster) processes which occur between the coincidence points. A communication between the two submodel types occurs only at every coincidence point (Fig. T10). By definition the coincidence interval c is a positive integer and must have a size of at least 1. In the context of simulations it is meaningful to match the values of the two time variables; thus at every coincidence point it must hold t = k. This requirement is guaranteed if the following conditions are satisfied:

$$t_o \;=\; k_o \qquad \text{and} \qquad t_{end} \;=\; k_f \qquad \text{where } k_o, k_f \in \Im \qquad (11)$$

Any structured model mixed of continuous and discrete time submodels can be subdivided into two portions: the first is the continuous time portion Ξ consisting of the set of all continuous time submodels with their related continuous time inputs and outputs plus the continuous time global input and output; the second is the discrete time portion Δ consisting of the set of all discrete time submodels with their related discrete time inputs and outputs plus the discrete time global input and output. At every coincidence point the system is fully defined and all submodels are fully coupled (System ~ $\Xi + \Delta$). At these points the real time t is mapped to the discrete time k as follows:

$$k = \mathrm{INT}(t) \qquad \text{where INT yields the integral part of its argument} \qquad (12)$$

Between coincidence points, the dynamics of the system collapse or degenerate to the continuous time portion Ξ, the other portion of the system Δ remains constant but is still accessible to Ξ. This corresponds to a sample and hold technique (sample at coincidence points, hold between) (Fig. T10).

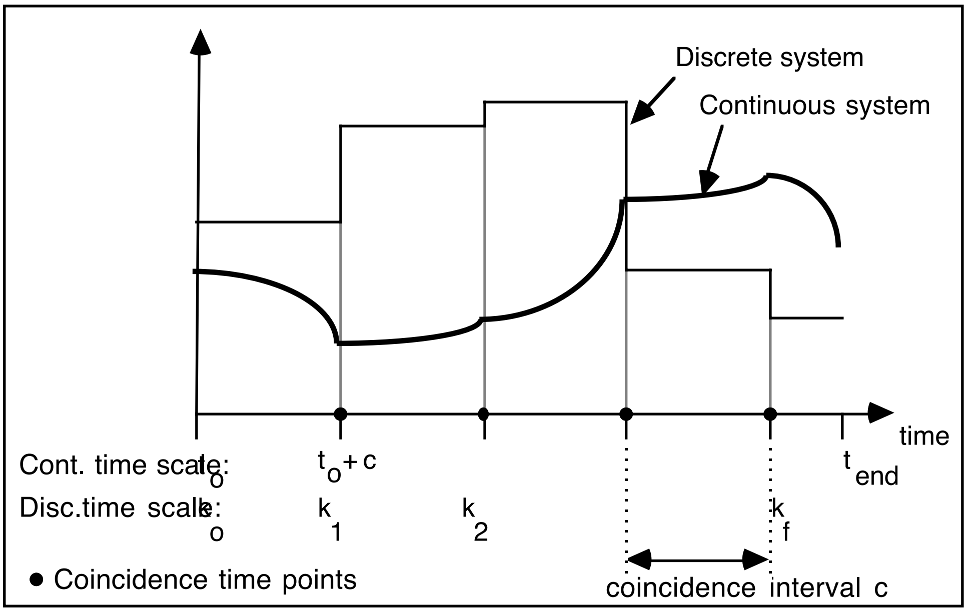


Fig. T10: Coupling of discrete and continuous time submodels: The figure shows the results of a simulation of a structured model system composed of one discrete and one continuous time submodel. A communication between the two submodels occurs at every *coincidence time point*, when the output of the discrete submodel determines the rate of change of the continuous time submodel. No data exchange takes place during the *coincidence interval*, during which the rate of change of the discrete time submodel remains constant (sample and hold).

The global input consists of two vectors, one for the global continuous time input $\underline{u}^{*\xi}$ and the other for the global discrete time input $\underline{u}^{*\delta}$:

$$\begin{aligned} \underline{u}^{*\xi} &= \underline{u}^{*}(t) \qquad (\in \Xi) \\ & \qquad\qquad\qquad\qquad \text{(global inputs)} \qquad (6c) \\ \underline{u}^{*\delta} &= \underline{u}^{*}(k) \qquad (\in \Delta) \end{aligned}$$

At the coincidence points the inputs of all submodels i depend on the continuous as well as the discrete time global input $\underline{u}^{*\xi}$ resp. $\underline{u}^{*\delta}$, and on the output of the continuous time submodels $j^{\xi} \in \Xi$ as well as the discrete time submodels $j^{\delta} \in \Delta$ (i, j^{ξ} ,$j^{\delta} \in \{1,2,... n\}$. Between coincidence points the inputs to the continuous submodel $i^{\xi} \in \Xi$ depend continuously on the continuous time global input $\underline{u}^{*\xi}$ and on the output of the continuous time submodels $i^{\xi} \in \Xi$. Any dependence of the continuous time submodels $j^{\xi} \in \Xi$ on the output of the discrete time submodels $j^{\delta} \in \Delta$ is resolved by using the last defined values (sample) of all variables of Δ while mapping time t to k using Eq. (12) (hold):

$$\begin{aligned}
\underline{u}_i^{\xi}(t) &= \underline{h}_i^{\xi}\big(\underline{u}^{*\xi}(t), \underline{u}^{*\delta}(k), \underline{y}_1^{\xi}(t), \underline{y}_2^{\xi}(t), \ldots \underline{y}_{n-1}^{\delta}(k), \underline{y}_n^{\delta}(k)\big) \quad && k = \mathrm{INT}(t) \quad && (\in \Xi) \\
\underline{u}_i^{\delta}(k) &= \underline{h}_i^{\delta}\big(\underline{u}^{*\xi}(t), \underline{u}^{*\delta}(k), \underline{y}_1^{\xi}(t), \underline{y}_2^{\delta}(k), \ldots \underline{y}_{n-1}^{\delta}(k), \underline{y}_n^{\xi}(t)\big) \quad && t = \mathrm{INT}(t) = k \quad && (\in \Delta)
\end{aligned} \qquad (7c)$$

The dynamic equations for the calculation of the derivatives for Ξ or the new values for Δ of the state variables of the submodels i^{ξ} resp. i^{δ}:

$$\begin{aligned}
\underline{dx}_{i\xi}(t) &= \underline{f}_{i\xi}\big(\underline{x}_{i\xi}(t), \underline{u}_{i\xi}(t), \underline{p}_{fi\xi}(t), t\big) \quad && (\in \Xi) \\
\underline{x}_{i\delta}(k+1) &= \underline{f}_{i\delta}\big(\underline{x}_{i\delta}(k), \underline{u}_{i\delta}(k), \underline{p}_{fi\delta}(k), k\big) \quad && (\in \Delta)
\end{aligned} \qquad \text{(dynamics of submodels } i^{\xi}, i^{\delta}) \qquad (8c)$$

The output of the submodels i^{ξ} resp. i^{δ} are calculated of the states and the parameter set of the particular submodel i^{ξ} resp. i^{δ}. An output variable must not depend directly on an input variable (no direct output-input coupling, avoids unresolvable circularity).

$$\begin{aligned}
\underline{y}_{i\xi}(t) &= \underline{g}_{i\xi}\big(\underline{x}_{i\xi}(t), \underline{p}_{gi\xi}(t), t\big) \quad && (\in \Xi) \\
\underline{y}_{i\delta}(k) &= \underline{g}_{i\delta}\big(\underline{x}_{i\delta}(k), \underline{p}_{gi\delta}(k), k\big) \quad && (\in \Delta)
\end{aligned} \qquad \text{(outputs of submodels } i^{\xi}, i^{\delta}) \qquad (9c)$$

Some of these outputs are not connected to other submodels but are global outputs. These elements from $\underline{y}_{i\xi}(t)$ resp. $\underline{y}_{i\delta}(k)$ form for each submodel the global output vectors $\underline{y}_{i\xi}^{*}(t)$ resp. $\underline{y}_{i\delta}^{*}(k)$.

The global output $\underline{y}^{*}$ of the structured model consists of two vectors, one for the global continuous time output $\underline{y}^{*\xi}$ and the other for the global discrete time output $\underline{y}^{*\delta}$. Each is again composed from the global output vectors $\underline{y}_{i\xi}^{*}(t)$ of the continuous time submodels $i^{\xi} \in \Xi$ resp. the global output vectors $\underline{y}_{i\delta}^{*}(k)$ of the discrete time submodels $j^{\delta} \in \Delta$:

$$\begin{aligned}
\underline{y}^{*\xi}(t) &= \begin{bmatrix} y_{1\xi}^{*}(t) \\ y_{2\xi}^{*}(t) \\ \cdot \\ \cdot \end{bmatrix} \quad && (\in \Xi) \\
\underline{y}^{*\delta}(k) &= \begin{bmatrix} \cdot \\ \cdot \\ y_{n-1\delta}^{*}(k) \\ y_{n\delta}^{*}(k) \end{bmatrix} \quad && (\in \Delta)
\end{aligned} \qquad \text{(global outputs)} \qquad (10c)$$

The general definition of the couplinghas two special cases which are often of interest to the modeler:

- Structured model consisting of several, but uncoupled submodels: The inputs of the submodels do not depend on any output of another submodel: $\underline{u}_i(t) = \underline{h}_i(\underline{u}^{*}(t))$ resp. $\underline{u}_i(k) = \underline{h}_i(\underline{u}^{*}(k))$. Such submodels coexist as completely independent units. Implementing them in such a way offers the advantage that the models can be simulated in parallel at once. This is useful to work simultaneously with a set of identical or similar models, e.g. to test different model versions of the same real system, or to compare a measured time series (parallel model) with a simulated trajectory (model).

- The structured model is composed of hierarchically organized submodels (several levels): An example of such a hierarchical model system is given in Fig. T11 (two levels). Note however, that ModelWorks ignores the hierarchical organization, which is only of concern to the modeler. ModelWorks treats all models exactly the same way, regardless of the level on which they are declared.

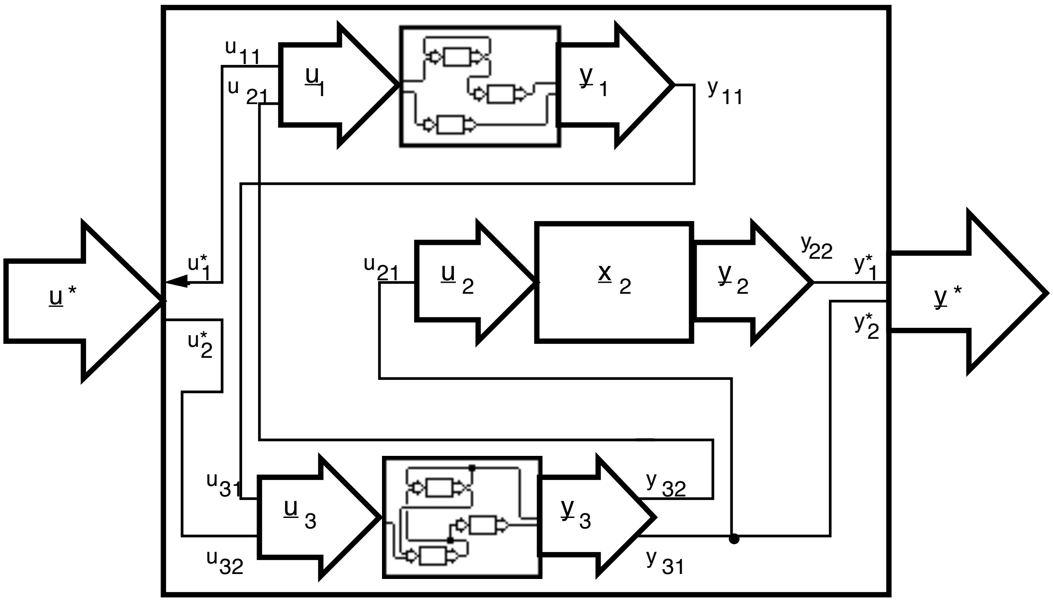


Fig. T11: Example of a hierarchically organized structured model system composed of several submodels, which are themselves structured model systems consisting of several internally, coupled submodels.

Structuring model systems as defined in Eq. (7a,b or c) requires a particular calculation sequence during simulation which may affect the results in a way which has to be considered by the modeler. In particular it must ensure that all input values are calculated first, i.e. at the begin of an integration step. Further, the results must be independent of the calculation order of the submodels. This can be guaranteed given that the following conditions are observed:

1. The calculation of a model is split into the following three parts:

   a) Calculation of the input variables $\underline{u}_i(t)$ for the submodel i: Eq. (7a, b or c)

   b) Calculation of the derivatives resp. the new values of the state variables of the submodel i (integration): Eq. (8a, b, or c)

   c) Calculation of the output variables $\underline{y}_i(t)$ of the submodel i: Eq. (9a, b, or c)

2. The calculation order is that shown in Fig. T12.

ModelWorks guarantees that the prerequisit under point two is always met, but cannot ensure that none of the model equations are misplaced, e.g. that a derivative is calculated in a part reserved for the calculation of inputs.

Note also that the calculation order shown in Fig. T12 has a further consequence to be considered by the modeler: It may affect the precision of the numerical results depending on how the equations are distributed among the continuous-time submodels. Differential equations coupled within a submodel are integrated differently from those coupled via submodel boundaries when using higher order integration methods. This fact should be considered when subdividing a model into several submodels unless the simulationist should restrict himself to single step integration methods only (s.a. the following example and Fig. T14).

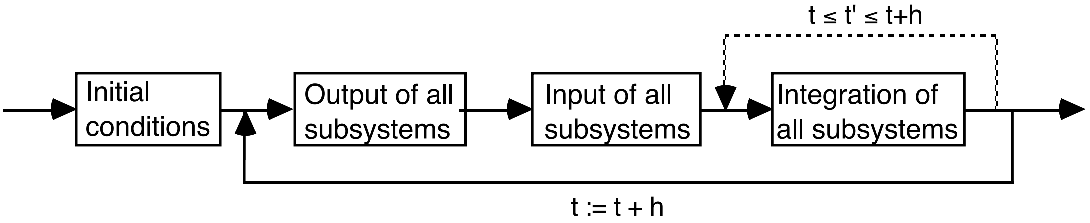


Fig. T12: Calculation order applied by ModelWorks during integration. The larger loop corresponds to a single time step (h = current integration step); the inner loop is used only by integration methods with order > 1 (e.g. Heun, Runge-Kutta 4th order).

Fig. T12 shows how coupling within a single submodel, i.e. formulated within the equation section dynamic, is defined at every point in time, whereas the coupling between submodels, i.e. formulated within the equation sections output respectively input, takes place only at the end points of an integration step. Note also that this phenomenon is different from the coupling between continuous and discrete time submodels, where the coupling is usually happening even more rare, i.e. only at the coincidence points. They are mostly much further apart than the current size of the integration step h. Both kinds of coupling, the one at the end points of the discretisation interval h as well as the one at the end points of the coincidence interval c, are of the same type, i.e. ModelWorks applies the so-called sample and hold technique (see also below under *Simulation environment* of the next chapter *ModelWorks Functions*).

Finally a simple example shall illustrate the whole concepts discussed in this chapter. The model is a system consisting of two ordinary, nonlinear first-order differential equations. First it shall be modeled simply and secondly it shall be modeled as a structured model built from submodels:

Ex.: The following model equations shall be modeled, first within a single model (Eq. 13):

$$\dot{x}_1 = ax_1 - bx_1^2 - cx_1x_2 \qquad \text{(Model M)} \qquad (13)$$
$$\dot{x}_2 = c'x_1x_2 - dx_2$$

This system consists of two ordinary but coupled differential equations formulated according to Eq. (8a) with neither input nor output (completely autonomous system). See Fig. T13a for the relational diagram of this model system.

Secondly the two differential equations shall be distributed into two separated submodels (14) respectively (15), which are coupled with each other (Fig. T13b):

$u_1 = y_2$ *input according Eq. (7a)*

$\dot{x}_1 = ax_1 - bx_1^2 - cx_1u_1$ *dynamic according Eq. (8a)* (Submodel μ_1) (14)

$y_1 = x_1$ *output according Eq. (9a)*

respectively

$u_2 = y_1$ *input according Eq. (7a)*

$\dot{x}_1 = ax_1 - bx_1^2 - cx_1u_2$ *dynamic according Eq. (8a)* (Submodel μ_2) (15)

$y_2 = x_2$ *output according Eq. (9a)*

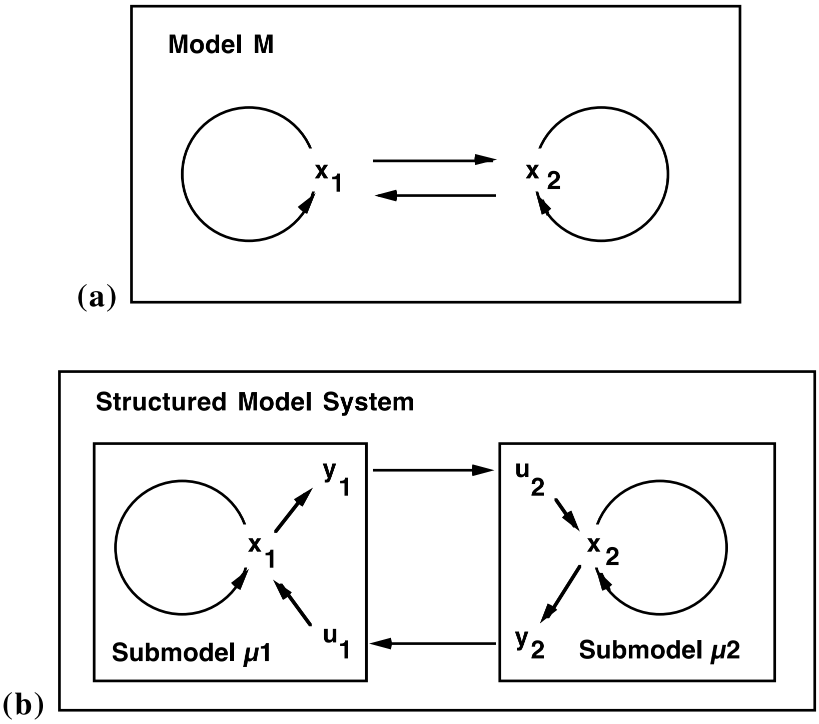
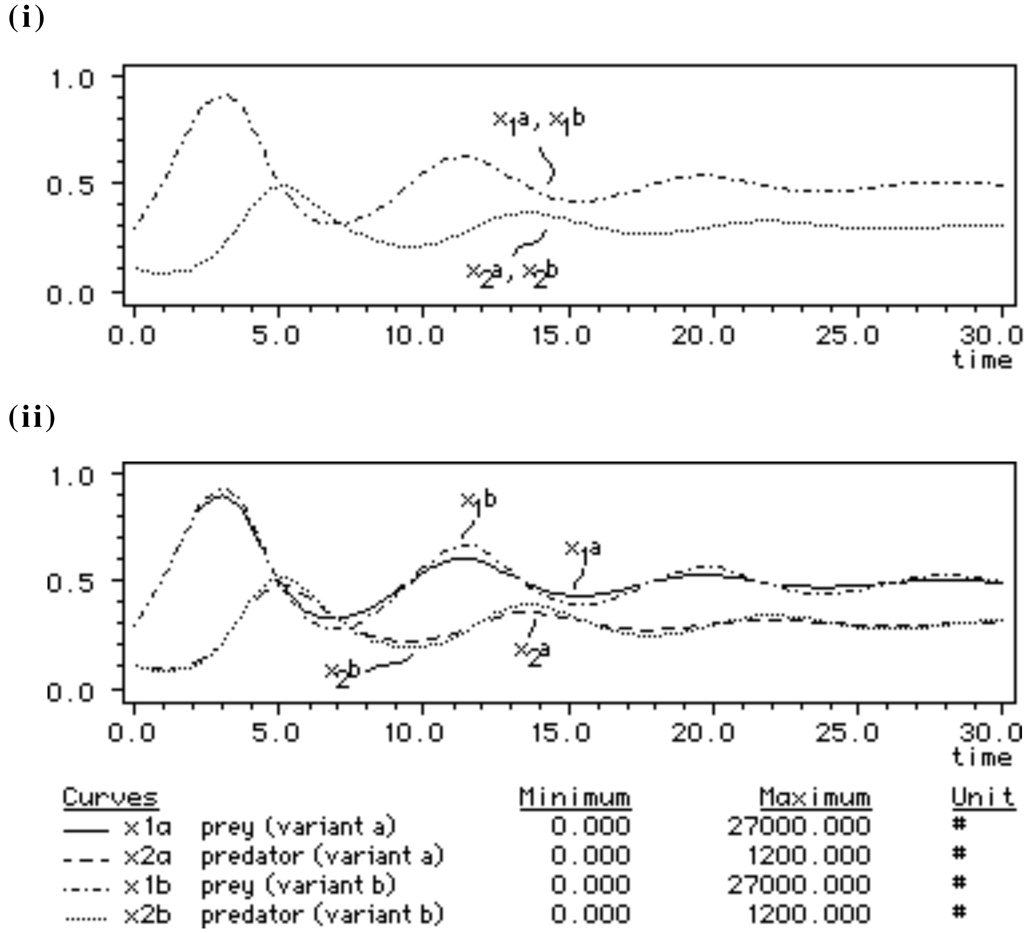


Fig. T13: Relational diagrams of a model once **(a)** formulated as a single elementary model M given by Eq. (13) and once **(b)** modeled as a structured model system consisting of two submodels μ_1 and μ_2 according to the Eq. (14) and (15).

Both submodels are of the type continuous time and case **(A)** applies with the equations (6.a) till (10a), but no global inputs nor global outputs are present. Each of these submodels has one input and one output defined according to Eq. (7a) and (9a). These inputs and outputs have only been introduced in order to couple the two submodels. They form a structured model system, each submodel containing one of the differential equations from Eq. (13). Mathematically the structured model system formed with (14) and (15) is equivalent to the one given by Eq. (13). However, discretisation errors may result in the sample and hold effect described above (see also below under *Simulation environment* of the next chapter) (Fig. T14).

This is because no information exchange across submodel boundaries takes place during an integration step. Thus coupling among submodels occurs only at the endpoints of an integration step (s.a. Fig. T12). In case a higher order integration method is used, the coupling of differential equations within a submodel takes place even in the middle of an integration step. Hence simulation results of the continuous-time part of a structured model might slightly differ for non-single step integration routines depending on where the modeler has chosen the submodel boundaries between the differential equations. However the smaller the integration step, the smaller becomes this effect . E.g. in order to make the effect clearly visible, case **(ii)** of Fig. T14 has been computed with a rather large integration step of h=0.15.



Curves		Minimum	Maximum	Unit
—— x1a	prey (variant a)	0.000	27000.000	#
- - - x2a	predator (variant a)	0.000	1200.000	#
-·-·- x1b	prey (variant b)	0.000	27000.000	#
······· x2b	predator (variant b)	0.000	1200.000	#

Fig. T14: Simulation results of two mathematically equivalent model variants a and b as given by Eq. (13) respectively Eq. (14-15). Results obtained using **(i)** - the first order Euler, **(ii)** - the second order integration method Heun with steplength h = 0.15. Although the two model variants (s.a. Fig. T13) ought to behave identically, their two implementation variants a and b yield the same results only in case **(i)**, but differing ones in case **(ii)**. This is a consequence of the calculation order within a simulation step (Fig. T12) and the order of the integration method: In case **(ii)** the information exchange between submodels is not so often done for variant b than for variant a, because it takes only place at the begin of, not during an integration step. x_{1a}, x_{2a} - state variables of variant a; x_{1b}, x_{2b} - of variant b.

5 ModelWorks Functions

ModelWorks functions are available in two ways: First by the simulationist in the simulation environment of ModelWorks and second by the modeler via the client interface (Tutorial Fig. T1). The simulation environment allows to access the ModelWorks functions interactively by the simulationist, the client interface to access them in a static predefined way, i.e. through the writing of a model definition program (Tutorial Fig. T3) by the modeler. Both techniques have their unique advantages and disadvantages.

The simulation environment of ModelWorks provides the run-time environment to define simulation experiments, e.g. by changing parameter values, to execute simulation runs, and to control the monitoring of the simulation results. A simulation run of ModelWorks corresponds to the numerical solution of an initial value problem of a set of ordinary differential equations or difference equations alone or in any mixed form. In particular note that this means that the current implementation of ModelWorks does neither provide a direct support for the solution of boundary value problems nor does it offer backward numerical integration.

All activities from the starting of the simulation environment till its quitting are termed a simulation session. In essence it is nothing else than the execution of the procedure *RunSimMaster* from module *SimMaster*. Values or attributes of the models plus their objects and the monitoring can be changed interactively from within the simulation environment for the following settings and parameter values:

- Global parameters and settings:
    - start and stop time for simulation runs
    - integration step[1] respectively maximum integration step plus maximum relative local error[2],
    - discrete time step (coincidence interval)[3]
    - monitoring interval
    - project description consisting of a title, remark, and footer string plus parameters which control the display of strings in the graph respectively the recording of information on models and model objects together with their current values and settings on the stash file (recording flags)
    - stash-file name
- Model specific attributes:
    - integration method
- Model objects specific attributes:
    - initial values of state variables
    - values of model parameters
    - kind of monitoring and scaling for monitorable variables

In addition, the simulation environment of ModelWorks offers a versatile reset mechanism which allows to reset any parameter or setting which may have been changed interactively during the simulation session by the simulationist or via the client interface by the model definition

[1] only if at least one continuous time (sub)model is present

[2] only if at least one continuous time (sub)model with a variable step length integration method is present

[3] only if at least one discrete time (sub)model is present

program. The values or settings to which ModelWorks resets are the so-called default values originally specified by the modeler via the client interface. This allows the simulationist to return any time to a well defined state of all parameters and settings. Further details on how to use ModelWorks during a simulation session can be found below in the section on the *Simulation environment* of this chapter.

The client interface is used to define, i.e. to declare the models, the model objects, the model equations, and the default values for all objects so that the run time system of ModelWorks may access and maintain them (Tutorial Fig. T2). It is important to note that ModelWorks does only know about those objects which have been made known to ModelWorks, i.e. which have been explicitly declared. Otherwise ModelWorks does not care what the modeler is doing with these objects, nor whether they are part of a complicated structure. For instance a state variable might be computed by retrieving values from a data base or might be part of a structured type such as a Modula-2 record or an array. On the other hand it is also important to understand that ModelWorks will perform calculations on objects, i.e. will assign values. E.g. at the begin of a simulation run ModelWorks assigns automatically the initial values to all state variables or updates the values of state variables during the simulation by assigning to them the results of numerical integrations. In order to use ModelWorks meaningfully it is necessary that the modeler obeys a minimum number of rules, so that ModelWorks and the modeler use and access model objects in harmony. The client interface has been designed to warrant this harmony automatically to a large extent as well as to offer the modeler at the same time as much flexibility as possible.

The modeler may also program a structured simulation, a so-called ModelWorks experiment. Typically an experiment consists of many simulation runs and will call ModelWorks functions similar to the way the simulationist would use them. The latter is important if the simulationist is to be relieved from cumbersome, repetitive command sequences or if simulations are used as parts of more complicated procedures. For instance in order to create a phase portrait the simulationist would have to assign a series of different initial values to the state variables as well as to start after each assignment a simulation run. All this can be easily accomplished by programming a structured simulation which the simulationist then can activate by a single command from within the simulation environment. Other examples are: After a model has been thoroughly explored interactively it is to be used for a sensitivity analysis or parameter identifications; both examples requiring the writing of special program sections, a task which is well supported by ModelWorks client interface.

Moreover ModelWorks allows to extend its functions via the client interface. Since ModelWorks is based on the Dialog Machine the modeler may also access Dialog Machine routines himself and mix them with the functions provided by ModelWorks alone. For instance the modeler might want to have an additional kind of monitoring not offered by the standard ModelWorks functions. To accomplish this he may add a new menu with commands to open a window in which simulation results are to be displayed in a problem specific graph, e.g. by coloring areas in a map according to the current values of model variables. Besides, since model objects belong to the model definition program and are fully accessible, the latter poses no problem for the modeler. Further details on the use of ModelWorks via the client interface are given below in the section *Model development* of this chapter.

5.1 Simulation Environment

5.1.1 PROGRAM STATES OF THE SIMULATION ENVIRONMENT

During a simulation session ModelWorks is always only in one of three states: *No simulation*, *Simulating*, or *Pause* (Fig. T15). States are characterized by the availability of certain commands. In the state *No simulation* model and model object attributes can be interactively changed. In the state *Simulating* user interactions are limited, e.g. IO-windows are inactivated. In the state *Pause* the simulation is temporarily brought to a halt to allow for interactive changes of parameters. Limitations have been introduced to ensure consistency and because certain commands are meaningful only in particular states.

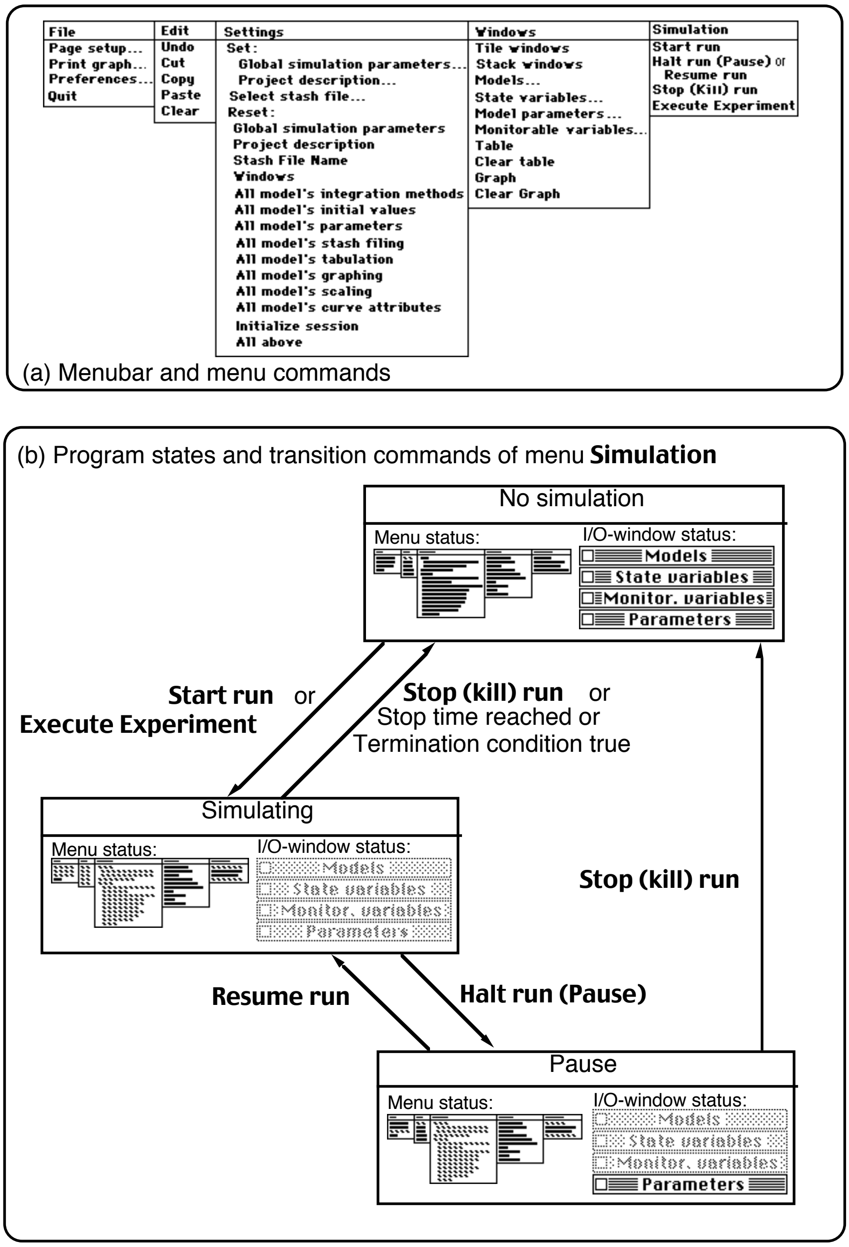


Fig. T15: Menu commands (a) and state transition diagram (b) of the simulation environment of ModelWorks. The simulation environment is always in one of the following three states: *No simulation*, the state in which the simulationist may change values or settings, e.g. simulation time, initial values of state variables, or values of model parameters. During a simulation run or a structured simulation experiment ModelWorks is in the state *Simulating*. In this state the simulationist may only temporarily pause or stop (kill) the running simulation. The state *Pause* allows to change model parameters with the attribute *RTC (Run Time Change)* set, or to resume respectively abort the simulation. For every state the status of the menu commands is symbolized as follows: A black line signifies an active, a grey an inactive or unavailable menu command. The availability of the button commands of a particular IO-window is indicated by a black (object selection possible, all buttons active) or grey (disabled selection, inactive buttons) window title bar.

For instance changing a parameter value while a simulation is running is prohibited, i.e. may not be issued in the state *Simulating*, in order to avoid the display of incorrect simulation results; or the command to stop a simulation is meaningless if there is no simulation run in progress, i.e. this command is available only in the states *Simulating* or *Pause*. In particular this design also ensures that the simulationist can not start a second simulation run on top of an already running one unless the first one has been terminated. The current states can be determined by the modeler via the client interface by calling the procedure *GetMWState*.

Transitions from one state to another are accomplished in several ways: Either the simulationist decides to issue a menu command available under the menu *Simulation*, or ModelWorks leaves the state *Simulating* due to one of the following two reasons: The simulation time has reached the stop time, or the terminate condition provided by the modeler returns true. Note that this implies that state transitions are under the control of either the simulationist or of the modeler, and/or are automatically controlled by the ModelWorks run time system. In case of conflict the commands of the simulationist have the highest priority followed by the conditions programmed by the modeler. It is possible to quit the simulation environment from within every ModelWorks state (menu command *Quit*).

5.1.2 SIMULATIONS

After starting an existing model definition program, i.e. execution of the procedure *RunSimMaster* the ModelWorks simulation environment appears on the screen with its menubar and the four IO-windows, one for each kind of model objects (Tutorial Fig. T4). They display the information, current settings and values of all model(s) and all model's objects. Any model object is recognized by ModelWorks only if it has been declared during execution of the corresponding declaration procedure. The latter is given by the actual parameter used while calling procedure *RunSimMaster*. Choosing the menu command *Quit* results in the termination of the procedure *RunSimMaster*, i.e. the simulation session is terminated and the simulation environment is left. All models and all model objects will cease to exist. The reverse is true also: The modeler must be careful to ensure that all models and model objects exist as long as the simulation session lasts; otherwise ModelWorks will not function properly. In particular this means that models or model objects variables such as state variables must never be declared as variables local to a Modula-2 procedure.

After startup, the simulationist has the choice either to start immediately a simulation with the predefined default values or to change interactively any settings. The client interface has been designed such that the modeler can't make an error by unintentionally leaving out a needed value to define fully the initial value problem of a ModelWorks simulation run. During simulations two additional windows, the graph and the table window, are automatically opened or brought to the front for the display of the simulation results. Simulation results may also be written to a so-called stash file for future references by ModelWorks or other application software such as a spreadsheet or a statistics program. Simulations and interactive changes of parameter values or settings can be done freely in any order.

To issue a command to ModelWorks the simulationist has several options: First the omnipresent menu bar offers a set of pull-down, pop-up, or tear-off menu commands; second some menu commands (their menu text is followed by "...") will open so-called entry forms offering from one to several editable fields to enter numbers or change settings via check boxes etc. Thirdly the so-called IO-windows allow to select particular models or model objects for modifications or to issue further commands. The use of menus, menu commands, and entry forms are intuitively appealing, easy to understand, and follow the user interface of the Dialog Machine described elsewhere (see *Appendix* and *Literature*).

There hold certain relationships among the tasks which are performed by ModelWorks during a simulation session (Fig. T16). Tasks are nested and each belongs to a particular, hierarchical level:

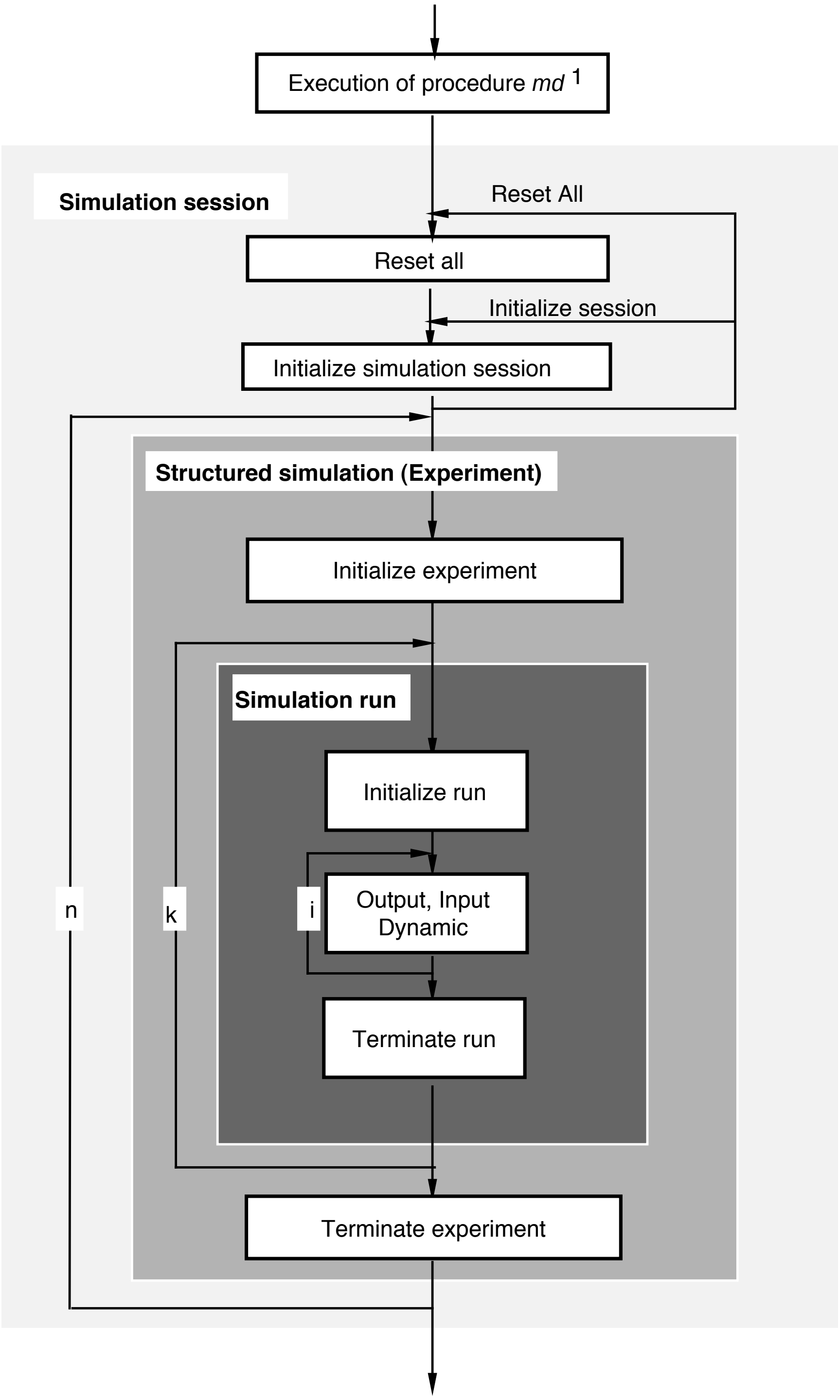


Fig. T16: Relationships among the nested ModelWorks tasks performed during a simulation session. The simulationist may execute an arbitrary number *n* of structured or elementary simulation runs. A structured simulation (experiment) consists of an arbitrary number *k* of elementary runs. Every elementary simulation run consists of the sections *Initialize*, dynamic (includes the sections *Output*, *Input*, plus *Dynamic* s.str.), and *Terminate*. The dynamic section is executed according to the chosen time step and simulation time an arbitrary number of times *i*. Unless defaults were changed a simulation session can be fully reset to the original start-up conditions (Reset all).

[1] argument passed in call to procedure RunSimMaster

5.1.2.a Simulation session

The simulation session (Fig. T16) consists of all activities done by means of the ModelWorks simulation environment during the execution of a typical model definition program. It represents the topmost level of all simulation tasks and corresponds to the execution of the procedure *RunSimMaster* from module *SimMaster*. It may be repeated with the same set of models as many times the simulationist wishes, but otherwise there are no relationships to other simulation tasks on the same level. In particular ModelWorks does not support any communication of data from a simulation session to another one except for the simulation results contained in the stash file. Neither does the current version of ModelWorks support the direct reading of the stash file. However, it is possible to construct a particular model which reads a stash file and declares the models and model objects needed for a post run analysis. ModelWorks writes data onto the stash file according to a syntax particularly designed for this purpose.

When ModelWorks enters a simulation session it always first executes a full reset (Fig. T16), i.e. it ensures that all current values to be used during the session have exactly the values as defined by the so-called defaults (s.a. chapter *Predefinitions, defaults, current values, and resetting*). Defaults can stem from different sources, i.e. they are either predefined by ModelWorks or have been specified by the modeler via the client interface.

Next ModelWorks initializes the simulation session (Fig. T16). The modeler can customize this initialization, e.g. in order to add an additional menu or to set particular defaults etc. This can be accomplished by installing an initialization procedure with a call to the procedure *DeclInitSimSession* from *SimMaster* before calling procedure *RunSimMaster*. ModelWorks will then automatically call the installed initialization procedure at the begin of a simulation session or whenever the simulationist requests this via the corresponding menu command provided in the simulation environment.

After the reset and the initialization, the program state is always *NoSimulation* (Fig. T15).

5.1.2.b Structured simulation (Experiment)

This level can be accessed by the simulationist by choosing the menu command *Execute experiment* under menu *Simulation*. It is the next level below that of the simulation session (Fig. T16). A structured simulation works similar to an elementary simulation run but differs slightly in the following aspects: Basically it is a procedure programmed by the modeler; typically it calls several elementary simulation runs by calling the procedure *SimRun* from module *SimMaster*. Since it is implemented as a client provided procedure, where the modeler has anyway already full control, no experiment specific initialization and termination procedures for experiments are offered by ModelWorks.

Structured simulations are optional and have to be installed first by the modeler via the client interface before they can be executed by the simulationist. If no experiment is known to ModelWorks this is the same as leaving this level out completely. Note also the simulationist may always bypass this level by directly starting an elementary simulation run.

The simulationist can execute experiments an arbitrary number of times n. A structured simulation calls elementary simulation runs k times, i.e. structured simulations are only of some interest if $k > 1$. The total number of simulation runs then becomes $k \cdot n$. To facilitate the orientation of the simulationist, ModelWorks displays in the time window (visible in the state *Simulating* in the upper right corner of the screen) not only the current simulation time, but also the number k of the current simulation run.

The state of ModelWorks during a structured simulation is always *Simulating*. If an experiment is stopped by the simulationist, not only the currently running elementary simulation is terminated but also all subsequently eventually following runs are skipped by ModelWorks. ModelWorks accomplishes this by emptying the body of the procedure *SimRun* from module

SimMaster. However ModelWorks is unable to actually stop the experiment procedure which will be otherwise executed till it ends as programmed by the modeler.

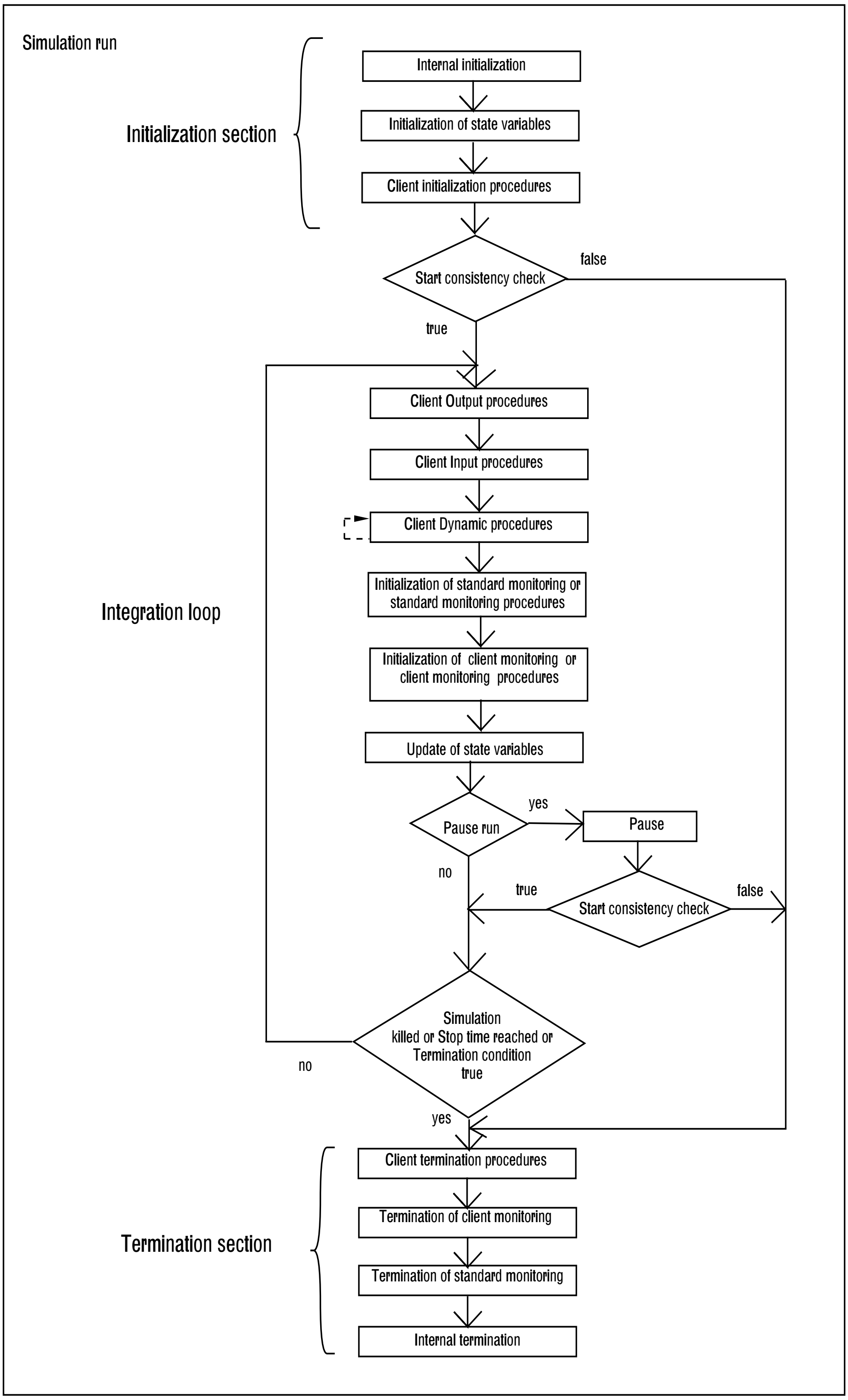

Simulation run
Initialization section
Internal initialization
Initialization of state variables
Client initialization procedures
Start consistency check
false
true
Client Output procedures
Client Input procedures
Client Dynamic procedures
Integration loop
Initialization of standard monitoring or standard monitoring procedures
Initialization of client monitoring or client monitoring procedures
Update of state variables
Pause run
yes
Pause
no
true
Start consistency check
false
Simulation killed or Stop time reached or Termination condition true
no
yes
Client termination procedures
Termination section
Termination of client monitoring
Termination of standard monitoring
Internal termination

Fig. T17: Simplified flow chart of an elementary simulation run as performed by ModelWorks. A run consists of the three basic steps: initialization, integration, and termination.

5.1.2.c Elementary simulation run

This level can always be accessed by the simulationist directly without going through the experiment level (see above)[4] by choosing the menu command *Start run* under menu *Simulation*. Otherwise this level is the next level below the level of the structured simulation (Experiment) (Fig. T16). An elementary simulation run is provided by ModelWorks and has not to be programmed by the modeler. It is exactly the same as calling the procedure *SimMaster.SimRun* via the client interface. ModelWorks supports this level by requiring the modeler to specify for each model an *Initialize* and *Terminate* procedure.

The organization of an elementary simulation run is shown in more details in Fig. T17.

ModelWorks will execute for every model in the sequence of their declaration the *Initialize* procedures once at the begin of the simulation run and the *Terminate* procedures once at the end of the simulation run. Note that the execution of the *Initialize* procedures happens at a moment when ModelWorks has already assigned the initial values to all state variables. This is important to know, since this design makes it possible to overwrite the values assigned by ModelWorks with other values, for instance during a structured simulation which is used to draw a phase portrait. Typical use of *Initialize* and *Terminate* procedures is also the opening and closing of a file at the begin respectively the end of a simulation run in order to write simulation results onto a file different from the stash file.

Note also that in contrast to the procedure *md* passed to ModelWorks as actual argument in the call to procedure *RunSimMaster* (it is called only once per simulation session and typically declares the models and model objects), the procedures *Initialize and Terminate* may be called many, i.e. n or n·k times during a single simulation session. The actual number depends on how many times the simulationist starts a simulation run directly or via an experiment and is not known to the modeler.

Whenever ModelWorks calls client procedures such as procedures *Initialize* or *Terminate*, the calling sequence is the same as the declaration order in the model definition program.

5.1.2.d Integration or time step

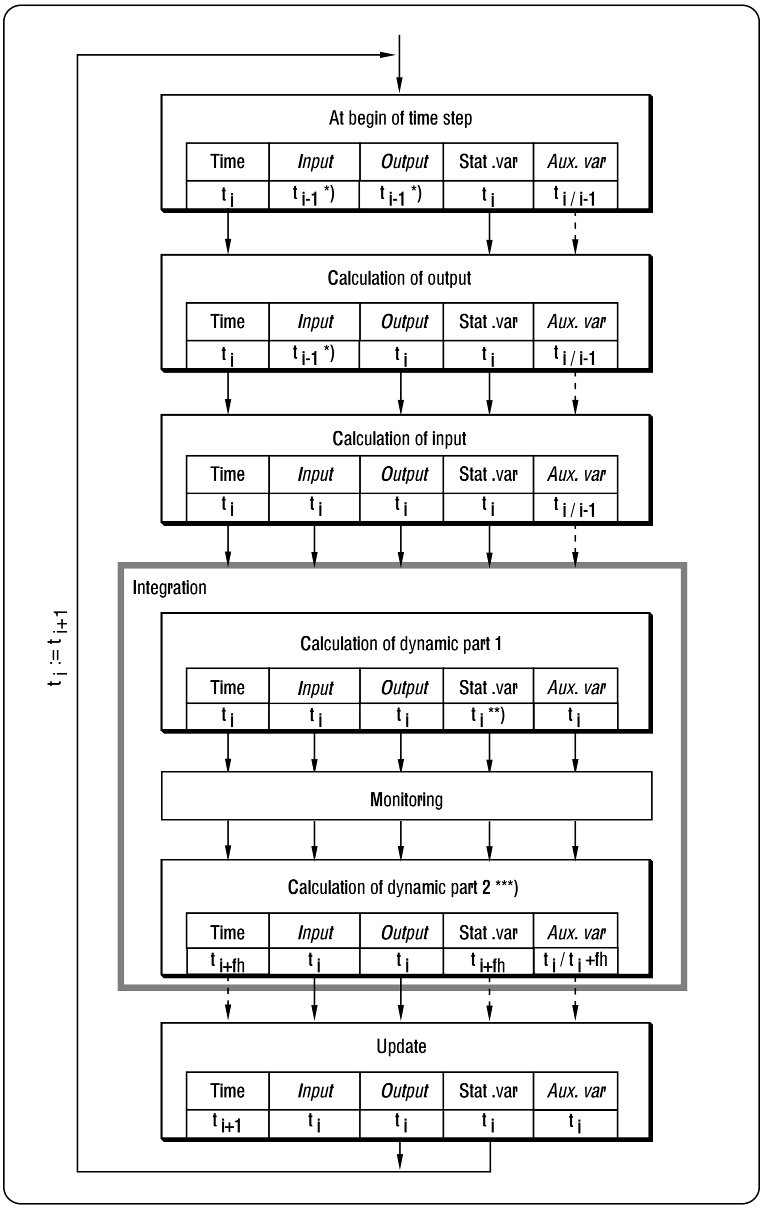
The lowest level is that of an integration or time step. ModelWorks supports this level by requiring the modeler to specify for each model an *Input*, *Output*, and *Dynamic* client procedure. ModelWorks will execute for every model the *Output*, *Input*, and *Dynamic* procedures during every integration step at least once. Only *Dynamic* may be called from once up to times the order of the current integration method during a single integration step. Note also that in contrast to the procedures *Initialize* and *Terminate* (which are called only once per simulation run), the procedures *Input*, *Output*, and *Dynamic* are called many, i.e. i times during an elementary simulation run (Fig. T16).

In the integration loop, user commands, such as pausing or stopping the simulation, are processed first. This enables an interactive control of the simulation. After that, the client procedures of the models are called. Their calling sequence guarantees a correct coupling of more than one model, independently of their installation order (see also chapter *Model formalisms*). The calculation order which meets all these requirements is shown in Fig. T18:

First, the *Output* procedures of all models, then all *Input* procedures are called. Thereafter, the numerical integration can be done. Depending on the integration algorithm, the procedure *Dynamic* will be called once or several times for the evaluation of the derivatives. Every submodel is integrated as an independent unit. Therefore it is possible to integrate different submodels with different integration algorithms. This can be of interest if some models are numer-

[4] This level could also be understood as a structured simulation (experiment) with k=1 (see above).

ically less stable than others. However, the same integration step length is used for all models to guarantee a coordinated data transfer between submodels.



At begin of time step

Time	*Input*	*Output*	Stat .var	*Aux. var*
t_i	t_{i-1} *)	t_{i-1} *)	t_i	$t_{i/i-1}$

Calculation of output

Time	*Input*	*Output*	Stat .var	*Aux. var*
t_i	t_{i-1} *)	t_i	t_i	$t_{i/i-1}$

Calculation of input

Time	*Input*	*Output*	Stat .var	*Aux. var*
t_i	t_i	t_i	t_i	$t_{i/i-1}$

Calculation of dynamic part 1

Time	*Input*	*Output*	Stat .var	*Aux. var*
t_i	t_i	t_i	t_i **)	t_i

Monitoring

Calculation of dynamic part 2 ***)

Time	*Input*	*Output*	Stat .var	*Aux. var*
t_{i+fh}	t_i	t_i	t_{i+fh}	$t_i / t_i + fh$

Update

Time	*Input*	*Output*	Stat .var	*Aux. var*
t_{i+1}	t_i	t_i	t_i	t_i

Fig. T18: Calculation of time, input, output, state, and auxiliary variables during an integration step. The calculation order guarantees that all calculations are based on valid values which have been calculated in a previous step. The arrows indicate which values have become valid. At the begin of the simulation run, only time and the state variables are available for t_i. These values are used to calculate the output variables for t_i. Next, the input variables can be calculated, since they depend on the previously calculated outputs. Next the numerical integration respectively the new state variables for time t_{i+1} are computed and if this step has been completed all state variables are assigned (update) the new values for t_i.

*) Not defined the first time the integration loop is entered

**) Value for t_{i+1} is calculated, but not yet assigned to state variable field

***) Only calculated if an integration method of higher order used ($f \in (0,1)$, e.g. f=0.5 for Runge-Kutta 4th order)

Once all dynamic client procedures, i.e. *Output*, *Input*, and *Dynamic*, have at least been called once, all model variables, i.e. input, output, state, plus auxiliary variables, are defined and have a correct value valid at the point t_i. This is the moment ModelWorks does the monitoring, i.e. the current value for any monitorable value is written onto the stash file, tabulated in the table, or drawn into the graph if the corresponding kind of monitoring is activated for the particular variable. The monitoring is followed by additional calls, now only of the client procedure *Dynamic*, in case of higher order integration methods used to solve continuous time models. Discrete time or single step integration methods will skip this step.

Finally the state variables and the independent variable (time) are updated to their new values. Afterwards the termination criteria is evaluated. The simulation will be terminated if either the simulation stop time has been reached, the simulation run was stopped (killed) by the simulationist, or if the termination condition from the model definition program has returned true. Depending on the result, the simulation continues or stops, which will result in a state transition from the state *Simulating* into the state *No simulation* (s.a. Fig. T15).

Discrete time models are treated analogous to the continuous time models. ModelWorks treats basically both the same, except that the discrete time submodels are «integrated» with a different integration method: The new value of a difference equation which is analogous to the derivative of a differential equation is treated like a derivative, but the formula to compute the new state differs, i.e. it is just the assignment of the «derivative» to the new state. The situation is more complicated in case of continuous with discrete time mixed simulations; since the discrete time step might be several times larger than the integration step needed for the continuous time submodels, it is obvious that the two types of models must be treated separately. Typically the discrete time submodels will then not be called as often as the continuous time ones and the *Output* of the discrete time submodels will have to be computed at the begin, the *Input* plus *Dynamic* only at the end of the coincidence interval.

Time steps usually vary, even if a fixed step integration method is used. This is because the time steps depend not only on the integration step, but also on the coincidence interval and/or the monitoring interval. ModelWorks is computing values exactly at any of the time points given by the current values of these global simulation parameters. E.g. a fixed integration step of h = 0.75 and a monitoring interval m = 1.0 will result in the following sequence of integration step lengths: 0.75, 0.25, 0.75, 0.25, 0.75, 0.25 ...

5.1.3 MONITORING

ModelWorks displays simulation results only via a monitoring concept. It is based on the so-called monitorable variables, which are declared in the model definition program. Once a variable has been declared as monitorable variable via the client interface, it can be selected interactively in the corresponding IO-window in order to activate a certain kind of monitoring. Any variable can be monitored as long as it is a real number. In this way the simulationist may observe the values of any variable, might it be an input, state, auxiliary or output variable. Monitorable variable might be understood as nothing else than probes attached to any information flow circulating within the model system. They measure anytime anywhere any quantity without any disturbance of the dynamics of the system. This is different from conventions in systems theory, but this solution has been favored over other possible designs due to its flexibility and convenience.

Since continuous time measurement would result in an exorbitant amount of data, actual monitoring is possible only at discrete points in time, the monitoring times. They are equidistant and the time interval between monitoring times is constant and global, i.e. the same for all models and all kinds of monitoring, the so-called monitoring interval h_m. ModelWorks computes values exactly at the time points t_m for which monitoring is requested, that is $t_m = t_o + i \cdot h_m$ (t_o - simulation start time; i - 0, 1, 2, ...).

Predefined, standard monitoring of ModelWorks is available in one or any combination of the following three kinds: Values, typically simulation results, may be written and stored on a so-called stash file for later usage, tabulated as numbers in a table, or shown as curves in a graph.

The stash file can store an arbitrary amount of information on models, model objects, and their values and it is usually produced for further numerical, e.g. statistical analysis, of the simulation results or for future report generation to document simulation runs in all details. The size to which the stash file may grow is limited only by the available disk space. The file is written in a formally defined syntax and contains several types of information, partly always included and partly included only selectively by means of the so-called recording flags. The content consists of:

- General information on the simulation session consisting of a) the date and time of the session's begin, b) date and time of begin and end of simulation runs, c) project title, remarks and footer, d) date and time when the file was closed. It is always written.
- Values of all global simulation parameters (Start and stop time of simulation, integration step respectively maximum integration step plus maximum local relative error, discrete time step respectively coincidence interval, and monitoring interval). The parameters actually written on the stash file depend on the type of models currently present: continuous time only, discrete time only or both types mixed as well as the used integration methods (with or without variable step length methods). This type of information is written always and in particular also repeatedly for every simulation run.
- Lists of all models and their integration methods, of all state variables and their current values, of all model parameters and their current values, of monitorable variables and their settings, curve attributes and scaling are written selectively under control of the recording flags. Note that not all monitorable variables are recorded but only those for which either the stash filing is currently set (F/*writeOnFile*) or those which are present in the graph, given that the recording flag for graph dumping is currently set.
- Tabulation of numerical simulation results for those monitorable variables for which the stash filing is currently set (F/*writeOnFile*).
- Dumping of graphical simulation results (encoded, only machine readable) under control of a particular recording flag

ModelWorks can handle only one stash file at a time. In the state *No simulation* it is always closed to allow for the inspection of its content by the simulationist. ModelWorks automatically opens respectively closes the stash file at the begin respectively at the end of an elementary simulation run of a structured simulation experiment. Unless the stash file name is changed (its default name is *ModelWorks.DAT*), ModelWorks will use always the same file, i.e. if a file with the same name already exists, that file's old content will be lost and completely rewritten.

The stash file is written in a format which is not too difficult to read by a human being as well as easy to scan by a computer program (post run analysis). Furthermore it is also possible to transfer the results into another program, e.g. a spreadsheet program, or into a document processing program which understands the RTF[5] format. These formats can not be changed.

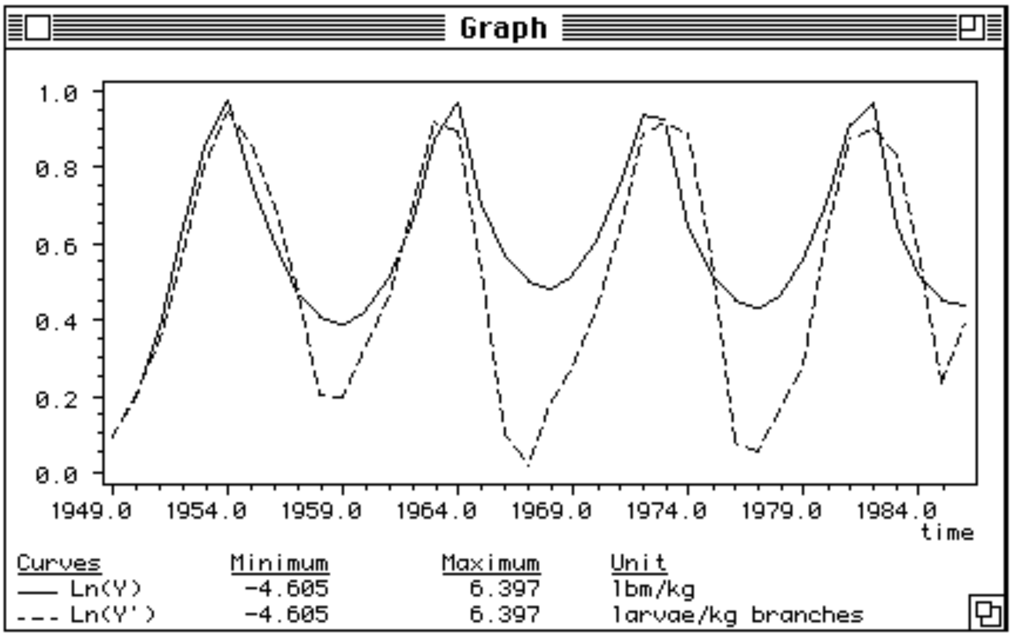
At the heart of the information written to the stash file is the writing of the values of the monitorable variables for which the stash file monitoring has been set at every monitoring time t_m. The format is such that these results can be transferred directly, for instance via the clipboard, into another application: Only horizontal tab characters τ (ASCII ht = octal 11C) separate the values and all values at a particular monitoring time are written on the same line terminated with a carriage return ρ (ASCII cr = octal 15C). E.g.:

[5] RTF stands for Rich Text Format. It is based on ASCII characters only but contains coded formatting information and can be interpreted by many commercially marketed text processing applications.

```
'time'  τ  'Ident var 1'  τ  'Ident var 2'ρ
0.000000  τ  1.0000000  τ  0.9025031  ρ
0.200000  τ  1.1764115  τ  0.6883310  ρ
0.400000  τ  1.2954322  τ  0.4211738  ρ
0.600000  τ  1.3516583  τ  0.0882961  ρ
0.800000  τ  1.3498297  τ  -0.3198467  ρ
…
```

Normally the stash file is only opened and written if at least one monitorable variable has been requested for the recording. However, if the particular simulation environment mode (preferences) is set appropriately, the stash file is opened during every simulation run and data are recorded according to the current settings of the recording flags.

The table used to tabulate the values of monitorable variables during a simulation appears in a window on the screen. Values are written in a similar way as shown above under the stash file monitoring. Currently, only the values which fit into the window are displayed. Once the window is full, ModelWorks erases most of its content[6] and restarts tabulating from the top again (called a «page up»). In the current version of ModelWorks any erased values are lost and the simulation has to be repeated to display them again.



```
Curves        Minimum     Maximum   Unit
—— Ln(Y)       -4.605      6.397    lbm/kg
--- Ln(Y')     -4.605      6.397    larvae/kg branches
```

Fig. T19: The graph window of ModelWorks.

ModelWorks can display in the graph window one graph only. The graph has a linear abscissa (x-axis) with time or any monitorable variable as independent variable (allowing for state space curves), and a linear ordinate (y-axis) with a fixed scaling from [0,1]. According to the currently set minimum and maximum values for the range of interest, an arbitrary number of dependent variables (range shown in the legend), can be plotted simultaneously in the graph. An unlimited number of simulation runs can be recorded in one graph. The graph will be automatically cleared after changes of the graph definition, the global simulation parameters (e.g. if the start or stop time has been changed and time is the abscissa), or if the window is resized after a

[6] Actual number of rows erased depends on the currently set preferences or simulation environment modes: The number specified as *Common rows between page ups in table* defines what happens during a page up: First it specifies how many rows at the bottom are not erased but copied to the top of the next page. Second only the space below these now top rows will be used to add new rows. Hence this number specifies how many rows are common to two consecutive pages.

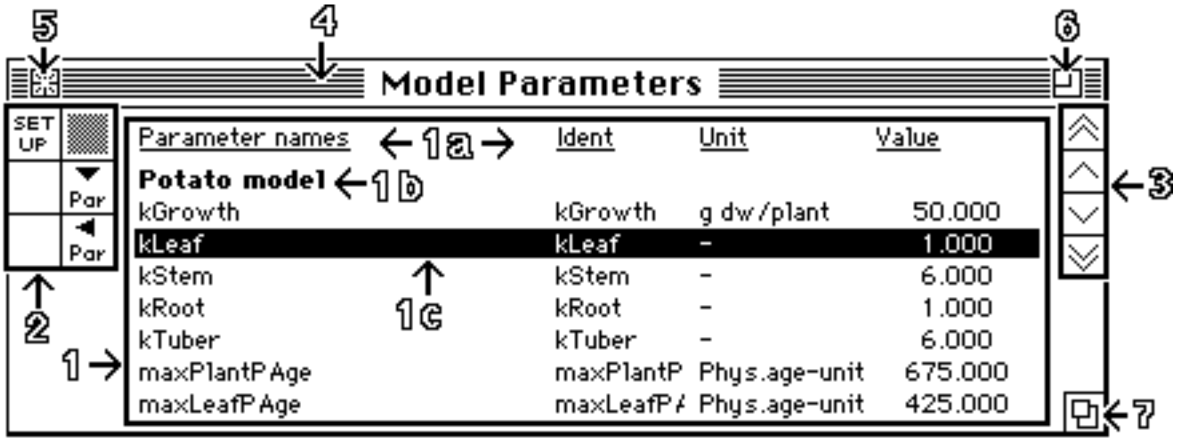
simulation. However, this behavior may differ depending on the currently set mode of the simulation environment (preferences). An example graph is shown in Fig. T19.

The graph's size is automatically fit to the window's size. The actual graph is drawn as large as possible, which depends on the number of curves to be listed in the legend at the bottom of the window. However, if there are too many curves requested so that the legend would become too big and there would not be left a minimal space for the panel of the graph, ModelWorks will not be able to list all curves in the legend. Only the first ones will be visible, the remaining ones at the bottom of the list will be missing.

If an other than the standard monitoring of ModelWorks is required, the modeler can program and install it by calling the procedure *DeclClientMonitoring*. Any kind of monitoring will then be possible, e.g. the writing of simulation results onto a file or the drawing of animated graphical objects which move within a window according to computed positions etc. Typically, in order to accomplish such tasks, the modeler uses the Dialog Machine, to which he/she has full access. Concerning values of state and other variables, the client monitoring will be done as often and at the same time as the standard monitoring. The exact sequence observed is that the client monitoring comes last, so that it can also be used to customize or extend the just having made standard monitoring, e.g. by drawing tangents along a solution of a differential equation.

5.1.4 IO-windows (Input-Output-windows)

IO-windows are available during a simulation session and have two functions: First they display all models and all model objects plus their current values and settings (Output). Second they allow to modify interactively the current values and settings of these objects (Input). For instance, the value of an individual model parameter can be changed or reset, or the kind of monitoring for a particular variable during simulations can be defined. There are four IO-windows: The first IO-window with the title *Models* lists all models known to ModelWorks, i.e. which have been declared by the modeler via the client interface. The second IO-window *State variables* lists all declared state variables, the third *Parameters* all parameters, and the fourth *Monitorable variables* all monitorable variables.



Model Parameters

Parameter names	Ident	Unit	Value
Potato model			
kGrowth	kGrowth	g dw/plant	50.000
kLeaf	kLeaf	-	1.000
kStem	kStem	-	6.000
kRoot	kRoot	-	1.000
kTuber	kTuber	-	6.000
maxPlantPAge	maxPlantP	Phys.age-unit	675.000
maxLeafPAge	maxLeafP/	Phys.age-unit	425.000

Fig. T20: Basic structure of IO-windows subdivided into three fields: In the middle the object list (1), on the upper left corner the palette of button commands (2), and on the upper right corner the scrollers to scroll the items in lists too large to show all items at once (3) (s.a. text).

All IO-windows have a common structure: The content area of any IO-window is subdivided into three fields (Fig. T20). First the field in the middle of the window contains a list of ModelWorks objects (1). Its title line (1a) displays the headers of the columns currently in use, which describe, display, and designate ModelWorks objects and their values. Below, there is the actual list of the objects, e. g. the parameters, which have been installed in ModelWorks by the model definition program. The order follows the declaration order in the model definition program, and objects belonging to the same model appear together under the bold title of the corresponding model (1b). An object in the list can be selected as an operand by a mouse click on the corresponding line, which is confirmed to the simulationist by inverting the line (1c).

The selection of the bold model title is interpreted as the selection of all objects belonging to this model.

From this follow scopes and scope rules for the selection of operands. For the IO-windows containing the state variables, model parameters, and monitorable variables exist the following scopes:

- all objects of a particular kind of all models
- all objects of a particular kind of a model
- individual object of a particular kind

Since model objects belong to models, the selection of a model in the models IO-window also implies the selection of all its objects. Hence the scopes in the models IO-window are:

- individual model respectively all objects of a model
- all models respectively all objects of all models

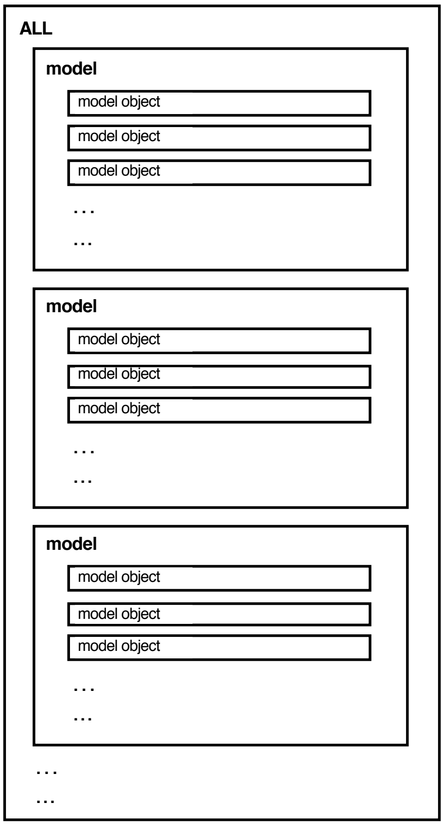


Fig. T21: Scopes used for the selection of operands in the IO-windows. Selecting a model implies the selection of all model's objects.

Note that the operands actually affected by an operator are determined also by the operator itself. For instance: The selection of an individual model does not only allow to change an attribute such as the integration method of this model, but also to reset the values of all its objects, such as the resetting of all initial values of the model's state variables to their defaults.

In an inactive IO-window no objects can be selected. The simulationist can recognize this status if clicking within the list field does not invert any lines.

Second the button field (2) on the left side contains a palette of adjacent, square buttons. Each button has a separate function (operator), which can be activated by clicking on the little button picture with the mouse. There are two kinds of functions: basic window functions, such as window set up, and functions (operators) on the selected elements (operands). Two buttons are common to all windows: The button SET UP activates an entry form where the columns to be displayed in the object field can be selected. The button ▨ serves to select all objects of the particular kind shown in the IO-window, e.g. all parameters of all models (Scope All in Fig. T21). While ModelWorks is executing a button function, the button picture will be shown inverted. In an inactive IO-window no button functions can be activated. The simulationist can recognize this status if clicking on buttons does not invert them.

Third on the right side, there are the scrollers to scroll lines individually or whole pages of the object list field up and down in case, that the window is too small to show all objects at once (3). During the actual scrolling the button picture will be shown inverted. In an inactive IO-window no scrolling can be done. The simulationist can recognize this status if clicking on scrollers does not invert them.

The last group of elements are not specific to ModelWorks but are general and may be present in any window: the title bar to move the window (4), the close box to close it (5), the zoom box to enlarge it to the size of the screen or back (6), and the grow box to change the size of the window to any shape (7).

5.1.5 PREDEFINITIONS, DEFAULTS, CURRENT VALUES, AND RESETTING

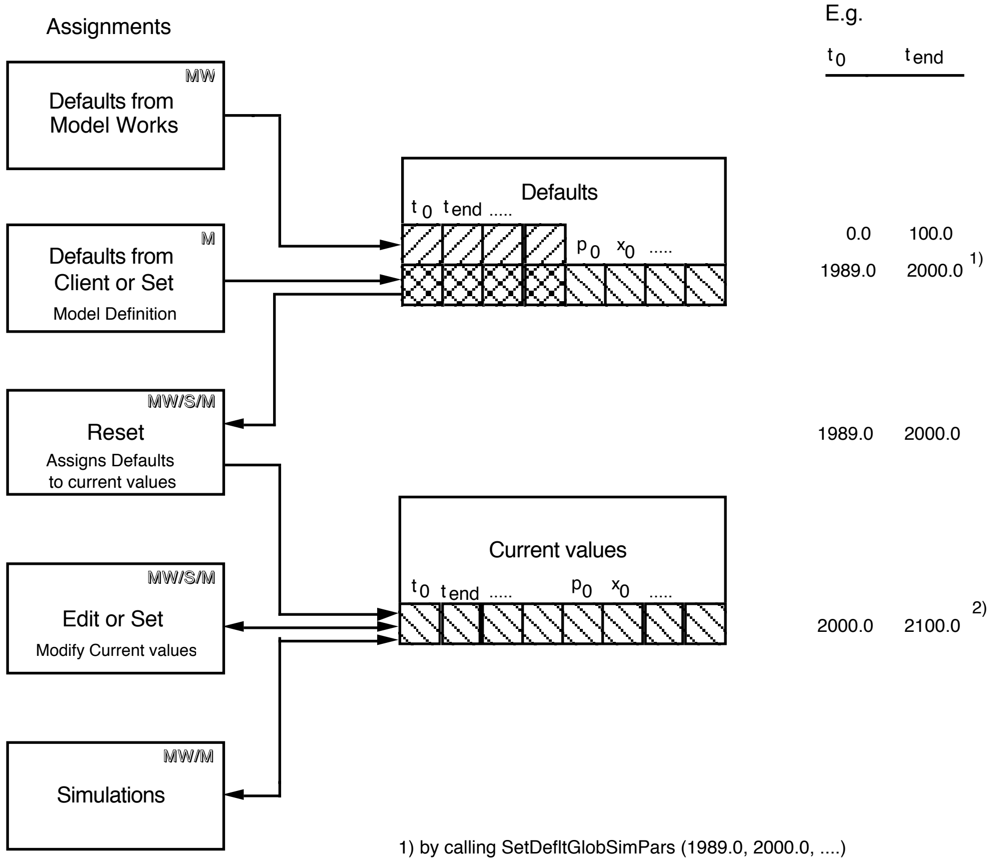
ModelWorks maintains for many values such as global simulation parameters, a model's integration method, the initial values of state variables, model parameters, or monitoring settings two copies: One is the default value, the other is the current value. All simulations use only the current values and unless accessed via the client interface, the defaults cannot be changed by the simulationist from within the standard simulation environment (Fig. T22).

The defaults are defined by two mechanisms: First ModelWorks assigns to every global simulation parameter, the project description, and the stash file name a predefined default value (Tab. T1). Then the model definition program may overwrite these values with the defaults as specified by the modeler. E.g. does Model Works use a predefined default simulation start and simulation stop time of $t_o = 0.0$ respectively $t_{end} = 100.0$. If the modeler wishes to use a different default simulation time range, he calls the procedure *SetDefltGlobSimPars* from module *SimBase* to define it, e.g.with the statement:

```
    SetDefltGlobSimPars (1989.0, 2000.0,...)
```

While starting a model definition program ModelWorks always assigns automatically all defaults, either provided by ModelWorks or overwritten by the modeler, to the current values (Fig. T22). The modeler is forced by the client interface to specify defaults for all models and model objects. They are the values passed to ModelWorks while declaring the particular objects. E.g. the value 0.1 is the default of the model parameter *c1*. This requires that the modeler declares the parameter *c1* with the following call: DeclP (c1,0.1, ... ModelWorks will keep a copy of the object's default values in order to be able to reassign them to the current values if a reset is requested by the simulationist. Executing a ModelWorks command such as *Reset all model's parameters* in a simulation session while running above example will then assign 0.1 to the variable *c1* (Fig. T22) regardless of what the current value of *c1* might be.

Interactive modifications of values from within the standard simulation environment by using entry forms or the IO-windows affect always only the current values, not the defaults. Calling a reset function from ModelWorks will then reassign the default values to the current values. All current values affected by the reset, e.g. all initial values of a particular model, will then be set to their defaults as have been defined by the modeler via the client interface (Fig. T22).



1) by calling SetDefltGlobSimPars (1989.0, 2000.0, ...)

MW	by Model Works
S	by Simulationist
M	by Modeller

2) by calling SetGlobSimPars (2000.0, 2100.0, ...) or by menu command **Set global simulation parameters** under menu **Setting**

Fig. T22: Relationship between default and current values and the reset mechanism of ModelWorks. For most values ModelWorks maintains two copies: One is the default, the second is the current value, which is actually used for simulations. During a reset, also executed at program start up, the default values are copied (assigned) to the current values. Interactive modifications (editing) of values during the simulation session affect only the current values. Via the client interface it is possible to change the defaults as well as the current values.

Note that as long as the simulationist remains within the standard simulation environment of ModelWorks, a reset resumes the initial program state which existed at the very begin of the simulation session. This is because in contrast to the client interface, it is not possible to access and modify defaults via the user interface. However, if the modeler, by using the client interface, has programmed extensions, which also allow to change interactively the defaults, the reset mechanisms provided by ModelWorks will no longer allow the simulationist to reset this initial start-up condition. Instead the state as defined by the last default specifications is resumed. However, if the client has defined a simulation session initialization procedure, ModelWorks will call it also during a full reset; hence, if programmed accordingly, this would allow to resume initial start-up conditions even if defaults should have been modified.

Symbol	Meaning of variable	Predefined default
Global simulation parameters		
t_o/k_o	Start time for simulation	0.0
t_{end}/k_f	Stop time for simulation	100.0
h/h_{max}	Fixed integration step or maximum integration step for continuous time (sub)models	0.05
e_r	Maximum relative local integration error	0.001
c	Discrete time step for discrete time (sub)models or coincidence interval for mixed time structured models	1
h_m	Monitoring interval	0.25
	Descriptor, identifier, and unit for independent variable	"time" "t" " "
Project description		
	Project title string	""
	Use project title string in graph	TRUE
	Remarks string	""
	Use remarks string in graph	TRUE
	Footer string	"dd/mon/yyyy hh:mm Run 1" [7]
	Automatic update of date, time, and run # in footer	TRUE
	Recording of data on models in stash file	TRUE
	Recording of data on state variables in stash file	FALSE
	Recording of data on model parameters in stash file	FALSE
	Recording of data on monitorable variables in stash file	TRUE
	Recording of graph in stash file	FALSE
Stash filing		
	Stash file name	ModelWorks.DAT [8]
Automatic definition of curve attributes		**Predefined value**
	colors and line-styles	i[9] MOD 4 = 0: coal unbroken 1: ruby broken 2: emerald dashSpotted 3: turquoise spotted
	symbols	i = 4: • 5: * 6: o 7: Δ else " "

Tab. T1: Predefined defaults and values: Unless overwritten by the modeler, ModelWorks assigns the listed default values to the various parameters during start up of a model definition program. For all other defaults, i.e. the defaults of models and model objects, the modeler is forced to specify them while declaring the models and the model objects in the model definition program. Predefined values can not be overwritten by the modeler.

[7] The abbreviations stand for: dd - current day, e.g. 01 for the first day of a month; mon - current month, e.g. Jan for January; yyyy - current year, e.g. 1989; hh - current hour, e.g. 22 for 10 pm; mm - current minute, e.g. 04 in 10:04 pm

[8] On the IBM PC *MODELWOR.DAT*. Will be created in the folder where the application resides, which has started the model definition program respectively on the IBM PC in the current working directory.

[9] Order of activation of monitorable variables. The first variable has the value i = 0.

Resets may affect only a single model object, all objects of a single model, or all objects of all models (s.a. Fig. T21). Furthermore resets can be executed for a particular class of model objects only, e.g. only model parameters or only the curve attributes of monitorable variables.

Unless curve attributes are assigned to the monitorable variables either interactively by changing the current curve attributes in the monitorable variable window or via the client interface by calling the procedures *SetCurveAttributesForMV* or *SetDefltCurveAttributesForMV*, ModelWorks adopts the so-called automatic definition of curve attributes. It has been designed so that curves can be optimally told apart on black and white as well as color devices, such as monochrome or color screens, on laser printers or on color ribbon matrix printers, on slide recorders, plotters etc. However, this has the disadvantage that for a particular monitorable variable the curve attributes may change too often, i.e. as soon as the automatic curve attribute of another, previously activated monitorable variable is changed. To avoid the latter, the user has to override the automatic definition. Note that the curve attributes assigned by the automatic definition are predefined by ModelWorks only and can not be changed by the user. ModelWorks uses the values listed in Tab. T1. Attributes are distributed according to the position *i* in the sequence in which the monitorable variables have been activated for graphical monitoring.

5.2 Modeling

5.2.1 The model development cycle

Starting with a mathematical model given in form of the Equ. (4) or (5) respectively (6), (7) to (10) the modeler or client has to write first the so-called model definition program. It solves numerically the initial value problem of the system of differential and/or difference equations. This corresponds to a translation process of the initial value problem of the mathematical model to a simulation model. The latter may also be termed a numerical problem with the initial values, model and global simulation parameters as inputs plus the monitorable variables as outputs. The algorithms are given by the run time system of ModelWorks.

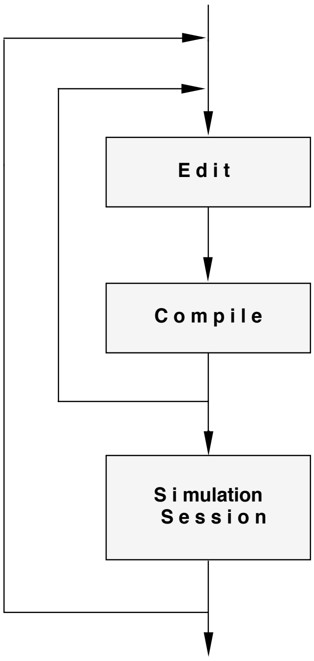


Fig. T23: Development cycle of the modeler writing ModelWorks model definition programs.

The modeling process consists of the model development cycle with the steps editing, compilation, and execution of the model definition program (Fig. T23).

5.2.2 Structure of model definition programs

A model definition program may be built from as many modules as the modeler wishes. Typically structured models are built from several modules (external or library modules), each submodel corresponding to a Modula-2 module (Fig. T24). If the modeler makes use of modular modeling, the only thing to pay attention to, is to make sure that outputs from one submodel are computed in its procedure *Output*, and the depending inputs of another submodel in its procedure *Input* (Fig. R16).

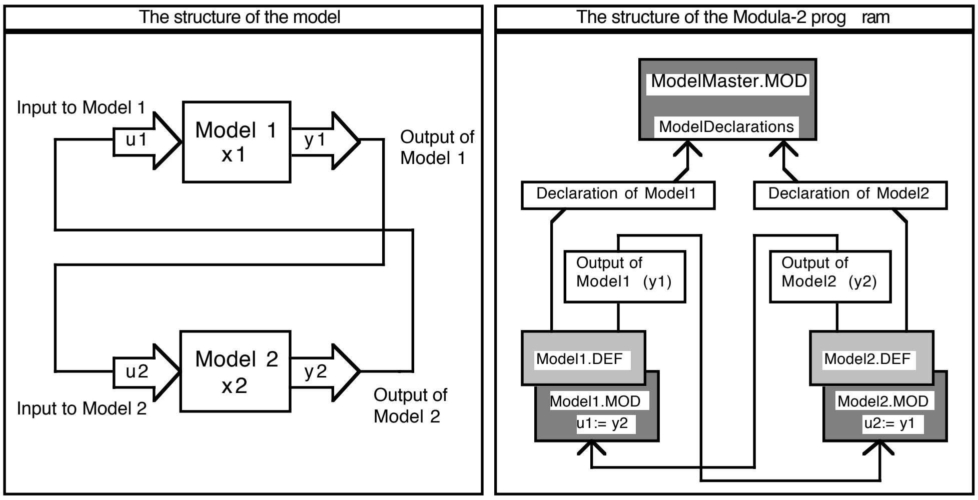


Fig. T24: Mapping of a structured model composed of two subsystems (left) onto a Modula-2 model definition program (right). The outputs are exported by the definition modules (DEF) and imported by the implementation modules (MOD) of the other submodel. The program module *ModelMaster* links both submodels by importing and executing the submodel declarations. All modules together form the model definition program.

5.2.3 Model installation

ModelWorks allows to install any number of models and model objects. The actual limitations are not inherent in the software but are only given by the available computer resources, i.e. the currently available heap space and the computing power needed to numerically solve the models.

The body of the main module from the model definition program calls the procedure *RunSimMaster* from module *SimMaster*. Typically the actual definition of the models and model objects is indirectly executed by *RunSimMaster* . It takes place in a procedure which is not called by the model definition program itself, but instead is passed to ModelWorks as an actual parameter while calling procedure *RunSimMaster*. Executing this procedure will result in the loading and linking of the model together with the eventual set of submodels in the ModelWorks simulation environment (Tutorial Fig. T3).

From within the standard simulation environment, once installed, neither the number of models nor the number of model objects may be changed without going through a full development cycle (Fig. T16, T23). However, if the modeler extends the simulation environment by corresponding menu commands, the dynamic declaration and the removing of models and model objects becomes possible and there applies no longer any restriction to the model installation (s.a. part III *Reference* the chapter *Client interface*). For this purpose the modeler has to use the procedures *DeclM* resp. *RemoveM* from the client interface and to install menu commands using the procedures *InstallMenu* and *InstallCommand* from module *DMMenus* of the *Dialog Machine*. Removing a model implies the removing of all its model objects.

5.2.4 MODULE STRUCTURE OF MODELWORKS

In order to link model definitions to ModelWorks, the modeler needs the client interface. It consists of a mandatory and an optional part and an auxiliary library: The mandatory part consists of the two library modules *SimBase* plus *SimMaster* and the optional portion of the modules *TabFunc*, *SimIntegrate* and *SimGraphUtils* (Fig. T25). Any model definition program has to import from the mandatory client interface.

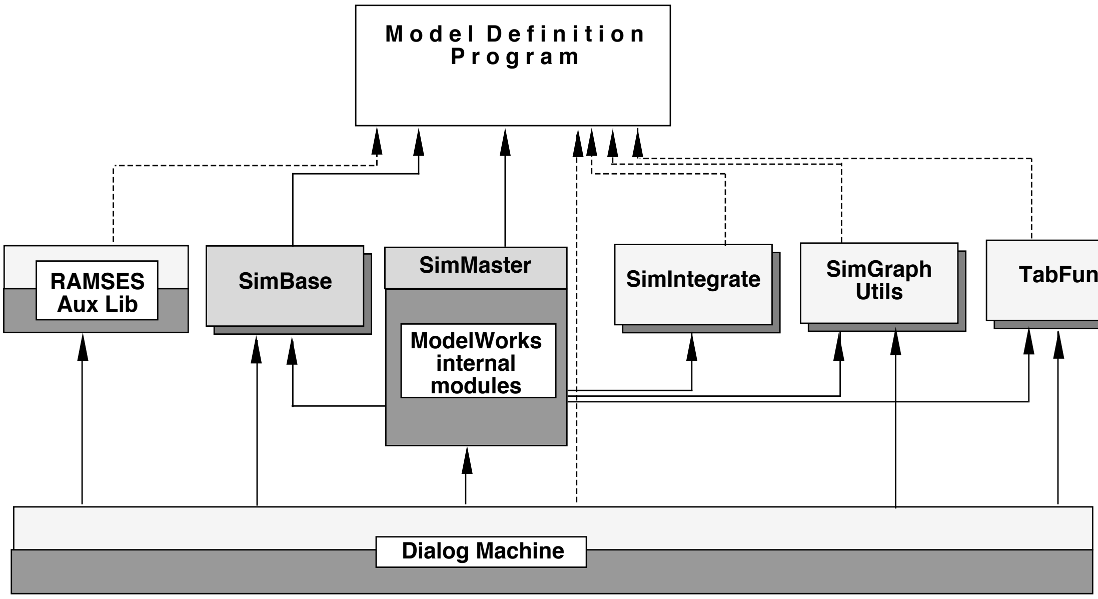


Fig. T25: Module structure of ModelWorks programs: The model definition program imports from the client interface, which consists at least of the modules SimBase and SimMaster (mandatory part). The model definition program may actually consist of just one program module up to any number of modules. The internal ModelWorks modules are linked together in SimMaster.OBM. —— mandatory imports; - - - optional imports.

The optional client interface *TabFunc* is useful if the modeler uses nonlinear functions, which are defined by a table of supporting points, so-called table functions. During simulations ModelWorks will then linearly interpolate or extrapolate needed values. *SimIntegrate* can be used to integrate a model anytime without actually running a simulation. The global simulation time of the simulation environment will remain unaffected by such an integration. *SimGraphUtils* can be used to draw into the standard graph window. This feature can be used to draw measurements with error bars into the graph or to customize the graph in any desired way by using routines from the *Dialog Machine* module *DMWindowIO*.

In the current ModelWorks version the auxiliary library consists among others of the modules *ReadData*, *JulianDays*, *DateAndTime*, *WriteDatTim*, *RandGen*, and *RandNormal*. *ReadData* facilitates the reading of data from text files, for instance when the simulationist wishes to compare simulation results with measurements. *JulianDays* provides functions useful for the mapping of the simulation time to calendar dates and vice versa. *DateAndTime* and *WriteDatTim* allow to access the built-in computer clock in order to record real time events, such as begin and end of a long simulation. *RandGen* and *RandNormal* return uniformely (within (0,1]) and normally (N~(μ,σ)) distributed variates to support stochastic simulations. Since this auxiliary library is completely independent of ModelWorks, the modeler is free to add any modules he/she wishes.

5.2.5 ModelWorks objects and the run time system

ModelWorks maintains the model objects, e.g. during numerical integration, although the variables representing these objects are contained only in the model definition program. The advantage is that the modeler may define and access these variables in whichever way he likes, e.g. by using state variables as part of an array or a record data structure. Note however, that ModelWorks can do so only by using the following mechanism: During declarations ModelWorks stores the addresses of the variables declared as objects. Later during simulations, ModelWorks will access the model objects and their associated variables (Tutorial Fig. T2) for reading or writing (Tab. T2) by assuming that these objects still exist. Hence the modeler must be very careful to ensure that any model object exists as long as the program environment exists, i.e. is always declared as a global Modula-2 variable and not as a variable local to a procedure.

Symbol	Meaning of variable	Action by ModelWorks
State variables		
x	State variable	
	overwrite with initial value during declaration	write
	overwrite with initial value at begin of run	write
	integration (continuous time only)	read and write
	update with new value obtained via integration	write
$\dot{x}$/x(k+1)	Derivative (continuous time)/ new value (discrete time)	
	integration	read
x_o	Initial value[10]	
	overwrite with default during declaration	write
	overwrite with default while resetting initial values	write
	editing of value via IO-window	read and write
Model parameters		
p	Model parameter	
	overwrite with default during declaration	write
	overwrite with default while resetting parameters	write
	editing of value via IO-window	read and write
Monitorable variables		
o	Monitorable variable	
	overwrite with 0.0 during declaration	write
	monitoring	read
	Stash filing, Tabulation, or Graphing attribute[11]	
	overwrite with default during declaration	write
	overwrite with default while resetting parameters	write
	editing of value via IO-window	read and write

Tab. T2: Actions of ModelWorks performed on installed model objects.

[10] variable belongs to ModelWorks not to the client's model definition program

[11] see previous footnote

Models are always calculated in parallel, regardless of the presence of any coupling among them, i.e. the calculation order of the client procedures is: first all *Output* of all submodels, second all *Input* of all submodels etc. The actual sequence of the computations of a particular kind of client procedures, e.g. the sequence with which ModelWorks calls the procedures *Dynamic*, is given by the sequence of their declarations in the model definition program.

In the current version of ModelWorks input, output, and auxiliary variables do not appear expli-

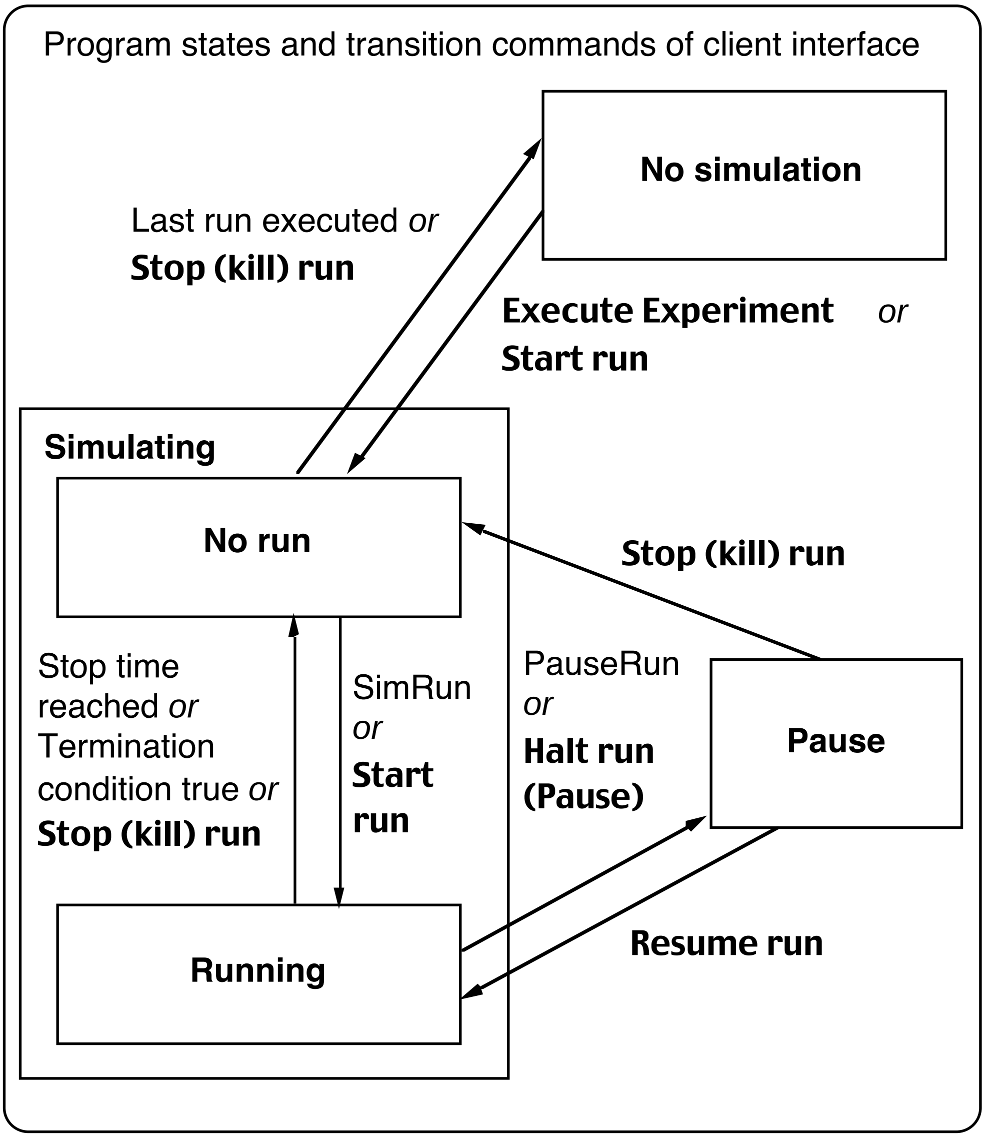


Fig. T26: State transition diagram of the client interface of ModelWorks. In contrast to the program states viewed by the simulationist (Fig. T15, a simplified projection of this diagram) the modeler has a different view. While programming structured simulations (*Experiment*) the modeler needs to consider two sub-states in the state *Simulating*: *No run* and *Running*. The state *No run* allows the modeler to modify current values, e.g. initial values, parameters, or the integration step. In the state *Running* no changes may be made to global simulation parameters. Note that some transitions are only available to the simulationist (bold text of menu commands, e.g. **Start run** or **Execute experiment**), some are also under the control of the modeler (plain procedure identifiers, e.g. PauseRun). Note also that some commands which are available to the simulationist (e.g. **Start run**) actually encompass several transitions, a fact only visible to the modeler.

citly in the ModelWorks concept. Inputs and outputs were formally defined in chapter *Theory*, and the model definition program is responsible for a correct handling of them. Auxiliary variables may be used freely and belong completely to the model definition program. Note, this implies that ModelWorks does neither initialize nor otherwise maintain auxiliary variables. Often auxiliary variables are computed in the procedure *Dynamic*; hence, they will only hold a correct value if the procedure *Dynamic* has at least been called once, i.e. only after a simulation run has already begun (s.a. Fig. T16, T17, and T18); attempts to use them in the procedure *Initialize* may lead to wrong results, since their values may not yet be defined.

5.2.6 Program states of the client interface

In addition to the program states of the simulation environment there are two sub-states of the state *Simulating*: the sub-state *No run* and the sub-state *Running* (Fig. T26).

They can be determined via the client interface by calling the procedure *GetMWSubState*. Their purpose is to distinguish between a state in which no changes may be made to current values and one in which such changes are allowed. For instance, in order to avoid inconsistencies with an on-going simulation but still to allow changes of global simulation parameters, they may be changed in the state *No run*, but not in the state *Running*. The possibility to change current values is essential for structured simulations, since the modeler may wish to change current values between two consecutive simulation runs, e.g. initial values, parameters during a parameter identification, the integration step, or the simulation start and stop time (see section on Programming structured simulations (Experiments)).

Some state transitions are under the control of the simulationist only (e.g. **Start run** or **Execute experiment**; **Resume run** or **Stop (kill) run** from state *Pause*), all other transitions are controlled by both, the simulationist and the modeler (e.g. SimRun or **Start run**; PauseRun or **Halt run (Pause)** etc.). If the modeler calls procedure *SimRun* the state *No run* is left and ModelWorks enters the state *Running*. If a simulation run is finished because the simulation time has reached the stop time, the termination condition has become true, or the simulationist has stopped the simulation, the state *Running* is left and the state *No run* is entered (Fig. T26). Note that if the simulationist stops (kills) a structured simulation, ModelWorks will execute all remaining statements, eventually calling procedure *SimRun* many times, till the procedure *Experiment* is actually finished. However, note that in the latter case no integration and monitoring will take place, since ModelWorks empties the body of the procedure *SimRun*, so that the structured simulation will terminate without any further computations by the ModelWorks run time system. The procedures *ExperimentRunning* and *ExperimentAborted* from module *SimMaster* allows to determine, if an experiment has been started respectively aborted by the simulationist. This allows the modeler to program structured simulations with maximum flexibility.

5.2.7 Programming structured simulations (Experiments)

Many functions of ModelWorks are also available via the client interface. For instance it is possible to start an elementary simulation run by calling procedure *SimRun* from module *SimMaster*. A structured simulation or experiment consists typically of a sequence of calls to procedure *SimRun*. The following example illustrates a situation in which four initial state vectors ([x,y] = [1, 1], [2, 2], [-1, -1] and [-2, -2]) for a second order system of differential equations are to be used to produce a phase portrait. Each combination will be used in a simulation run:

```
PROCEDURE MyExperiment;
BEGIN
  SetSV(m,x,1.0);   SetSV(m,y,1.0);   SimRun;
  SetSV(m,x,2.0);   SetSV(m,y,2.0);   SimRun;
  SetSV(m,x,-1.0);  SetSV(m,y,-1.0);  SimRun;
  SetSV(m,x,-2.0);  SetSV(m,y,-2.0);  SimRun;
END MyExperiment;
```

With the exception of the declaration procedures *DeclM*, *DeclSV*, *DeclP*, and *DeclMV*, it is basically possible to use any procedure from the client interface to program a structured simulation experiment. However, since some procedures affect values currently in use, such as e.g. the simulation time, this might lead to inconsistencies.

Hence the modeler should observe some restrictions and consider the following rules:

- The current program state determines which procedures may be called effectively. The program state during an experiment is always *Simulating*. However ModelWorks makes a difference between the two sub-states *No run* (still executing procedure *Experiment*, but not procedure *SimRun*) and *Running* (executing procedure *SimRun*). In analogy to the state *No simulation* the state *No run* allows the modeler to program changes to current values in a similar way the simulationist might do it in state *No simulation* (Fig. T26). In the state *Running* the modeler may not change any of the following classes of current values:
  - Global simulation parameters (procedures *SetGlobSimPars*, *SetDefaultIndepVarIdent*)
  - Stash file (procedure *SwitchStashFile*)
  - minimum and maximum for the scaling and monitoring settings (stash filing, tabulation, and graphing) for monitorable variables (procedure *SetMV*)

- Attempts to call procedures modifying current values of the listed kinds in the state *Running* will have no immediate effect. In the case of the global simulation parameters they will affect the next simulation run, in all other cases the attempts to change will have no effect at all.

- Attempts to call procedures modifying current values of other values than the listed kinds, will have an effect as soon as these values are actually used. However note that this may lead to unpredictable results, e.g. if the integration method is changed in the middle of an integration, i.e. by calling *SetM* from within procedure *Dynamic*, the results of the integration will most likely be wrong. However, if the modeler calls *SetM* from within procedure *Output* or *Input*, no problems should occur.

- Changes programmed by calling procedures which affect default values only (procedures *SetDeflt…*, *StashFileName* etc.) will not become effective until a reset of the corresponding type of values is executed.

The feature programming experiments offers unlimited possibilities; they can't be all explained here. Instead it is left to the modeler's responsibility to understand what ModelWorks is exactly doing (see this chapter and in particular section on ModelWorks objects and the run time system) and to program the problem at hand accordingly.

Structured simulations are not only most useful, but a necessity if a model is to be used for a parameter identification or a sensitivity analysis etc. To illustrate this point the example of a little sensitivity analysis is presented: Given a set of n model parameters and for each parameter a triple of values: lower boundary of a confidence interval, mean, and upper boundary of the confidence interval ($\alpha = 5\%$). The values are stored on a text file in this format:

```
min p1    mean p1        max p1        descriptor of p1             p1            unit p1
min p2    mean p2        max p2        descriptor of p2             p2            unit p2
...
...
...
...
...
min pn    mean pn        max pn        descriptor of pn             pn            unit pn
```

For instance this parameter file might look like:

```
0.109     0.234         0.472         Growth rate[12]                           r              day^-1
35.6      42.3          49.8          Half-saturation c.            Ks            µg/l
1.0E5     2.5E5         5.0E5         Initial algal dens.           x0            cells/ml
```

A sensitivity analysis can be easily realized in form of the following program code:

```
CONST n = 3;
TYPE PVal = (cur, min, mean, max);
  PType = RECORD
          v: ARRAY [cur..max] OF REAL;
            descr,ident,unit: ARRAY [0..64] OF CHAR;
          END;
VAR  p: ARRAY [1..n] OF PType;

PROCEDURE DeclObjects;
  VAR i: [1..n]; j: [min..max]; parFile: TextFile[13];
BEGIN
  GetExistingFile(parFile, "Open parameter file");
  FOR i:= 1 TO n DO
    FOR j:= min TO max DO GetReal(parFile,p[i].v[j]) END;
    SkipGap(parFile);  ReadChars(parFile,p[i].descr);
    SkipGap(parFile);  ReadChars(parFile,p[i].ident);
    SkipGap(parFile);  ReadChars(parFile,p[i].unit);
  END;
  Close(parFile);
  FOR i:= 1 TO n DO WITH p[i] DO
    DeclP(v[cur],v[mean],0.0,MAX(REAL),noRtc,descr,ident,unit)
  END END;

  DeclSV(...
  ...
END DeclObjects;

PROCEDURE MyExperiment;
  VAR i,j,k: [min..max];
BEGIN
  FOR i:= min TO max DO
    FOR j:= min TO max DO
      FOR k:= min TO max DO
    SetP(m,p[1].v[cur], p[1].v[i]);
    SetP(m,p[2].v[cur], p[2].v[j]);
    SetP(m,p[3].v[cur], p[3].v[k]);
    SimRun
  END END END;
END MyExperiment;
```

or alternatively the procedure *MyExperiment* may be programmed in the general recursive variant, which works for any n:

```
PROCEDURE MyExperiment;
  PROCEDURE Sensitivity(i: CARDINAL);
    VAR j: [min..max];
  BEGIN
    FOR j:= min TO max DO SetP(m,p[i].v[cur], p[i].v[j]);
      IF i<n THEN Sensitivity(i+1) ELSE SimRun END;
    END(*FOR*);
  END Sensitivity;
BEGIN
  Sensitivity(1);
END MyExperiment;
```

Note that the latter form makes it less obvious how fast such a structured simulation may grow to an enormous task; given n model parameters each with k values and each combination is to be tested, the number of simulation runs becomes k^n. Our most simple example has n = 3 parameters, each with k = 3 values (min, mean, max), yet for a full sensitivity analysis, there are already 3^3 = 27 simulation runs needed.

[12] In order to be able to use blanks in the middle of a descriptor and still be able to write the data onto the text file in a free format use so-called hard spaces (Option^space-bar) within a descriptor.

[13] The objects *TextFile*, *GetExistingFile*, *GetReal*, *SkipGap*, *ReadChars*, and *Close* are to be imported from the "Dialog Machine" module *DMFiles*.

Part III: Reference

This reference part contains a description of the usage of every feature ModelWorks offers. However, it contains only little information on the elementary and typical usage or the theoretical concepts of ModelWorks. In case you should not be familiar with the basic concepts of ModelWorks, please read first the ModelWorks tutorial. In particular you should read the first chapter of the tutorial: *General Description.*

The descriptions given in this reference are brief and relate only to specific properties of individual commands. In order to avoid redundancy they do not explain the general principles behind a class of commands and functions of ModelWorks which are described in the part II, *ModelWorks Theory*, in particular in the chapter *ModelWorks Functions*.

This part contains two chapters:

The chapter *User interface* lists all commands which are available to the simulationist via the user interface.

The chapter *Client interface* contains the specifications of the client interface used by the modeler. All functions and the use of all program objects exported by the ModelWorks modules *SimMaster* and *SimBase* are explained.

Any serious modeling with ModelWorks requires to read at least the Part II *ModelWorks Theory* and the second chapter on the client interface of the Part III *Reference.*

Reading Hint: For easier orientation, the pages, figures and tables of Part III *Reference* are prefixed with the letter R. Within this part figures and tables are numbered separately, starting with Fig. R1 respectively Tab. R1.

6 User Interface

The user interface of the various ModelWorks versions differ slightly. This text has been made using the standard Macintosh version (see *Appendix*). As long as just the appearance is affected by the differing implementations (holds in particular for the PC version, which has a slightly different appearance), the following information should be easy to interpret also for a non-standard ModelWorks version.

Reading Hint: If there is a functional difference to the standard version, the fact will be stated in a phrase within brackets with a font similar to the following: [Not available in Reflex and PC version].

6.1 Menus and Menu Commands

This section explains all menu commands in detail. Many and often used menu commands can also be invoked by using the keyboard instead of the mouse. For easier remembering the keys to be used for the keyboard shortcuts are shown to the right of the command text (Fig. R1). Keyboard shortcuts or so-called keyboard equivalents are entered by pressing the command key (clover-leaf key) simultaneously with another key "X"[1].

Reading Hint: Throughout this reference manual such keyboard equivalents are abbreviated as "/ X".

The following keyboard commands are globally available in the simulation environment: In all entry forms the simulationist may press the key *Return* or *Enter* instead of clicking into the push button *OK*. Pressing the keys " ." or *Escape* is equivalent to the clicking into the push button *Cancel*[2]. The latter two keyboard equivalents may also be used to stop a simulation run (*Stop (Kill) run*). Pressing the key *tab* in an entry form allows to move to the next edit field plus to fully select its content. In some edit fields the key combination *Shift tab* is available to move backwards from field to field (e.g. in the data table provided by the module *TabFunc*). While a selection is currently made, the simulationist may use within an edit field the key equivalents " C" for copying the selection into the clipboard, " X" to cut (copy plus delete) the selection into the clipboard, and " B" to blank (delete without copy) the selection. The current content of the clipboard (if text) may be pasted into an edit field at the current location of the insertion bar or as a replacement for the current selection by pressing " V". This technique allows also to transfer textual data between different entry forms and between different applications (given they support the clipboard for text). If no entry form or other dialog box is currently in use, the clipboard accessing keyboard equivalents have the usual meaning (see below *Menu Edit*).

[1] On the IBM PC press the Ctrl-key simultaneously with the key "X".

[2] On the IBM PC keyboard shortcuts function only if a letter is involved, hence the cancel function with "Ctrl^." is not available. Use *Escape* instead.

6.1.1 Overview over ModelWorks standard menus

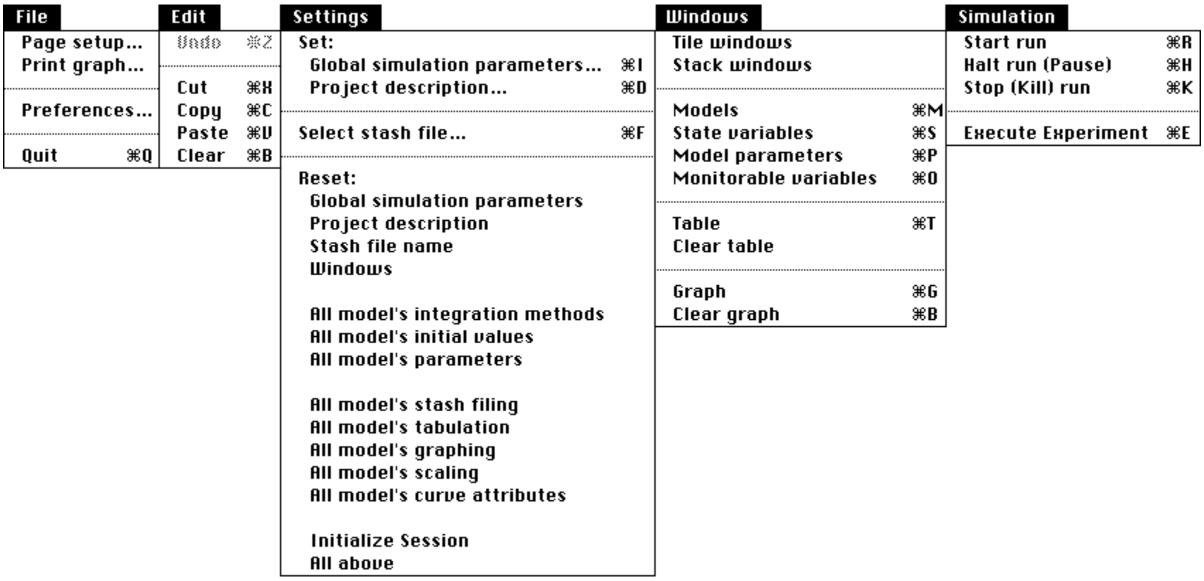


Fig. R1: All ModelWorks standard menus

Fig. R1 shows an overview of all standard menus and menu commands of the ModelWorks simulation environment. A detailed explanation is given below:

If the modeler imports from module *TabFunc*, an additional menu will appear (Fig. R11.). [In the PC version any of the menu commands starting with the phrase *All model's...* are missing, but note that these functions are also available in the IO-windows].

6.1.2 Menu *File*

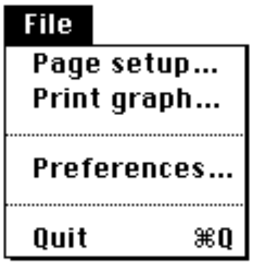
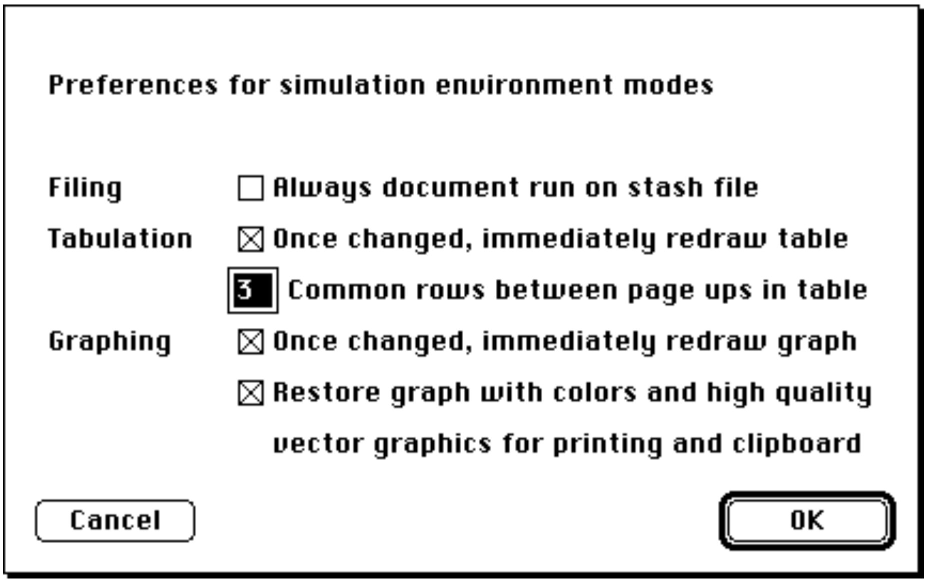


Fig. R2: Menu *File*

Page setup...: Usual page set up dialog box used for the printing of the graph on the currently chosen printer. [Not available in Reflex and PC version].

Print graph...: Prints the graph on the currently chosen printer. [Not available in Reflex and PC version].

Preferences...: Allows to set the modes of the simulation environment.



Preferences for simulation environment modes

Filing □ Always document run on stash file

Tabulation ☒ Once changed, immediately redraw table

3 Common rows between page ups in table

Graphing ☒ Once changed, immediately redraw graph

☒ Restore graph with colors and high quality vector graphics for printing and clipboard

Fig. R2: Entry Form of the menu command *Preferences…* shown with settings recommended for the beginner.

Filing

If the simulation environment mode *Always document run on stash file* is active, the stash file is opened at the begin of every simulation regardless of the current setting for stash filing of the monitoring variables. If this mode is inactive, the stash file will only be opened in case that at least one monitoring variable has the stash filing currently set (F). In case you rather use the stash file for run documentation purposes than for post run analysis purposes, it is recommended to have this simulation environment mode active. It will then force the opening of the stash file always and document every simulation. The recording flags and the stash file settings (F) of the monitorable variables will then no longer affect the file opening, but only determine which data are to be written to the stash file (s.a. below menu command *Set Project description…* recording flags).

Tabulation

If the simulation environment mode *Once changed, immediately redraw table* is active, the table is redrawn immediately after each change in the tabulation settings. Otherwise the last table will be kept untouched until the next simulation run is started. Only at that time the old table is cleared and a new one will be drawn.

The number *Common rows between page ups in table* defines what happens during a page up. A page up occurrs when the table window is full but more rows should be written; then ModelWorks attempts to erase most of the table and restarts tabulating from the top again. This number specifies first how many rows at the bottom are not erased but copied to the top of the next page. All remaining space below is then used to add the rows of the new page. Thus this number specifies how many rows are common to two consecutive pages.

Graphing

If the simulation environment mode *Once changed, immediately redraw graph* is active, the graph is redrawn immediately after each change in the graph settings. Otherwise the last graph will be kept untouched until the next simulation run is started. Only at that time the old graph is cleared and a new one will be drawn.

Activating the simulation environment mode *Restore graph with colors and high quality vector graphics for printing and clipboard* is active, the graph is restored with colors when a previously covered graph portion becomes visible again or will be printed or transferred to the clipboard in colors and with high quality. If this mode is turned off a bitmap is used instead for restoring, printing, or transfer into the clipboard (pixel based raster graphics). Graph restoration becomes necessary whenever the simulationist moves, rearranges, or closes windows and the graph window is involved. Note that with this option active, graphs may be restored slower and more memory may be needed. Otherwise graphs are restored in black and white only[3]. Vector graphics contain data about particular objects and the coordinates defining them; e.g. a line is stored as a line object together with the coordinates of its begin and end point. Hence vector graphics are usually of a higher quality than raster graphics. However, the printing of a vector graph may require too much time if draft quality of a graph would be sufficient. Note that with this option active complicated graphs, particularly if drawn during large experiments, may use up tremendous amounts of memory. On black and white monitors activate this mode if you wish to use color printers or transfer the graph via the clipboard to other color devices. [Not available in Reflex and PC version].

Quit / Q: Terminates the program and goes back to the program level from which the model has been started. Usually this is either the MacMETH programming environment or the Finder.

6.1.3 MENU *EDIT*

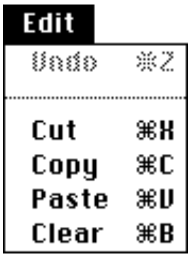


Fig. R4: Menu *Edit*

[The whole menu is not available in the Reflex and PC version].

Undo / Z: not available (present only for compatibility with the user interface guidelines).

Cut / X: Clears the graph and copies it into the clipboard if no other window than a ModelWorks window is the frontmost window. Otherwise, e.g. if a desk accessory is the frontmost window, this command will perform the standard *Cut* command as described in the Macintosh owner's guide. The quality of the transferred graph depends on the current simulation environment mode as described under menu command *File/Preferences…*.

[3] Note that these simulation environment modes have no default values. The current values are written in the resource fork of the MacMETH-Shell. They are read from there at the startup of your model definition program.

Copy / C: Copies the graph into the clipboard if no other window than a ModelWorks window is the frontmost window. Otherwise, e.g. if a desk accessory is the frontmost window, this command will perform the standard *Copy* command as described in the Macintosh owner's guide. The quality of the transferred graph depends on the current simulation environment mode as described under menu command *File/Preferences…*.

Paste / V: Not available unless another window than a ModelWorks window is the frontmost window. For instance if a window of a desk accessory is the frontmost window, the content of the clipboard will be pasted into the desk accessory such as the scrapbook.

Clear / B: Clears the graph if no other window than a ModelWorks window is the frontmost window. Otherwise, e.g. if a desk accessory is the frontmost window, this command will perform the standard *Clear* command as described in the Macintosh owner's guide.

Keyboard equivalents of these commands are available often even when the simulation environment is in a mode which prohibits choosing menu commands, e.g. when an entry form is currently in display. The meaning of these commands is then such that textual objects and not the graph are exchanged with the clipboard. For a more detailed description of these commands see the first section of this chapter.

6.1.4 MENU *SETTINGS*

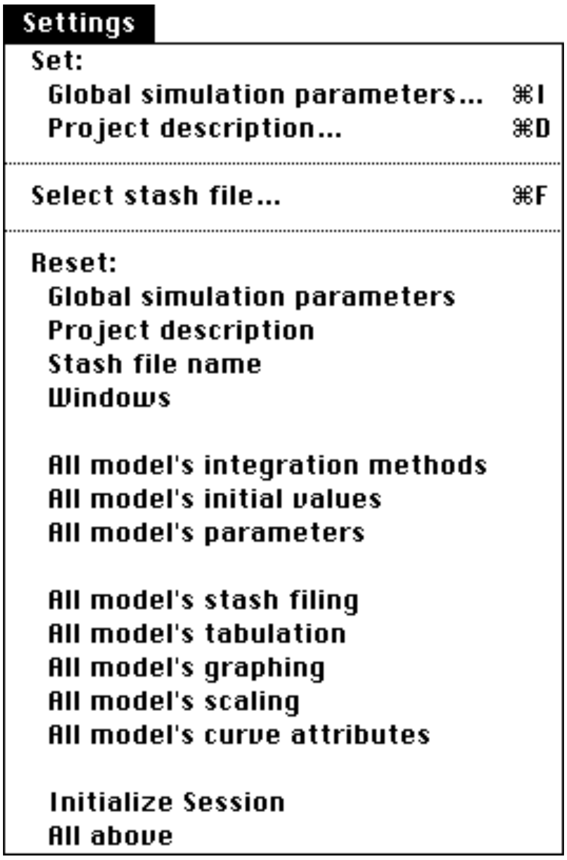


Fig. R5: Menu *Settings* used to set or reset current values.

This menu consists basically of three parts: *Set, Select stash file...,* and *Reset* (Fig. R5).

The first part lets you set the global simulation parameters such as the simulation start and stop time, plus the project description. The second determines which file is going to be used as the stash file. The third is used to reset the current values of global parameters, settings, and of model objects; resetting means to copy the defaults to the corresponding current values (Fig. 22 part II *Theory*). [The PC version will not offer any of the menu commands starting with the phrase *All model's…*(are available in IO-windows)].

Set:

Set Global simulation parameters.../ I: Displays an entry form (Fig. R5a-c) to set the global simulation parameters such as the integration step. Note that all of these parameters are valid globally, i.e. they determine time and integration parameters for all present (sub)models together.

Start time for simulation [t_o/k_o]: The next simulation run will start with this time. If only discrete time models are present (case B, Fig. R5b) k_o is an integer, otherwise t_o is a real (case A, Fig. R5a).

Stop time for simulation [t_{end}/k_f]: The next simulation run will stop with this time. If only discrete time models are present (case B, Fig. R5b) k_f is an integer, otherwise t_{end} is a real (case A, Fig. R5a).

The following one or two fields vary depending on the kind of models which are present. In the case A only continuous time (sub) models (Fig. R5a), in case B only discrete time (Fig. R5b), and in case C continuous time as well as discrete time submodels, i.e. a mixed time structured model (Fig. R5c) , are present:

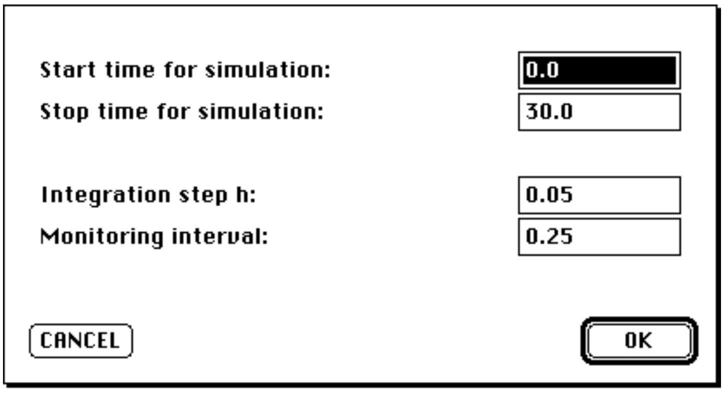
Integration step h [h]: If at least one continuous time (sub)model is present, h is the fixed time step[4] for the numerical integration of the differential equations. Moreover, if a variable step length integration method is in use by at least one of the continuous time (sub)models, this simulation parameter becomes the

Maximum integration step h [h_{max}]: The actual integration step will be determined by the variable step numerical integration algorithm and globally used as the integration step for all other submodels, even if they should be solved with a fixed step length method.

Maximum relative local error [e_r]: Only if at least one continuous time (sub)model is using a variable step length integration method, this simulation parameter appears in the entry form. It determines the maximum relative local integration error $\underline{\varepsilon}$ estimated by comparing a higher order result with a lower order result. If a norm of this error vector $|\underline{\varepsilon}|$ divided by a norm of the state vector $|\underline{x}|$ exceeds e_r, the integration step length h is halved till $|\underline{\varepsilon}| / |\underline{x}| <= e_r$. Otherwise h is doubled unless one of the following two conditions would become true $|\underline{\varepsilon}| / |\underline{x}| > e_r$ or $h > h_{max}$.

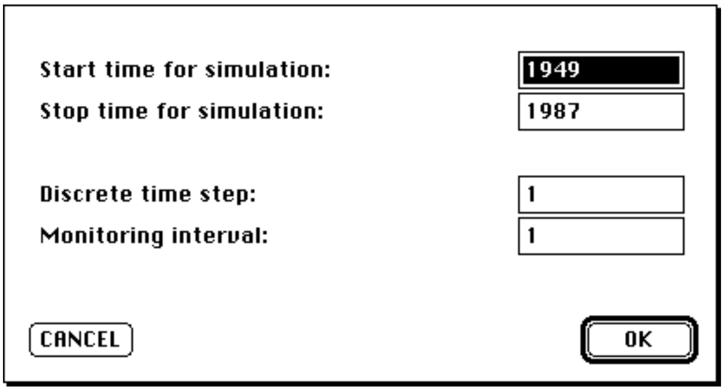
Discrete time step [c]: If only discrete time (sub)models are present (case B) c may be edited in place of the integration step h. However, in this case the actual value of c is irrelevant, since the length of an interval between two discrete time points has no meaning if only discrete time (sub)models are present. This

[4] The smaller the step h is, the more accurate is the calculation (unless h gets so small that truncation errors become dominant); the larger h is, the faster runs the simulation. Therefore the simulationist has to select a good compromise, which depends on the integration method used <u>and</u> on the nature of the model.



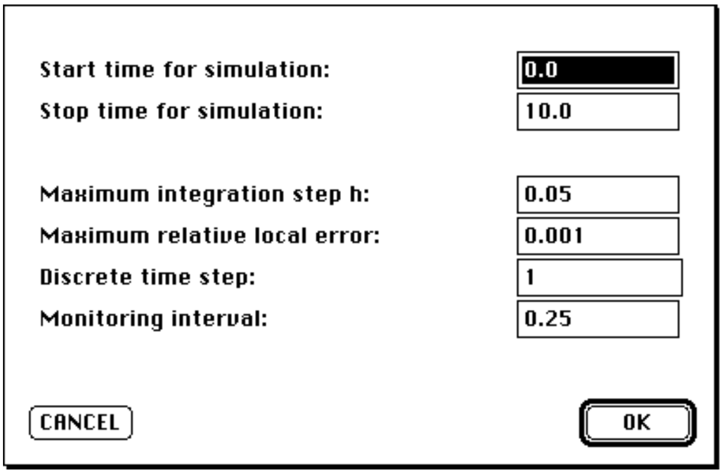
Start time for simulation:	0.0
Stop time for simulation:	30.0
Integration step h:	0.05
Monitoring interval:	0.25

Fig. R5a: Entry form *Global simulation parameters...*/ I for case A: only continuous time (sub)models are present.



Start time for simulation:	1949
Stop time for simulation:	1987
Discrete time step:	1
Monitoring interval:	1

Fig. R5b: Entry form *Global simulation parameters...*/ I for case B: only discrete time (sub)models are present.



Start time for simulation:	0.0
Stop time for simulation:	10.0
Maximum integration step h:	0.05
Maximum relative local error:	0.001
Discrete time step:	1
Monitoring interval:	0.25

Fig. R5c: Entry form *Global simulation parameters...*/ I for case C: some continuous as well discrete time (sub)models are present. In addition a variable step length integration method is used.

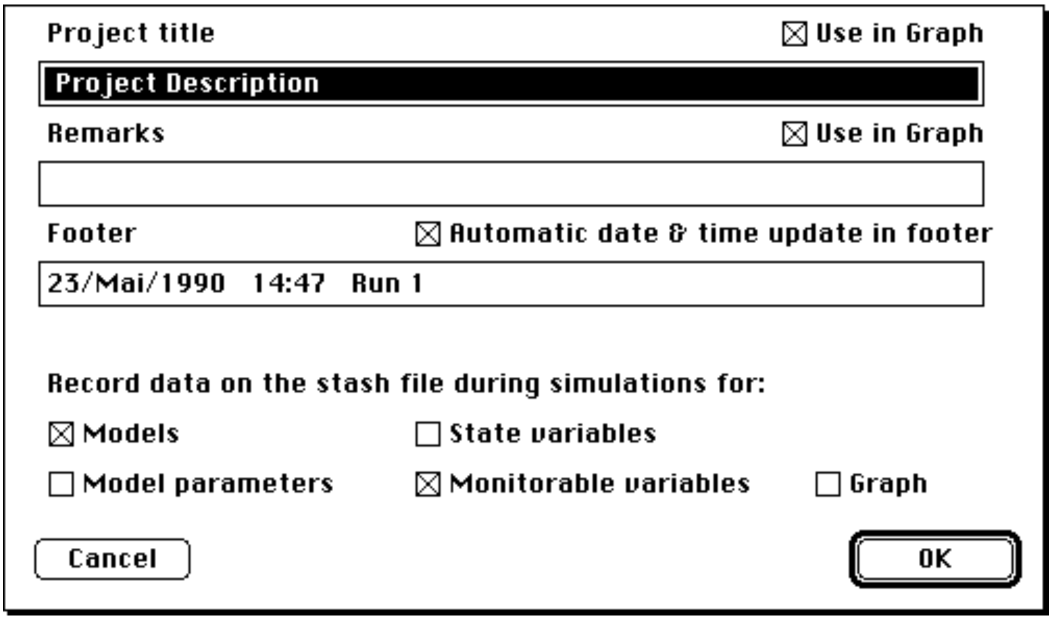
differs from case C, where not only discrete time, but also continuous time (sub)models are present. In the latter case c may be edited in addition to h and becomes the *Coincidence interval* [c]: The variable c is always an integer.

Monitoring interval [h_m]: Interval at which the values of all monitorable variables are either written onto the stash file, tabulated in the table, or drawn into the graph, depending on their current monitoring settings.

Set Project description.../ D: Displays the entry form to edit a global project description and control the recording of data on the stash file.

Project title: String which can be freely used to describe the on-going project, i.e. for instance a title for the current simulation session. If the menu command *Print graph...* is chosen, this *Project title* string will always be printed in bold above the graph. However, the graph displayed and transferred into the clipboard will contain this string only if the flag *Use in Graph* has been checked. In the graph window this string will be displayed in the middle and at the top of the data panel.

Remarks: String which can be freely used to add some remarks on the on-going project. For instance it may be used as a sub-title similar to the project title string or it may contain some information on specific model parameter settings used in the simulations. If the menu command *Print graph...* is chosen, this *Remarks* string will always be printed just below the title in a smaller font and with style plain. However, the graph displayed and transferred into the clipboard will contain this string only if the flag *Use in Graph* has been checked. In the graph window this string will be displayed to the right of the legend at the bottom of the window.



Project title ☒ Use in Graph

Project Description

Remarks ☒ Use in Graph

Footer ☒ Automatic date & time update in footer

23/Mai/1990 14:47 Run 1

Record data on the stash file during simulations for:

☒ Models ☐ State variables

☐ Model parameters ☒ Monitorable variables ☐ Graph

Fig. R7: Entry form *Project description.../* D

Footer: By default the footer contains the date, the time, and the simulation run number, but it may also be used to store any other information. If the flag *Automatic data & time update in footer* is turned on, ModelWorks will update this information at the begin of each simulation run. If the menu command *Print graph...* is chosen, this footer string will always be printed in a small font size below the graph. However, the graph transferred into the clipboard will never contain this string.

Record data on the stash file during simulations for: With these recording flags the simulationist may control which information and values are written onto the stash file. Check the appropriate boxes for models, model parameters, state variables, monitorable variables, and the graph if you wish to have them written onto the stash file at the begin (for all except the graph) and at the end (graph only) of simulation runs.

Note that the flags *Models*, *Model parameters*, *State variable*, and *Monitorable variables* mean that information about these objects is written to the stash file. They are: the descriptor, the identifier, the unit (unless a model), and the object specific current values.

Except for the monitorable variables, information about all objects will be recorded. In case of the monitorable variables only the information about those monitorable variables is recorded, which are involved in the stash filing (F) or in the graph (X or Y). The latter requires also that the corresponding recording flag (*Graph*) has been set.

The recording flag *Graph* controls whether graphical simulation results are written to the stash file. [Graph recording not available in Reflex and PC version].

Note that ModelWorks will record information on the stash file at the begin and end of each simulation run, in particular also during experiments.

The data are written to the stash file in the so-called RTF-Format[5] which can be opened by the Microsoft® Word, WriteNow™, or MacWrite II document processing software[6]. Opening the file with other text editors is also possible, but the graph will not be interpreted correctly and control strings which can not be interpreted will also remain in the text. However data from simulation results are written in a format which allows to paste or import them directly into many other applications, such as the spread-sheet program Excel from Microsoft® or the presentation graphics program Cricket Graph[7]. The format of the stash file has also been designed to allow for an efficient and simple post run analysis. In particular check the recording flags for models and monitoring variables if you wish to produce a stash-file which can be interpreted successfully by a post analysis[8].

Note that in case the simulation environment mode *Always document run on stash file* is currently not active, the recording flag settings are irrelevant if no monitoring variable has currently the stash file setting active (F). Only as soon there is at least one variable, the stash file will be actually opened and the recording flags then control which information is wirtten onto the stash file in

[5] RTF stands for Rich Text Format. It is based on ASCII characters only but contains coded formatting information and can be interpreted by many commercially marketed text processing applications.

[6] Microsoft® Word is available from Microsoft® Corporation. WriteNow™ has been written by Anderson, D.J., Tschumy, B. & Stinson, C. and is available from NeXT Inc. MacWrite II is available from Claris Corp.

[7] Cricket Graph is a program to edit and produce presentation graphics for science and business by Rafferty, J. & Norling, R. and is available from Cricket Software Inc.

[8] The current version of ModelWorks does not feature a post analysis session. However RAMSES (Research Aids for the Modeling and Simulation of Environmental Systems), a software package which encompasses not only the full functionality of ModelWorks but also interactive modeling and experimental frame definition, will contain also a post analysis tool capable of interpreting ModelWorks stash-files.

addition to the simulation results. If you plan to run a post analysis from the stash file, you should at least have the recording flags *Models*, and *Monitorable variables* active. If you rather use the stash file for run documentation purposes it is recommended to have the simulation environment mode *Always document run on stash file* active. The recording flags together with the stash file setting (F) of the monitorable variables will then solely control the kind of information and data written to the stash file (s.a. menu command *Preferences…*).

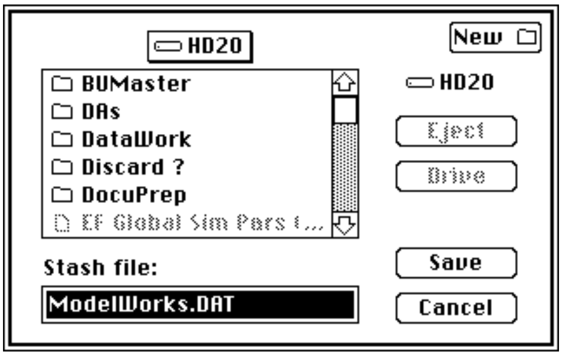


Fig. R8: Dialog box *Select stash file.../* F

Select stash file.../ F Allows to select a stash file (Fig. R8) with the usual open file dialog box. Note that this command will not really open the file, so that the simulationist may open it for inspection during the program state *No simulation.*

Once a simulation starts, i.e. ModelWorks enters the program state *Simulating*, the stash file will be automatically opened and remains open till the state *Simulating* will be left. Since during a whole structured simulation ModelWorks remains in the state *Simulating* this means that all results from all simulation runs are normally written on the same stash file. The default name used in the file selection dialog box is the current stash file name. Note that if there is not at least one monitorable variable present for which the current stash filing setting is activated (F/*writeOnFile*), ModelWorks will never open a stash file regardless of the current settings of the recording flags (see above).

Reset:

The reset menu commands (Fig. R5) assign to the selected element(s) the default value(s) (s.a. section on Resetting, Fig. T22 part II *Theory*). The latter have been defined by the modeler in the model definition program or have been predefined by ModelWorks. All commands in this menu operate on the scope of all models respectively all objects of all models (Fig. T21 part II *Theory*); other scopes are available in the IO-windows only.

Reset Global simulation parameters: Resets all global simulation parameters.

Reset Project description: Resets all strings and flags to their defaults.

Reset Stash file name: Resets the stash file name, i.e. defines that the stash file used during the next simulation run will be the default stash file.

Reset All model's integration methods: Resets the integration methods of all models. [Not available as a menu command in Reflex and PC version].

Reset All model's initial values: Resets the initial values of all state variables of all models. [Not available as a menu command in Reflex and PC version].

Reset All model's parameters: Resets all parameters of all models. [Not available as a menu command in Reflex and PC version].

Reset All model's stash filing: Resets the stash file setting (*writeOnFile/ notOnFile*) of all monitorable variables of all models. The stash file name and directory as defined with the menu command *Select stash file...* is not affected. [Not available as a menu command in Reflex and PC version].

Reset All model's tabulation: Resets the tabulation settings (*writeInTable/ notInTable*) of all monitorable variables of all models. [Not available as a menu command in Reflex and PC version].

Reset All model's graphing: Resets the graph settings (*isX/isY/notInGraph*) of all monitorable variables of all models. [Not available as a menu command in Reflex and PC version].

Reset All model's scaling: Resets the minimum and maximum values used for the scaling of all monitorable variables of all models on the ordinate. These scaling extremes define the range of interest (Fig. T2 part *Tutorial*) and are used during the drawing of values of the monitorable variables in the graph. [Not available as a menu command in Reflex and PC version].

Reset All model's curve attributes: Resets the *curve attributes* of all monitorable variables of all models to their default values. [Not available as a menu command in Reflex and PC version].

Initialize session Calls the procedure again, which was installed by the modeler with *DeclInitSimSession* from module *SimMaster*. Note that this procedure has already been called at least once during the start-up of the simulation session. Be warned that it could contain erroneously calls to procedures, which must not be called repeatedly. For instance the installation of an additional menu should normally only be done once at the very begin of a simulation session (see also chapter *Simulation environment* section *Simulations* in the previous part II *Theory* and the next chapter *Client interface* of this part).

Reset All above: Encompasses a reset of all reset commands listed above, in particular: resetting of the global simulation parameters, of the project description, of the stash file name, of all integration methods for all models, of all initial values, of all parameters, and of all monitoring settings (Stash filing, tabulation, graphing). See Resetting in the part *Theory*. In addition the windows are all closed and reopened at their original position at which they were at the begin of the simulation session and the eventually installed (*DeclInitSimSession*) procedure to initialize the simulation session is called. If the modeler has not changed any defaults by calling a *SetDeflt*-procedure (see module *SimBase*), the status and the current values of all objects will be exactly the same as it was right after the start up of the model definition program.

6.1.5 MENU *WINDOWS*

This menu contains all commands which operate on windows (Fig. R9). These menu commands rearrange size and position of all ModelWorks windows, open the corresponding window, or bring it to the front. If the simulationist closes a window, ModelWorks remembers its size and position and will reopen it at exactly the same place it was before its closing.

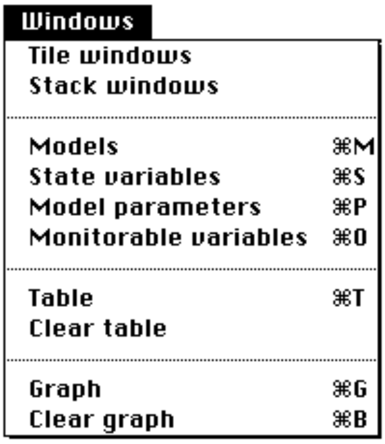


Fig. R9: Menu *Windows*

Tile windows: All IO-windows, plus the table and graph window are closed and reopened so that they do no longer overlap. On small screens the IO-windows for the state variables, model parameters, and monitorable variables are shown beside each other on top of the screen, on larger screens all four IO-windows are displayed in two rows on top of the screen. The remaining windows are fit into the bottom portion of the screen, making the graph window as large as possible. The column display in the IO-windows is also affected. Only the short identifiers (*ident*) and the current value columns are shown: current integration method for models, current initial values for state variables, current values for model parameters, and current monitoring settings for the monitorable variables.

Stack windows: All IO-windows, plus the table and graph window are closed and reopened in a stacked fashion. The locations and sizes of all windows, plus the columns displayed in the IO-windows are the same as at the begin of a simulation session. However in contrast to that situation, the table and the graph window are also opened.

Models/ M: The IO-window *Models* is opened respectively brought to the front.

State variables/ S: The IO-window *State variables* is opened respectively brought to the front.

Model parameters/ P: The IO-window *Model parameters* is opened respectively brought to the front.

Monitorable variables/ O: The IO-window *Monitorable variables* is opened respectively brought to the front.

Table / T: The table window is opened respectively brought to the front. If there are no monitorable variables which have an active tabulation setting (T), this window may not be opened in the program state *Simulating*.

Clear table: This command clears the table, i.e. erases the content of the table window if it is currently open.

Graph / G: The graph window is opened respectively brought to the front. If there are no monitorable variables which have an active graphing setting (Y/*isY*), this window may not be opened in the program state *Simulating*.

Clear graph / B: Clears (blanks) all curves in the panel of the graph if the graph window is currently open. If the latter condition is true it is the same command as *Edit*/*Clear* (see above *Menu Edit*).

6.1.6 MENU *SIMULATION*

If a simulation is started by any of the menu commands available under this menu (Fig. R10), ModelWorks will enter the state *Simulating* (Fig. T15 part II *Theory*)

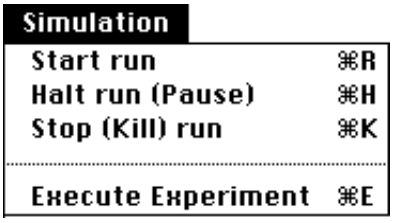


Fig. R10: Menu *Simulation*

Start run / R: Starts an elementary simulation run with the current settings of all values. Previously drawn curves are not erased unless demanded by a change of the graph settings since the last simulation (a curve added or removed, scaling changed). In the upper right corner, the current run number (k) and the current simulation time (t) are displayed in a small window ('k: t'). This command lasts as long as the simulation runs. It may be terminated by the simulationist (menu command *Stop (Kill) run*) or by the model, i.e. if the simulation time reaches the stop time or if the installed termination condition returns true. Note that the menu command *Halt run (Pause)* does not really terminate this command.

Halt run (Pause) / H or *Resume run* / R: Temporarily halts or pauses a simulation run if the current program state is *Simulating*. The new program state entered is *Pause*. If the current program state is *Pause*, this menu command will resume the interrupted simulation run where it has been left, i.e. reenter the state *Simulating* and continue with the integration, monitoring etc.. A pause can be used to study a curve or a tabulated result in more detail, or can be used to change model parameters in the middle of a simulation. Note however, that current values of model parameters can only be modified if the flag rtc (run time change) has been set for that particular parameter. [Keyboard equivalent for *Resume run* is not available in PC version].

Stop (Kill) run / K: This command terminates the simulation before the simulation time reaches the stop time t_{end}/k_f or without the termination condition returning true. This command is the only one available to the simulationist to terminate a simulation interactively. It may be chosen from both program states *Simulating* as well as *No simulation.*

Execute Experiment / E: Executes the currently installed structured simulation a so-called experiment. It enters the program state *Simulating* and calls the procedure which has been declared as the *Experiment* procedure by the model definition program (see procedure *DeclExperiment* from module *SimMaster*). If no such procedure has been installed, this command will appear dimmed (inactive) and can not be chosen.

If the monitoring settings for the stash filing of at least one monitorable variable is set (F/*writeOnFile*), a stash file with the current stash file name is automatically opened and data are written onto it according to the current recording flags (see menu command *Project description...*). However, this behavior depends also on the current simulation environment mode (see above menu command *File/Peferences…*). In case that the mode *Always document run on stash file* is currently active, the stash file is opened even if the stash filing is set for no monitorable variable.

Important notice: In case there exists already a file with the same name as the current stash file name, this file will be overwritten without any warning![9] Due to the nature of interactive simulation, the overwriting is quite normal and frequent and causes usually no harm. Hence, the display of an alert would be too cumbersome, but the quiet overwriting can become dangerous if the modeler programs the stash file name erroneously (see procedure *SwitchStashFile* from module *SimBase*).

If the monitoring settings for tabulation or graphing are activated, the corresponding windows are automatically opened or brought to the front. If already any of the windows *Table* or *Graph* are the frontmost window, ModelWorks will not automatically open the other window or bring it to the front. This allows the simulationist to suppress the automatic opening or bringing to the front of either the table or graph window by bringing first the other one to the front before he starts or resumes a simulation. If there are no monitorable variables which have an active tabulation setting (T/*writeInTable*), the table window may not remain open and will be automatically closed in case it should be already open at the begin of the simulation. If there are no monitorable variables which have an active graphing setting (Y/*isY*), the graph window may not remain open and will be automatically closed in case it should be already open at the begin of the simulation. In all other cases ModelWorks leaves the windows where they are.

6.1.7 OPTIONAL MENU *TABLE FUNCTIONS*

In addition to model parameters ModelWorks offers the optional possibility to use non-linear functions as parts of equations which are not given in form of a closed, analytical form but which are given by a table of values, so-called table functions (Fig. R13). ModelWorks will then linearly interpolate or extrapolate missing values during simulations. As soon as the modeler imports any objects from the optional client interface *TabFunc* (Fig. T25 part II *Theory*), ModelWorks will add an additional menu to the right of the menu *Simulation* (Fig. R11). This menu serves the editing and resetting of the declared table functions.

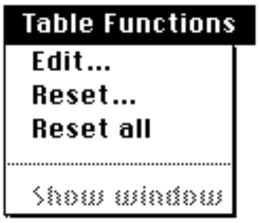
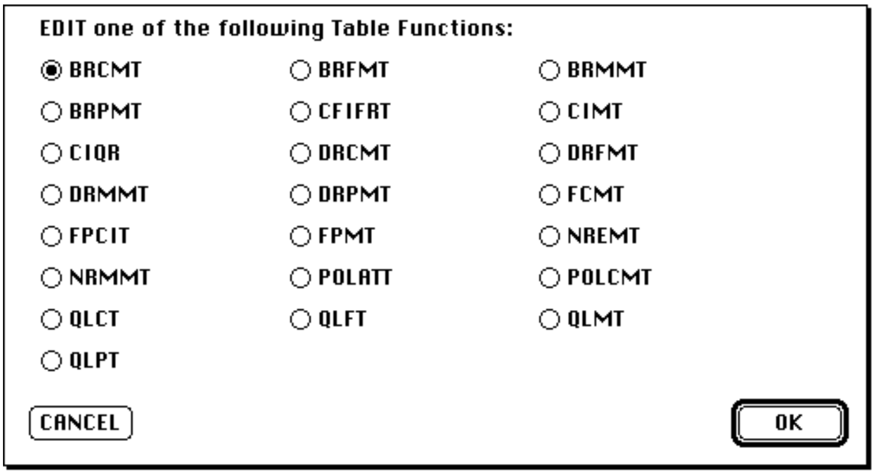


Fig. R11: Menu *Table Functions*

Edit...: Lets the simulationist edit a table function.

[9] When using the menu command *Select stash file...* the simulationist will always be first asked if he really wants to overwrite in case there should already exist a file with the same name as the stash file.

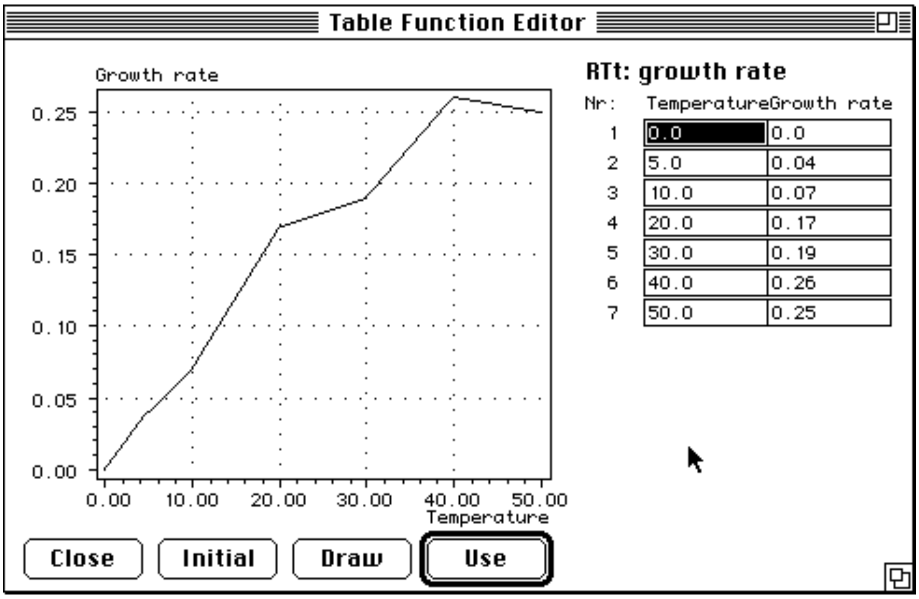
First the table function has to be selected by clicking into the corresponding radio button in an entry form similar to the one shown in Fig. R12. Every table function will be associated with a short identifier, which will be used by ModelWorks in this entry form.



EDIT one of the following Table Functions:

● BRCMT ○ BRFMT ○ BRMMT
○ BRPMT ○ CFIFRT ○ CIMT
○ CIQR ○ DRCMT ○ DRFMT
○ DRMMT ○ DRPMT ○ FCMT
○ FPCIT ○ FPMT ○ NREMT
○ NRMMT ○ POLATT ○ POLCMT
○ QLCT ○ QLFT ○ QLMT
○ QLPT

Fig. R12: Entry form to select a table function for the editing of the values of a particular table function. The functions are listed with their identifiers.



RTt: growth rate

Nr:	Temperature	Growth rate
1	0.0	0.0
2	5.0	0.04
3	10.0	0.07
4	20.0	0.17
5	30.0	0.19
6	40.0	0.26
7	50.0	0.25

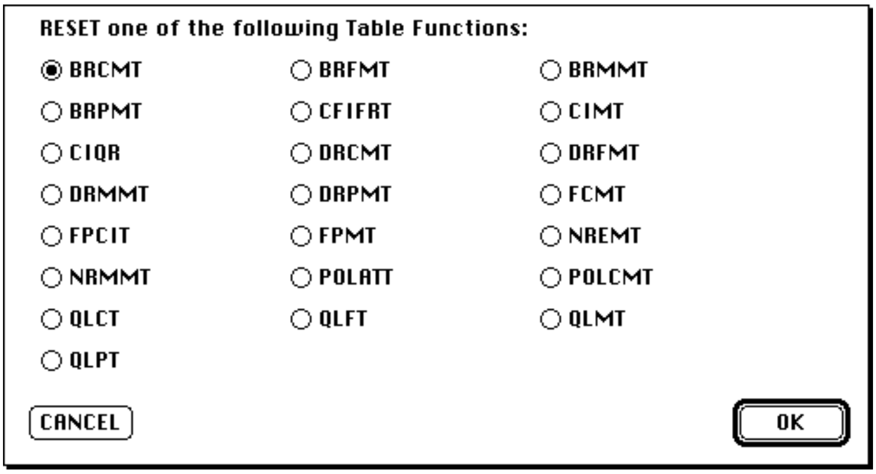
Fig. R13: Table Function Editor to display (Draw) and edit values of a table function.

Secondly a window will be displayed similar to the one shown in Fig. R13. It shows a graph of the table function and all its values at the right of the graph. The first column in this table contains the values of the independent variable (x-values) and the right column the values of the dependent function value (y-values). All these values may be edited, however, note that it is required that the x-values are always in ascending order and that all x-values must be different, i.e. if there are n x-values with the index i, they must satisfy the condition $x_1 < x_2 < x_3 < ... < x_i < ... < x_{n-1} < x_n$. The simulationist is asked to correct values which do not satisfy this condition.

Several push buttons at the lower left corner may be used to issue commands. The two in the middle (*Initial*) or (*Draw*) may be used any time. Button *Initial* discards the momentary editing and reloads the default values into the value table at the right of the graph. Do not confound this with a reset, since a reset would also require to click into the button *Use* immediately after having clicked the button *Initial*, i.e. without any editing inbetween. For actual resets use the menu command *Table Functions/Reset…*. To (re)draw the graph with the current coordinates of the supporting values, as shown at the right of the graph, click into button *Draw*. The push button *Use* accepts the edited coordinates of the supporting points for the new current values and redraws the graph (Since it is the default button, it may also be used by pressing either the key *Return* or *Enter*). Note that from then on computations of the model will use the new values to evaluate function values. The push button *Close* discards (!) all editing and closes the window; the table function will remain untouched, exactly as it was before the menu command *Edit...* has been chosen.

Editing of table functions is possible in the states *NoSimulation* and *Pause*. It is also only available if there is currently at least one table function present, which is modifiable (see below section *Declaration of table functions* and and usage of module *TabFunc* in the next chapter of this part). This may change even during a simulation session, since the modeler may add or remove table functions, or change their attributes dynamically via the client interface.

Reset...: Resets the values of an individual table function to their defaults. This command displays an entry form similar to the one shown in Fig. R14. Select the table function to be reset by clicking in the corresponding radio button. Again table functions are selected via their short identifiers.



RESET one of the following Table Functions:

◉ BRCMT ○ BRFMT ○ BRMMT
○ BRPMT ○ CFIFRT ○ CIMT
○ CIQR ○ DRCMT ○ DRFMT
○ DRMMT ○ DRPMT ○ FCMT
○ FPCIT ○ FPMT ○ NREMT
○ NRMMT ○ POLATT ○ POLCMT
○ QLCT ○ QLFT ○ QLMT
○ QLPT

Fig. R14: Entry form to select a table function for an individual of all values of a particular table function. The functions are listed with their identifiers.

Reset all: Resets all values of all table functions to their defaults without asking the simulationist for a selection of a particular table function.

Show window: Shows the table function editor window by bringing it to the front.

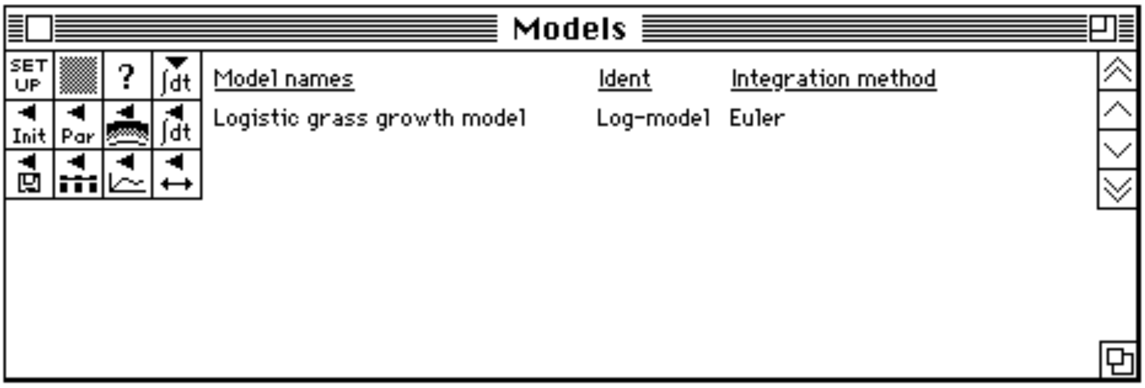
Note that the resetting of table functions is only available in the state *NoSimulation*.

6.2 IO-Windows (Input-Output-Windows)

IO-windows serve the entering of new data (Input) and the display of the current values (Output) of models and model objects. For a description of the general operation of IO-windows see also the section on IO-windows and in particular Fig. T20 in part II *Theory*.

6.2.1 IO-WINDOW *MODELS*

The IO-window *Models* (Fig. R15) displays information (name, identifier, current integration method) about the installed models. Furthermore it offers a mechanism to select models and to execute functions, which operate on the selected models and/or their objects, by clicking on the buttons in the window.

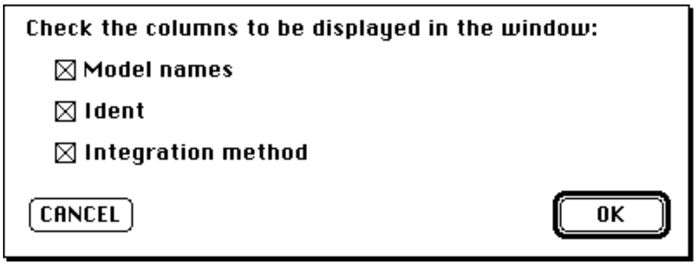


```
Model names                    Ident       Integration method
Logistic grass growth model    Log-model   Euler
```

Fig. R15: IO-window *Models* showing the list of all (sub)models and offering a palette of button functions operating on models and model objects.

SET UP *Columns set-up*: Activates an entry form in which the display of the columns in the IO-window *Models* can be controlled (Fig. R16). The columns of which the display can be turned on or off are:

- *Model names*: Full names of the models.
- *Ident*: Short identifiers of the models.
- *Integration method*: Current integration method.



Check the columns to be displayed in the window:

☒ Model names

☒ Ident

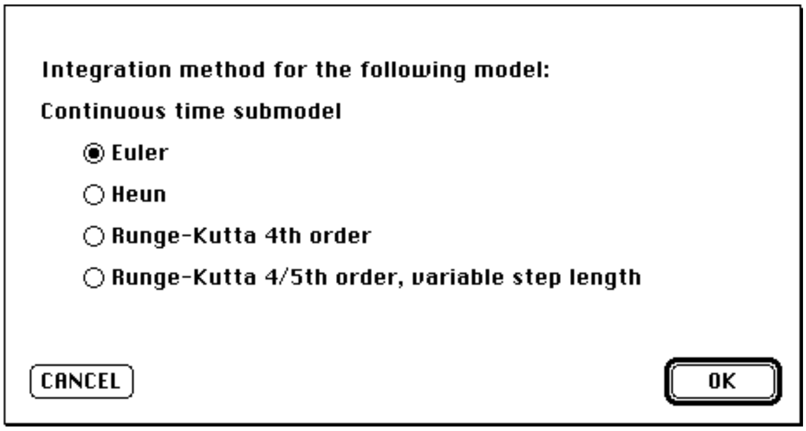
☒ Integration method

Fig. R16: Entry form opened by the SET UP button in the IO-window *Models*.

▨ *Selects all models*. All subsequent button functions will operate on the scope *All* (Fig. T21 part II *Theory*), i.e. on all models respectively all objects of all models.

? *Help respectively model information*: Opens or brings a window with the title *Model Help/Info* to the front and executes the help or about procedure for the currently selected model (works only on single model and not on multiple selections). ModelWorks opens only the window, but writes nothing into it. It is up to the procedure *About* to write information into this window. The latter procedure has been installed by the modeler while declaring the model (see procedure *DeclM* from module *SimBase*). Typically this function is to inform the simulationist about some model characteristics. For instance the written information may consist of the model equations, the name of the author(s), or some help information on the model. The *Model Help/Info* window remains open until the simulationist closes it. It may be closed, moved, or resized freely.

∫dt *Set integration method*: Opens an entry form in which the integration method for the currently selected model(s) can be set (Fig. R17). This is possible only for continuous time models; of course the «integration method» for discrete time models can not be altered. The following integration methods are available:



Integration method for the following model:

Continuous time submodel

● Euler

○ Heun

○ Runge-Kutta 4th order

○ Runge-Kutta 4/5th order, variable step length

Fig. R17: Entry form to select the numerical *integration method* with which a continuous time (sub)model is to be integrated during simulations.

- *Euler*: Simple first order, one-step integration method with fixed integration step (also Euler-Cauchy method or Runge-Kutta 1st order). This method is fast, but should be used with care as it can lead to large errors.
- *Heun*: Second order one-step integration method with constant integration step (also Runge-Kutta 2nd order). This method is similar to the trapezoidal rule, but differs from it inasmuch as it is not iterative.
- *Runge-Kutta-4th order*: Fourth order one-step integration method with constant integration step.
- *Runge-Kutta-4/5th order, variable step length* 4th/5th order, variable step length Runge-Kutta-Fehlberg method (ATKINSON & HARLEY, 1983; ENGELN-MüLLGES & REUTTER, 1988). The local error is estimated comparing the 5th order with the 4th order result. Depending on the error estimate the step length is increased or reduced to obtain optimal results in terms of efficiency and accuracy. This method is most useful for solving models with time constants, which strongly vary during the course of a simulation. [Not available in Reflex and PC version]

The number of times the procedure *Dynamic* is called is equal to the order of the integration method. Be aware that despite their higher computing load, high order methods are often more efficient than those of lower order. This is because higher order methods allow for larger integration steps while retaining the same accuracy. The latter may result in a reduction of the total number of times the procedure *Dynamic* has to be computed. However, since the actual performance depends also on the characteristics of the model, the best method for a particular model has often to be identified by numerical experiments.

Reset integration method: Resets the integration method of the currently selected model(s) to their default.

Reset initial values: Resets all initial values of the state variables of the currently selected model(s) to their default values.

Reset parameters: Resets all parameters of the currently selected model(s) to their default values.

Reset stash filing: Resets the monitoring settings for the stash filing (F/*writeOnFile*/*notOnFile*) of all monitorable variables of the currently selected model(s) to their default settings.

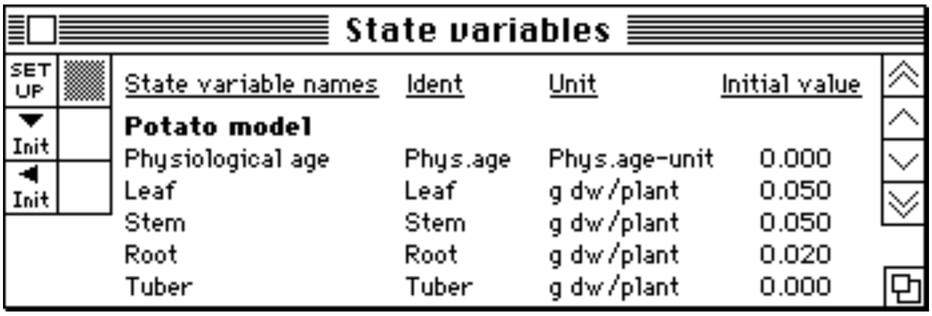
Reset tabulation: Resets the monitoring settings for the tabulation (T/*writeInTable*/*notInTable*) of all monitorable variables of the selected model(s) to their default settings.

Reset graphing: Resets the monitoring settings for the graphing (X/Y/*isX*/*isY*/*notInGraph*) of all monitorable variables of the selected model(s) to their default settings.

Reset scaling: Resets the scaling (minimum and maximum on ordinate) of all monitorable variables of the selected model(s) to their default values.

Reset curve attributes: Resets all curve attributes (color or stain, line style, and symbol) of all monitorable variables of the selected models to their default values.

6.2.2 IO-window *State variables*



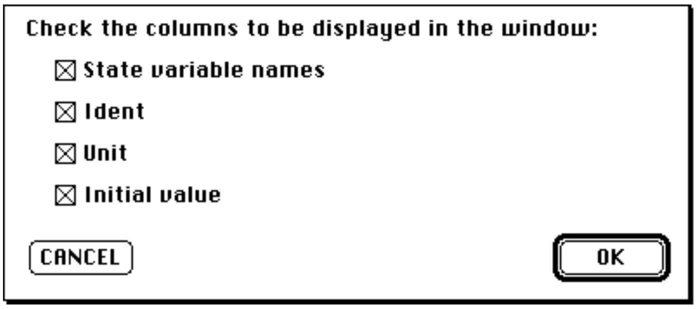
State variable names	Ident	Unit	Initial value
Potato model			
Physiological age	Phys.age	Phys.age-unit	0.000
Leaf	Leaf	g dw/plant	0.050
Stem	Stem	g dw/plant	0.050
Root	Root	g dw/plant	0.020
Tuber	Tuber	g dw/plant	0.000

Fig. R18: IO-window *State variables* showing the list of all state variables and offering a palette of button functions operating on the current values of the currently selected state variables.

The IO-window *State variables* displays information (name, identifier, unit, current initial value) about the installed state variables of all models (Fig. R18). Furthermore it offers a mechanism to select state variables and to execute functions, which operate on the current initial values of the selected state variables, by clicking on the buttons in the window.

SET UP *Columns set-up* Activates an entry form in which the display of the columns in the IO-window *State variables* can be controlled (Fig. R19). The columns of which the display can be turned on or off are:

- *State variable names*: Full names of the state variables.
- *Ident*: Short identifiers of the state variables.
- *Unit*: Unit in which to measure the values of the state variables.
- *Initial value*: Current initial value of the state variable used to initialize the state variables at the begin of each simulation run.



Check the columns to be displayed in the window:

☒ State variable names

☒ Ident

☒ Unit

☒ Initial value

Fig. R19: Entry form opened by the SET UP button in the IO-window *State variables.*

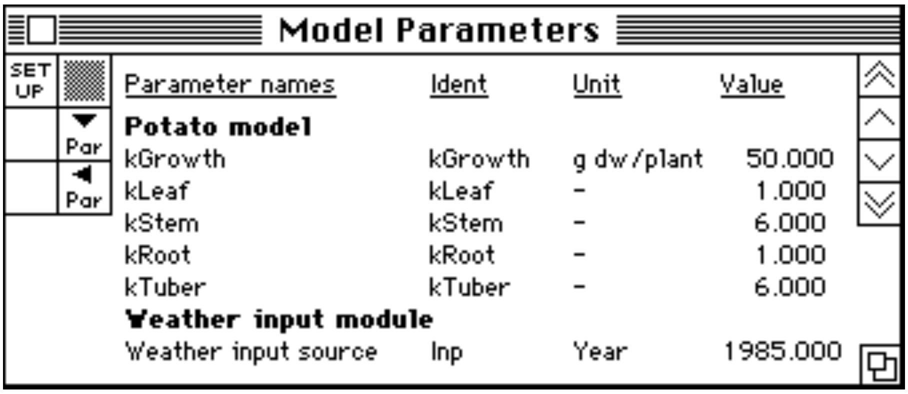
▨ *Selects all state variables*: All subsequent button functions will operate on the scope *All* (Fig. T21 part II *Theory*), i.e. on all state variables of all models.

▼ Init *Set initial value*: Opens an entry form in which the current initial value for the selected state variable(s) can be edited. ModelWorks rejects any attempt to enter a value out of the range as defined by the modeler in the model definition program. If a multiple selection of state variables has been made, not only one but a series of entry forms will be offered, one form for each state variable. This sequence can be terminated by pressing the push-button *Cancel.* Note however, that in the latter case all changes which have been made to state variables before, can no longer be reversed. Only eventual changes made to the state variable currently in display will be discarded.

◀ Init *Reset initial value*: Resets the initial values of the currently selected state variable(s) to their default values.

6.2.3 IO-WINDOW *MODEL PARAMETERS*

The IO-window *Model parameters* displays information (name, identifier, unit, value, change at run time enabled/disabled) about the installed model parameters of all models (Fig. R20). Furthermore it offers a mechanism to select model parameters and to execute functions, which operate on the current values of the selected model parameters, by clicking on the buttons in the window.

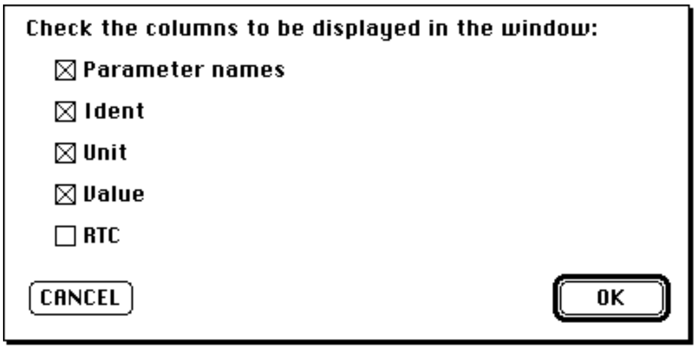


Parameter names	Ident	Unit	Value
Potato model			
kGrowth	kGrowth	g dw/plant	50.000
kLeaf	kLeaf	-	1.000
kStem	kStem	-	6.000
kRoot	kRoot	-	1.000
kTuber	kTuber	-	6.000
Weather input module			
Weather input source	Inp	Year	1985.000

Fig. R20: IO-window *Model parameters* showing the list of all model parameters and offering a palette of button functions operating on the current values of the currently selected model parameters.

SET UP *Columns set-up*: Activates an entry form in which the display of the columns in the IO-window *Model parameters* can be controlled (Fig. R21). The columns of which the display can be turned on or off are:

- *Parameter names*: Full names of the model parameters.
- *Ident*: Short identifiers of the model parameters.
- *Unit*: Unit in which to measure the values of the model parameters.
- *Value*: Current value of the model parameters.
- *RTC*: (*rtc*/*noRtc* - runtime change/no runtime change). The value in this column shows whether a parameter may be changed during a simulation run or not. In order to warrant consistency, the modeler may prevent the changing of a parameter value in the middle of a simulation by disabling this flag (*noRtc*). By default, this column is not shown.



Check the columns to be displayed in the window:

☒ Parameter names

☒ Ident

☒ Unit

☒ Value

☐ RTC

Fig. R21: Entry form opened by the SET UP button in the IO-window *Model parameters*.

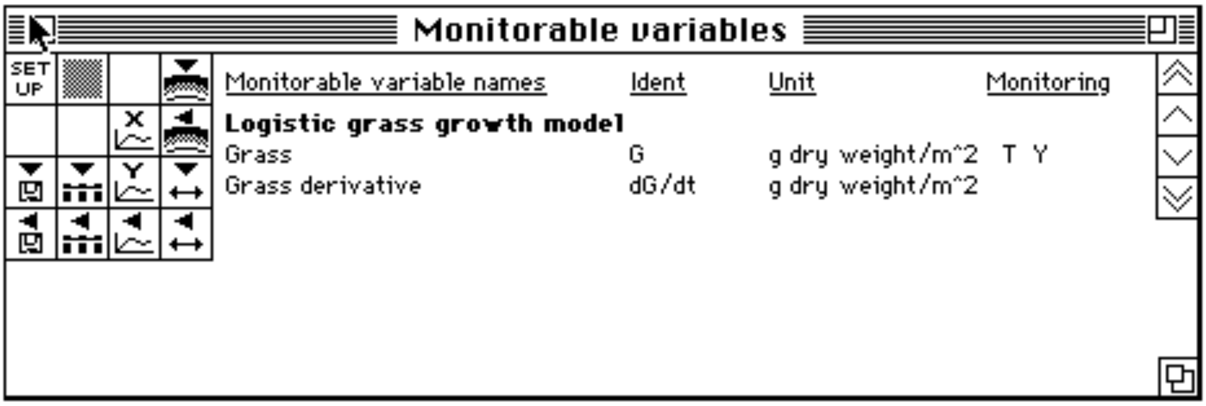
▨ *Selects all model parameters*: All subsequent button functions will operate on the scope *All* (Fig. T21 part II *Theory*), i.e. on all model parameters of all models.

▼ Par *Set model parameter value*: Opens an entry form in which the current parameter value for the selected model parameter(s) can be edited. ModelWorks rejects any attempt to enter a value out of the range as defined by the modeler in the model definition program. If a multiple selection of model parameters has been made, not only one but a series of entry forms will be offered, one form for each model parameter. This sequence can be terminated by pressing the push-button *Cancel*. Note however, that in the latter case all changes which have been made to model parameters before, can no longer be reversed. Only eventual changes made to the model parameter currently in display will be discarded.

◀ Par *Reset model parameter*: Resets the parameter values of the currently selected model parameter(s) to their default values.

6.2.4 IO-WINDOW *MONITORABLE VARIABLES*

The IO-window *Monitorable variables* displays information (name, identifier, unit, minimal and maximal value for scaling, current output selection) about the installed monitorable variables of all models (Fig. R22). Furthermore it offers a mechanism to select monitorable variables and to execute functions, which operate on the current monitoring settings of the selected monitorable variables, by clicking on the buttons in the window.



Monitorable variable names	Ident	Unit	Monitoring
Logistic grass growth model			
Grass	G	g dry weight/m^2	T Y
Grass derivative	dG/dt	g dry weight/m^2	

Fig. R22: IO-window *Monitorable variables* showing the list of all monitorable variables and offering a palette of button functions operating on the current monitoring settings of the currently selected monitorable variables.

SET UP *Columns set-up*: Activates an entry form in which the display of the columns in the IO-window *Monitorable variables* can be controlled (Fig. R23). The columns of which the display can be turned on or off are:

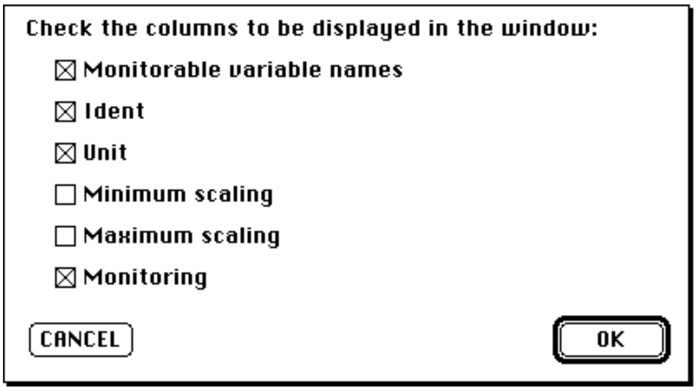
- *Monitorable variable names*: Full names of the monitorable variables.
- *Ident*: Short identifiers of the monitorable variables.
- *Unit*: Unit in which to measure the values of the monitorable variables.
- *Minimum scaling*: Lower value used to scale the values of the monitorable variable on the ordinate of the graph. By default this column is not shown.
- *Maximum scaling*: Upper value used to scale the values of the monitorable variable on the ordinate of the graph. By default this column is not shown.
- *Monitoring*: This column shows the current output settings, where:

F: Monitorable variable is written onto the stash file

T: Monitorable variable is tabulated in the table

X: Monitorable variable is used as independent or abscissa variable (x-values). If there is no monitorable variable selected as the abscissa variable, ModelWorks provides the so-called default independent variable, the simulation time.

Y: Monitorable variable is used to draw a curve. Its values are drawn as ordinate values (y-values) versus the current independent variable (x-values).



Check the columns to be displayed in the window:

☒ Monitorable variable names

☒ Ident

☒ Unit

☐ Minimum scaling

☐ Maximum scaling

☒ Monitoring

Fig. R23: Entry form opened by the SET UP button in the IO-window *Monitorable variables.*

Selects all monitorable variables: All subsequent button functions will operate on the scope *All* (Fig. T21 part II *Theory*), i.e. on all monitorable variables of all models.

Set/delete stash filing (F/*writeOnFile*/*notOnFile*): Adds the selected monitorable variable(s) to the list of variables which are to be written onto the stash file. The function toggles actually the setting, i.e. if the current setting is on (F) it is disabled, otherwise enabled. In the monitoring-column of the IO-window the monitorable variables to be written onto the stash file are marked with an F (Fig. R22). If a multiple selection is active, the function adds or removes *all* currently selected variables to or from the list, reversing the current setting of the first variable in the selection.

Reset stash filing: Resets the stash filing of the currently selected monitorable variable(s) to their defaults.

Set/delete tabulation (T/*writeInTable*/*notInTable*): Adds the selected monitorable variable(s) to the list of variables which are to be tabulated in the table window. The function toggles actually the setting, i.e. if the current setting is on (T) it is disabled, otherwise enabled. In the monitoring-column of the IO-window the monitorable variables to be tabulated are marked with an T (Fig. R22). If a multiple selection is active, the function adds or removes *all* currently selected variables to or from the list, reversing the current setting of the first variable in the selection.

Reset tabulation: Resets the tabulation of the currently selected monitorable variable(s) to their defaults.

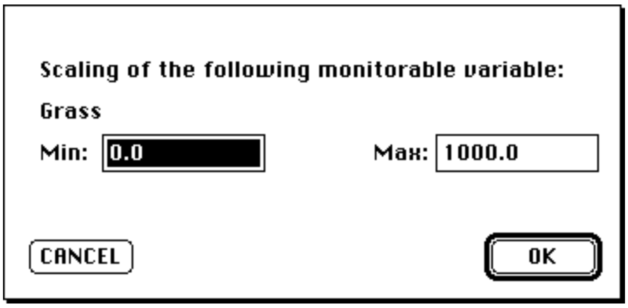
Note, that in case that the user has made any fundamental changes to the graph such as a redefinition of scales, or the activation of new curves, the current version of ModelWorks redraws the graph latest at the begin of the next simulation run. The actual redrawing time is determined by the current settings of the mode *RedrawGraphAlwaysMode* of the simulation environment.

Set/cancel variable as x-axis in the graph (X/*isX*): Sets the selected variable as independent or abscissa variable (x-values) for the graph. The function toggles actually the setting, i.e. if the current setting is on (X) it is disabled, otherwise enabled. In the monitoring-column of the IO-window the monitorable variable to be used as abscissa variable is marked with an X. If another variable was already selected as the abscissa variable, that is automatically deselected, since ModelWorks allows only one independent variable at a time. In case that no monitorable variable is selected as abscissa variable, ModelWorks uses the default independent variable *time*. This function will completely erase and redraw the content of the graph window. This is because it has to redraw the x-axis. This function does not work on a multiple selection.

*Set/delete curve (*Y/*isY)*: Adds the selected monitorable variable(s) to the list of variables which are to be drawn as curves in the graph window. The function toggles actually the setting, i.e. if the current setting is on (Y) it is disabled, otherwise enabled (Fig. R22). In the column *Monitoring* of the IO-window the symbols F, T, or Y are shown in the same color as that which is used to draw values of the corresponding variable in the graph. If a multiple selection is active, the function adds or removes all currently selected variables to or from the list, reversing the current setting of the first variable in the selection. This function will completely erase and redraw the content of the graph window, if the mode *RedrawGraphAlwaysMode* of the simulation environment is currently active (see above *File/ Preferences*).

Reset graphing: Resets the graphing (X/Y/*isX*/*isY*/*notInGraph*) of the selected monitorable variable(s) to their defaults.

Set scaling: Opens an entry form in which minimum and maximum values for the scaling of the selected monitorable variable in the graph can be edited (Fig. R24).



Scaling of the following monitorable variable:

Grass

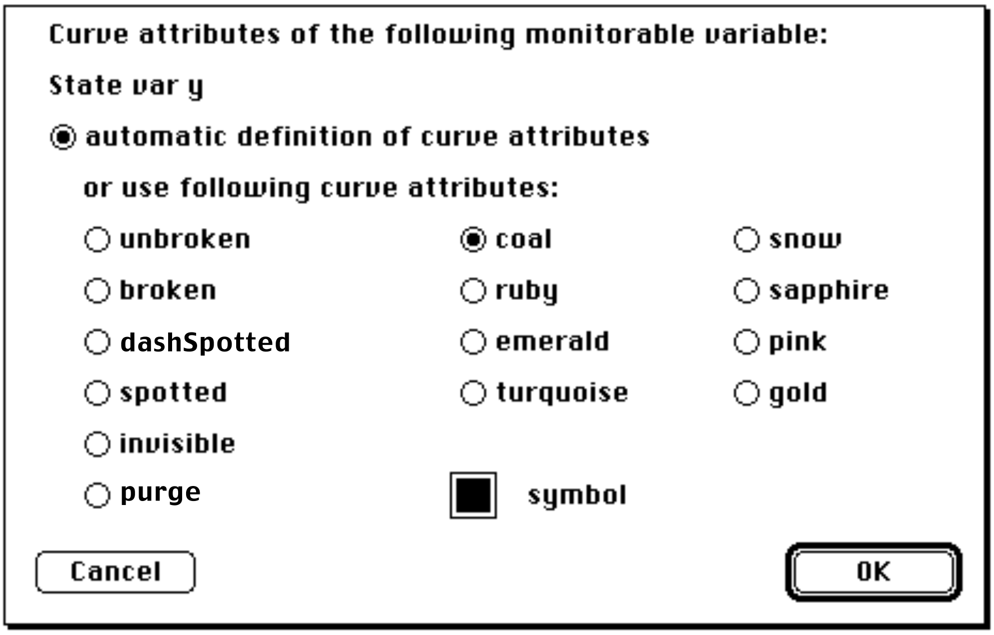
Min: 0.0 Max: 1000.0

Fig. R24: Entry form opened by the ↔ button in the IO-window *Monitorable variables* to set the scaling of a particular monitorable variable. Only values within these limits will be displayed in the graph.

If a multiple selection of monitorable variables has been made, not only one but a series of entry forms will be offered, one form for each monitorable variable. This sequence can be terminated by pressing the push-button *Cancel.* Note however, that in the latter case all changes which have been made to variables before, will not be reversed. Only eventual changes made to the monitorable variable currently in display will be discarded. This function causes sooner or later a complete erase and redrawing of the content of the graph window, because it always affects the legend. The actual redrawing takes place according to the current settings of the mode *RedrawGraphAlwaysMode* of the simulation environment.

Reset scaling: Resets the scaling (minimum and maximum) of the selected monitorable variable(s) to their default values.

Set curve attributes: Opens an entry form in which the attributes for the drawing of a monitorable variable's curve in the graph window can be edited (Fig. R25). This editing serves to set or override the automatic definition of curve attributes by ModelWorks. [Since no colors are available in the PC version any settings of the curve attribute stain (color) is without effect].



Curve attributes of the following monitorable variable:

State var y

● automatic definition of curve attributes

or use following curve attributes:

○ unbroken	● coal	○ snow
○ broken	○ ruby	○ sapphire
○ dashSpotted	○ emerald	○ pink
○ spotted	○ turquoise	○ gold
○ invisible		
○ purge	■ symbol	

Fig. R25: Entry form opened by the button in the IO-window *Monitorable variables.*

The following curve attributes are available: A color with which curves are drawn on color screens, printed on color printers, or exposed on slide recorders. Line styles affect the style with which connecting lines between points are drawn. Points can be emphasized by drawing plotting symbols.

The colors are *coal* (black), *snow* (white), *ruby* (red), *emerald* (green), *sapphire* (blue), *turquoise* (cyan), *pink* (magenta), and *gold* (yellow). The graph monitoring procedure produces line charts, i.e. points are connected with lines, which can be drawn with one of the following styles:

unbroken	__________
broken	- - - - - - - -
dashSpotted	-·-·-·-·-·-·-
spotted	....
invisible	no drawing at all, may be used to stop drawing of a particular curve, while others are still drawn
purge	used to erase already drawn curves

autoDefStyle line style will be determined by ModelWorks according to the automatic definition mechanism of curve attributes

Any character can be used as a plotting symbol, for instance using the plotting symbol "*" results in curves like ---*---*---. Note that using a blank will result in the drawing of no plotting symbol at all.

If automatic definition of curve attributes is active for one or several monitorable variables, ModelWorks follows a strategy to distribute four colors (stains), four line styles and four symbols to draw curves (see Tab. T1 in part II *Theory*) for these monitorable variables. This strategy helps the simulationist to tell curves optimally apart, regardless whether they are displayed on a color screen or are printed on a black and white printer only. Colors, line styles, and symbols are distributed among the monitorable variables which currently have the automatic definition of curve attributes setting active. Which attribute, e.g. color, is used for which curve is influenced by the position of monitorable variables within the sequence in which they have been activated for the monitoring. For instance if four monitorable variables have been activated for graphing, the first activated will automatically be drawn in black, the second in red, the third in blue, and the fourth in green. However, if the second is removed from the monitoring, the previously third will be drawn in red and the previously fourth in blue.

The user may override this automatic definition and use a particular color, line pattern, and marking symbol for a curve of a specific monitorable variable. This allows e.g. to use always the same color for the same variable, such as green for state variable *Grass* or blue for a water level. Mark symbols are characters drawn exactly at the points as defined by the monitoring, line patterns are used to connect these points with lines. With this technique it is also possible to draw only scatter-grams, instead of line charts. The color currently in use for a particular monitorable variable is not only shown in the legend and used to draw curves in the graph, but also displayed in the column *Monitoring* of the IO-window *Monitorable variables* while displaying the current monitoring settings (F, T, or Y).

In order to toggle between automatic definition and its overriding, the simulationist must click into one of the line style radio buttons or into the radio button *Automatic definition*. In particular note, that in the current version of ModelWorks it is not sufficient to select just another color (stain) to turn automatic definition off without selecting also a new line style. This is because automatic definition can not be set individually for the various curve attributes but hold for all attributes of a monitorable variable together; either the curve attributes of a particular monitorable variable are all defined automatically or all are user defined.

If a multiple selection of monitorable variables has been made, not only one but a series of entry forms will be offered, one form for each monitorable variable. This sequence can be terminated by pressing the push-button *Cancel*. Note however, that in the latter case all changes which have been made to variables before, can no longer be reversed. Only the eventual changes made to the monitorable variable currently in display will be discarded.

This function causes sooner or later a complete erase and redrawing of the content of the graph window, because it always affects the legend. The actual redrawing takes place according to the current settings of the mode *RedrawGraphAlwaysMode* of the simulation environment.

Reset curve attributes: Resets the curve attributes of the selected monitorable variable(s) to their default values.

7 Client Interface

The client interface consists of a mandatory part, an optional part and an auxiliary library (Fig. T25 part II *Theory*). The mandatory part consists of the two modules *SimBase* and *SimMaster*, and the optional part of the modules *TabFunc, SimIntegrate* and *SimGraphUtils*. Although every model definition program must import from both modules of the mandatory part, only a small subset of the exported Modula-2 objects are really needed always. These few Modula-2 objects, five procedures and six data types, form the core of the ModelWorks client interface (Fig. T25 part II *Theory*).

All other types and procedures also exported from this interface are optional. Their purpose is either to serve the convenience of the simulationist or to support the modeler in the programming of advanced structured simulations. For instance if the simulationist wishes to run a model in a time range different from the one predefined by ModelWorks, the modeler can overwrite the ModelWorks defaults (Tab. T1 part II *Theory*) with the values the simulationist prefers. This is much more convenient as if the simulationist would always have to assign the desired values interactively at the begin of each simulation session. If a simulation study has advanced to a later stage, it is often desirable to be able to run multiple simulation runs in a systematic well defined way. The interactive control of the simulations becomes then rather an obstacle than a help. On the other hand, if much effort has been invested in the development of a complex model it is desirable to be able to run structured simulations under program control using the same model implementation. To support the modeler in such tasks is exactly the purpose of most of the additional objects exported by the client interface.

The principles behind the usage of the client interface have been described elsewhere (Manual Part II *Theory*, in the chapter *Modeling*). Please consult also the listings of the client interface definition modules, *SimMaster* and *SimBase*, plus the sample model definition programs in the appendix while reading the following explanations of the Modula-2 objects exported by the client interface.

The following two modules belong to the **optional part** of ModelWorks and are only briefly described here[1]:

SimIntegrate: Provides means to integrate autonomous models without any monitoring and without affecting the global simulation time of the simulation environment.

SimGraphUtils: provides utilities to make output to the graph window and the graph such as drawing of additional curves and displaying of validation data at discrete time points with or without error bars.

The following two modules belong to the **auxiliary library** of ModelWorks and are only briefly described here[2]:

ReadData: Allows to read data from an input file and to test the various conditions (such as a minimum-maximum range) in an easy way. It is typically used to enter measurements stored on text data files into ModelWorks, for instance to compare simulated with observed data.

[1] For detailed description of the functions of these modules refer to the listings of the definition modules in the appendix.

[2] For detailed description of the functions of these modules refer to the listings of the definition modules in the appendix.

JulianDays: provides calendar procedures to convert calendar dates into julian days and vice versa. Julian days can be used for calculations, e.g. to compute an elapsed time between two dates.

DateAndTime and *WriteDatTim* can be used to access the built in clock and to write dates and times.

RandGen: contains a pseudo-random number generator for variates uniformly distributed within interval (0,1].

RandNormal: provides a pseudo-random number generator for normally distributed variates ~$N(\mu,\sigma)$.

Since ModelWorks has been designed as an open architecture and is based on Modula-2, the modeler is free to add any module he wishes to the auxiliary library. The modules of the auxiliary library distributed with the current version of ModelWorks have been included in the release, since they are often used in the context of modeling and simulation.

Besides, there is also the possibility to use any object from the "Dialog Machine". The majority of the latter is contained in the kernel of ModelWorks and resides together with any model definition program already in the memory. Hence this part of the "Dialog Machine" can be used by the modeler without any penalty. Those modules of the "Dialog Machine" which are not in use by ModelWorks can then be considered as a particular extension of the auxiliary library (Fig. T25 in part II *Theory*).

7.1 Declaring Models and Model Objects

This section describes the core of the ModelWorks client interface, i.e. those procedures and types which are used by every model definition program.

7.1.1 Running a simulation session

The simulation session is started whenever a program calls the procedure *RunSimMaster* from the client interface module *SimMaster*. The simulation session is terminated upon returning from the procedure *RunSimMaster* .

```
  PROCEDURE RunSimMaster(md: PROC);
```

This is the only statement which the model definition program must execute in order to use ModelWorks. The argument *md* refers to a procedure which typically declares the models including all their model objects by calling the procedure *DeclM* from module *SimBase* (s.a. below section *Declaration of model*). The procedure often contains also calls to procedures which set defaults for the global simulation parameters such as *SetDefltGlobSimPars.*

However, it is also possible to use this procedure only for the installation of extra menus and menu commands in the "Dialog Machine" to expand the standard simulation environment (*InitDialogMachine* from module *DMMaster* has already been called). For instance the procedure may contain no calls to any model object declarations at all, but the menu commands it installs allow for the activation of models, since they are bound to procedures which call the model and model object declaration procedures *DeclM*, *DeclSV*, *DeclP*, and *DeclMV* (s.a. below section *Declaration of model*). There may also be menu command procedures installed which remove models, so that a full dynamic model loading and unloading becomes possible during a simulation session (for an example see the research sample model *Population dynamics of larch bud moth* in the *Appendix*). Any menu installation called within procedure *md* will be placed on the right side of the menu bar as it is installed by ModelWorks' simulation environment. After the execution of the *md* procedure *RunSimMaster* starts the "Dialog Machine" by calling procedure *RunDialogMachine* from module *DMMaster*.

The modeler can declare a procedure *issp* to ModelWorks by calling *DeclInitSimSession* from *SimMaster*. ModelWorks will then call this procedure at the beginning of each simulation session, i.e. after the start-up of the simulation environment or when the simulationist chooses the command *Settings/Initialize session*.

```
PROCEDURE DeclInitSimSession(issp: PROC);
```

7.1.2 DECLARATION OF MODELS

A model or a submodel is declared to ModelWorks or installed in the simulation environment with the procedure *DeclM*:

```
TYPE
  Model;

PROCEDURE DeclM  (VAR m: Model;
                  defaultMethod: IntegrationMethod;
                  initialize, input, output, dynamic, terminate: PROC;
                  installModelObjects: PROC;
                  descriptor, identifier: ARRAY OF CHAR;
                  about: PROC);
```

This procedure can be called any number of times, but should be called for each model only once[3], unless it has been removed in the meantime. *DeclM* may not be called in the sub-state *Running* (s.a. part II *Theory* Fig. T26).

m is a variable of the opaque type *Model* exported by *SimBase*. It may be used for further references to the model, e.g. when accessing a model in order to change its integration method with procedure *SetM*. It must be declared in the model definition program. It does not matter where, but *m* must be a global variable which exists as long as the model definition program.

```
IntegrationMethod = (Euler, Heun, RungeKutta4,
                     RungeKutta45Var, stiff,
                     discreteTime);
```

defaultMethod is the default integration method with which the model will be solved during simulations. Moreover the modeler defines with this parameter also the type of model, i.e. whether it is a continuous time or a discrete time model. If the method *discreteTime* is specified, the model is declared as a discrete time model. All other integration methods may be used for the class of the continuous time models. The default integration method is (re)assigned to the current integration method by ModelWorks during the initialization phase of the simulation session or after every reset of the integration methods. During a simulation session the current integration method may be changed by the simulationist (using an IO-window) or by the modeler via the procedure *SetM* for any of the continuous time models. For a discrete time model, however, once declared, its «integration method» may of-course never be changed. Note that this mechanism makes it possible, that every continuous time model uses a different integration method.

[3] Should *DeclM* be called for the same model variable *m* more than once, ModelWorks will display an error message and the simulation program will be halted.

The following five formal procedure parameters are procedures which will be called by ModelWorks during simulations:

initialize is called only once at the begin of each simulation run (Fig. T16 part II *Theory*). It may be used freely to execute any task at the begin of a run, such as opening a file for writing data during the simulation run or assigning new initial values to state variables by calling *SetSV*.

input calculates the input variables of (sub)model m (Eq. 4.4 resp. 5.4). It is called only once during a time step, but many times during a simulation run (Fig. T16).

output calculates the output variables of (sub)model m (Eq. 4.2 resp. 5.2). It is called only once during a time step, but many times during a simulation run (Fig. T16). Note the implementation restriction that output variables must not depend directly on input variables (see Manual Part II *Theory*, chapter *Model formalisms*.

dynamic Contains the the model equations of (sub)model m (Eq. 4.1 resp. 5.1 or 8a, 8b, and 8c). In the case of a continuous time model it calculates the new derivatives from the current values of the state variables (Eq. 4.1 or 8a and 8c). Depending on the order of the integration method, this procedure is called at least once up to several times during a time step. In the case of a discrete time model (Eq. 5.1 or 8b and 8c) it calculates the new state vector directly. It is only called once during a time step (Fig. T16).

terminate called once at the end of each simulation run (Fig. T16). May be used freely to execute any task at the end of a run, such as closing a file which has been written during the simulation run etc.

installModelObjects Procedure declaring all model objects, i.e. state variables, model parameters, and monitorable variables of (sub)model *m*. Typically this procedure contains calls to the procedures *DeclSV*, *DeclP*, and *DeclMV*. It is also possible to leave the body of this procedure empty, e.g. by using *NoModelObjects*, and to defer all model object declarations to a later time (note that this requires proper programming of such a feature, since it is not available in the standard simulation environment).

The modeler does not need to install any one of his/her implementation for the procedure parameters *initialize*, *input*, *output*, *dynamic*, *terminate*, or *installModelObjects*; for a convenient use the following procedures from module *SimBase* with an empty body can be used as actual arguments when calling *DeclM*:

```
PROCEDURE NoInitialize;
PROCEDURE NoInput;
PROCEDURE NoOutput;
PROCEDURE NoDynamic;
PROCEDURE NoTerminate;
PROCEDURE NoModelObjects;
PROCEDURE NoAbout;
PROCEDURE DoNothing;
```

See to it that calculations, which should be performed only once per time step, are included in the procedure *input* or *output* only, not in the procedure *dynamic*, which may called more than once per time step. For further information on the correct use of these procedures see part II *Theory*, chapter *Simulations* of this manual (s.a. Fig. T16, T17, and T18).

Finally, the last formal procedure parameters are used to identify and describe a model, so that the simulationist may recognize it during simulation sessions:

descriptor String containing a long description of the (sub)model m

identifier Short string identifying the (sub)model m. Although there is no limit to the actual size of this string, it is advisable to keep it as short as possible.

about Procedure writing additional information about the (sub)model, e.g. by using routines such as *WriteString*, *WriteLn* etc. from the "Dialog Machine" module *DMWindowIO*, into the help window.

Once a model has been declared, it is ready for the declaration and the attaching of model objects to it. Typically model object declaration procedures are called immediately following the call to *DeclM*. However, the following procedure can be used to change this behavior, so that model objects can be attached to models in any sequence:

```
PROCEDURE SelectM (m: Model; VAR done: BOOLEAN);
```

The latter is particularly important if models and their model objects are declared dynamically during a simulation session. This feature is not supported by the standard simulation environment, but such an extension can be easily programmed via the client interface by the modeler. He/She will then use procedure *SelectM* to attach model objects to the proper model.

7.1.3 Declaration of state variables

State variables are declared as real variables in the model definition program. They may be declared anywhere in the program and may be part of a structured data type. E.g. the following variables x and z may be used as state variables respectively state vector:

```
VAR x, xDot: REAL;  z, zDot: ARRAY [1..n] OF REAL;
```

In order to declare a state variable *s* to ModelWorks or install it in the simulation environment, the procedure *DeclSV* must be called. It may not be called another time, unless the state variable has been removed in the meantime. *DeclSV* may not be called in the sub-state *Running* (s.a. part II *Theory* Fig. T26).

```
PROCEDURE DeclSV (VAR s, ds: REAL; initial, minRange, maxRange: REAL;
                  descriptor, identifier, unit: ARRAY OF CHAR);
```

The model to which the state variable will belong is normally the last model declared with a call to procedure DeclM, unless the procedure *SelectM* has been called for another model. The meanings of the formal procedure parameters of *DeclSV* are:

s Variable to be declared as state variable. *DeclSV* does assign to *s* the value *defaultInitial*. The real *s* can be declared anywhere in the model definition program and may be even part of any data structure. However make sure that it is declared as a global real variable and does exist as long as the model definition program.

ds Variable to be declared as the derivative d*s*/dt (for continuous time models using time t as independent variable) or the new value *s*(k+1) (for discrete time models using time k as independent variable) of *s*. For every state variable the derivative or the new value must be assigned to this variable by the procedure *dynamic*, which is called during numerical integration. Normally *ds* appears only on the left side of the dynamic equations in procedure *dynamic*. *DeclSV* assigns to *ds* the value 0.0.

defaultInitial Default initial value for state variable *s*. ModelWorks uses the current initial value at the beginning of each simulation run to initialize *s*. The default initial value is (re)assigned to the current initial value by ModelWorks during the initialization phase of the simulation session or after every reset of the state variables. During a simulation session the current initial value may be changed by the simulationist (using an IO-window) or by the modeler via the procedure *SetSV*. The modeler could also overwrite the value of *s* with another value within procedure Initial (see procedure *DeclM*), since ModelWorks has already assigned the current initial value to the state variable *s*. Note however, that in the latter case inconsistencies might occur between the display of the current value in the IO-window with the current values actually used in the simulations. Avoid this method and use the procedure *SetSV* instead.

minCurInit, *maxCurInit* Lower and upper bounds for the current initial value. Attempts by the simulationist to assign values out of this range are not accepted.

descriptor String containing a long description of the state variable *s*. This string may have any length, but might not be visible till its end when it is too long to fit into the IO-window column where it is displayed during a simulation session (see also identifier). Example: "Density of alga Scenedesmus obliquus".

identifier Short string identifying the state variable *s*. This string should be kept as small as possible in order to ensure full visibility for the display in small IO-windows during a simulation session. In particular on small screens, IO-windows become small in the tiled window position (see menu command *Tile windows*) and they will display only this *identifier* to denote the state variable *s*. Example: "sa".

unit String containing the unit used to measure values of the state variable *s*. This string is displayed in IO-windows during a simulation session. Example: "cells/ml".

7.1.4 Declaration of model parameters

A time invariant model parameter *p*, which the simulationist should be able to change interactively during simulation sessions, has to be declared with the procedure *DeclP*.

```
PROCEDURE DeclP  (VAR p: REAL; defaultVal, minVal, maxVal: REAL;
                  runTimeChange: RTCType;
                  descriptor, identifier, unit: ARRAY OF CHAR);
```

DeclP may not be called another time, unless the model parameter has been removed in the meantime. *DeclP* may not be called in the sub-state *Running* (s.a. part II *Theory* Fig. T26). The meaning of the formal procedure parameters are:

p Real variable to be declared as model parameter. *DeclP* assigns to *p* its default value *defaultVal*. The real *p* can be declared anywhere in the model definition program and may be even part of any data structure. However make sure that it is declared as a global real variable and does exist as long as the model definition program.

defaultVal Default value for the model parameter *p*. The default value is (re)assigned to the current parameter value *p* by ModelWorks during the initialization phase of the simulation session or after every reset of the model parameters. During a simulation session the current parameter value *p* may be changed by the simulationist (using an IO-window) or by the modeler via overwriting the value of *p* with another value, e.g. within procedure *initialize* (see procedure *DeclM*) by calling procedure *SetP*.

minVal, *maxVal* Lower and upper value bounds for *p*. Attempts by the simulationist to assign values out of this range are not accepted.

runTimeChange rtc (=run time change) interactive changing of values of model parameter *p* during a simulation run in the program state *Pause* is enabled. *noRtc* (=no run time change) disallows completely any changing of values of the model parameter *p* during a simulation run, even in the program state *Pause*.

descriptor String containing a long description of the model parameter *p*. This string may have any length, but might not be visible till its end when it is too long to fit into the IO-window column where it is displayed during a simulation session (see also identifier). Example: "Half saturation constant for algal growth".

identifier Short string identifying the model parameter *p*. This string should be kept as small as possible in order to ensure full visibility for the display in small IO-windows during a simulation session. In particular on small screens, IO-windows become small in the tiled window position (see menu command *Tile windows*) and they will display only this *identifier* to denote the model parameter *p*. Example: "Ks".

unit Unit in which to measure values of the model parameter *p*. This string is displayed in IO-windows during a simulation session. Example: "µg/l".

Thereafter, the value of the parameter *p* can be changed within the range [*minRange*, *maxRange*], and be reset to its default value *defaultVal*. A parameter change in the middle of a simulation run can lead to data inconsistencies. It can selectively be allowed or prevented with the parameter runTimeChange of the type

```
 TYPE RTC Type = (rtc, noRtc);
```

Normally only time invariant parameters are declared as model parameters. Time variant parameters are often better treated as input variables, or, if the simulationist wishes to edit their values interactively during a simulation session, it is advisable to use the series of values as a table function depending on time and the parameter is treated as an auxiliary variable (see section on *Declaration of table functions*).

7.1.5 Declaration of monitorable variables

Every real variable may be declared as a monitorable variable. This allows the simulationist to monitor or observe its values from within the simulation environment. There apply no restrictions nor does the monitoring exert any influence on the variables monitored. Simply call procedure *DeclMV*

```
PROCEDURE DeclMV(VAR mv: REAL; defaultScaleMin, defaultScaleMax: REAL;
                 descriptor, identifier, unit: ARRAY OF CHAR;
                 defaultSF: StashFiling; defaultT: Tabulation;
                 defaultG: Graphing);
```

and the real *mv* passed as actual argument is associated with the ModelWorks monitoring mechanism, i.e. its values may be written onto the stash file, tabulated or plotted in the graph from within the simulation environment. *DeclMV*may not be called another time for the same real variable *mv*, unless it should have been removed in the meantime. *DeclMV*may may not be called in the sub-state *Running* (s.a. part II *Theory* Fig. T26). The meaning of the formal procedure parameters are:

The following types control the actual monitoring settings for each kind of monitoring:

```
TYPE
  StashFiling = (writeOnFile, notOnFile);
  Tabulation  = (writeInTable, notInTable);
  Graphing    = (isX, isY, isZ, notInGraph);
```

The monitoring settings can be independently activated or deactivated and for every monitorable variable the simulationist can control them interactively during simulation sessions. The meaning of the formal procedure parameters of *DeclMV* are:

mv The variable to be declared as monitorable variable. Note: *DeclMV* assigns to *mv* the value 0.0. The real *mv* can be declared anywhere in the model definition program and may be even part of any data structure. However make sure that it is declared as a global real variable and does exist as long as the model definition program.

defaultScaleMin/*defaultScaleMax* Default minimum and maximum values used for the scaling of the curve to the ordinate while drawing values of the monitorable variable *mv* in the graph. The default minimum and maximum of the ordinate scale is (re)assigned to the current scale minimum and scale maximum by ModelWorks during the initialization phase of the simulation session or after every reset of the scaling. During a simulation session the current scale minimum and scale maximum may be changed by the simulationist (using an IO-window) or by the modeler via procedure *SetMV*. There apply no restrictions to the values of these variables. During interactive changes ModelWorks will use the range boundaries MIN(REAL) and MAX(REAL).

descriptor String containing a long description of the monitorable variable *mv*. This string may have any length, but might not be visible till its end when it is too long to fit into the IO-window column where it is displayed during a simulation session (see also identifier). Example: "Density of alga Scenedesmus obliquus".

identifier Short string identifying the monitorable variable *mv*. This string should be kept as small as possible in order to ensure full visibility for the display in small IO-windows during a simulation session. In particular on small screens, IO-windows become small in the tiled window position (see menu command *Tile windows*) and they will display only this *identifier* to denote the monitorable variable *mv*. Example: "xa".

unit String containing the unit used to measure values of the monitorable variable *mv*. This string is displayed in IO-windows during a simulation session. Example: "cells/ml".

defaultSF, *defaultT*, *defaultG* Default settings for the kind of monitoring for the monitorable variable *mv*. If *defaultSF*, *defaultT*, *defaultG* are selected to be written on a file, tabulated or to be plotted, the values of the variable *mv* is written in the default stash file, resp. table, or drawn in the graph as a curve versus the current independent variable, usually simulation time. The defaults for the kind of monitoring are (re)assigned to the current kind by ModelWorks during the initialization phase of the simulation session or after every reset of the stash filing, tabulation respectively graphing. During a simulation session the current kind of monitoring may be changed by the simulationist (using the IO-window for monitorable variables) or by the modeler via procedure *SetMV*.

7.1.6 Declaration of table functions

Functions given by a table of values may be declared with the procedure *DeclTabF*, which has to be imported from the optional module *TabFunc* (s.a. section *Optional menu Table Functions* manual Part III *Reference*).

```
TYPE
  TabFUNC;

PROCEDURE DeclTabF( VAR  t       : TabFUNC;
                    xx, yy       : ARRAY OF REAL;
                    NValPairs    : INTEGER;
                    modifiable   : BOOLEAN;
                    tabName,
                    xName, yName,
                    xUnit, yUnit : ARRAY OF CHAR;
                    xMin, xMax,
                    yMin, yMax   : REAL );
```

This procedure can be called any number of times, but should be called for each table function only once, unless it should have been removed in the meantime. *DeclTabF*may not be called in the sub-state *Running* (s.a. part II *Theory* Fig. T26). The meanings of its formal parameters are as follows:

t The variable *t* is a variable of the opaque type *TabFUNC* which is exported by the module *TabFunc*. It is used to identify and update the table function values and parameters when accessing the table function. This may be for the linear interpolation procedures, for reading or changing the function's current values, or for removing the function.

xx, yy The vector *xx* contains the independent and *yy* the dependent values of the table function being defined. Note that the *xx* vector must be given sorted ascendingly, otherwise the program will halt execution.

NValPairs Contains the number of the first elements of the vectors *xx* and *yy* which hold a valid value.

modifiable If this formal parameter is set to TRUE the table function may be modified by means of the table function editor from within the simulation environment (s.a. section *Optional menu Table Functions* manual Part III *Reference*)

tabName Is used for the identification of the table function in the simulation environment, e.g. for its selection in the table function editor's entry form (s.a. section *Optional menu Table Functions* manual Part III *Reference*).

xName, yName, xUnit, yUnit The names of the table function's axis variables and their unit. These strings will be used by the table function editor from within the simulation environment .

xMin, xMax, yMin, yMax Define the upper and lower bounds for each axis' values. Attempts by the simulationist to enter values outside of this range will not be accepted by the table function editor.

7.2 Accessing Defaults and Current Values

During simulations ModelWorks uses many internal parameters, settings and other variables, the so-called defaults and current values (Fig. T22). They can be accessed by the modeler in order to control simulations in a similar way the simulationist may access them. One class of procedures lets the modeler retrieve values, but not change them (read only values), e.g. the simulation time or the default independent variable. Another class of procedures lets the modeler get and set values, e.g. *GetGlobSimPars* or *GetP* respectively *SetGlobSimPars* or *SetP*. The accessible values are grouped into several categories: First there are the global simulation parameters, project description variables, variables controlling the stash filing, and the variables associated with the models and the model objects. Secondly each category exists in two copies: the defaults and the current values.

7.2.1 Global simulation parameters and project description

Among the global values controlling simulations there are internal read-only variables (Tab. R1) and the global simulation parameters listed in Tab. R2.

The variables listed in Tab. R3 are used for the project description. The variables in the tables Tab. R1, R2 and R3 are referenced in the program texts below with the listed identifiers. The symbols listed are the ones which have been used to denote the variables in the manual, in particular in the part II *Theory*.

Identifier	Symbol	Meaning
CurrentTime	t	Current simulation time or independent variable (read only) for continuous time (sub)models
CurrentStep	k	Current simulation time or independent variable (read only) for discrete time (sub)models
CurrentSimNr	-	Number of the current simulation run (read only)

Tab. R1: Read-only global simulation variables internally used by ModelWorks. The first column contains the identifiers used to designate the corresponding variables in the client interface, the second the symbol used to denote the corresponding variable in this manual.

Identifier	Symbol	Meaning
t0	t_o/k_o	Simulation start time
tend	t_{end}/k_f	Simulation stop time
h	h/h_{max}	Integration step (if fixed step length method) maximum integration step (if at least one variable step length method in use) (h is only used if at least one continuous time model present, otherwise ignored)
er	e_r	Maximum relative local error (er is only used if at least one variable step length method in use)
c	c	Discrete time step (if only discrete time models present)Coincidence interval (if continuous as well as discrete discrete time models present)
hm	h_m	Monitoring interval

Tab. R2: Global simulation parameters of ModelWorks. The first column contains the identifiers used to designate the corresponding variables in the client interface, the second the symbol used to denote the corresponding variable in this manual.

Identifier	Symbol	Meaning
title	-	Project title string
remark	-	Remark string
footer	-	Footer string
wtitle	-	With title in graph
wremark	-	With remarks in graph
autofooter	-	Automatic update of date, time, and run number in footer

Identifier	Symbol	Meaning
recM	-	Recording of data on models in stash file
recSV	-	Recording of data on state variables in stash file
recP	-	Recording of data on model parameters in stash file
recMV	-	Recording of data on monitorable variables in stash file
recG	-	Recording of graph in stash file at end of run

Tab. R3: Global project description of ModelWorks. The first column contains the identifiers used to designate the corresponding variables in the client interface.

7.2.1.a Retrieval of read only current values

A user can access internal variables (Tab. R1) of ModelWorks by means of special procedures. This guarantees undisturbed data consistency. For instance, the procedure

```
  PROCEDURE CurrentStep(): INTEGER;
```

exported by module *SimBase*, returns the current simulation step, i.e. the current value of discrete time (must not be confounded with the integration step used by numerical integration for continuous time models). Note that this simulation step can only be read but not changed.

```
  PROCEDURE CurrentTime(): REAL;
```

Returns the current simulation time, i.e. the current value of continuous time. Note the simulation time can only be read but not changed.

```
  PROCEDURE CurrentSimNr(): INTEGER;
```

Returns the current simulation run number k during structured simulations (k = 1, 2, 3...) (Fig. T16). Note that even aborted runs are numbered. This procedure is typically called in the client procedure *initialize*, e.g. to assign parameter values depending on the current run. Note k can only be read but not changed.

7.2.1.b Modification of defaults

The predefined values ModelWorks uses as defaults are listed in Tab. T1 (manual part II *Theory*). If the modeler wishes to change, i.e. overwrite, them he may access any of the variables listed in the tables Tab. R2 or R3 with a *SetDefltxyz* procedure, i.e. a procedure with an identifier starting with *SetDeflt.*

```
  PROCEDURE SetDefltGlobSimPars(    t0, tend, h, er, c, hm: REAL);
  PROCEDURE GetDefltGlobSimPars(VAR t0, tend, h, er, c, hm: REAL);

  PROCEDURE SetDefltProjDescrs(title,remark,footer: ARRAY OF CHAR;
                               wtitle,wremark,autofooter,
                               recM, recSV, recP, recMV, recG: BOOLEAN);

  PROCEDURE GetDefltProjDescrs(VAR title,remark,footer: ARRAY OF CHAR;
                               VAR wtitle,wremark,autofooter,
                               recM, recSV, recP, recMV, recG: BOOLEAN);
```

Above procedures set or get the defaults for the global simulation parameters, the project description, or the recording flags. The meaning of the formal procedure parameters are listed in the tables Tab. R2 and R3.

The call of procedure *SetDefltGlobSimPars* or *SetDefltProjDescrs* will have no effect until the global simulation parameters respectively the project description are reset.

ModelWorks solves equations, e.g. differential equations, by using an independent variable, which is normally time. It also needs the independent variable if no monitorable variable has been selected as abscissa variable (X, *isX*).

```
  PROCEDURE SetDefltIndepVarIdent(descr,ident,unit:   ARRAY OF CHAR);
```

SetDefltIndepVarIdent overwrites the defaults of the descriptor *descr*, identifier *ident*, and the unit *unit* of the independent variable. The predefined default values ModelWorks uses are the *descr* "time", *ident* "t", and no *unit* (empty string). The call of this procedure will have no effect until the global simulation parameters are reset.

The following procedures are actually only kept for convenience and upward compatibility with previous versions of the ModelWorks client interface. In ModelWorks versions later than V1.1 their functions are also available by using the procedures *SetDefltGlobSimPars* respectively *SetGlobSimPars*.

```
        PROCEDURE SetMonInterval(hm: REAL);
```

Sets the default of the monitoring interval only, not the current value. The call of this procedure will have no effect until the global simulation parameters are reset.

```
        PROCEDURE SetIntegrationStep(h: REAL);
```

Sets the default integration step only, not the current value. The call of this procedure will have no effect until the global simulation parameters are reset.

```
        PROCEDURE SetSimTime(t0,tend: REAL);
```

Sets the defaults for the simulation start and stop time as well as the current simulation start and stop time. It differs in this respect from all other parameter setting routines, which affect either only the defaults or only the current values. Do not call this procedure from within a model, during a simulation run or an experiment, since the simulation time must not be changed during a simulation run. This procedure is ineffective if called in the sub-state *Running* (s.a. part II *Theory* Fig. T26).

7.2.1.c Modification of current values

Current values of the parameters and variables listed in Tab. R2 and R3 can be accomplished by the following *Setxyz* procedures, i.e. procedures whose identifiers start with *Set*:

```
  PROCEDURE SetGlobSimPars(    t0, tend, h, er, c, hm: REAL);
  PROCEDURE GetGlobSimPars(VAR t0, tend, h, er, c, hm: REAL);

  PROCEDURE SetProjDescrs(    title,remark,footer: ARRAY OF CHAR;
                              wtitle,wremark,autofooter,
                              recM, recSV, recP, recMV, recG: BOOLEAN);
  PROCEDURE GetProjDescrs(VAR title,remark,footer: ARRAY OF CHAR;
                              VAR wtitle,wremark,autofooter,
                              recM, recSV, recP, recMV, recG: BOOLEAN);
```

Above procedures set or get the current values for the global simulation parameters, the project description, or the recording flags. The meaning of the formal procedure parameters are listed in the tables Tab. R2 and R3. Note that the call of procedure *SetGlobSimPars* in the sub-state *Running* will have no effect until the next simulation run (s.a. part II *Theory* Fig. T26).

ModelWorks solves equations, e.g. differential equations, by using an independent variable, which is normally time. It also needs the independent variable if no monitorable variable has been selected as abscissa variable (X, *isX*).

```
  PROCEDURE SetIndepVarIdent(descr,ident,unit:   ARRAY OF CHAR);
```

SetDefltIndepVarIdent overwrites the defaults of the descriptor *descr*, identifier *ident*, and the unit *unit* of the independent variable. The predefined default values ModelWorks uses are the *descr* "time", *ident* "t", and no *unit* (empty string). The call of this procedure will have no effect until the next simulation run.

7.2.2 INSTALLED MODELS AND MODEL OBJECTS

Once declared, model and model objects may be modified in any way, except for their binding to a particular variable in the model definition program. In order to break even this binding, you have to remove the model or model object completely by calling a remove procedure (see below section *Removing models and model objects*). Modifications affect attributes and values associated with a model or model object. To support model and model object editing there exists for each object class a procedure pair: a get and a set procedure. The get procedure retrieves the objects attributes, the set procedure modifies (overwrites) them. Moreover the procedures are grouped into two sets: The first set is to modify the defaults, the other to modify the current values. The meaning of the formal procedure parameters are the same as described under the declaration procedures *DeclM*, *DeclSV*, *DeclP*, *DeclMV*, and *DeclTabF*. Also the parameter lists were kept similar to the ones used by the declaration procedures.

7.2.2.a Modification of defaults

Setting defaults with any of the listed procedures will not imply a setting of the current values also, i.e. no implicit reset. Until the next corresponding reset, no changes will become effective or visible. Only the change of the descriptors, identifiers, and the unit strings as well as the change of the range boundaries (used during the interactive changing of initial values or model parameter values via IO-windows) will become effective immediately.

```
  PROCEDURE GetDefltM(VAR m: Model; VAR defaultMethod: IntegrationMethod;
                      VAR initialize, input, output, dynamic, terminate: PROC;
                      VAR descriptor, identifier: ARRAY OF CHAR;
                      VAR about: PROC);
  PROCEDURE SetDefltM(VAR m: Model; defaultMethod: IntegrationMethod;
                      initialize, input, output, dynamic, terminate: PROC;
                      descriptor, identifier: ARRAY OF CHAR;
                      about: PROC);

  PROCEDURE GetDefltSV(m: Model; VAR s: REAL;
                       VAR defaultInit, minCurInit, maxCurInit: REAL;
                       VAR descriptor, identifier, unit: ARRAY OF CHAR);
  PROCEDURE SetDefltSV(m: Model; VAR s: REAL;
                       defaultInit, minCurInit, maxCurInit: REAL;
                       descriptor, identifier, unit: ARRAY OF CHAR);

  PROCEDURE GetDefltP(m: Model; VAR p: REAL;
                      VAR defaultVal, minVal, maxVal: REAL;
                      VAR runTimeChange: RTCType;
                      VAR descriptor, identifier, unit: ARRAY OF CHAR);
  PROCEDURE SetDefltP(m: Model; VAR p: REAL;
                      defaultVal, minVal, maxVal: REAL;
                      runTimeChange: RTCType;
                      descriptor, identifier, unit: ARRAY OF CHAR);
```

```
PROCEDURE GetDefltMV(m: Model; VAR mv: REAL;
                       VAR defaultScaleMin, defaultScaleMax: REAL;
                       VAR descriptor, identifier, unit: ARRAY OF CHAR;
                       VAR defaultSF: StashFiling; VAR defaultT: Tabulation;
                       VAR defaultG: Graphing);
  PROCEDURE SetDefltMV(m: Model; VAR mv: REAL;
                       defaultScaleMin, defaultScaleMax: REAL;
                       descriptor, identifier, unit: ARRAY OF CHAR;
                       defaultSF: StashFiling; defaultT: Tabulation;
                       defaultG: Graphing);
```

Note that there is no procedure available for changing the defaults of table functions. To achieve a similar effect, first remove it and then declare it anew.

7.2.2.b Modification of current values

Most of the so-called set procedures affect the corresponding current values immediately. However, there are some exceptions:

- If *SetMV* is called in the middle of a simulation run (program state *Running*, Fig. T26 part II *Theory*) the call will have no effect at all.

- *SetM* should not be called from within procedure *dynamic*.

All other set procedures may be called freely. Note in particular that calling of *SetSV* in the procedure *Initialize* results in the immediate use of the new initial values for the current run. Any new or changed values will be displayed in the corresponding IO-windows. However, note that the updating of some changes may require some time before they become actually visible on the screen, because the "Dialog Machine" may need several integration steps till all updates have been completed.

```
  PROCEDURE GetM (VAR m: Model; VAR curMethod: IntegrationMethod);
  PROCEDURE SetM (VAR m: Model; curMethod: IntegrationMethod);

  PROCEDURE GetSV (m: Model; VAR s: REAL; VAR curInit: REAL);
  PROCEDURE SetSV (m: Model; VAR s: REAL; curInit: REAL);

  PROCEDURE GetP (m: Model; VAR p: REAL; VAR curVal: REAL);
  PROCEDURE SetP (m: Model; VAR p: REAL; curVal: REAL);

  PROCEDURE GetMV (m: Model; VAR mv: REAL; VAR curScaleMin, curScaleMax: REAL;
                  VAR curSF: StashFiling; VAR curT: Tabulation;
                  VAR curG: Graphing);
  PROCEDURE SetMV (m: Model; VAR mv: REAL; curScaleMin, curScaleMax: REAL;
                  curSF: StashFiling; curT: Tabulation; curG: Graphing);
  PROCEDURE GetTabF( t: TabFUNC;
                    VAR xx, yy       : ARRAY OF REAL;
                    VAR NValPairs    : INTEGER;
                    VAR modifiable   : BOOLEAN;
                    VAR tabName,
                        xName, yName,
                        xUnit, yUnit : ARRAY OF CHAR;
                    VAR xMin, xMax,
                        yMin, yMax   : REAL );
  PROCEDURE SetTabF( t            : TabFUNC;
                    xx, yy       : ARRAY OF REAL;
                    NValPairs    : INTEGER;
                    modifiable   : BOOLEAN;
                    tabName,
                    xName, yName,
                    xUnit, yUnit : ARRAY OF CHAR;
                    xMin, xMax,
                    yMin, yMax   : REAL );
```

It is recommended to avoid the direct modification of state variables, parameters etc. by assigning them a new value. There are two reasons why: First there may result a confusing discrepancy in the value actually used for simulations and the one visible in IO-windows. Secondly ModelWorks is likely to overwrite the value, so that the assignment is fictitious and the simulationist may have difficulties to understand subsequent simulation results. To avoid any such problems, use always the set procedures and they will preserve consistency between the model definition program and ModelWorks.

In the case of table functions note that the dimensions of the vectors *xx* and *yy* may not be changed; only the coordinate values but not the number of supporting points may be modified. Otherwise remove and redeclare the whole table function. Note that if *SetTabF* disables for the last table function its property of beeing editable (modifiable = FALSE), the menu *Table Functions* will be removed from the menu bar.

7.2.2.c Inter- and extrapolation with table functions

Table functions as provided by the optional module *TabFunc* allow to compute function values within the defined domain [MIN(*xx[i]*), MAX(*xx[i]*)] by linear interpolation or outside this range by extrapolation (Fig. R26) (*xx[i]* are the elements of the vector *xx* containing the indepenent values of the supporting points; s.a. section on *Declaration of table functions*). The latter is done by retuning the value *yy[i]* if *x* > MAX(*xx[i]*) respectively *yy[i]* if *x* < MIN(*xx[i]*). Such extrapolations are allowed only if the function procedure *Yie* from *TabFunc* is used (read *Yie* as returns dependent value Y by linear inter- or extrapolation). In case you use *Yi* (returns dependent value Y by interpolation only) any attempt to compute a function value *y* for an independent value *x* outside the defined range [MIN(*xx[i]*), MAX(*xx[i]*)] will result in a program halt.

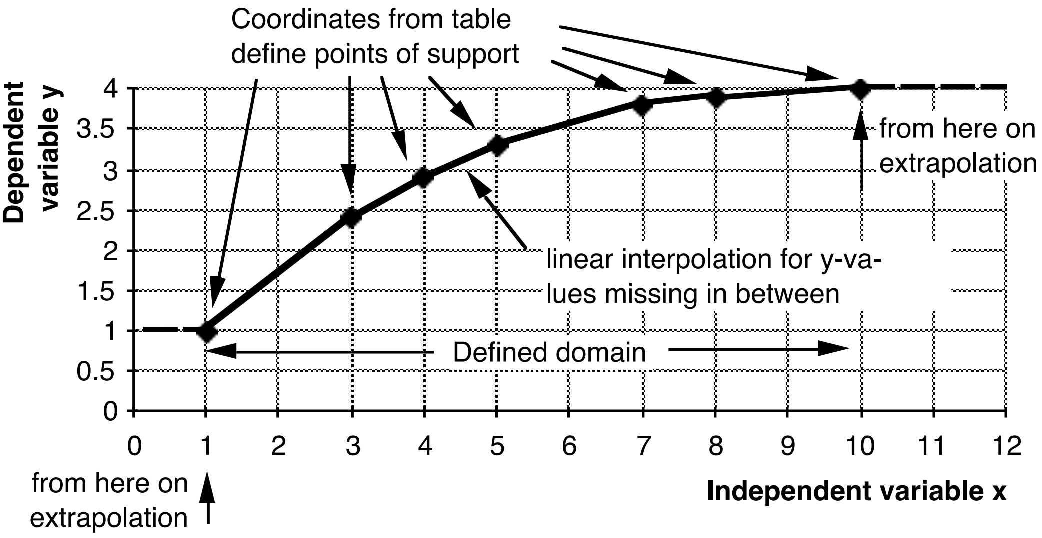


Fig. R26: Interpolation and extrapolations computed by the function procedures *Yie* (inter- and extrapolation) and *Yi* (only interpolation) from the optional module *TabFunc* for a non-linearity declared as a so-called table function. The table function is defined by supporting points given in form of coordinates within the domain of definition. Inside the domain ModelWorks computes interpolations, outside *Yie* computes extrapolations.

7.3 Removing Models and Model Objects

Models and model objects can be removed by calling any of the procedures listed below. Note that removing means only that the linkage of, e.g. a state variable *s* to the simulation environment is removed, not the real variable *s* itself, which remains a part of the model definition program. Once removed, a model or model object is completely unknown to ModelWorks and has become inaccessible by ModelWorks' routines. E.g. removed model objects are no longer listed in IO-windows and can no longer be integrated.

```
PROCEDURE RemoveM      (VAR m: Model);
PROCEDURE RemoveAllModels;
PROCEDURE RemoveSV     (m: Model; VAR s : REAL);
PROCEDURE RemoveMV     (m: Model; VAR mv: REAL);
PROCEDURE RemoveP      (m: Model; VAR p : REAL);
PROCEDURE RemoveTabF( VAR t: TabFUNC );
```

Remove procedures may not be called another time, unless the model or the model object has been redeclared in the meantime. Remove procedures may not be called in the sub-state *Running* (s.a. part II *Theory* Fig. T26). Calling procedure *RemoveM* results in an implicit removal of all model objects belonging to this model. Note that if *RemoveTabF* removes the last editable table function, the menu *Table Functions* will also be removed.

7.4 Simulation Control and Structured Simulation Runs

The following Modula-2 objects serve the control of simulations.

```
PROCEDURE SimRun;
```

This procedure performs an elementary simulation run with the current parameter and other variable settings. Typically this routine is used to execute a series of simulation runs, e.g. in a loop within procedure *DeclExperiment* (see below this section). Simulation runs can then be executed under the control of the modeler, for instance to construct a whole phase portrait by means of a single menu command or to identify a model parameter. Precondition is that the simulation environment has been called (procedure *RunSimMaster*, see chapter *Starting a simulation session*) and that it is still active.

```
PROCEDURE CurrentSimNr(): INTEGER;
```

Returns the current simulation run number k during structured simulations (k = 1, 2, 3...) (Fig. T16). A typical usage of this procedure looks similar to the following statement:

```
REPEAT SimRun UNTIL CurrentSimNr()=maxSimNr
```

Note however that even aborted runs are numbered. To handle properly abortion of structured simulation runs see below procedure *ExperimentAborted.*

```
TYPE
  StartConsistencyProcedure = PROCEDURE(): BOOLEAN;
  TerminateConditionProcedure = PROCEDURE(): BOOLEAN;

PROCEDURE InstallStartConsistency(sc: StartConsistencyProcedure);
```

Procedure *sc* is called at the begin of a simulation run, right after the execution of the procedure *initialize* (see procedure *DeclM*) and after resuming a run from the state *Pause*.. If it returns FALSE, the simulation will be aborted and the simulation environment immediately returns into the program state *No simulation*. Otherwise the simulation is normally continued. Typically this procedure is used to check consistency in the initial conditions, e.g. to test relations among parameters and initial values. Since the simulationist may interactively change values of parameters independently from each other (entry forms test only syntax and ranges), this consistency test is important in case the model equations would become undefined if the conditions were not met. Moreover, the modeler may use this procedure to compute values of auxiliary variables, which depend on the current values of parameters.

```
  PROCEDURE InstallTerminateCondition(tc: TerminateConditionProcedure);
```

Procedure *tc* is called at the end of each time (integration) step during simulation. If it returns TRUE, the simulation will be terminated. This behavior can be used to program state events which lead to the simulation termination. Note however, that this does not fully conform to a proper handling of state events, since ModelWorks performs no iterations to find the exact location of the event. You have to program *tc* such that the value returned is correct even if the current time is not exactly that of the event, i.e. the procedure *tc* must be able to detect the state event even if it occurs anywhere in the time interval of the current integration step *h*

```
  PROCEDURE PauseRun;
```

Makes a state transition from the program state *Simulating* into the program state *Pause* (Fig. T15 and T26) and will only return after the simulationist has chosen the menu command *Resume run* under menu *Simulation.* This feature allows to temporarily interrupt a simulation run exactly at a particular point, such as a state event (e.g. a state variable becomes negative), and allows the simulationist to take some action, e.g. changing a parameter value, before resuming the simulation.

```
  PROCEDURE DeclExperiment(e: PROC);
```

Installs an experiment which may be executed by the user by selecting the menu command *Execute experiment* under menu *Simulation* which corresponds to the call of procedure *e*. The procedure *e* is provided by the modeler and contains typically calls to the procedure *SimMaster.SimRun.* If the procedure *DeclExperiment* has at least been called once in the course of a simulation session, the menu command *Execute experiment* under menu *Simulation* will no longer appear dimmed but as active and can be chosen by the simulationist in the state *No Simulation.*

```
  TYPE
    MWState =  (noSimulation, simulating, pause);

  PROCEDURE GetMWState(VAR s: MWState);
```

The current state of the simulation environment can be determined by calling procedure *GetMWState* from *SimMaster*. The meaning of the returned value *s*, either *noSimulation*, *simulating*, or *pause*, corresponds exactly to the program states shown in Fig. T15 (part II *Theory*).

```
  TYPE
     MWSubState =  (noRun, running, noSubState);

  PROCEDURE GetMWSubState(VAR ss: MWSubState);
```

The current substate of the simulation environment while a structured simulation (experiment) is currently in execution, can be determined by calling procedure *GetMWSubState* from *SimMaster*. The meaning of the returned value *ss*, either *noRun*, *running*, or *noSubState*, corresponds exactly to the program substates shown in Fig T26 (part II *Theory*). If the value *noSubState* is returned, no experiment is currently running, i.e. the simulationist has reached state *simulating* by choosing the menu command *Simulation/Start run* (s.a. below procedure *ExperimentRunning*).

```
PROCEDURE ExperimentRunning(): BOOLEAN;
```

ExperimentRunning from *SimMaster* returns TRUE if a structured simulation (experiment) is currently in execution, i.e. if the simulationist has reached the state *simulating* by choosing the menu command *Simulation/Execute experiment* (s.a. above procedure *GetMWSubState*).

```
  PROCEDURE ExperimentAborted(): BOOLEAN;
```

ExperimentAborted from *SimMaster* returns TRUE if the simulationist has stopped (killed) a running structured simulation (experiment). A typical use of this procedure is to skip superfluous calls to procedure *SimRun*. E.g.:

```
  REPEAT
    SimRun;
  UNTIL (CurrentSimNr()=maxRunNr) OR ExperimentAborted()
```

7.5 Display and Monitoring

7.5.1 WINDOW OPERATIONS

The following Modula-2 objects serve to control the display on the screen, e.g. the arrangement of windows or the monitoring.

```
  PROCEDURE TileWindows;
  PROCEDURE StackWindows;
```

The two procedures stack or tile windows on the screen. Stacking is with overlapping windows similar to the ModelWorks predefined start-up display. Tiled windows don't overlap and fill the screen as much as possible. The actual arrangement may depend on the screen in display.

The following type enumerates all windows of the ModelWorks simulation environment except for the window in the top right corner of the main screen used to display the current simulation time while in substate *running*:

```
  TYPE
    MWWindow = (MIOW, SVIOW, PIOW, MVIOW, TableW, GraphW, AboutMW);
```

MIOW, *SVIOW*, *PIOW* and *MVIOW* designate the IO-windows for the models, state variables, model parameters, and the monitorable variables. *TableW*, *GraphW* and *AboutMW* are the table, graph, and the about model window with the title "Model Help/Info". The latter window is displayed if the simulationist clicks into the question mark button of the models IO-window.

The following procedures operate on ModelWorks windows:

```
  PROCEDURE SetWindowPlace(mww: MWWindow; x,y,w,h: INTEGER);
```

SetWindowPlace places the window *mww* with its lower left corner at the position *x,y* and resizes it to the width *w* and height *h* (size of outer frame including title bar, frame, and shadows). The point [*x,y*] is given in pixel coordinates with an origin at the lower left corner of the main computer screen. If this procedure is called in case the window should not already be open, it will open the window in the proper size at the specified location.

```
PROCEDURE CloseWindow(w: MWWindow);
```

CloseWindow closes the window *w* and remembers the location plus size for the next reopening.

```
  PROCEDURE GetWindowPlace(mww: MWWindow; VAR x,y,w,h: INTEGER;
                           VAR isOpen: BOOLEAN);
```

GetWindowPlace returns the current position of the window *mww* and whether it is currently open or not. Since the simulation environment remembers the location and size of a window when it was open the last time, this procedure returns meaningful values even if *isOpen* should be FALSE.

```
  PROCEDURE SetDefltWindowPlace(mww: MWWindow; x,y,w,h: INTEGER);
```

SetDefltWindowPlace sets the default position of the window *mww*.

```
  PROCEDURE GetDefltWindowPlace(mww: MWWindow; VAR x,y,w,h: INTEGER;
                                               VAR enabled: BOOLEAN );
```

GetDefltWindowPlace returns the default position of the window *mww* plus the current IO-window status. If *enabled* is TRUE, it means that the editing functions of the IO-window are currently available to the simulationist. This is the case in the state *No simulation* or partially in the state *Pause*, but editing is disabled in the state *Simulating* (s.a. Fig. T15, in particular the title bars with horizontal lines vs. dimmed bars in part II *Theory*)

To control the format in which information is displayed in a particular IO-window use the following data structure:

```
  TYPE
    IOWColsDisplay = RECORD
      descrCol, identCol : BOOLEAN;
      CASE iow: MWWindow OF
        MIOW  : m : RECORD
                      integMethCol: BOOLEAN;
                    END(*RECORD*);
      | SVIOW : sv: RECORD
                      unitCol, sVInitCol: BOOLEAN;
                      fw,dec: INTEGER;
                    END(*RECORD*);
      | PIOW  : p : RECORD
                      unitCol, pValCol, pRtcCol: BOOLEAN;
                      fw,dec: INTEGER;
                    END(*RECORD*);
      | MVIOW : mv: RECORD
                      unitCol, scaleMinCol, scaleMaxCol, mVMonSetCol: BOOLEAN;
                      fw,dec: INTEGER;
                    END(*RECORD*);
      END(*CASE*)
    END(*RECORD*);
```

The booleans determine whether a column is to be displayed or not; they correspond to the check boxes which may be set by the simulationist in the entry form which is activated when the IO-window button *Set Up* is clicked. The integers specify the format in which to display real numbers, where *fw* is the field width and *dec* is the number of decimal digits.

```
  PROCEDURE SetIOWColDisplay( mww: MWWindow;     wd: IOWColsDisplay );
```

SetIOWColDisplay allows to set a new setup of the columns and new display formats in the IO-window *mww*. The predefined default of the simulation environment is 3 decimal digits to display or parameter values; this procedure allows to alter this format to any other value.

```
  PROCEDURE GetIOWColDisplay( mww: MWWindow; VAR wd: IOWColsDisplay );
```

GetIOWColDisplay returns the setup of the columns and the display formats currently in use by the IO-window *mww*.

Instead of the current values, the following two procedures affect the default values; otherwise they function the same way as the previous two procedures:

```
  PROCEDURE SetDefltIOWColDisplay( mww: MWWindow;     wd: IOWColsDisplay );
  PROCEDURE GetDefltIOWColDisplay( mww: MWWindow; VAR wd: IOWColsDisplay );
```

The following procedures allow the modeler to customize the simulation environment even a step further; he/she may even completely disallow or allow any usage of an IO-window. This control is only available to the modeler but not to the simulationist.

```
  PROCEDURE DisableWindow(w: MWWindow);
```

DisableWindow disables the IO-window *w* for any usage, i.e. neither the opening, editing, nor the closing of the IO-window by the simulationist is any more possible (Only supported for the IO-Windows). In case the IO-window *w* should be currently open, it is closed. The corresponding menu commands are disabled (dimmed).

```
  PROCEDURE EnableWindow (w: MWWindow);
```

EnableWindow reverses the effect of *DisableWindow* and enables the subsequent usage of the IO-window *w* by the simulationist to its normal and full functionality.

```
  PROCEDURE UseCurWSettingsAsDefault;
```

Copies all the current settings of the windows to their defaults. A typical usage may be:

```
    TileWindows;
    SetWindowPlace(MIOW,...
    SetWindowPlace(SVIOW,...
    SetWindowPlace(GraphW,...
    ...
    UseCurWSettingsAsDefault;
```

The calls to *SetWindowPlace* customize particular locations of windows. The final call to *UseCurWSettingsAsDefault* saves all the current settings as the new defaults to be used if the simulationist performs a reset of the windows. This solution is more convenient than having to specify first the current values and then the defaults again with exactly the same values.

7.5.2 General monitoring

After having called *SuppressMonitoring*, all subsequent monitoring will be suppressed.

```
  PROCEDURE SuppressMonitoring;
```

The next procedure

```
  PROCEDURE ResumeMonitoring;
```

resumes all monitoring exactly as it was before procedure *SuppressMonitoring* has been called.

```
PROCEDURE DeclClientMonitoring(initmp, mp, termmp: PROC);
```

Installs in ModelWorks a client provided monitoring procedures *mp*. At the begin respectively the end of every simulation run the procedures *initmp* respectively *termmp* are called (for exact calling sequence see Fig. T17 in part *Theory*). During the simulation run the monitoring procedure *mp* is called every time or integration step once. *mp* will be called as the last monitoring procedure, i.e. after ModelWorks calls the stash file, the tabulation, and the graph monitoring procedures. This allows for instance to draw into the ModelWorks graph window from within the *mp*.

7.5.3 STASH FILING

```
PROCEDURE StashFileName(sfn: ARRAY OF CHAR);
```

Sets the default name of the stash file (may contain a path, e.g. Disk:Folder:MyFile.DAT). The call of this procedure will have no effect until the stash file name is reset. Important notice: if a file with the same name should already exist, it will be overwritten without any warning.

```
PROCEDURE SwitchStashFile(newsfn: ARRAY OF CHAR);
```

Switch the stash file by closing the one currently in use (if called between two simulation runs, state *No run* Fig. T26) and open a new stash file with the name *newsfn* (may contain a path, e.g. Disk:Folder:MyFile.DAT) at the begin of the next simulation run. Calling this procedure in the middle of a simulation run will have no effect. Important notice: if a file with the same name should already exist, it will be overwritten without any warning!

```
PROCEDURE Message(m: ARRAY OF CHAR);
```

Writes the text *m* onto the stash file and inserts it in the table. This procedure surrounds the string *m* with quotation marks '"' and precedes it with the reserved word MESSAGE. This procedure allows to bring state events to the user's attention, which would otherwise slip by undetected or it helps the user to locate particular events while reading large stash files.

```
PROCEDURE DumpGraph;
```

If the stash file is currently open (currently *stashFiling* attribute (F) for at least one monitorable variable active), *DumpGraph* writes the current graph onto the stash file. The data are written in the so-called RTF-Format which can be opened by several, commercially available document processing software (s.a. previous section on recording flags in the entry form *Project description…* under menu *Settings*). [Not available in Reflex and PC version]

7.5.4 GRAPHICAL MONITORING

The following objects allow to control the curve attributes used by ModelWorks for the monitoring of the simulation results in the graph for the specified monitorable variable.

```
TYPE
  Stain =
    (coal,  snow,  ruby, emerald, sapphire, turquoise, pink,    gold,
     autoDefCol);

  LineStyle = (unbroken, broken, dashSpotted, spotted, invisible, purge,
               autoDefStyle);
CONST
     autoDefSym = 200C;
```

Stains and color variables from module *DMWindowIO* correspond to each other. They can be paired following this sequence:

```
black, white, red,  green,   blue,     cyan,      magenta, yellow
```

Stain *coal* is *black*, *snow* is *white*, *ruby* is *red* etc. The following line styles are available to connect points in the graph:

unbroken	________
broken	- - - - - - - -
dashSpotted	-·-·-·-·-·-·-
spotted	....
invisible	no drawing at all, may be used to stop drawing of a particular curve, while others are still drawn
purge	used to erase already drawn curves
autoDefStyle	line style will be determined by ModelWorks according to the automatic definition mechanism of curve attributes

To set or get defaults respectively current curve attributes for the monitorable variable *mv* belonging to model *m* use the following procedures:

```
PROCEDURE SetCurveAttrForMV(m: Model; VAR mv: REAL;
                            st: Stain; ls: LineStyle;
                            sym: CHAR);
PROCEDURE GetCurveAttrForMV(m: Model; VAR mv: REAL;
                            VAR st: Stain; VAR ls: LineStyle;
                            VAR sym: CHAR);

PROCEDURE SetDefltCurveAttrForMV(m: Model; VAR mv: REAL;
                                 st: Stain; ls: LineStyle;
                                 sym: CHAR);
PROCEDURE GetDefltCurveAttrForMV(m: Model; VAR mv: REAL;
                                 VAR st: Stain; VAR ls: LineStyle;
                                 VAR sym: CHAR);
```

Where:

st *Stain* (color) is used to draw the lines and/or plotting symbols of a curve

ls Style of the connecting lines drawn between monitoring points.

sym Plotting symbol drawn at monitoring points

The latter two procedures which affect the defaults require a reset before becoming effective. This is not the case for the first two procedures, which take effect immediately. [Colors are not available in the PC version].

Note that if either *autoDefCol*, or *autoDefStyle*, or *autoDefSym* is used, the automatic definition mechanism for colors, line styles, and for symbols as provided by the simulation environment becomes active (see Tab. T1, part II *Theory*). Hence if you wish to really set a curve attribute, make sure that all(!) attributes are set different from an *autoDef*-value.

In particular note, that the procedures affecting current values function also in the middle of a simulation. This behavior may be useful, for instance to make a portion of a curve for a certain time invisible. A typical application is the simultaneous display of a measured time series and the monitoring of solutions of a system of differential equations; if some measurements are missing there arises the need to suppress partially the monitoring, i.e. to display nothing for the measurements but to monitor the behavior of the model equations. Using procedure *SetCurveAttrForMV* with the line style *invisible* will allow to achieve the desired effect.

Note that if curve attributes are changed dynamically there may appear inconsistencies between the curve attributes used for the curves themselves and those used to draw the legend. This is because the legend shows only those curve attributes which are currently active while it is drawn. Unfortunately the simulation environment draws the legend in many situations for different reasons and the modeler can not directly control this drawing. However if the modeler follows the following guidelines there should result a satisfying behavior: The model which changes curve attributes dynamically during the course of a simulation must set all curve attributes exactly as they should appear in the legend at the end of the procedure *Output* if current time $t = t_o$ resp. $k = k_o$ and always at the end of the procedure *Terminate* (for an example see the research sample model *LBM* module *LBMObs* in the *Appendix*).

```
  PROCEDURE ClearGraph;
```

Clears the panel of the graph.

7.5.5 Simulation environment modes

The following four procedures allow to define the so-called simulation environment modes. They can be used to set any preference.

```
  PROCEDURE SetDocumentRunAlwaysMode(dra: BOOLEAN);
  PROCEDURE GetDocumentRunAlwaysMode(VAR dra: BOOLEAN);
```

If the mode «document run always» is activated, every execution of a simulation run will be documented onto stash file according to the current settings of the project descriptors. Note that the stash file gets rewritten with every new run.

```
  PROCEDURE SetRedrawTableAlwaysMode(rta: BOOLEAN);
  PROCEDURE GetRedrawTableAlwaysMode(VAR rta: BOOLEAN);
```

The mode «redraw table always» describes the behaviour of the table window in respect to modifications of the tabulation monitoring settings. For further explanations see mode «redraw graph always» above.

```
  PROCEDURE SetCommonPageUpRows(rows: CARDINAL);
  PROCEDURE GetCommonPageUpRows(VAR rows: CARDINAL);
```

This mode controls the number of common rows between page ups in the table window. A page up occurrs when the table window is full but more rows should be written; then ModelWorks attempts to erase most of the table and restarts tabulating from the top again. The number *rows* specifies how many rows at the bottom are not erased but scrolled to the top of the next page. The rest of the table window is then used to add the rows of the new page. Thus *rows* specifies how many rows are common to two consecutive pages.

```
  PROCEDURE SetRedrawGraphAlwaysMode(rga: BOOLEAN);
  PROCEDURE GetRedrawGraphAlwaysMode(VAR rga: BOOLEAN);
```

If the mode *RedrawGraphAlways* is activated, each modification of the graphing settings will be displayed immediately, not only at the begin of the next simulation run. This implies an immediate loss of all simulation results eventually currently visible in the graph as soon the simulationist edits any graphing settings. If this mode is not active, the current graph will not be touched unless the user starts another simulation; at its begin the whole graph will be redrawn.

```
  PROCEDURE SetColorVectorGraphSaveMode(crg: BOOLEAN);
  PROCEDURE GetColorVectorGraphSaveMode(VAR crg: BOOLEAN);
```

Above procedures allow to control the mode of graph restoration, graph printing, and transfer of graph into clipboard. If the mode «color and vector graph saving» is activated, *crg* is TRUE, each time the graph window needs to be redrawn the graph will be reconstructed in colors. Restoration is necessary after some parts of it become visible again after they have been covered by another window (see also description of restore or update mechanism in module DMWindows of the 'Dialog Machine'). Deactivation of this mode results in storing graphical output in a hidden bitmap without colors, with a coarser resolution and more modest memory requirements. Note that this mode won't affect the very first drawing of the graph, i.e. on a color screen you may still get colored curves, even if this mode should be turned off. Since the full reconstruction in colors for complicated graphs may be slow, especially on monochrome monitors it may be preferable to deactivate this mode (trade-off between colors and speed). In addition to the colors all graphical output is stored as vectorized objects. This allows printing and copying to the clipboard of graphs in high resolution quality, but requires a corresponding amount of memory. [Not available in Reflex and PC version]

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Appendix

Reading Hint: For easier orientation, the titles, pages, figures and tables of this Appendix are prefixed with the letter A. Within this part figures are numbered separately, starting with Fig. A1.

A ModelWorks Version and Implementations

The ModelWorks version described in this text is version V2.0 made in May 1990. There exist in fact four, slightly differing implementations or versions:

1) The standard Macintosh version V2.0. Runs on all Macintosh computers with at least 1 MBytes of memory and offers all ModelWorks functions without restrictions.

2) The Reflex Macintosh version V2.0/Reflex. It is a reduced subset from the standard version and runs on 512KBytes machines like the Macintosh Reflex (Mac 512KE). The following restrictions apply: no graph printing except screen dumps, no clipboard support, and no dumping of graphs onto the stash file. Colors are available on color screens and on printer systems which support color screen dumps. However the simulation environment mode «restore graph with colors» is not available.

3) The IBM PC version V1.1/PC. It is also a reduced subset from the standard Macintosh version. Besides the same restrictions which apply to the Reflex Macintosh version, this version can not support colors. This is because of the MS DOS memory limitation of 640 KBytes. Furthermore this version requires static linking.

4) The Macintosh II version V2.0/II. It is functionally identical with the standard Macintosh version but takes full advantage of the Motorola 68020 resp. 68030 32-Bit CPU and the arithmetic coprocessor Motorola 68881 resp. 68882[1]. It is faster, however, it runs on Macintosh II family computers only.

The usage of the software for noncommercial purposes is free and unrestricted as long as the authorship of the used software is stated clearly on any redistributed model or other program, i.e. any product descriptions or labels must state in writing that the «Interactive ModelWorks Simulation Software by A. Fischlin *et al.* from the Swiss Federal Institute of Technology Zürich ETHZ» has been used to develop the product. All copyrights are reserved and are held by the authors and the Swiss Federal Institute of Technology Zürich ETHZ. ModelWorks may not be sold, nor included in any sold product as an incentive, nor otherwise redistributed for a profit without prior written consent by the authors and the Swiss Federal Institute of Technology Zürich ETHZ.

[1] Note that for heavy computations the gain in computing speed is substantial (up to two magnitudes, for certain functions, such as Ln, up to several hundred times faster); this is because this implementation bypasses SANE and accesses the mathematical coprocessor directly, hereby making maxium use of its power without sacrificing much in numerical precision.

B Hard- and Software Requirements

B.1 Macintosh Versions

The standard and the Reflex Macintosh ModelWorks versions V2.0 resp. V2.0/Reflex run on all Apple® Macintosh™ computer models except the 128K Mac and the 512K Mac («Fat Mac») unless the machines should be equipped with ROM versions of 128K Bytes or later and with sufficient memory (see below). All three versions require at least one 800 KBytes double-sided floppy disk drive, and either a second 800 KBytes disk drive or a hard disk. For serious model development, a hard disk is recommended. You have to use a Finder version 5.3 or later and a System version 3.1 or later, and it is recommended to work with HFS (Hierarchical File System) disks only. The Reflex version V2.0/Reflex of ModelWorks needs at least 512K Bytes of memory (RAM); the full standard version V2.0 runs on all Macintosh computers with at least 1 MB of memory (RAM). The Macintosh II version V2.0/II requires in addition to requirements of the standard version the Motorola 68020[1] 32-Bit CPU and the arithmetic coprocessor Motorola 68881 or later, upward compatible chips.

If applicable, all ModelWorks versions have been thoroughly tested to run on the following Macintosh™ models: Mac Reflex (512KE), Mac Plus, Mac SE, Mac II, Mac IIx, and Mac IIcx. It should also run on the models Mac IIci, Mac SE/30, Mac Portable, and Mac IIfx. All ModelWorks code is 32-Bit clean and ModelWorks is expected to run under system 7.0 and later versions.

Currently the fully functional Macintosh ModelWorks software kits are not sold but distributed as public domain software. They can be obtained from the Swiss Federal Institute of Technology Zürich ETHZ against a minimum handling charge[2]. Besides the user provided hardware, the user obtains with the distributed software everything needed to work fully with ModelWorks, i.e. included is even a system software[3], a full Modula-2 development system (editor, compiler plus utilities such as symbolic debugger, application linker), the Dialog Machine, and ModelWorks.

For a detailed description of the ModelWorks software kit see below, the section *Installation of ModelWorks.*

B.2 IBM PC Version

The IBM PC ModelWorks version requires an IBM PC or 100% IBM-compatible computer, either a fast XT Turbo, an AT, or a PS/2 model equipped with a hard disk and a mouse (almost any type of mouse will do). The computer should be equipped with 640 KBytes of RAM[4], and should be operated under the MS DOS operating system. The resolution of the monitor should be better than 512 x 342 pixels (EGA, VGA or Hercules are OK; CGA and MGA are not). For ModelWorks the resolution should not be higher than 600 x 800 (640 K limit of DOS leaves not enough memory to store the window bitmaps).

[1] Upward compatible CPUs are: Motorola 68030 or 68040; upward compatible numerical coprocessors are: 68882.

[2] Order ModelWorks Macintosh V2.0 from the following address: Projekt-Zentrum IDA, re ModelWorks, Swiss Federal Institute of Technology ETHZ, ETH-Zentrum, CH-8092 Zürich, Switzerland; V2.0/Reflex and V2.0/II from the address: Systems Ecology, re. ModelWorks, Department of Environmental Sciences ETHZ, ETH-Zentrum, CH-8092 Zürich, Switzerland

[3]Of course the use of the distributed system software is optional and the user may use instead any other system he/she wishes, given the system version is equal or newer to that mentioned above.

[4] 512KBytes might just work with the Dialog Machine alone, but not with ModelWorks

Together with a GEM-supported mouse, the GEM desktop software must be installed in order to execute existing ModelWorks model definition programs. To develop new models, a particular ModelWorks GEM license must be obtained from ETHZ. Furthermore it is necessary to purchase a TopSpeed Modula-2 license in order to be able to develop, compile, and link ModelWorks model definition programs. Together with the ModelWorks software you may buy a full ModelWorks development kit for a reduced price from the Swiss Federal Institute of Technology Zürich ETHZ[1]. Note that similar to the Macintosh versions, the ModelWorks software itself is not sold but distributed as public domain software.

For a detailed description of the ModelWorks software kit see below, the section *Installation of ModelWorks*.

C How to Work With ModelWorks on Macintosh Computers

All descriptions in this section are valid for all Macintosh ModelWorks versions.

C.1 Installation of ModelWorks

ModelWorks is distributed on two 800 KBytes floppy diskettes. They are organized similarly to those shown in Fig. A1 and Fig. A2:

The first diskette 1/2 contains the ModelWorks development system for the daily work, the second diskette 2/2 a system, the documentation and a collection of sample models.

ModelWorks contains partially the MacMETH - Fast Modula-2 Language System software, in particular the compiler, debugger, and linker (Files and folders: *RMSMacMETH*, *User.Profile*, *M2MiniLib*, *M2Tools*). Moreover it contains also a complete copy of the Dialog Machine software (folders *DMLib*, *AuxLib*, and *RAMSESLib*). With this software you can fully develop your own model definition programs without any limits. However, if you should wish to obtain the full *MacMETH Fast Modula-2 Language System* together with its library and a manual, you have to purchase a separate license for MacMETH[2] . Furthermore, if you should wish to obtain the original Dialog Machine software, consisting of a fully described interface to its library, an optional auxiliary library, sample programs and texts explaining concepts and typical usage, you have to order a separate Dialog Machine distribution[3] (s.a. appendix section *How to work with the Dialog Machine*).

Before you continue, please lock the distribution diskettes and make first a working copy. Then store the distribution diskettes in a safe place!

[1] Order a full ModelWorks Development Kit V1.1/PC from the following address: Projekt-Zentrum IDA, re ModelWorks, Swiss Federal Institute of Technology ETHZ, ETH-Zentrum, CH-8092 Zürich, Switzerland

[2] Order MacMETH from the following address: Institut für Informatik ETHZ, Swiss Federal Institute of Technology, ETH-Zentrum, CH-8092 Zürich, Switzerland

[3] Order the Dialog Machine from the following address: Projekt-Zentrum IDA, re Dialog Machine, Swiss Federal Institute of Technology ETHZ, ETH-Zentrum, CH-8092 Zürich, Switzerland

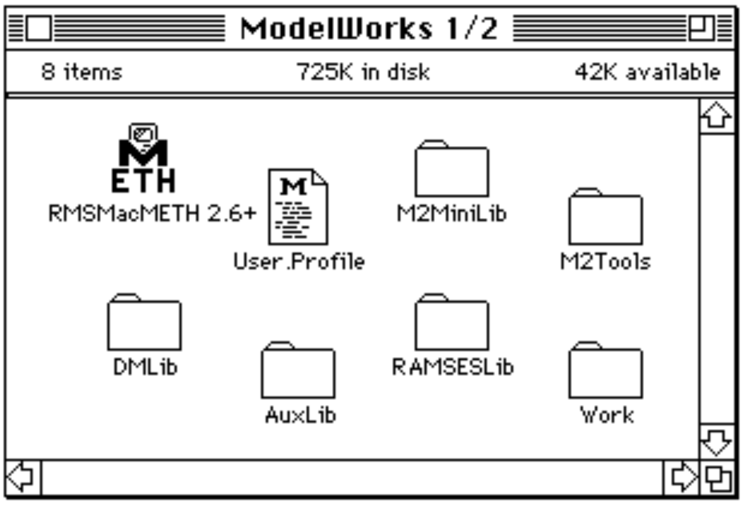


Fig.A1: Contents of the first Macintosh ModelWorks distribution diskette 1/2.

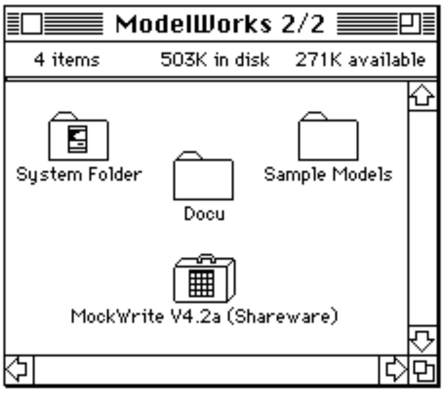


Fig.A2: Contents of the Macintosh ModelWorks distribution diskette 2/2.

There are two ways to work with ModelWorks: with a hard disk or with two floppy diskettes.

In case you should have a hard disk, the installation is very simple[1]: Copy the whole contents of the first diskette into a new folder, which you may name something like *ModelWorks*, on your hard disk, and you are ready to start working.

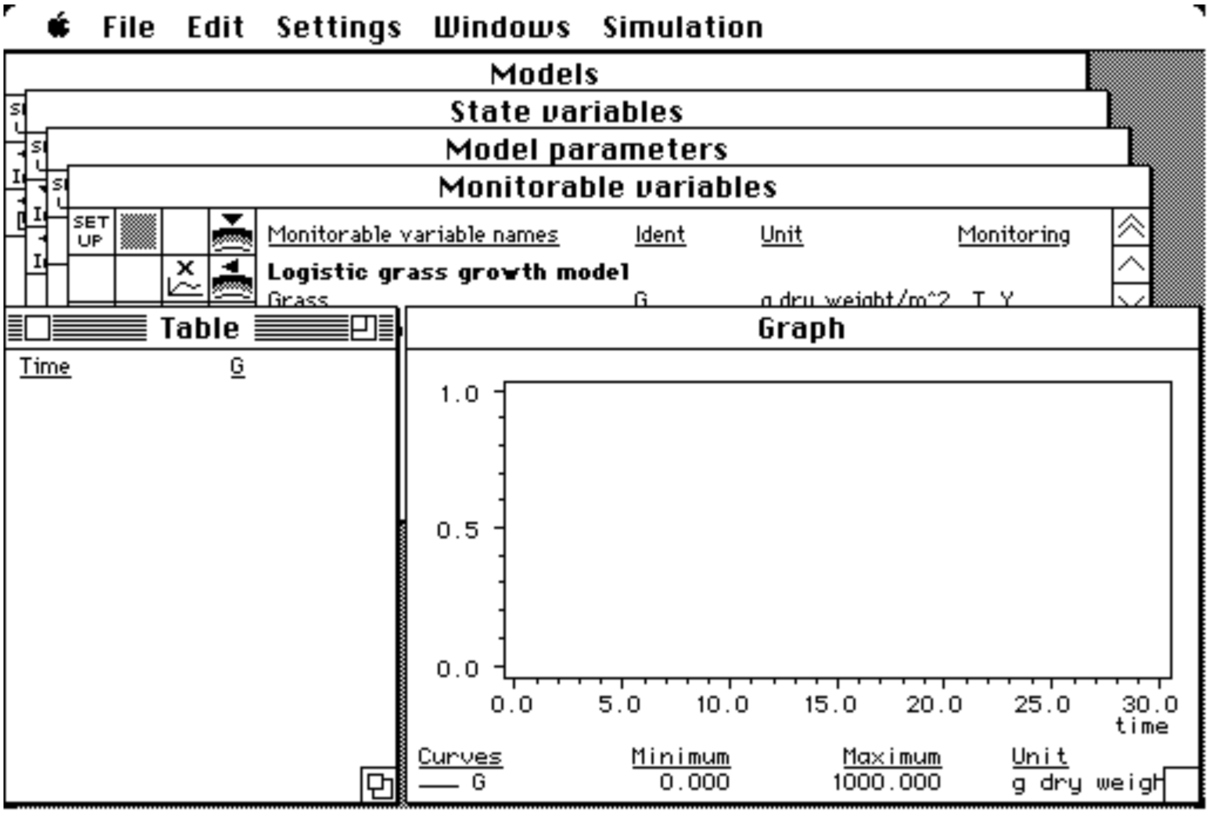
In case you should have no hard disk, you can work directly with the working copy of the two distribution diskettes (**never use your original distribution diskettes for this purpose!**).

The second diskette contains a system with the desk accessory *MockWrite MEdit 4.2a* already installed. You can use this desk accessory to edit your models. In case you prefer a different system than the one provided on disk 2/2, you can freely replace it with your favorite system folder. However, in this case it is either recommended you install first the desk accessory

[1] You should have at least 800 KBytes of free disk space. For large model development projects it is recommended to have 1 MBytes available; in case large data sets are involved, enlarge the needed disk space accordingly. Models tend to remain small, e.g. within 40 K (for source, OBM, and RFM files) fits already quite a sophisticated model definition program.

MockWrite[1] in your system or you copy your favorite text editor onto the disk 2/2. In case you intend to use *MockWrite* regularly, please don't forget to pay the shareware fee[2]!

Please quickly test your installation by starting first the MacMETH shell *RMSMacMETH* (with a doubleclick) and by choosing the menu command *Execute*. If the standard file selection dialog box appears, select the sample model *Logistic.OBM* contained in the folder *Work* on the first diskette 1/2. If you see a screen like the one in Fig. A3, the installation is complete.



Monitorable variable names Ident Unit Monitoring
Logistic grass growth model
Grass G g dry weight/m^2 T Y

Time G

Curves Minimum Maximum Unit
—— G 0.000 1000.000 g dry weigh

Fig. A3: Screen which should appear while testing the installation of the ModelWorks software and activating the already compiled model definition program *Logistic.OBM*.

If you are not yet familiar with ModelWorks please quit the program now by choosing the menu command *Quit* under the menu *File*. Then consult *Part I - Tutorial* of this text.

C.2 How to Work With MacMETH

Modeling with ModelWorks Macintosh versions (V2.0, V2.0/Reflex, V2.0/II) is done by developing Modula-2 model definition programs using the *MacMETH - A Fast Modula-2 Language System* (Wirth et al., 1988). The sequence of steps to follow is shown in Fig. 23 in part II *Theory*, section *The model development cycle*. MacMETH consists of an application plus several subprograms: the first is the development shell *RMSMacMETH* and the subpro-

[1] Use the Font/DA Mover, a system utility which you obtained from Apple as part of the system software together with your Macintosh computer

[2] Although small and plain-vanilla, *MockWrite* has proven to be a very reliable text editor and the author probably suffers already too much from happy, but nevertheless non-paying customers!

grams are the compiler, the linker, the debugger and several other utilities. The application *RMSMacMETH* is an ordinary Macintosh application and can be treated as such, i.e. start it with a double-click. Most of the time you will only work with the MacMETH shell. It fully supports compilation and execution of Modula-2 program modules as sub-programs, e.g. the compiler or your model, all run as subprograms under the shell.

Basics (very brief): Edit source file (e.g. model definition program) with any editor (*MacWrite* and save as text only, *MockWrite*, *Edit*, or *MEdit* etc.). To compile choose the menu command *File/Compile/* C and type the name of the module, followed by a "." and a return (extension MOD will be added automatically) => compilation starts. If you encounter errors repeat sequence *File/Merge/* M, edit source file, recompile, till you obtain no more compiler errors. For a last time choose *File/Merge/* M to remove remaining comments with error messages from last erroneous compilation. Choose the menu command *File/Execute/* X and select OBM file to be executed (normally model definition program). To debug either execute a HALT statement (needs recompilation) or press interrupt button (not reset button) of the programmers button at the side of your Macintosh (see owner's guide). You may look at current values and location of error but you can't change any variable's values. Quit debugger by choosing menu command *File/Quit* and resume program. Clicking into the source code while having the command key ( ) pressed allows to debug dynamically (program execution will continue till the clicked statement is actually executed and the debugger is automatically reentered); don't forget to actually leave the debugger with *File/Quit* when you debug dynamically.

Please refer to the separate MacMETH manual for general and more detailed information on how to work with the MacMETH software. In the following you find some often useful hints and specific information on how to work with MacMETH when using ModelWorks.

Note that the *RMSMacMETH* shell reads a configuration file (type TEXT) with the name *User.Profile* when it is started. This file, which must have exactly this name and which must reside in the same folder as the shell, contains the path names of the folders and disks where the modules and subprograms can be found. Make sure that the names of your disks and folders, where you keep the tools such as the compiler and the library modules, match exactly the names given in the *User.Profile*. Experience shows that many user problems with MacMETH are only due to inconsistencies between the names in the *User.Profile* and actual disk or folder names. The ModelWorks distribution disk already contains a *User.Profile* which allows you to work directly with the disks, given you do not change any folder names.

Path names are a list of names separated by colons and always end with a colon. There are relative and absolute path names. An absolute path starts with the name of the disk as its first element and lists all folders as they reside within each other. E.g. the absolute path name "ModelWorks 1/2:RAMSESLib:" listed in the *User.Profile* will result in file searches, e.g. by the compiler, within the folder named *RAMSESLib* on the disk named *ModelWorks 1/2*. Any path name starting with the special character ":" is interpreted as a relative path name. All searches start relative to the location, i.e. the folder, where the MacMETH shell *RMSMacMETH* resides. E.g. the relative path name ":Work:ProjectLib:" will cause the compiler or linking-loader to search for files in the folder *ProjectLib* contained within the folder *Work*. Note that this example would function properly only if the MacMETH shell is in the same folder or on the same disk as the folder *Work*. From this follows that files residing on other disks than the MacMETH shell can only be accessed by absolute paths. Absolute paths are more error prone than relative paths; try to avoid them. In case you have to use them, always remember to update the *User.Profile* each time you move or copy the MacMETH system. Note also that it is futile to change the *User.Profile* while running the shell unless you execute the utility *SetProfile* after having changed the *User.Profile*.

To work with the MacMETH Modula-2 development shell, start it with a double click on the icon of the file named *RMSMacMETH*[1], exactly as you do with any other Macintosh application program. The file menu of MacMETH offers at least the commands *Edit*, *Compile*, *Execute*, and *Quit*. (the actual content of the commands in this menu depend on the "User.Profile") *Edit* will only produce a message, that you should use the utility *Merge* to detect compilation errors. *Execute* displays a dialog box, in which the program to be started can be chosen, e.g. a ModelWorks model. *Quit* terminates the MacMETH-shell. In case that compiler errors were detected, use the utility *Merge* after the compilation. *Merge* inserts the corresponding error messages at the violating locations in your source file. Then use *MockWrite* or any other text editor to correct your errors in the model definition program. Search for comments containing 4 hash marks ("####"); they contain the inserted compiler error messages and point with a little arrow "↑" to the position within the source code line where the error has been detected. Note, that *Merge* can insert the error messages only into your file, if the path of its location is also contained in the *User.Profile*. You don't have to remove the inserted error messages your-self; the next call to *Merge* removes any messages no longer valid and all messages are removed after an error-free compilation.

There are three methods to tell the compiler where to find the input file containing the source code:

Type the name and hit return or click the mouse. Note that this method may require that you type not only the file name but also its path, preceding the name. E. g. the source code is stored in a file *MyFile.MOD* within the folder *Subfolder1*, which again is within the folder *Work* which is in the same folder as the MacMETH shell; in this case you would have to enter ":Work:Subfolder1:MyFile.MOD" unless your profile contains already the path ":Work:Subfolder1:".

Press the TAB-key instead of typing a file name. This method will let you choose the file containing the source code with the ordinary Macintosh file selection dialog box.

Press simultaneously the Command-key, the shift key, and the key "0" on the numeric keypad instead of typing a file name. This method lets you choose a text file with the ordinary Macintosh file selection dialog box, however, this file will not contain the source code but the name of the file(s) you wish to compile. This method is most useful if you have to compile a whole set of modules. Instead of typing each time several module names you enter them into a text file, e.g. called *MyModelSet.MAKE*, exactly as you would enter them after the compiler prompt. Then each time you want to compile all modules belonging to your model system, simply choose the file *MyModelSet.MAKE* after entering Command-key^Shift^0. For instance all the sample models distributed together with the ModelWorks release can be compiled with this technique. The needed file named *MAKE Sample Models* is distributed together with the sample models.

MacMETH uses the following extensions in file names:

- .MOD: Text files. Implementation and program modules
- .DEF: Text files. Definition modules
- .OBM: Object files (compiled implementation/program modules)
- .SBM: Symbol files (compiled definition modules)
- .RFM: Reference files used for debugging.

[1] The exact name may be slightly different, e.g. *RMSMacMETH 2.6+*, indicating also the shells version.

Files produced by the compiler (in particular SBM, OBM, and RFM) get their names not from the name of the source file but from the module identifier. Note also, that files names (extension included) should not be longer than 16 characters. Hence module identifiers should not be longer than 12 characters and should be identical to the source file name (except for the extensions). E.g.: The following model definition program *MyModel*

```
MODULE MyModel;
  FROM SimBase IMPORT ...
  ...
END MyModel.
```

should be saved in a text file with the name *MyModel.MOD*. In particular linking, loading, and debugging will function without problems and more conveniently if you obey these conventions and restrictions.

C.3 Configuring ModelWorks

The ModelWorks software can be configured by file renaming any time in the following ways:

- <u>SANE (Standard Apple Numeric Environment) usage by procedures from module *MathLib*</u>

  File *MathLib.OBM* in the folder *M2MiniLib* on diskette *ModelWorks 1/2* comes in two versions:

  α *MathLib.OBM(NO SANE)*

  β *MathLib.OBM(SANE)*

  These files are different implementations of module *MathLib* (for exported procedures see e.g. quick reference listing of the Dialog Machine), one uses SANE, the other not. Implementation α does not use SANE but instead much more efficient but less precise 32-bits floating point arithmetics which are not available in SANE. Implementation β uses SANE, which is much slower but results are computed with maximum precision (80-bits floating point arithmetics) even exceeding requirements of the IEEE standard 754 for binary floating-point arithmetic (Cody, 1981; IEEE Std 754-1985, 1985).

  In general it is recommended to use implementation α if you work with single reals (type REAL uses 32 bits) and standard ModelWorks 2.0. The loss in accuracy stems mostly from the fact that you store in particular the intermediate results only as single precision reals (type REAL). According to our research the latter effect is so dominant on the precision of the final results that it is rarely worth using SANE in expressions of type REAL. However, the situation is different if you use reals of type LONGREAL, then the MacMETH compiler uses by default SANE and for math functions you should use module *LongMathLib* which also uses SANE.

  Note also that if your machine has an arithmetic coprocessor, in particular if you work with version II V2.0/II, SANE should be avoided in order to gain maximum performance. This can be achieved by importing math functions from module SYSTEM instead of using any MathLib and compiling the code with the V2.0/II compiler *compile20*. Then you bypass SANE completely and can take full advantage of the speed of the coprocessor without much loss in precision regardless of the real types you are using (always maximum coprocessor precision, i.e. 80-bits arithmetics). Although a bit less precise as when using SANE, the results still conform to the precision requirements of the IEEE standard 754 for binary floating-point arithmetic.

Configure your installation by deleting the already existing file *MathLib.OBM* (it is actually a copy of file α) in the folder and renaming the copy of any of these files to *MathLib.OBM* will result in the corresponding SANE usage by the exported math functions.

- Supervision of heap usage by Dialog Machine and ModelWorks

File *DMHeapWatch.OBM* in the folder *DMLib* on diskette *ModelWorks 1/2* comes in two versions:

α *DMHeapWatch.OBM (check)*

β *DMHeapWatch.OBM (no checks)*

These files are different implementations of module *DMHeapWatch*, one watches the heap management, the other does not. The module is actually just used internally of the Dialog Machine, but depending on the implementation you use, the software will behave slightly different. Implementation α tests whether allocations of memory blocks in the heap are exactly matched by deallocations. In case a mismatch is detected, a warning message is displayed at the end of the program. Implementation β ignores the heap management. Normally it is recommended to use implementation β, but in case you suspect heap problems, you may gain insights using implementation α.

Configure your installation by deleting the already existing file *DMHeapWatch.OBM* (it is actually a copy of file α) in the folder and renaming the copy of any of these files to *DMHeapWatch.OBM* will result in the corresponding heap watching behavior of any Dialog Machine program (e.g. ModelWorks).

- Bundling of text files produced by all ModelWorks software (compiler, module *DMFiles* etc.) with a particular editor application.

File *FileSystem.OBM* in the folder *M2MiniLib* on diskette *ModelWorks 1/2* comes in two versions:

α *FileSystem.OBM (MEdit)*

β *FileSystem.OBM (orig, 2.6)*

If you double click on a text document produced with ModelWorks, e.g. *ModelWorks.DAT*, the bundled text editor will be opened. For file α this is *MEdit*[1] (Macro editor), an excellent shareware editor we favor over all other editors known to us (commercial products included) because of its powerful macro capability. File β is bundled with the wide spread *MS Edit*.

Configure your installation by deleting the already existing file *FileSystem.OBM* (it is actually a copy of file α) in the folder and renaming the copy of any of these files to *FileSystem.OBM* will result in the corresponding bundling.

[1] *MEdit* can be obtained from Matthias Aebi, Hirschgartnerweg 25, CH-8057 Zürich, Switzerland. It can also be obtained as part of the Dialog Machine release together with Modula-2 and ModelWorks supporting Macros from Projekt-Zentrum IDA, re Dialog Machine, Swiss Federal Institute of Technology ETHZ, ETH-Zentrum, CH-8092 Zürich, Switzerland (shareware fee has still to be paid separately to Mr. Aebi).

C.4 How to Make a Stand-alone Application

Typically MacMETH's linking-loader is used when developing and running models. The only disadvantage of this technique is that models require the Modula-2 development environment to be present always. Once developed and tested the modeler may wish to make the model independent from this development environment, i.e. to convert a model definition program into a normal Macintosh application. This can be achieved easily by linking a ModelWorks model definition program to a stand-alone application. The latter may be started with a double-click like any other ordinary Macintosh application. To link an application start the MacMETH linker from within the MacMETH shell and specify the object file (.OBM file) of the model definition program (functions only by typing the name) and add the linking option "/a".

You get an application which will work fine, but which does not have its own icon and is still bundled with MacMETH. Normally this causes only troubles (very confusing icon behavior in the Finder desktop) and should be avoided. Follow the steps described below to create a true stand-alone application conforming fully to the standard user interface of your Macintosh™ computer:

Procedure A: In case you should have access to the shareware application *Iconia 6.3* or a later commercially available version[1] there is a simple way to unbundle the application from MacMETH and provide the new application with its its own unique icon and bundle. Just start *iconia* and define the icon, its mask, the creator string (4 letters not conflicting with any already existing creator present on your disk), the version information (shown by the Finder via the menu command *File/Get Info*) and execute the menu command *File/Compile...* by selecting as the destination file your just linked application. That's it. If you use the shareware version, please don't forget to pay the shareware price!

Procedure B: First start the resource editor *ResEdit*[2] and remove all resources of the following types:

- BNDL
- ETHM
- FREF
- ICN#
- MLNK
- SIZE

This is already sufficient to unbundle your application from MacMETH and avoids any user interface problems.

In case you wish to add to the new application its own unique icon instead of the default application icon provided by the Macintosh™ system perform also the following two steps: First edit a new desktop icon using the resource editor (resource of type "ICN#"). Second start the application *IconSwitcher*[3]. You simply have to use the option install and make sure that the option *Update Desktop* is active before quitting this tool. That's it.

[1] *Iconia 6.3* (shareware $10) or *Iconia 7.0* are available fromHenrik Floberg of PHP Innovation, Mätaregränden 6, S-222 47 Lund, Sweden, Phone (046) 12 69 14 or in case of *Iconia 6.3* from a user group.

[2] The development tool *ResEdit* may be obtained from your Apple dealer, from a software developer, or from a user group

[3] This tool is often available from the same sources as you can obtain the resource editor *ResEdit* (see above)

Problems with the linker: Linking stand-alone applications may not be possible because the linker cannot find all modules he needs. This may happen even if the same program could be run successfully, because contrary to the linking-loader the linker may have troubles to find prelinked modules. This is often the case with the file *SimMaster.OBM* which contains almost the whole Dialog Machine and all ModelWorks object files. The search strategy of the linker is the reverse from that during the dynamic linking-loading applied by the MacMETH shell. Fortunately there is an easy work-around to any "file not found" problems during linking for modules already prelinked in *SimMaster.OBM*: Simply add the imports from module *SimMaster* at the end of all the imports in the model definition program, e.g.like this:

```
FROM ...
FROM SimBase IMPORT ...
FROM SimMaster IMPORT RunSimMaster;
```

Recompile the model and link the application as described above.

Should you encounter any new run-time problems with the resulting application, which were never visible while running the unlinked program, check the contents of the resource fork with the resource editor. The following resources should be present:

TYPE	name (not always present)	IDs
ALRT	"DM error alert proc/module"	1003
	"DM simple error alert"	1004
CNTL		3
CODE		0, 1, 3
DITL	"ErrorAlert "Dialog Machine""	1003, 1004
		314, 6000, 313, 410, 310, 311, 312
DLOG	"Prog. Stat. Big"	304
	"Message"	6000
	"Logo-Date"	303
	"About MacMETH ..."	400
	"Modula-2 Error"	300
	"Loader Status"	301
	"Program Status"	302
ICON		240, 401
PICT	"mvButtAct"	803
	"mButtAct"	800
	"svButtAct"	801
	"pButtAct"	802
	"simpScrAct"	804
	"aboutResource 2.0"	29800
STR	"ModelWorks preferences"	7418

Any resource listed above but missing in the application will result in an application not functioning properly. However, additional resources should cause no harm.

D How to Work With ModelWorks on IBM PCs

Written by Daniel Keller, Project Centre IDA, ETHZ, 26. April 1990

D.1 INSTALLATION

For the following description of the installation procedure was assumed that you have obtained a full ModelWorks software kit from the Project Centre IDA of the Swiss Federal Institute of Technology[1]

D.1.1 Preparing installation

The ModelWorks software installation kit consists of:

1. The **GEM Desktop** kit; six 360K (5 1/4 in.) disks or three 720K (3 1/2 in.) disks plus two booklets. GEM is the graphical user interface which provides overlapping windows, mouse and menu controls, dialog boxes, etc. You have purchased a license to install GEM on one computer.

2. The **Dialog Machine** kit; four 360K disks (or two 720K disks) plus documentation. The Dialog Machine is a set of subroutines which allow to write programs using a mouse, menus, and windows, etc. in a machine-independent way. The resulting programs can be compiled and run practically without change on both Apple Macintoshes and MS DOS PCs.

   The Dialog Machine kit also contains a licensed version 1.17 of the JPI TopSpeed Modula-2 compiler plus its documentation. You have the right to install the TopSpeed compiler on one computer.

3. The **ModelWorks** kit (optional); two 360K disks (or one 720K disk) plus documentation. ModelWorks is a simulation environment that uses the dialog machine for programming

As a first thing you should check the amount of free main memory and disk space on your computer. At the DOS prompt type CHKDSK (or use MAPMEM or Norton SI). You should have at least 2 MB of disk space and significantly more than 500K of free main memory for ModelWorks, a minimum of about 350K for the Dialog Machine alone. If you do not have enough room clean up the disk and remove unneeded drivers or TSRs.

Before you start with the installation of GEM, please have the following technical specifications ready:

- the type of monitor you are using

- the type of mouse you are using and to which serial port it is connected (if it is not a bus mouse)

- the type of printer you are using and to which port it is connected

[1] Order ModelWorks PC V1.1/PC from the following address: Projekt-Zentrum IDA, re ModelWorks PC, Swiss Federal Institute of Technology ETHZ, ETH-Zentrum, CH-8092 Zürich, Switzerland. Phone (01) 256 5440.

D.1.2 Installation of GEM Desktop

First begin with the installation of GEM. Start your machine and when it is ready, put the GEM Master Disk into drive A and type

```
A:
```

and press the <ENTER> key. Now type

```
GEMSETUP
```

and press <ENTER> again. The program GEMSETUP will ask you a few questions about your system and will then copy some files to your hard disk. Just follow the instructions given in the dialog.

IMPORTANT: The Dialog Machine and ModelWorks in their DOS/PC version do not use colors. Even if you do have a color monitor, you should configure GEM as a monochrome system. When you make the selection of monitors in the GEMSETUP dialog you can select different color options for the same color monitor, e.g. for an EGA monitor you have the options "EGA 16 colors" or "EGA Monochrome". Always choose the monochrome option to get the desired configuration. Although the software might run under color GEM, you will encounter memory/space problems, and draw/restore of screens will be noticeably slower.

To test the installation of GEM you can copy the files MAKEPIC.APP and WELCOME.IMG from the Dialog Machine disk 2 onto the hard disk. Then start GEM (type GEM at the DOS prompt) and start MAKEPIC.APP by double-clicking its icon. You can read and display the file WELCOME.IMG with the command “GEM-Bild einlesen...”.

NOTE: GEM uses its own mouse drivers. You may encounter problems with the mouse movement if any other software using the mouse is installed on your system. In case of problems check that no other mouse software has its driver installed (see the AUTOEXEC.BAT file).

D.1.3 Installation of the *Dialog Machine*

Copy the whole directory TOPSPEED onto your hard disk (use either GEM or the DOS XCOPY/S command). If you you have the 360K disks you must copy the rest of the TopSpeed files (from disk 2 of 4) manually into the directory C:\TOPSPEED. Thus everything which is in the directories A:\TOPSPEED on both 360K disks goes into one directory C:\TOPSPEED on your hard disk.

Copy the whole directory DM (including its sub-directories) onto your hard disk. If you have the 360K disks you must copy the rest of the \DM\OBJ files (from disk 4 of 4) manually into the directory C:\DM\OBJ (analogous to the TopSpeed files above).

Now edit the AUTOEXEC.BAT file on your hard disk. The TopSpeed directory must be included in the PATH statement (this line in the file should look something like PATH=C:\DOS;C:\MOUSE;C:\TOPSPEED;C:\ depending on your system usage). After having edited the AUTOEXEC.BAT file you must restart the computer.

To test the installation of the Dialog Machine we will compile and run a little program. Dialog Machine programs must be edited, compiled, and linked with JPI TopSpeed Modula-2 under DOS, but the finished programs run under GEM.

If you are within GEM, exit. At the DOS prompt type CD \DM\EXAMPLES to get to the directory where the test program is. Then type M2 to start the TopSpeed compiler. Before compiling the file I would strongly recommend to set the compiler option (shortcut to get to the compiler options: ALT-O, C) “Runtime checks default” to ON (it's like driving without a seat belt otherwise). Options must only be set once per directory; the compiler keeps a list of your preferences in the file M2.SES which is read automatically at each start of a session.

Load (F3) the file FIRST.MOD and compile it (ALT-C). Then link it (ALT-L). If this was all successful, exit the TopSpeed environment (ALT-X) and rename the file FIRST.EXE to FIRST.APP (GEM recognizes a real GEM application by the extension.APP). Now type GEM and start the program FIRST.APP.

If you had problems compiling or linking, check the PATH statement (type PATH at the DOS prompt) and make sure that the TopSpeed directoy is included in your path. If you have named the directories other than \TOPSPEED and \DM you must edit the file M2.RED in the compiler directory to reflect the different names. Also make sure that the DM directory has been copied completely, including the subdirectories \DM\DEF, \DM\OBJ, and \DM\EXAMPLES. If you have the 360K disks, you might not have copied the extra files from disks 2 and 4 into the appropriate places.

D.1.4 Installation of ModelWorks

Copy the whole directory MW onto your hard disk. If you you have the 360K disks you must copy the rest of the ModelWorks files (from disk 2 of 2) manually into the directory C:\MW. Copy the file M2.RED into the compiler directory \TOPSPEED.

To test ModelWorks, go to the directory \MW\SAMPLES, start the compiler (don`t forget to set the compiler option “Runtime checks...” to ON) and use the Make facility (ALT-M) to create the LOGISTIC program. Exit and rename LOGISTIC.EXE to LOGISTIC.APP, run GEM and see how it runs. Once within LOGISTIC, check the free memory status by calling “System Info” from the leftmost menu (the one with the “*”).

For further information about GEM or the compiler consult the manuals. For more information about the Dialog Machine see this appendix the section below *How to work with the Dialog Machine*.

D.2 How to Develop Models

Modeling with ModelWorks PC version (V1.1/PC) is done by developing Modula-2 model definition programs using the JPI TopSpeed Modula-2. The sequence of steps to follow are shown in Fig. 23 in part II *Theory*, *The model development cycle*. Once all installations as described above have been made, the model development cycle is exactly the same as that for any other Modula-2 program. Therefore, please consult the instructions as given in the JPI TopSpeed Modula-2 documentation.

Caution: Do not invoke the TopSpeed linker from the DOS command line with M2/L, this will cause linkage errors. However, it works correctly when you start the linker from within the editor (with ALT-L or ALT-M).

E How to Work With the Dialog Machine

ModelWorks has been built as a *Dialog Machine* program (s.a.ModelWorks module structure Fig. 25 part II *Theory*). This allows to use the *Dialog Machine* directly while programming models in two ways:

Either the model developer uses any of the *Dialog Machine* objects, e.g. an entry form to edit values of some variables, or an additional window to display simulation results in a fashion not provided by ModelWorks, or to install an additional menu, without activating the Dialog Machine itself. E.g. the installation of an extra menu with its own customized menu commands can be easily made in the procedure passed as the actual parameter of the procedure *SimMaster.RunSimMaster*. Any object needed from the *Dialog Machine* can be imported and used in the usual way one writes *Dialog Machine* programs. This method is easy, straight-forward, and should cause no problems to any programmer developing models. For examples see also the sample models, in particular *Lorenz.MOD* and the reasearch sample models (*Markov.MOD* and *LBM.MOD*).

The other method, however only available in the Macintosh versions, is to call a full *Dialog Machine* program as a subprogram. This will activate the *Dialog Machine* a second time, resulting in a multilevel *Dialog Machine* program, which imposes certain restrictions on the programming. In particular one should note that any object, e.g. an allocated portion of the heap space, does belong only to a certain program level. This implies that such an object will only be able to exist as long as the level exists. In particular the *Dialog Machine* as well as MacMETH will automatically remove objects upon leaving a program level. The programmer should make sure that this does not lead to any inconsistencies, e.g. pointer variables from a low program level pointing to a memory block no longer existing. Apart from that, this method should work as well as the first one, although it is likely that a full *Dialog Machine* program installs too many menus, so that the menu bar will not be able to hold all menus (ModelWorks uses already most of the menu bar for its own menus).

For more specific information on how to program with the *Dialog Machine* please refer to the *Dialog Machine* software description and documentation[1].

F Bug Report Form

If you encounter an error in ModelWorks please use a copy of the following bug report form, fill it in, and mail it to the address listed at the bottom.

See next page

[1] Order the Dialog Machine from the following address: Projekt-Zentrum IDA, re Dialog Machine, Swiss Federal Institute of Technology ETHZ, ETH-Zentrum, CH-8092 Zürich, Switzerland

Eidgenössische
Technische Hochschule
Zürich

Ecole polytechnique fédérale de Zürich
Politecnico federale di Zurigo
Swiss Federal Institute of Technology Zurich

Fachgruppe Systemökologie / Systems Ecology Group

Bug Report Form

Use a copy of this form to report ONE software problem or documentation error; please use additional forms to report multiple problems. Thanks!

Your Name____

Your Address____

City, State_______________________ Country___________________

Your Phone_______________________ Date______________________

Name of Product:
__________________________ Version:___________ Date of Product______

Error Category (check where appropriate)

( )Software Error ( )Documentation Error

( )Software Enhancement (use reverse side) ( )Other, please specify_____________

Problem Description:

(Please answer/check the applicable questions ***using the space below or the back*** *of this form.)*

Software Error Encountered:

( )Bomb, ID Number_____ ( )System Freeze ( )Recoverable Error ( )Modula-2 Error__________

Error #___ Module Name____________ Memory Address______ ( )Other:____________

1. What circumstances led to the problem or list the last action before the error? ( )Mouse click, Where?_______( )Keyboard strike, Key?___ ( )Menu command, Which?__________
2. Have you a suggestion as to the cause of the problem?______________________
3. Describe any additional details necessary to reproduce the error (Please send a copy of the program together with all necessary files in a condition which produces the error).

Software Description *(Indicate the software used when the software error occurred)***:**

1. Finder Version: ____ ( )Multifinder System Version: ___ File System: ( )HFS or ( )MFS
   MS DOS Version: ____
2. Software used? ( )Switcher ( )MacMETH, Version___ ( )JPI TopSpeed-Modula Version: ___ ( )Dialog Machine Version____ ( )ModelWorks, Version___
3. ( )Other, please list name, version:_______________________________

Hardware Description *(Indicate the hardware used when the software error occurred)***:**

Macintosh: ( )Reflex ( )Plus ( )SE ( )II ( )IIx ( )IIcx ( )SE/30 ( )Portable ( )IIci ( )IIfx

IBM PC or compatible: Model, configuration? ______________________________

Documentation Error Found:

1. Where is the exact location of the error?_____________________________
2. Describe why you believe it is an error:______________________________
3. Do you have any suggestions for the correction? (Use back)

____

Thank you for your report and helping us to correct and improve the software you are using!

(For internal use only: Date Received_________Date Resolved:________ Action Taken:__________
____)

Mail to: Systems Ecology Group, re ModelWorks Bug, ETH-Zentrum, CH-8092 Zürich, Switzerland. Phone (01) 256' 58'93

G Definition Modules

G.1 OPTIONAL CLIENT INTERFACE

G.1.1 *TabFunc*

The listing of this definition module has been omitted, since its exported objects are already fully described in the part *Reference* section *Client interface*.

G.1.2 *SimIntegrate*

```
DEFINITION MODULE SimIntegrate;

   (*******************************************************************

    Module  SimIntegrate     (MW_V2.0)

               Copyright ©1989 by Andreas Fischlin and Swiss
               Federal Institute of Technology Zürich ETHZ

      Version written for:
               'Dialog Machine' V2.0  (User interface)
               MacMETH V2.6+     (1-Pass Modula-2 implementation)

      Purpose Provides means to integrate an autonomous
               differential equation system without any
              monitoring

      Remarks This  module is part of ModelWorks MW_V2.0 an interactive
               Modula-2 modeling and simulation environment.

      Programming

          · Design
              A. Fischlin         26/06/89

          · Implementation
              A. Fischlin         26/06/89

           Swiss Federal Institute of Technology Zurich ETHZ
           Department of Environmental Sciences
           Systems Ecology Group
           ETH-Zentrum
           CH-8092 Zurich
           Switzerland

           Last revision of definition:  26/06/89  af

   *******************************************************************)

  FROM SimBase IMPORT Model;


  PROCEDURE Integrate ( m: Model; from, till: REAL);
    (*
      Integrate the autonomous system of model equations m within
      the interval [from, till] of the independent variable
      simulation time with the current integration method
      associated with model m. The integration will be performed
      for every state variable belonging to model m.  As initial
      values ModelWorks will use the current initial values
      associated with the declared state variables. Either
      stopping the simulation permanently (kill) or encountering
      the termination condition will stop the integration.
    *)

END SimIntegrate.
```

G.1.3 *SimGraphUtils*

For a typical usage of this module see the sample model *Lorenz.MOD*.

```
DEFINITION MODULE SimGraphUtils;

  (*****************************************************************

    Module  SimGraphUtils     (MW_V2.0)

              Copyright ©1989 by Olivier Roth and Swiss
              Federal Institute of Technology Zürich ETHZ

      Version written for:
              "Dialog Machine" DM_V2.0  (User interface)
              MacMETH_V2.6+     (1-Pass Modula-2 implementation)
              ModelWorks MW_V2.0  (Modeling & Simulation)

      Purpose: provides some utilities to make I/O to the graph window and the
               graph of the modeling and simulation environment "ModelWorks".

      Remarks: most procedures behave similar to those of the module DM2DGraphs
               and may now be combined with many procedures from DMWindowIO.
               The window and its associated graph are objects of the ModelWorks
               environment and should therefore not be removed.

      Programming

          · Programming and Implementation
              O. Roth             12.09.89

          · Implementation
              O. Roth             12.09.89

          Swiss Federal Institute of Technology Zurich ETHZ
          Department of Environmental Sciences
          Systems Ecology Group
          ETH-Zentrum
          CH-8092 Zurich
          Switzerland

          Last revision of definition: 12.09.89  or

  *****************************************************************)

  FROM SimBase    IMPORT Model, Stain, LineStyle;
  FROM DMWindowIO IMPORT Color;


  TYPE
    Curve;

  VAR
    nonexistent : Curve;  (* read only! *)


(* - - - - - - - - - - - - - - - - - - - - - - - - - - -
   Procedure to access the ModelWorks 'Graph' WINDOW:
   - - - - - - - - - - - - - - - - - - - - - - - - - - - *)

  PROCEDURE SelectForOutputGraph;
  (* This procedures brings the ModelWorks 'Graph' window to front
  and makes it the current output window.  This allows subsequently
  calls to almost all of the I/O procedures of the 'Dialog
  Machine' module 'DMWindowIO'.  *)


(* - - - - - - - - - - - - - - - - - - - - - - - - - - -
   Procedures to access the GRAPH in the 'Graph' window:
   - - - - - - - - - - - - - - - - - - - - - - - - - - -  *)

  PROCEDURE DefineCurve( VAR c: Curve;
                          col: Stain;  style: LineStyle;  sym: CHAR );
  (* Every curve has it own plotting style and color.This allows
  for the simultaneous drawing of an arbitary number of curves
  within the ModelWorks graph. sym specifies a character which is
  drawn repeatedly at the data points, they help identifying a
  curve (sym = 0C, no mark is plotted).
  Use this procedure also if you want to alter an allready existing
  curve.  *)
```

```
PROCEDURE RemoveCurve( VAR c: Curve );
  (* This procedure removes a curve definition. This procedure sets c
  to nonexistent. *)


  PROCEDURE DrawLegend( c: Curve;  x, y: INTEGER;  comment: ARRAY OF CHAR );
  (* Draws a portion of curve c with the current attributes at position
  x and y and writes the comment to the right of c. After this procedure
  the pen location is just to the right of the string "comment", so it´s
  possibe to add for example values of parameters by calling DMWindowIO
  procedures WriteReal (etc.) just after this procedure. *)


  PROCEDURE Plot( c: Curve;  newX, newY: REAL );
  (* You can plot (draw a curve) from the last (saved) position to the point
  specified by the new coordinates newX and newY.
  Note:   ModelWorks resets the pen position when clearing the graph.
  Errors: If the point specified by newX and newY lies outside the integer
          (pixel) range DM2DGraphsDone will be set to FALSE. *)


  PROCEDURE Move( c: Curve;  newX, newY: REAL );
  (* moves the pen to postion (x,y). Typically used to draw several curves
  with the same attributes to reset the pen position after having drawn a
  curve.
  Errors: If the point specified by x and y lies outside the integer (pixel)
          range DM2DGraphsDone will be set to FALSE. *)


  PROCEDURE PlotSym( x, y: REAL;  sym: CHAR );
    (* draws the symbol sym at the position (x,y). May be used as an alternate
    method to make scatter grams.
    Errors: If the point specified by x and y lies outside the integer (pixel)
            range DM2DGraphsDone will be set to FALSE. *)


  PROCEDURE PlotCurve( c: Curve; nrOfPoints: CARDINAL; x, y: ARRAY OF REAL );
  (* Plots an entier sequence of nrOfPoints coordinate pairs contained within
  the two vectors x and y. May also be useful to implement an update mechanism.
  Errors: - If the point specified by x and y lies outside the integer (pixel)
            range DM2DGraphsDone will be set to FALSE.
          - If the maximum number of elements of x or y is less than nrOfPoints,
            then only the lower number of elements of either x or y will be
           plotted. *)


  PROCEDURE GraphToWindowPoint( xReal, yReal: REAL;
                               VAR xInt, yInt: INTEGER );
  (* Calculates the pixel coordinates (xInt and yInt) of the graph's
  window (see WindowIO) from the specified graph coordinates
  (xReal and yReal). Note that the vertical axis of the ModelWorks
  graph is transformed to yMin = 0.0 and yMax = 1.0.
  Errors: If the point specified by xReal and yReal lies outside the integer
          (pixel) range, DM2DGraphsDone will be set to FALSE and xInt and
          yInt is set to MIN(INTEGER) or MAX(INTEGER) respectively. *)


  PROCEDURE WindowToGraphPoint( xInt, yInt: INTEGER;
                               VAR xReal, yReal: REAL );
  (* Calculates graph coordinates (xReal and yReal) from the
  specified pixel coordinates (xInt and yInt) of the graph's
  window (see WindowIO). Note that the vertical axis of the
  ModelWorks graph is transformed to yMin = 0.0 and yMax = 1.0.
  Errors: If the point specified by xReal and yReal lies outside the integer
          (pixel) range, DM2DGraphsDone will be set to FALSE and xInt and
          yInt is set to MIN(INTEGER) or MAX(INTEGER) respectively. *)


  PROCEDURE TimeIsX() : BOOLEAN;
  (* Returns TRUE if time is the current setting of the x axis, otherwise FALSE *)

  TYPE
    Abscissa = RECORD isMV: POINTER TO REAL; xMin,xMax: REAL END;

  PROCEDURE CurrentAbscissa(VAR a: Abscissa);
  (* Returns a pointer (isMV) to the monitoring variable currently used as
  abscissa and its extremes (xMin~curScaleMin,xMax~curScaleMax). In case that
  time is in use, isMV will point to timeIsIndep *)



(* - - - - - - - - - - - - - - - - - - - - - - - - - -
   Procedures to convert different Color Types:
   - - - - - - - - - - - - - - - - - - - - - - - - - - *)

  PROCEDURE TranslStainToColor( stain: Stain;  VAR color: Color );
  PROCEDURE TranslColorToStain( color: Color;  VAR stain: Stain );
  (* Translates Stain from module SimBase to Color from module
  DMWindowIO and vice versa; exception for TranslStainToColor:
  autoDefCol is translated to black. *)



(* - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
   Display data series (i.e. for validation) all at once:
   - - - - - - - - - - - - - - - - - - - - - - - - - - - - - *)

   (*
   Follow these steps to use the data display feature of that module:
   1. Declare an ordinary monitoring variable with the procedure 'DeclMV'
      as a "master" monitoring variable for data arrays to be
      declared later (see next step). Several properties, i.e. descr,
      ident, unit, (and curve attributes as color, linestyle, symbol)
      will be inheritated by the later associated data arrays. So if the
      monitoring variable's graphing variable is set 'isY' the data are
      selected to be displayed.
   2. Since the data arrays symbol (CHAR), line style (LineSTyle) and
      color (Stain) will be taken from the "master" monitoring variable
      call 'SetCurveAttrForMV' and ev. 'SetDefltCurveAttrForMV'.
   3. Declare the associated data arrays with the "master" monitoring
      variable, the independent monitoring variable, and all the data
      arrays with a call to 'DeclDispData'.
   4. To enable the display mechanism the monitoring variable mvDepVar
      must be isY and mvIndepVar must be isX. If another monitoring
      variable represents the current x axis then nothing can be
      displayed.
   5. ModelWorks will display automatically all declared data in the
      normal graph of the "Graph" window at the specified moment,
      i.e. typically at InitMonitoring, or at TermMonitoring. To
      allow for a general control of the moment of display the
      procedure 'DisplayDataNow' and 'DisplayAllDataNow' are also
      exported.
   Caution:
      - Be sure to follow the steps given above in the correct
        order or no data can be declared and displayed.
      - Do not assign any values to the "master" monitoring variable
        to avoid conflicts with the data declaration.
      - Setting writeInTable or writeOnFile of the "Master" monitoring
        variable is not prohibited but makes no sence, since a
        dummy value {NAN(017)} and not the data series will be displayed.
  *)


  TYPE
    DisplayTime = ( showAtInit, showAtTerm, noAutoShow );


  VAR
    timeIsIndep: REAL;


  PROCEDURE DeclDispData( mDepVar     : Model;  VAR mvDepVar   : REAL;
                          mIndepVar   : Model;  VAR mvIndepVar: REAL;
                          x, v,
                          vLo, vUp    : ARRAY OF REAL;
                          n           : INTEGER;
                          withErrBars: BOOLEAN;
                          dispTime    : DisplayTime      );

  (* In order to display a data series (e.g. validation data) f.ex. before a
  simulation run, the necessary data have to be declared beforehand, i.e.
  normally just at the end of all other ModelWorks objects declarations.
  The variables are as follows (real arrays are called by name for
  efficiency only):
    mDepVar     : model to which belongs the mvDepVar
    mvDepVar    : monitoring variable representing the dependent data array
    mIndepVar   : model to which belongs the mvIndepVar
    mvIndepVar : monitoring variable representing the independent data array,
                 if mvIndepVar is specified
                 "timeIsIndep" (or is not a declared monitoring var), then
                 "time" is assumed to be the independent variable,
    x           : array of independent values,
    v           : array of dependent values,
    vLo         : array of lower e.g. confidence values,
    vUp         : array of upper e.g. confidence values,
    n           : number of given data,
    withErrBars: flag if TRUE error bars will be drawn,
    dispTime    : the time when the data should be displayed,

  Note:
  The curve attributes of the data to display can be set through the
  procedure 'SetCurvAttrForMV' on the monitoring variable 'mvDepVar'
  and the default strategy for curve attributes assignments are the same as
  for ordinary monitoring variables for color and symbol but not for the
  lineStyle:
    the default line style is hidden which means that the connections from
    [x,v]-point to [x,v]-point are not drawn. In that case and if withErrBars
    is set true then the error bars are displayd solidly. All other line styles
    are applied to the connections from point to point as well as to the error
    bars themselves.

  This procedure allows also redeclare such data series, i.e. to associate
  other data to the same mvDepVar and mvIndepVar.
   *)


  PROCEDURE DisplayDataNow( mDepVar : Model;  VAR mvDepVar   : REAL );
  (* This procedure allows to display a series of e.g. validation data
  before a simulation run. The previously declared data are displayed
  in the current graph window under the following conditions:
    + the data have been declared properly and are valid;
    + the associated monitoring variable is selected to be displayed (isY);
    + the declared indepVar is the currently active independent
      monitoring variable (isX);
    + the declared indepVar is either not a monitoring variable (for
      example 'timeIsIndep' what implies that time is meant) and time is
      the selected independent var;
    + the data fall into the declared scaling range;
   *)


  PROCEDURE DisplayAllDataNow;
  (* Displays all declared datasets at the specified moments. The same conditions
  apply as for 'DisplayDataNow'.
   *)


  PROCEDURE RemoveDispData( mDepVar : Model;  VAR mvDepVar   : REAL );
  (* This procedure allows to free the memory from the declared data
  to display.
   *)


END SimGraphUtils.
```

G.2 AUXILIARY LIBRARY

G.2.1 *ReadData*

For a typical usage of this module see the research sample model *LBM*.

```
DEFINITION MODULE ReadData;

   (******************************************************************

    Module  ReadData     ( Version 1.0 )

               Copyright ©1989 by Andreas Fischlin and CELTIA,
               Swiss Federal Institute of Technology Zürich ETHZ

               Version for 'Dialog Machine' V2.0 and MacMETH V2.6+
               1-Pass Modula-2 implementation

       Purpose Export of several utilities to read and test data
               while reading from a file with data in columnar form.

      Programming

          · Design
              A. Fischlin            ( 12 Feb 89 )

          · Implementation
              A. Fischlin            ( 12 Feb 89 )
              T. Nemecek             ( 9 Sep 89 )
              O. Roth                ( 23 Nov 89 )

           Swiss Federal Institute of Technology Zurich
          Systems Ecology Group
          ETH-Zentrum
          CH-8092 Zurich
          Switzerland

          Last revision:  23 Nov 89    or

  *****************************************************************)
(* Import list for this module:
  FROM ReadData IMPORT
       negLogDelta, SkipGapOrComment, ReadCharsUnlessAComment,
       SetMissingValCode, GetMissingValCode, SetMissingReal, GetMissingReal,
       SetMissingInt, GetMissingInt, dataF, OpenADataFile, OpenDataFile,
       ReReadDataFile, CloseDataFile, SkipHeaderLine, ReadHeaderLine, ReadLn,
       GetChars, GetStr, GetInt, GetReal, SetEOSCode, GetEOSCode,
       FindSegment, SkipToNextSegment, AtEOL, AtEOS, AtEOF, TestEOF, Relation,
       Compare2Strings;
*)


  FROM DMStrings IMPORT String;
  FROM DMFiles   IMPORT TextFile;


  CONST
    negLogDelta = 0.01; (*offset to plot log scale if values <= 0*)



  (* File handling: *)
  VAR dataF: TextFile;

  PROCEDURE OpenADataFile( VAR fn: ARRAY OF CHAR;  VAR ok: BOOLEAN );
  (* opens a file using the standard open file dialog *)

  PROCEDURE OpenDataFile ( VAR fn: ARRAY OF CHAR;  VAR ok: BOOLEAN );
  (* opens a file specified by fn automatically, and calls OpenADataFile
   * if fn couldn't be found *)

  PROCEDURE ReReadDataFile;

  PROCEDURE CloseDataFile;


  (* Reading and number testing *)

  PROCEDURE SkipGapOrComment;
  (*  skips all characters <= " " and all text enclosed in comment
   *  brackets as used in Modula-2, i.e. "(* ..... *)"
   *  This procedure is used in this module. *)

  PROCEDURE ReadCharsUnlessAComment( VAR string: ARRAY OF CHAR );
  (* reads a string beginning from the current position until
   *  a character <= " " or a comment is encountered. *)

  (* Missing values: *)

  (* default missingValCode = "N" *)
  PROCEDURE SetMissingValCode( missingValCode     : CHAR );
  PROCEDURE GetMissingValCode( VAR missingValCode: CHAR );

  (* default missingReal = 0.0 *)
  PROCEDURE SetMissingReal( missingReal     : REAL );
  PROCEDURE GetMissingReal( VAR missingReal: REAL );

  (* default missingInt = 0 *)
  PROCEDURE SetMissingInt( missingInt     : INTEGER );
  PROCEDURE GetMissingInt( VAR missingInt: INTEGER );


  PROCEDURE SkipHeaderLine;

  PROCEDURE ReadHeaderLine( VAR labels: ARRAY OF String;
                            VAR nrVars: INTEGER );
  (* IMPORTANT NOTE: labels must be initialized to NIL before first use! *)

  PROCEDURE ReadLn  ( VAR txt: ARRAY OF CHAR );

  PROCEDURE GetChars( VAR str: ARRAY OF CHAR );

  PROCEDURE GetStr  ( VAR str: String );


  (*  In the following procedures the two first parameters desc and
   *  loc are only needed for the display of error messages and help
   *  the user to identify an erronous location within the data file:
   *   - desc a string describing the kind of data to be read, e.g.
   *             population density or number of individuals
   *   - loc      a location number indicating where the error has
```

```
    *               been found, e.g. a line number
    *)

   PROCEDURE GetInt ( desc : ARRAY OF CHAR;  loc: INTEGER;
                      VAR x: INTEGER;   min, max: INTEGER );

   PROCEDURE GetReal( desc : ARRAY OF CHAR; loc:  INTEGER;
                      VAR x: REAL;      min, max: REAL    );


   (* Working with data segments (EOS means End Of Segment): *)

   PROCEDURE SetEOSCode( eosCode     : CHAR );
   PROCEDURE GetEOSCode( VAR eosCode: CHAR );
   PROCEDURE FindSegment( segNr: CARDINAL; VAR found: BOOLEAN );
   PROCEDURE SkipToNextSegment( VAR done: BOOLEAN );


   (* Testing: *)

   PROCEDURE AtEOL(): BOOLEAN;
   PROCEDURE AtEOS(): BOOLEAN;
   PROCEDURE AtEOF(): BOOLEAN;
   PROCEDURE TestEOF; (* use only where you don't yet expect EOF (shows alert) *)

   TYPE Relation = ( smaller, equal, greater );

   PROCEDURE Compare2Strings( a, b: ARRAY OF CHAR ): Relation;


END ReadData.
```

G.2.2 *JulianDays*

```
DEFINITION MODULE JulianDays;

   (*******************************************************************

     Module  JulianDays     (Version 1.0)

               Copyright ©1989 by Andreas Fischlin and Swiss
               Federal Institute of Technology Zürich ETHZ

       Version written for:
               'Dialog Machine' V2.0  (User interface)
               MacMETH V2.6+     (1-Pass Modula-2 implementation)
               ModelWorks V2.0  (Modeling & Simulation)

       Purpose Translates back and forth dates into a number of
               days (Julian days) in order to allow the computing
              with dates.

       Remark  This implementation is based on the Gregorian
               calendar, which is valid after 15.Oct.1582. Note that
               this date followed immediately after 4.Oct.1582 to
               correct for accumulated errors in the Julian calendar
               introduced by Julius Cäsar "ab urbe condiata", the
               foundation of Rome, i.e. 753 BC (Gregorian calendar
               correction by Pope Gregor XIII). The Gregorian
               calendar will need no corrections for 3333
              years.

               Note there is also the so-called Julian Period, which
               is used in astronomy as proposed by Joseph Justus
               Scaliger (1581): First Julian Date (J.D.) is middle
               noon, 1. Jan.4713 BC.  The Julian time is calculated
               in days, and is a real defining hours, minutes plus
               seconds. Note that in this method a day starts at
               noon of standard world time or Greenwich time. There
               is a modified Julian Date (M.J.D.) in use today (much
               used in space travel) which starts at 17.Nov.1858
              00h00'00" ~24 00 000.5 J.D.

       Programming

           · Design
              A. Fischlin         24/09/89

           · Implementation
              A. Fischlin         24/09/89

          Swiss Federal Institute of Technology Zurich ETHZ
           Department of Environmental Sciences
           Systems Ecology Group
           ETH-Zentrum
           CH-8092 Zurich
           Switzerland

           Last revision of definition:  24/09/89  af

   ******************************************************************)

  CONST
     Jan = 1; Feb = 2; Mar = 3; Apr = 4; Mai = 5; Jun = 6;
     Jul = 7; Aug = 8; Sep = 9; Oct = 10; Nov = 11; Dec = 12;

     Sun = 1; Mon = 2; Tue = 3; Wed = 4; Thur = 5; Fri = 6; Sat = 7;


  PROCEDURE DateToJulDay(day,month,year: INTEGER): LONGINT;
  PROCEDURE JulDayToDate(julday: LONGINT; VAR day,month,year,weekday: INTEGER);
  (*
     Convert between a julian day and an ordinary calendar date.
     (Note: Only valid for dates between 1.Jan.1949 and 31.Dec.2036).
  *)
  PROCEDURE LeapYear(yr: INTEGER): BOOLEAN;

  PROCEDURE SetCalendarRange(firstYear,lastYear,firstSunday: INTEGER);
     (*
       This procedure allows to set the calendar range for which the
       algorithms of this module shall work.  They work correctly
       from the date 15.Oct.1582 onwards for the next 3333 years and
       given the following restrictions are satisfied:  The first
       year must be an year following immediately a leap year.  The
       day of the first Sunday in January in the first year
       (firstSunday) must be specified, otherwise weekdays won't be
       computed correctly. If faulty values are specified
       this routine will lead to an error condition.

       The default range is firstYear = 1949, lastYear = 5282,
       firstSunday = 2, since the 2nd January 1949 is a
       Sunday. (Other possibilities:  Sunday, 6.Jan.1805).

       Note that calling this procedure may be useful in order to
       use Julian days of type INTEGER instead of LONGINT. Then the
       calendar routines can cover fully 137 years without causing
       an overflow when assigning the LONGINT result of procedure
       DateToJulDay to an INTEGER variable.
     *)

END JulianDays.
```

G.2.3 *DateAndTime*

The module *DateAndTime* is only present in the Macintosh versions. It allows to access the clock which is built into any Macintosh™ computer. In the context of simulations it is typically used in conjunction with module *WriteDatTim* (see below) to record data and time at the begin and end of a long, several hours lasting structured simulation (see sample model *Markov.MOD* for such a use). Hence it is only available for the ModelWorks Macintosh versions. ModelWorks uses this module too and the compiled implementation *DateAndTime.OBM* is linked into file *SimMaster.OBM*.

```
DEFINITION MODULE DateAndTime;  (*A.F., 3/7/89*)

  CONST
    Jan = 1; Feb = 2; Mar = 3; Apr = 4; Mai = 5; Jun = 6;
    Jul = 7; Aug = 8; Sep = 9; Oct = 10; Nov = 11; Dec = 12;
    Sun = 1; Mon = 2; Tue = 3; Wed = 4; Thur = 5; Fri = 6; Sat = 7;

  TYPE
    Months = INTEGER;
    WeekDays = INTEGER;
    DateAndTimeRec =
        RECORD
          year: INTEGER;     (* 1904,1905,...2040 *)
          month: Months;
          day,               (* 1,...31 *)
          hour,              (* 0,...,23 *)
          minute,            (* 0,...,59 *)
          second: INTEGER;   (* 0,...,59 *)
          dayOfWeek: WeekDays;
```

```
      END;

   PROCEDURE SetDateAndTime(d: DateAndTimeRec);
   PROCEDURE GetDateAndTime(VAR d: DateAndTimeRec);
   PROCEDURE DateToSeconds(date: DateAndTimeRec; VAR s: LONGINT);
   PROCEDURE SecondsToDate(s: LONGINT; VAR d: DateAndTimeRec);
   (* s is the number of seconds passed since 1st Jan 1904 *)

   (* All date operations are only valid within [1st January 1904 till
   31st December 2040 *)

END DateAndTime.
```

G.2.4 *WriteDatTim*

```
DEFINITION MODULE WriteDatTim;

   (*****************************************************************

     Module    WriteDatTim     (Version 1.0)

               Copyright ©1988 by Andreas Fischlin and CELTIA,
               Swiss Federal Institute of Technology Zürich ETHZ

               Version for MacMETH V2.4
               1-Pass Modula-2 implementation

       Purpose Writing of date and time

       Uses    DateAndTime

       Programming

           • Design/Implementation
              A. Fischlin             (16/Mai/88)

           Swiss Federal Institute of Technology Zurich
           Project Centre IDA
           Pilot Project CELTIA
           [Computer-aided Explorative Learning and Teaching
           with Interactive Animated Simulation]
           ETH-Zentrum
           CH-8092 Zurich
           Switzerland

           Last revision:  16 Mai 88    (A.F.)

   *****************************************************************)

   FROM DateAndTime IMPORT DateAndTimeRec;

   TYPE
     WriteProc = PROCEDURE (CHAR);
     DateFormat = (  brief,       (* only numbers: e.g. 31/05/88 *)
                     letMonth,    (* month in letters: e.g. 31/Mai/1988 *)
                     full         (* full in letters: e.g. 31st Mai 1988 *)
                  );
     TimeFormat = (  brief24h,        (* 24 hour format brief: e.g. 23:15 *)
                     brief24hSecs,    (* 24 hour brief & secs: e.g. 23:15:02 *)
                     let24hSecs,  (* hour in letters: e.g. 23h 15' 02" *)
                     full24hSecs,     (* full in letters: e.g. 23 hours
                                      15 minutes 02 seconds*)
                     brief12h         (* 24 hour format brief: e.g. 11:15 pm *)
                  );

   (* the following procedures write information in English only *)
   PROCEDURE WriteDate(d: DateAndTimeRec; w: WriteProc; df: DateFormat);
   PROCEDURE WriteTime(d: DateAndTimeRec; w: WriteProc; tf: TimeFormat);

END WriteDatTim.
```

G.2.5 *RandGen*

For a typical usage of this module see the research sample model *Markov.MOD*.

```
DEFINITION MODULE RandGen;

   (******************************************************************

      Module     RandGen      (Version 1.0)

                 Copyright ©1988 by Andreas Fischlin and Systems
                 Ecology Group ETHZ, Swiss Federal Institute of
                 Technology Zürich ETHZ

                 Version for 'Dialog Machine' V2.0 and MacMETH V2.6+
                 1-Pass Modula-2 implementation

       Purpose   Basic pseudo-random number generator producing
                 uniformly distributed variates within interval (0,1).
                 The generator is based on a combination of three
                 multiplicative linear congruential random number
                 generators.

      Remarks    The generator is highly portable and produces
                 very-long-cycle random-number sequences.  They
                 exceed the usual period length of MAX(INTEGER)
                 given by the machine dependent word length.  Thus
                 the generator produces satisfactory results even on
                 a personal computer with a small word length (e.g.
                 16-Bit machines) and it is efficient, since it does
                 not require double precision arithmetics.  On
                 32-Bit machines like IBM main-frames or the Apple®
                 Macintosh™ PC this means that the slow 64-Bit
                 multiplication and division can be
                 avoided.

                 The cycle length of the generator is estimated to
                 be > 2.78 E13 so that the sequence will not repeat
                 for over 220 years in case that 1000 variates were
                 calculated per second (Wichmann & Hill, 1987)

      References:
                 Wichmann, B.A. & Hill, I.D., 1982.  An efficient and
                    portable pseudo-random number generator.  Algorithm
                    AS 183. Applied Statistics, 31(2): 188-190.

                 Wichmann, B. & Hill, D., 1987.  Building a random-number
                    generator.  A Pascal routine for very-long-cycle
                    random-number sequences. Byte 1987(March):
                   127-28

      Programming

          · Design
              A. Fischlin               (21 Dez 88)

          · Implementation
              A.Fischlin/O.Roth         (21 Dez 88)

           Swiss Federal Institute of Technology Zurich
          Systems Ecology
           Department of Environmental Sciences
          ETH-Zentrum
          CH-8092 Zurich
          Switzerland

          Last revision:  31 Jan 89    (A.F.)

   ******************************************************************)

  PROCEDURE SetSeeds(z0,z1,z2: INTEGER);
    (*defaults:  z0 = 1, z1 = 10000, z2 = 3000 *)
  PROCEDURE GetSeeds(VAR z0,z1,z2: INTEGER);
  PROCEDURE Randomize;
    (*set seeds using seed values depending on a particular, unique
    and non repeatable event in real time, e.g. date and time of
    the clock.  Implies a call to SetSeeds*)
  PROCEDURE ResetSeeds;
    (*reset seeds to values defined by last call to SetSeeds*)


  PROCEDURE U(): REAL;
    (*returns within (0,1) uniformly distributed variates*)

    (*
       Based on a combination of three multiplicative linear
       congruential random number generators of the form   z(k+1) =
       A*z(k) MOD M   with a prime modulus and a primitive root
       multiplier (=> individual generator full length period). The
       multipliers A are: 171, 172, and 170; the modulus' M are:
```

```
      30269, 30307, and 30323.
    *)

END RandGen.
```

G.2.6 *RandNormal*

```
DEFINITION MODULE RandNormal;

   (*****************************************************************

    Module  RandNormal     (Version 1.0)

               Copyright ©1987 by Andreas Fischlin and CELTIA,
               Swiss Federal Institute of Technology Zürich ETHZ

               Version for MacMETH V2.6+ 1-Pass Modula-2
               implementation

       Purpose Computation of normally distributed variates

      References
               Bell, J.R. 1968.  Normal random deviates.  Algorithm
                 334.  Colected Algorithms from CACM (Communications
                 of the Association for Computing Machinery):  334-P 1-R1

               Box, G. & Muller, M. 1958.  A note on the generation of
                 normal deviates.  Ann. Math. Stat. 28: 610.

               Von Neumann, J. 1959.  Various techniques used in
                 connection with random digits.  In: Nat. Bur.
                 Standards Appl. Math. Ser. 12, US GTovt. Printing Off.,
                 Washington, D.C., p. 36.

       Remark  This implementation allows to be completely independent
               from any particular random number generator (see InstallU).
               NOTE: The module won't crash if InstallU is never called,
               but it will not be able to produce correct results!

       Imported modules:  System, MathLib

      Programming

          · Design
              A. Fischlin             (17 Dec 87)

          · Implementation
              A. Fischlin             (17 Dec 87)

          Swiss Federal Institute of Technology Zurich
          Project Centre IDA
          Pilot Project CELTIA
          [Computer-aided Explorative Learning and Teaching
          with Interactive Animated Simulation]
          ETH-Zentrum
          CH-8092 Zurich
          Switzerland

          Last revision:  24/Mar/88    (A.F.)

   *****************************************************************)

  TYPE
    URandGen = PROCEDURE(): REAL;

  PROCEDURE InstallU(U: URandGen);
    (*
      Installs procedure U which returns variates
      from a random variable uniformally distributed within
      interval [0..1).  (NOTE:  Always call
      this procedure before calling N).
    *)

  PROCEDURE SetPars(mu,stdDev: REAL);
  PROCEDURE GetPars(VAR mu,stdDev: REAL);
    (*
      Set or get the current parameters μ (mean) and the
      stdDev (standard deviation = SQRT(variance)) for
      the normally distributed random variable for which
      procedure N returns variates.
    *)

  PROCEDURE N(): REAL;
    (*
      Returns a variate from a normally distributed random
      variable with mean mu and the standard deviation stdDev
      as currently set by procedure SetPars. The default
      values for μ (mu) respectively stdDev are 0 resp. 1.0.
      Method: The variates are computed by the method
      Box and Muller and the Von Neumann rejection technique.
    *)

  PROCEDURE ResetN;
    (*
      The used method computes each second time two values, which
      are returned by N upon the next call.  In order to produce
      completely defined results, for instance after setting a
      new seed value in the basic random number sequence used by
      U, call this procedure in order to reset the internal modes.
    *)

END RandNormal.
```

H Sample Models

The following sample models have all been implemented and tested with the ModelWorks Macintosh versions V2.0, V2.0/Reflex, V2.0/II and some with the PC version 2.0/PC. They are distributed in source form together with some additional sample models not listed here on the Macintosh versions distribution diskette *ModelWorks 2/2* in the folder *Sample Models* or on the PC version distribution diskettes in directory *\MW\SAMPLES*. Depending on the actual ModelWorks version you are using, minor changes to the listings given here might be necessary. This is in particular the case for the PC version and the following sample models: *Markov.MOD* (DM/PC 1.5 provides a random number generator in *DMMathLib*).

H.1 The Sample Model - Logistic Grass Growth *Logistic.MOD*

The following program code contains the sample model described in the manual Part I *Tutorial* in the section *Getting started with the simulation environment* especially the subsection *Simulating the sample model*:

```
MODULE Logistic; (*mu, 9.4.88. Version used in ModelWorks manual.*)

  (*************************)
  (* Logistic grass growth *)
  (*************************)

  FROM SimBase IMPORT
    Model, IntegrationMethod, DeclM, DeclSV, DeclP, RTCType,
    StashFiling, Tabulation, Graphing, DeclMV, SetSimTime,
    NoInitialize, NoInput, NoOutput, NoTerminate, NoAbout;

  FROM SimMaster IMPORT RunSimMaster;


  VAR
    m: Model;
    grass, grassDot, c1, c2: REAL;

  PROCEDURE Dynamic;
  BEGIN
    grassDot:=  c1*grass - c2*grass*grass;
  END Dynamic;

  PROCEDURE Objects;
  BEGIN
    DeclSV(grass, grassDot,1.0, 0.0, 10000.0,
      "Grass", "G", "g dry weight/m^2");

    DeclMV(grass, 0.0,1000.0, "Grass", "G", "g dry weight/m^2",
      notOnFile, writeInTable, isY);
    DeclMV(grassDot, 0.0,500.0, "Grass derivative", "dG/dt", "g dry weight/m^2/time",
      notOnFile, notInTable, notInGraph);

    DeclP(c1, 0.7, 0.0, 10.0, rtc,
      "c1 (growth rate of grass)",  "c1", "day^-1");
    DeclP(c2, 0.001, 0.0, 1.0, rtc,
      "c2 (self inhibition coefficient of grass)",  "c2", "m^2/g dw/day");
  END Objects;
```

```
   PROCEDURE ModelDefinitions;
   BEGIN
     DeclM(m, Euler, NoInitialize, NoInput, NoOutput, Dynamic,
           NoTerminate, Objects, "Logistic grass growth model",
           "LogGrowth", NoAbout);
     SetSimTime(0.0,30.0);
   END ModelDefinitions;


BEGIN
  RunSimMaster(ModelDefinitions);
END Logistic.
```

H.2 The New Model - *GrassAphids.MOD*

The following program code contains the sample model described in the manual Part I *Tutorial* in the section *Getting started with modeling* especially the subsection *The new model*:

```
MODULE GrassAphids; (*tn, 15.6.90. Version used in ModelWorks manual.*)

   (*************************************************************)
   (* Model of a predator-prey system for aphids feeding on grass, *)
   (* with Lotka-Volterra equations                               *)
   (*************************************************************)

  FROM SimBase     IMPORT  DeclM, IntegrationMethod, DeclSV, StashFiling,
                            Tabulation, Graphing, DeclMV, DeclP, RTCType,
                            Model, SetSimTime, NoInitialize, NoInput, NoOutput,
                           NoTerminate, NoAbout;

  FROM SimMaster   IMPORT  RunSimMaster;


  VAR
    m: Model;
    grass,  grassDot,  c1, c2:              REAL;
    aphids, aphidsDot, c3, c4, c5:          REAL;


  PROCEDURE Dynamic;
  BEGIN
    grassDot  :=  c1*grass - c2*grass*grass - c3*grass*aphids;
    aphidsDot :=  c3*c4*grass*aphids - c5*aphids;
  END Dynamic;

  PROCEDURE ModelObjects;
  BEGIN
    DeclSV(grass,  grassDot, 200.0, 0.0, 10000.0,
      "Grass",  "G", "g dry weight/m^2");
    DeclSV(aphids, aphidsDot,20.0,  0.0, 1000.0,
      "Aphids", "A", "g dry weight/m^2");

    DeclMV(grass, 0.0, 10000.0, "Grass", "G", "g dry weight/m^2",
      notOnFile, writeInTable, isY);
    DeclMV(grassDot, -1000.0,1000.0, "Grass derivative", "dG/dt", "g dry weight/m^2/time",
      notOnFile, notInTable, notInGraph);
    DeclMV(aphids, 0.0, 1500.0,"Aphids", "A","g dry weight/m^2",
      notOnFile, writeInTable, isY);

    DeclP(c1, 0.4, 0.0, 10.0, rtc,
      "c1 (growth rate of grass)",  "c1", "day^-1");
    DeclP(c2, 8.0E-5, 0.0, 1.0, rtc,
      "c2 (self inhibition coefficient of grass)",  "c2", "m^2/g dw/day");
    DeclP(c3, 1.5E-3, 0.0, 1.0, rtc,
      "c3 (coupling parameter)",  "c3", "m^2/g dw/day");
    DeclP(c4, 0.1, 0.0, 10.0, rtc,
      "c4 (ratio of grass net use by aphids)",  "c4", "-");
    DeclP(c5, 0.2, 0.0, 10.0, rtc,
      "c5 (death rate of aphids)",  "c5", "day^-1");
  END ModelObjects;


  PROCEDURE ModelDefinitions;
  BEGIN
    DeclM(m, Heun, NoInitialize, NoInput, NoOutput, Dynamic, NoTerminate,
      ModelObjects, "Aphid-grass model (Lotka-Volterra)", "AG-model", NoAbout);
    SetSimTime(0.0,100.0);
  END ModelDefinitions;
```

```
BEGIN
  RunSimMaster(ModelDefinitions);
END GrassAphids.
```

H.3 Sample Model Using Table Functions *UseTabFunc.MOD*

The following program code contains a sample model demonstrating the use of the table function editor (see also in the manual Part III *Reference* in the section *Client interface* especially the subsection *Declaration of table functions*:

```
MODULE UseTabFunc;

  (*******************************************************************

    ModelWorks model:  UseTabFunc

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             Federal Institute of Technology Zurich ETHZ
             Department of Environmental Sciences
             Systems Ecology Group
             ETH-Zentrum
             CH-8092 Zurich
             Switzerland

      Version written for:
                 'Dialog Machine' V2.0  (User interface)
                 MacMETH V2.6+     (1-Pass Modula-2 implementation)
                 ModelWorks V2.0  (Modeling & Simulation)

      Purpose Demonstrates the use of optional ModelWorks module
                 TabFunc

      References

           deWit, C.T. & Goudriaan, J., 1978.  Simulation of ecological
             processes. Simulation monograhs.  Wageningen, Centre for
             Agricultural Publishing and Documentation.  ISBN
             90-220-0652-2.


           Implementation and Revisions:
           ============================

           Author     Date           Description
           ------     ----           -----------

           af         10/03/89     First implementation (DM 1.0,
                                     MacMETH 2.5.1)

  *******************************************************************)


  FROM SimBase IMPORT
    Model, IntegrationMethod, DeclM,
    DeclSV,
    RTCType, DeclP,
    StashFiling, Tabulation, Graphing, DeclMV,
    CurrentStep, CurrentTime,
    SetDefltGlobSimPars,
    TerminateConditionProcedure, InstallTerminateCondition,
    StashFileName, DeclExperiment,
    NoInitialize, NoInput, NoOutput, NoTerminate, NoAbout;
  FROM SimMaster IMPORT RunSimMaster, SimRun;

  FROM TabFunc IMPORT TabFUNC, DeclTabF, Yie;
  FROM MathLib IMPORT Sin;


  VAR
    m: Model;
    x, xDot,
    temp, tm, ta: REAL;

    RTt: TabFUNC;  (* the table function R(T(t)) *)
```

```
PROCEDURE Dynamic;
  BEGIN
    temp:= tm + ta*Sin(6.2832*CurrentTime()/24.0);
    xDot:= Yie(RTt,temp)*x;     (* interpolates growth rate for any temp *)
  END Dynamic;



  PROCEDURE Objects;
  BEGIN
    DeclSV(x, xDot,1.0, 0.0, MAX(REAL),
      'Bacterial population size', 'x', 'g/l');

    DeclMV(x,0.0,100.0,
      'Population size','x','g/l',
      notOnFile,writeInTable,isY);
    DeclMV(xDot,0.0,100.0,
      'Relative growth rate','xDot','g/l/h',
      notOnFile,writeInTable,isY);
    DeclMV(temp,0.0,100.0,
      'Temperature','temp','°C',
      notOnFile,writeInTable,isY);

    DeclP(tm, 20.0, -10.0, 70.0, rtc,
      'mean temperature',  'tm', '°C');
    DeclP(ta, 10.0, 0.0, 40.0, rtc,
      'amplitude of temperature fluctuations',          'ta', '°C');
  END Objects;


  PROCEDURE ModelDefinitions;
    VAR
      tempVect, grVect: ARRAY [0..7-1] OF REAL;
  BEGIN
    DeclM(m, Euler, NoInitialize, NoInput, NoOutput, Dynamic, NoTerminate, Objects,
      'Bacterial growth varying with temperature temp', 'm', NoAbout);

    tempVect[0]:=   0.0;  grVect[0]:= 0.0;
    tempVect[1]:=   5.0;  grVect[1]:= 0.04;
    tempVect[2]:=  10.0;  grVect[2]:= 0.07;
    tempVect[3]:= 20.0;  grVect[3]:= 0.17;
    tempVect[4]:=  30.0;  grVect[4]:= 0.19;
    tempVect[5]:=  40.0;  grVect[5]:= 0.26;
    tempVect[6]:=  50.0;  grVect[6]:= 0.25;
    DeclTabF(RTt, tempVect, grVect, 7,       TRUE,
       "RTt: growth rate vs. temperature",
       "Temperature", "Growth rate", "°C", "/h",
      0.0, 60.0, 0.0, 1.0);

    SetDefltGlobSimPars(0.0, 48.0, 0.5, 0.0001, 1.0, 1.0);
  END ModelDefinitions;


BEGIN
  RunSimMaster(ModelDefinitions);
END UseTabFunc.
```

H.4 A MIXED CONTINUOUS AND DISCRETE TIME SAMPLE MODEL *COMBINED.MOD*

The following program code contains a sample model demonstrating the mixing of a continuous time submodel with a discrete time submodel. Both models form together a structured model of mixed type (see also in the manual Part II *Theory* in the section *Model formalisms* especially the subsection *Structured models (Coupling of submodels)*:

```
MODULE Combined;

(*********************************************************************)
(*
   Structured model built from a continuous and discrete time submodel
   The continuous time submodel consists of a simple linear differential
   equation whereby its paramater depends on an input which has been
   coupled with the output from the discrete time submodel.  The discrete
   time submodel contains a simple step function.  Every submodel is
   modeled as a local module.

   af   29/Mai/1988
                                                                    *)
(*********************************************************************)
```

```
IMPORT SimMaster;
FROM SimBase     IMPORT  SetSimTime, SetMonInterval;
IMPORT SimBase;
FROM SimMaster   IMPORT  RunSimMaster;



MODULE SubModDisc; (*************************************************)

  FROM SimBase     IMPORT  DeclM, IntegrationMethod,DeclSV, StashFiling,
                           Tabulation, Graphing, DeclMV, DeclP, RTCType,
                           Model, SetSimTime, SetMonInterval,
                           NoInitialize, NoInput, NoTerminate, NoAbout;

  EXPORT DeclSubModDisc, y;

  VAR
    discM: Model;
    step, newStep, a, flip, y: REAL;


  PROCEDURE Dd;
  BEGIN
    newStep:= flip*step;
  END Dd;

  PROCEDURE Od;
  BEGIN
    y:= a*step;
  END Od;


  PROCEDURE ObjectsDisc;
  BEGIN
    DeclSV(step, newStep,1.0, -1.0E3, 1.0E3,
           "Step of discrete time submodel", "Step", "-");

    DeclMV(step, -5.0, 2.0,
           "Step of discrete time submodel",
           "Step", "-", notOnFile, writeInTable, isY);

    DeclP(a, 1.0, -100.0, 100.0, rtc,
          "Amplitude of step function",  "a", "---");

    DeclP(flip, -1.0, -1.0, 1.0, rtc,
          "Factor to reverse sign of step function",  "f", "---");
  END ObjectsDisc;

  PROCEDURE DeclSubModDisc;
  BEGIN
    DeclM(discM, discreteTime, NoInitialize, NoInput, Od, Dd,
          NoTerminate, ObjectsDisc,
          "Discrete time submodel",
          "DiscSubMod", NoAbout);
  END DeclSubModDisc;

END SubModDisc; (****************************************************)




MODULE SubModCont; (*************************************************)

  FROM SimBase     IMPORT  DeclM, IntegrationMethod,DeclSV, StashFiling,
                           Tabulation, Graphing, DeclMV, DeclP, RTCType,
                           Model, SetSimTime, SetMonInterval,
                           NoInitialize, NoOutput, NoTerminate, NoAbout;
  IMPORT y;
  EXPORT DeclSubModCont;

  VAR
    contM: Model;
    x, xDot, r, u: REAL;


  PROCEDURE Ic;
  BEGIN
    u:= y;
  END Ic;

  PROCEDURE Dc;
  BEGIN
    xDot:= r*u*x;
  END Dc;
```

```
    PROCEDURE ObjectsCont;
    BEGIN
      DeclSV(x, xDot,1.0, -1.0E3, 1.0E3,
              "State variable of continuous time submodel", "x", "-");

      DeclMV(x, 0.0, 5.0,
              "State variable of continuous time submodel", "x", "-",
              notOnFile, writeInTable, isY);

      DeclP(r, 1.0, -100.0, 100.0, rtc,
             "Intrinsic rate of change for continous time submodel",
            "r", "time^-1");
    END ObjectsCont;

    PROCEDURE DeclSubModCont;
    BEGIN
      DeclM(contM, Euler, NoInitialize, Ic, NoOutput, Dc,
            NoTerminate, ObjectsCont,
            "Continuous time submodel",
            "ContSubMod", NoAbout);
    END DeclSubModCont;

  END SubModCont; (****************************************************)



  PROCEDURE StructuredModelDef;
  BEGIN
    DeclSubModCont; DeclSubModDisc;
    SetSimTime(0.0,10.0);   SetMonInterval(0.25);
  END StructuredModelDef;


BEGIN
  RunSimMaster(StructuredModelDef);
END Combined.
```

H.5 RESEARCH SAMPLE MODELS

H.5.1 Third order finite Markov chain *Markov.MOD*

The following model definition program *Markov.MOD* demonstrates the typical use of the random number generators in the auxiliary library and serves as an example for stochastic simulations. The program models a finite, 3rd-order Markov chain process. Note that the program also directly accesses frequently the Dialog Machine; for instance it installs the custom menu *Markov*, which allows the simulationist to alter the meaning of the 3 states and to set the coefficients of the Markov matrix in an especially suitable form.

This program also demonstrates the use of the start consistency testing mechanism of ModelWorks (see function procedure *TestConsistency*): The coefficients of any probability vector or of a row of a Markov matrix must add up to the sum 1; otherwise the simulationist has defined an illegal probability vector or Markov matrix. Thus any simulation using a Markov matrix or an initial probability vector not satisfying these conditions would produce meaningless results. The here used start consistency testing mechanism of ModelWorks automatically prevents this.

This program also demonstrates the use of state events. Since the default process contains an absorbing state, further computations beyond the state «all dead», i.e. probability vector [healthy,ill,dead] becomes [0,0,1], are superfluous. The terminate condition testing mechanism of ModelWorks (see function procedure *AllDead*) allows to stop a running simulation anytime this state event is encountered.

As it holds in general for stochastic models, structured simulations are particularly important. The model definition program contains an experiment which asks first the simulationist how many runs the experiment shall encompass, suppresses all stash filing, and then writes the results for further statistical analysis onto a separate data file (default name *Markov.DAT*). The latter serves to reestimate the coefficients of the Markov matrix and can be directly opened by many applications for a subsequent statistical data analysis. For instance *StatView*[1] could successfully be used to enter the simulation results (by choosing menu command *Import*...and selecting file *Markov.DAT*) plus to compute and analyze the estimates.

```
MODULE Markov;

   (******************************************************************

    ModelWorks model:  Markov

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          ETH-Zentrum
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          Switzerland

      Version written for:
               'Dialog Machine'  V2.0  (User interface)
               MacMETH V2.6+     (1-Pass Modula-2 implementation)
               ModelWorks V2.0   (Modeling & Simulation)

      Purpose Simulates a stochastic process defined by a given
               Markov matrix in order to estimate the matrix
               from the statistics collected during the simulations.


         Implementation and Revisions:
         ============================

        Author  Date        Description
        ------  ----        -----------

        af       18/10/89    First implementation (DM 2.0,
                             MacMETH 2.6+, ModelWorks 1.3)
        af       21/10/89    Extended to interactive renaming of states
        af       03/05/90    Refining of experiment for direct import
                             by StatView 512+ statistics program

   ******************************************************************)

  FROM DateAndTime IMPORT GetDateAndTime, DateAndTimeRec;
  FROM WriteDatTim IMPORT DateFormat, TimeFormat, WriteDate, WriteTime;
  FROM SimBase IMPORT
    Model, IntegrationMethod, DeclM,
    DeclSV,
    RTCType, DeclP,
    StashFiling, Tabulation, Graphing, DeclMV,
    CurrentStep, CurrentTime,
    SetSimTime, SetMonInterval, SetIntegrationStep,
    TerminateConditionProcedure, InstallTerminateCondition,
    InstallStartConsistency,
    StashFileName,
    SetMV, GetMV, SetP, SetDefltP, SetDefltMV, GetDefltMV,
    LineStyle, GetCurveAttrForMV, SetCurveAttrForMV, ClearGraph,
    GetDefltCurveAttrForMV, SetDefltCurveAttrForMV, Stain,
    StackWindows, TileWindows,
    SetWindowPlace, SetDefltWindowPlace, MWWindow,
    UseCurWSettingsAsDefault,
    NoInput, NoOutput, NoTerminate, NoAbout;
  FROM SimMaster IMPORT RunSimMaster, SimRun, DeclInitSimSession,
    ExperimentAborted, DeclExperiment;

  FROM SYSTEM IMPORT VAL (*only for inverse of ORD*);
  FROM DMSystem IMPORT MenuBarHeight;
  FROM DMStrings IMPORT Concat, ConcatCh, AssignString;
  FROM DMConversions IMPORT IntToString;
  FROM DMWindowIO IMPORT BackgroundHeight, BackgroundWidth;
  FROM DMMenus IMPORT  Menu, Command, AccessStatus, Marking,
    InstallMenu, InstallCommand, InstallAliasChar,
    Separator, InstallSeparator,
    DisableCommand, EnableCommand, ChangeCommandText,
    InstallQuitCommand;
  FROM RandGen IMPORT U, ResetSeeds, Randomize;
  FROM DMFiles IMPORT TextFile, CreateNewFile, Close, WriteEOL, PutReal,
    Response, WriteChar, WriteChars, PutInteger;
  FROM DMEntryForms IMPORT FormFrame, WriteLabel, DefltUse,
```

[1] StatView 512+™ is an interactive statistics & graphics package from Abacus Concepts, Inc., published by Brainpower, Inc., 24009 Ventura Blvd., Suite 250, Calabasas, CA 91302

```
  CharField, StringField, CardField, IntField, RealField,
  PushButton, RadioButtonID, DefineRadioButtonSet, RadioButton,
  CheckBox, UseEntryForm;


CONST
  firstIndiv = 1; lastIndiv = 100;
TYPE
  Individuals = [firstIndiv..lastIndiv];

TYPE
  State = (one, two, three);
CONST
  firstState = MIN(State); lastState = MAX(State);

VAR
  m: Model;
  x,xDash: ARRAY [firstIndiv..lastIndiv] OF State;
            (* pseudo state vars, i.e. not declared to ModelWorks *)
  p: ARRAY [firstState..lastState],[firstState..lastState] OF REAL;
     (*Markov matrix*)
  pacc: ARRAY [firstState..lastState],[firstState..lastState] OF REAL;
     (*Matrix containing accumulated transition probabilities*)
  initP: ARRAY [firstState..lastState] OF REAL;
     (*Probabilities used to compute initial states*)
  c: ARRAY [firstState..lastState],[firstState..lastState] OF INTEGER;
     (*counting of transitions*)
  n: ARRAY [firstState..lastState] OF INTEGER;
     (*number of transitions starting from a state*)
  f: ARRAY [firstState..lastState],[firstState..lastState] OF REAL;
     (*frequencies of transitions*)
  fs: ARRAY [firstState..lastState] OF REAL;
     (*frequencies of states*)
  randomize: REAL; (* controls seed randomization *)



PROCEDURE PRED(s: State): State;
BEGIN (*PRED*)
  RETURN VAL(State,ORD(s)-1)
END PRED;

PROCEDURE SUCC(s: State): State;
BEGIN (*SUCC*)
  RETURN VAL(State,ORD(s)+1)
END SUCC;

PROCEDURE Initialize;
  VAR l: Individuals; is,js: State; u : REAL;
BEGIN (*Initialize*)
  IF randomize>0.0 THEN Randomize ELSE ResetSeeds END;
  FOR is:= firstState TO lastState DO fs[is] := 0.0 END(*FOR*);
  FOR l:= firstIndiv TO lastIndiv DO
    u := U();
    IF u<=initP[one] THEN
      x[l] := one
    ELSIF u<=(initP[one]+initP[two]) THEN
      x[l] := two
    ELSE
      x[l] := three
    END(*IF*);
    fs[x[l]] := fs[x[l]] + 1.0;
  END(*FOR*);
  FOR is:= firstState TO lastState DO
    FOR js:= firstState TO lastState DO
      c[is,js] := 0;
      f[is,js] := 0.0;
    END(*FOR*);
    n[is] := 0;
  END(*FOR*);
  FOR is:= firstState TO lastState DO
    pacc[is, firstState] := p[is,firstState];
    FOR js:= SUCC(firstState) TO lastState DO
      pacc[is,js] := pacc[is,PRED(js)] + p[is,js];
    END(*FOR*);
  END(*FOR*);
  fs[firstState] := fs[firstState]/FLOAT(lastIndiv-firstIndiv+1);
  FOR is:= SUCC(firstState) TO lastState DO
    fs[is] := fs[PRED(is)] + fs[is]/FLOAT(lastIndiv-firstIndiv+1);
  END(*FOR*);
END Initialize;

PROCEDURE InitSimSess;
  VAR is,js: State; curMin, curMax: REAL;
    curStain: Stain; curStyle: LineStyle; curSym: CHAR;
    curFiling: StashFiling; curTabul: Tabulation; curGraphing: Graphing;
```

```
BEGIN
  FOR is:= firstState TO lastState DO
    FOR js:= firstState TO lastState DO
      IF is<>three THEN
         GetCurveAttrForMV( m, f[is,js], curStain, curStyle, curSym );
         SetCurveAttrForMV( m, f[is,js], gold, spotted, 0C );
      ELSE
        GetMV( m, f[is,js], curMin, curMax,
                curFiling, curTabul, curGraphing);
        SetMV( m, f[is,js], curMin, curMax,
                curFiling, curTabul, notInGraph);
      END(*IF*);
    END(*FOR*);
  END(*FOR*);
  ClearGraph;
END InitSimSess;


PROCEDURE Transition(oldS: State; VAR newS: State);
  VAR u: REAL;
BEGIN
  u := U();
  IF u<=pacc[oldS,one] THEN
    newS := one
  ELSIF u<=pacc[oldS,two] THEN
    newS := two
  ELSE
    newS := three
  END(*IF*);
END Transition;

PROCEDURE Dynamic;
  VAR l: Individuals; is,js: State;
BEGIN
  (* init state frequencies *)
  FOR is:= firstState TO lastState DO fs[is] := 0.0 END;
  (* compute new state vars & compute statistics *)
  FOR l:= firstIndiv TO lastIndiv DO
    Transition(x[l],xDash[l]);
    INC(c[x[l],xDash[l]]); INC(n[x[l]]); fs[x[l]] := fs[x[l]] + 1.0;
  END(*FOR*);
  (* update pseudo state vars *)
  FOR l:= firstIndiv TO lastIndiv DO
    x[l] := xDash[l];
  END(*FOR*);
  FOR is:= firstState TO lastState DO
    FOR js:= firstState TO lastState DO
      IF n[is]<>0 THEN
         f[is,js] := FLOAT(c[is,js])/FLOAT(n[is]);
      ELSE
        f[is,js] := 0.0;
      END(*IF*);
    END(*FOR*);
  END(*FOR*);
  fs[firstState] := fs[firstState]/FLOAT(lastIndiv-firstIndiv+1);
  FOR is:= SUCC(firstState) TO lastState DO
    fs[is] := fs[PRED(is)] + fs[is]/FLOAT(lastIndiv-firstIndiv+1);
  END(*FOR*);
END Dynamic;

PROCEDURE CircaEqual(x,y,eps: REAL): BOOLEAN;
BEGIN (*CircaEqual*)
  RETURN ((x-eps)<=y) AND (y<=(x+eps))
END CircaEqual;

PROCEDURE TestConsistency(): BOOLEAN;
  VAR is,js: State; sum: REAL; sofarOk: BOOLEAN;
BEGIN (*TestConsistency*)
  sum := 0.0;
  FOR is:= firstState TO lastState DO
    sum := sum + initP[is];
  END(*FOR*);
  sofarOk := CircaEqual(sum,1.0,1.0E-3);
  FOR is:= firstState TO lastState DO
    sum := 0.0;
    FOR js:= firstState TO lastState DO
      sum := sum + p[is,js];
    END(*FOR*);
    sofarOk := sofarOk AND CircaEqual(sum,1.0,1.0E-3);
  END(*FOR*);
  RETURN sofarOk
END TestConsistency;

PROCEDURE AllDead(): BOOLEAN;
BEGIN
  RETURN CircaEqual(fs[one],0.0,1.0E-3)
```

```
          AND CircaEqual(fs[two]-fs[one],0.0,1.0E-3);
END AllDead;

VAR
  myMenu: Menu; defMarkovCmd: Command;
  nameStateOne, nameStateTwo, nameStateThree: ARRAY [0..40] OF CHAR;

PROCEDURE AssignStatesNames(n1,n2,n3: ARRAY OF CHAR);
  VAR l: Individuals; is,js: State;
  istr, descr,ident: ARRAY [0..40] OF CHAR;
  PROCEDURE StateToString (s: State; VAR str: ARRAY OF CHAR);
  BEGIN (*StateToString*)
    CASE s OF
       one : AssignString(nameStateOne,str);
     | two : AssignString(nameStateTwo,str);
     | three : AssignString(nameStateThree,str);
    END(*CASE*);
  END StateToString;
BEGIN
  AssignString(n1,nameStateOne);
  AssignString(n2,nameStateTwo);
  AssignString(n3,nameStateThree);
  FOR is:= firstState TO lastState DO
    AssignString("Initial prob. of state ",descr);
    StateToString(is,istr); Concat(descr,istr);
    ident := "initP[";
    IntToString(ORD(is)+1,istr,0); Concat(ident,istr);
    ConcatCh(ident,"]");
    SetDefltP(m,initP[is],initP[is],0.0,1.0,
          rtc,descr,ident,"");
  END(*FOR*);
  FOR is:= firstState TO lastState DO
    FOR js:= firstState TO lastState DO
      AssignString("Prob. Transition ",descr);
      StateToString(is,istr); Concat(descr,istr);
      Concat(descr,"–>");
      StateToString(js,istr); Concat(descr,istr);
      ident := "p[";
      IntToString(ORD(is)+1,istr,0); Concat(ident,istr);
      ConcatCh(ident,",");
      IntToString(ORD(js)+1,istr,0); Concat(ident,istr);
      ConcatCh(ident,"]");
      SetDefltP(m,p[is,js],p[is,js],0.0,1.0, rtc, descr,ident,"");
    END(*FOR*);
  END(*FOR*);
  (* declaration of monitorable variables *)
  FOR is:= firstState TO lastState DO
    AssignString("State freq. ",descr);
    StateToString(is,istr); Concat(descr,istr);
    ident := "fs[";
    IntToString(ORD(is)+1,istr,0); Concat(ident,istr);
    ConcatCh(ident,"]");
    SetDefltMV(m,fs[is],0.0,1.0, descr,ident,"",
      notOnFile,notInTable,isY);
  END(*FOR*);
  FOR is:= firstState TO lastState DO
    FOR js:= firstState TO lastState DO
      AssignString("Freq. transition ",descr);
      StateToString(is,istr); Concat(descr,istr);
      Concat(descr,"–>");
      StateToString(js,istr); Concat(descr,istr);
      ident := "f[";
      IntToString(ORD(is)+1,istr,0); Concat(ident,istr);
      ConcatCh(ident,",");
      IntToString(ORD(js)+1,istr,0); Concat(ident,istr);
      ConcatCh(ident,"]");
      SetDefltMV(m,f[is,js],0.0,1.0, descr,ident,"",
        writeOnFile,writeInTable,isY);
    END(*FOR*);
  END(*FOR*);
END AssignStatesNames;

PROCEDURE DefineMarkov;
  CONST lem = 3; tab1 = 25; tab2 = 35; tab3 = 45;
  VAR ef: FormFrame; ok: BOOLEAN; cl: INTEGER;
BEGIN
  cl := 2;
  WriteLabel(cl,lem,"Define Markov Process:"); INC(cl);
  WriteLabel(cl,lem,"State");
  WriteLabel(cl,tab1,"Transition probabilities"); INC(cl);
  StringField(cl,lem,15,nameStateOne,useAsDeflt);
  RealField(cl,tab1,7,p[one,one],useAsDeflt,0.0,1.0);
  RealField(cl,tab2,7,p[one,two],useAsDeflt,0.0,1.0);
  RealField(cl,tab3,7,p[one,three],useAsDeflt,0.0,1.0);
  INC(cl);
  StringField(cl,lem,15,nameStateTwo,useAsDeflt);
```

```
   RealField(cl,tab1,7,p[two,one],useAsDeflt,0.0,1.0);
   RealField(cl,tab2,7,p[two,two],useAsDeflt,0.0,1.0);
   RealField(cl,tab3,7,p[two,three],useAsDeflt,0.0,1.0);
  INC(cl);
   StringField(cl,lem,15,nameStateThree,useAsDeflt);
   RealField(cl,tab1,7,p[three,one],useAsDeflt,0.0,1.0);
   RealField(cl,tab2,7,p[three,two],useAsDeflt,0.0,1.0);
   RealField(cl,tab3,7,p[three,three],useAsDeflt,0.0,1.0);
  INC(cl);
  ef.x:= 0; ef.y:= -1 (*display entry form in middle of screen*);
  ef.lines:= cl+1; ef.columns:= 55;
  UseEntryForm(ef,ok);
   IF ok THEN AssignStatesNames(nameStateOne,nameStateTwo,nameStateThree) END;
END DefineMarkov;


PROCEDURE ModelObjects;
  VAR l: Individuals; is,js: State;
  istr, descr,ident: ARRAY [0..40] OF CHAR;
BEGIN (*Objects*)
  (* declaration of parameters *)
  FOR is:= firstState TO lastState DO
     DeclP(initP[is],1.0/FLOAT(ORD(lastState)+1),0.0,1.0,
           rtc,"","","");
  END(*FOR*);
   DeclP(randomize,0.0,0.0,1.0,
           rtc,"Randomize option (= 0 don't, = 1 do randomize)",
           "randomize","[0..1]");
  p[one,two] := 0.2;
  p[one,three] := 0.05;
  p[one,one] := 1.0 - p[one,two] - p[one,three];
  p[two,two] := 0.3;
  p[two,three] := 0.1;
  p[two,one] := 1.0 - p[two,two] - p[two,three];
  p[three,two] := 0.0;
  p[three,one] := 0.0;
  p[three,three] := 1.0;
  FOR is:= firstState TO lastState DO
    FOR js:= firstState TO lastState DO
       DeclP(p[is,js],p[is,js],0.0,1.0, rtc, "","","");
    END(*FOR*);
  END(*FOR*);

  (* compute initial states *)
  Initialize;

  (* declaration of monitorable variables *)
  FOR is:= firstState TO lastState DO
     DeclMV(fs[is],0.0,1.0, "","","",
       notOnFile,notInTable,isY);
  END(*FOR*);
   SetDefltCurveAttrForMV(m, fs[one], emerald, unbroken, "·" );
   SetDefltCurveAttrForMV(m, fs[two], ruby, unbroken, "o" );
   SetDefltCurveAttrForMV(m, fs[three], coal, unbroken, "+" );
  FOR is:= firstState TO lastState DO
    FOR js:= firstState TO lastState DO
       DeclMV(f[is,js],0.0,1.0, "","","",
         writeOnFile,writeInTable,isY);
       SetDefltCurveAttrForMV(  m, f[is,js], autoDefCol, autoDefStyle, 0C );
    END(*FOR*);
  END(*FOR*);
   AssignStatesNames("healthy","ill","dead");
END ModelObjects;

VAR
  recordF: TextFile;

PROCEDURE WriteOnFile(ch: CHAR);
BEGIN (*Write*)
  WriteChar(recordF,ch);
END WriteOnFile;

PROCEDURE TheExperiment;
  CONST TAB = 11C;
  VAR is,js: State;
     dt: DateAndTimeRec; curMin, curMax: REAL;
     curFiling: StashFiling; curTabul: Tabulation; curGraphing: Graphing;
     dummyStr, ident: ARRAY [0..63] OF CHAR;i, maxRuns: CARDINAL;
   PROCEDURE AskForNrRuns(): BOOLEAN;
     CONST lem = 5; tab = 35; VAR ef: FormFrame; ok: BOOLEAN; cl: INTEGER;
  BEGIN
    cl := 2;
     WriteLabel(cl,lem,"How many runs:");
      CardField(cl,tab,7,maxRuns,useAsDeflt,1,MAX(CARDINAL)); INC(cl);
     ef.x:= 0; ef.y:= -1 (* display entry form in middle of screen *);
     ef.lines:= cl+1; ef.columns:= 55;
```

```
      UseEntryForm(ef,ok);
      RETURN ok
    END AskForNrRuns;
    PROCEDURE RecordDateTime(s: ARRAY OF CHAR; dt: DateAndTimeRec);
    BEGIN (*RecordDateTime*)
      WriteChars(recordF,s);
      WriteDate(dt,WriteOnFile,letMonth); WriteChars(recordF," at ");
      WriteTime(dt,WriteOnFile,brief24hSecs); WriteEOL(recordF);
    END RecordDateTime;
  BEGIN (*TheExperiment*)
    maxRuns := 100;
    IF AskForNrRuns() THEN
      FOR is:= firstState TO lastState DO
        FOR js:= firstState TO lastState DO
          GetMV( m, f[is,js], curMin, curMax,
                  curFiling, curTabul, curGraphing);
          SetMV( m, f[is,js], curMin, curMax,
                  notOnFile, curTabul, curGraphing);
        END(*FOR*);
        GetMV( m, fs[is], curMin, curMax,
                curFiling, curTabul, curGraphing);
        SetMV( m, fs[is], curMin, curMax,
                notOnFile, curTabul, curGraphing);
        SetP( m, initP[is], 0.0);
      END(*FOR*);
      SetP(m,initP[one], 1.0);
      SetP(m,randomize,1.0);
      CreateNewFile(recordF,"Record results on file","Markov.DAT");
      IF recordF.res=done THEN
        GetDateAndTime(dt);
        WriteChars(recordF,"Run"); WriteChar (recordF,TAB);
        FOR is:= firstState TO lastState DO
          FOR js:= firstState TO lastState DO
            GetDefltMV(m,f[is,js],curMin, curMax,
                        dummyStr,ident,dummyStr,
                        curFiling, curTabul, curGraphing);
            WriteChars(recordF,ident); WriteChar (recordF,TAB);
          END(*FOR*);
        END(*FOR*);
        WriteChars(recordF,"N");
        WriteEOL(recordF);
        i := 1;
        WHILE (i <= maxRuns) AND NOT ExperimentAborted() DO
          SimRun;
          PutInteger(recordF,i,0); WriteChar (recordF,TAB);
          FOR is:= firstState TO lastState DO
            FOR js:= firstState TO lastState DO
              PutReal(recordF,f[is,js],8,4); WriteChar (recordF,TAB);
            END(*FOR*);
          END(*FOR*);
          PutInteger(recordF,CurrentStep(),0);
          WriteEOL(recordF);
          INC(i);
        END(*WHILE*);
        WriteChars(recordF, "Legend:"); WriteEOL(recordF);
        WriteChars(recordF, "  Run    - Number of simulation run within experiment");
        WriteEOL(recordF);
        WriteChars(recordF, "  f[i,j] - Relative frequency of transition from state i to
state j");
        WriteEOL(recordF);
        WriteChars(recordF, "  N      - Number of transitions used to estimate f[i,j]");
        WriteEOL(recordF);
        RecordDateTime("Experiment started on ",dt);
        GetDateAndTime(dt);
        RecordDateTime("Experiment ended on ",dt);
        Close(recordF);
      END(*IF*);
    END(*IF*);
  END TheExperiment;


  PROCEDURE ModelDefinitions;
    CONST marg = 2;
  BEGIN
    DeclM(m, discreteTime, Initialize, NoInput, NoOutput, Dynamic, NoTerminate,
      ModelObjects, 'Markov chain simulated', 'm', NoAbout);
    SetIntegrationStep(1.0);
    SetMonInterval(1.0);
    DeclInitSimSession(InitSimSess);
    InstallStartConsistency(TestConsistency);
    InstallTerminateCondition(AllDead);
    DeclExperiment(TheExperiment);
    TileWindows; UseCurWSettingsAsDefault;
    SetDefltWindowPlace(GraphW,marg,marg,
                        BackgroundWidth()-2*marg,
                        BackgroundHeight()-MenuBarHeight()-2*marg);
```

```
     SetDefltWindowPlace(TableW,marg,marg,
                         BackgroundWidth()-2*marg,
                        (BackgroundHeight()-2*marg)DIV 3);
     InstallMenu(myMenu,'Markov',enabled);
     InstallCommand(myMenu,defMarkovCmd,"Define...",
                    DefineMarkov,enabled, unchecked);
     InstallAliasChar(myMenu,defMarkovCmd, "W");
  END ModelDefinitions;


BEGIN
  RunSimMaster(ModelDefinitions);
END Markov.
```

H.5.2 Population dynamics of larch bud moth *LBM*

The following program code contains a sample model demonstrating the daily use of ModelWorks in a research project. This program demonstrates modular modeling, the use of a parallel model in order to allow the simulationist to compare simulation results with measured data, dynamic setting of curve attributes during simulation runs, and dynamic activation respectively deactivation of models during a simulation session. The model system is a structured system consisting of two submodels. The first submodel, module *LBMMod*, describes the ecological interaction of the host plant larch *Larix decidua* MILLER with the herbivorous insect larch bud moth *Zeiraphera diniana* GN. (*Lep*., *Tortricidae*) (FISCHLIN, 1982; BALTENSWEILER & FISCHLIN, 1988). The second submodel, module *LBMObs*, is a parallel model mimicking the real system by using field data. A master module, the program module *LBM*, combines all modules to a model definition program.

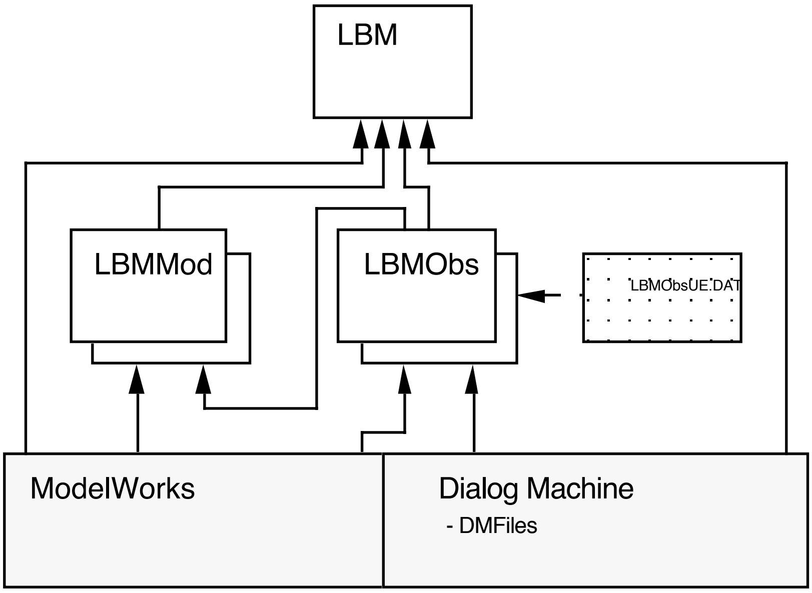

Fig. A4: Module structure of the research sample model.

The next two listings show the definition and the implementation parts of the module *LBMMod* containing the discrete time submodel describing the relationship between the host plant and the insect:

```
DEFINITION MODULE LBMMod;

  (*

    Purpose       Simulates Larch Bud Moth population dynamics for the
                  Upper Engadine valley from 1949 till 1977.  Model b:
                  local dynamics: larch - larch bud moth interaction

    Reference     Fischlin 1982, "Analyse eines Wald-Insekten Systemes:
```

```
                 Der subalpine Lärchen-Arvenwald und der Graue
                 Lärchenwickler Zeiraphera diniana Gn. (Lep.,
                 Tortricidae)", Diss ETHZ No. 6977.

    Remark       This program module contains the model which runs
                 under the simulation environment ModelWorks V0.5

    Programming  A.Fischlin, Systems Ecology, ETHZ, Dez. 1986

  *)

  VAR
    yt: REAL;     (* output: simulated larval density for whole valley *)
    ytLn: REAL;   (* output: ln of simulated larval density for whole valley *)

  PROCEDURE ActivateLarchLBMModel;
  PROCEDURE DeactivateLarchLBMModel;
  PROCEDURE LarchLBMModelIsActive(): BOOLEAN;

END LBMMod.


IMPLEMENTATION MODULE LBMMod;

  (*

        Revision history:
        =================

        Author  Date        Description
        ------  ----        -----------

        af      Dez.86      First implementation
        af      12/05/90    ModelWorks 2.0 adaptation, now
                            dynamic model activation and de-
                            activation supported
  *)

  FROM MathLib IMPORT Exp, Ln;
  FROM SimMaster IMPORT RunSimMaster;

  FROM SimBase IMPORT Model, DeclM, IntegrationMethod, DeclSV,
    StashFiling, Tabulation, Graphing, DeclMV, DeclP, RTCType,
    NoInput, NoTerminate, NoAbout, RemoveM, SetSimTime;

  FROM LBMObs IMPORT negLogDelta, yLL, yUL, kmin, kmax (* time domain *);



  VAR
    m: Model;
    c1,c2,c3,c4,c5,c6,c7,c8,c9,c10,c11,c12,c13,c14,c15,c16,c17,nrt: REAL;
    p1,p2,p3,p4,p5,p6,p7,p8,p9,p10,p11,p12,p13,p14: REAL;
    rt,rt1,et,et1: REAL;
    def, springEggs: REAL;
    curActive: BOOLEAN;



  PROCEDURE Initialize;

    PROCEDURE Parameters;
    BEGIN
      p1:=c4;
      p2:=c5;
      p3:=-c2*c6*(1.0-c1);
      p4:=c6*(1.0-c1)*(1.0 -c3);
      p5:=c2*c7*c9*c10*(1.0-c1);
      p6:=c9*(1.0-c1)*(c2*c7*c11-c10*(c2*(1.0-c8)+c7*(1.0-c3)));
      p7:=c9*(1.0-c1)*(c10*(1.0-c3)*(1.0-c8)-c11*(c2*(1.0-c8)+c7*(1.0-c3)));
      p8:=c9*c11*(1.0-c1)*(1.0-c3)*(1.0-c8);
      p9:=c12;
      p10:=c13;
      p11:=c14;
      p12:=c15;
      p13:=c16;
      p14:=c6*c17*nrt;
    END Parameters;

  BEGIN (*Initialize*)
    Parameters
  END Initialize;

  PROCEDURE Output;
  BEGIN
    yt:= (p3*rt+p4)*et/p14;
    ytLn:= Ln(negLogDelta+yt);
    springEggs:= (1.0 - c1) * et;
  END Output;


  PROCEDURE Dynamic;

    PROCEDURE gmstarv(x1,x2: REAL): REAL;
    BEGIN
      IF x2=0.0 THEN RETURN 0.0 END;
      IF x2>0.0 THEN RETURN Exp(-x1/x2) END;
    END gmstarv;

    PROCEDURE grecr(def,rt: REAL): REAL;
      CONST eps = 0.00001;
      VAR
        zrt: REAL;
    BEGIN (*grecr*)
      IF (def < p12) THEN
        IF (rt >= p9-eps) AND (rt <= p9) (* rt = p9 *) THEN
        RETURN 1.0
        ELSIF rt > p9 THEN
         zrt:= p10+ABS((p11-rt)/(rt-p9));
        IF zrt > rt-p9 THEN
          RETURN p9/rt
        ELSE (*zrt <= rt-p9*)
          RETURN 1.0-zrt/rt
        END(*IF*);
        ELSE
        (* " --- warning: rt < p9" *)
        HALT
        END(*IF*);
      ELSE (*def >= p12*)
        IF def < p13 THEN
         RETURN 1.0+(def-p12)*(p11-rt)/(p13-p12)/rt
        ELSIF (def > p12) (*AND (def >= p13)*) THEN
        RETURN p11/rt
        ELSE (*(def = p12) AND (def >= p13)*)
        HALT
        END(*IF*);
      END(*IF*);
    END grecr;

  BEGIN (*Dynamic*)
     def:= (1.0-gmstarv(p1*rt+p2,p3*rt*et+p4*et))*(p3*rt*et+p4*et)/(p1*rt+p2);
    rt1:=grecr(def,rt)*rt;
    et1:=(1.0-gmstarv(p1*rt+p2,p3*rt*et+p4*et))*
         (p5*rt*rt*rt+p6*rt*rt+p7*rt+p8)*et;
  END Dynamic;


  PROCEDURE ModelObjects;
  BEGIN
    DeclSV(rt, rt1, 15.0, 11.99, 18.5,
      "Raw fiber content (% fresh weight)", "rf", "%");
    DeclSV(et, et1, 4765975.0, 0.0, 1.0E12,
      "Larch bud moth eggs (individuals)", "eggs", "numbers");

    DeclMV(rt, 10.0, 20.0, "Raw fiber content (% fresh weight)", "rf",
      "%", notOnFile, writeInTable,notInGraph);
    DeclMV(springEggs, 0.0, 1.0E12,"Larch bud moth eggs in spring (individuals)",
      "eggs", "lbm", notOnFile, notInTable, notInGraph);
    DeclMV(yt, yLL, yUL,"Larval density (larvae/kg branches)",
      "Y", "lbm/kg", notOnFile, writeInTable, notInGraph);
    DeclMV(ytLn, Ln(negLogDelta), Ln(negLogDelta+yUL),
      "Ln of larval density (larvae/kg branches)",
      "Ln(Y)", "lbm/kg", notOnFile, notInTable, isY);
    DeclMV(def, 0.0, 1.0,"Defoliation",
      "def", "", notOnFile, notInTable, notInGraph);


    DeclP(nrt, 511147.0, 511147.0, 511147.0, noRtc,
      "nrt (number of trees)",  "trees", "trees");
    DeclP(c1, 0.5728, 0.4841, 0.6538, noRtc,
      "c1 (egg winter mortality)", "c1", "lbm");
    DeclP(c2, 0.05112, 0.016, 0.087, noRtc,
      "c2 (slope of small larvae mortality vs. rf)", "c2", "/%");
    DeclP(c3, -0.17932, -0.565, 0.206, noRtc,
      "c3 (y-intercept of small larvae mortality vs. rf)", "c3", "");
    DeclP(c4, -2.25933*nrt, -2.4129*nrt, -2.1057*nrt, noRtc,
      "c4 (slope of needle biomass vs. rf)",  "c4", "/%");
    DeclP(c5, 67.38939*nrt, 62.8076*nrt, 71.9712*nrt, noRtc,
      "c5 (y-intercept of needle biomass vs. rf)", "c5", "");
    DeclP(c6, 0.005472, 0.0027, 0.0106, noRtc,
      "c6 (food demand of a large larvae)", "c6", "kg/lbm");
    DeclP(c7, 0.124017, 0.1070, 0.1410, noRtc,
      "c7 (slope of large larvae mortality vs. rf)", "c7", "/%");
    DeclP(c8, -1.435284, -1.685, -1.1855, noRtc,
      "c8 (y-intercept of large larvae mortality vs. rf)", "c8", "");
    DeclP(c9, 0.44, 0.363, 0.517, noRtc,
      "c9 (sex ratio)", "c9", "");
    DeclP(c10, -18.475457, -24.7217, -12.2294, noRtc,
      "c10 (slope of fecundity vs. rf)", "c10", "lbm/%");
    DeclP(c11, 356.72636, 264.9847, 448.4680, noRtc,
      "c11 (y-intercept of fecundity vs. rf)", "c11", "lbm");
    DeclP(c12, 11.99, 11.79, 12.19, noRtc,
      "c12 (minimum rf)", "c12", "%");
    DeclP(c13, 0.425, 0.4, 0.5, noRtc,
      "c13 (minimum decrement of rf)", "c13", "%");
    DeclP(c14, 18.0, 17.5, 18.5, noRtc,
      "c14 (maximum rf)", "c14", "%");
    DeclP(c15, 0.4, 0.35, 0.6, noRtc,
      "c15 (defoliation threshold)", "c15", "");
    DeclP(c16, 0.8, 0.7, 1.0, noRtc,
      "c16 (defoliation threshold of maximum stress)", "c16", "");
    DeclP(c17, 91.3, 91.3, 91.3, noRtc,
      "c17 (branches per tree)", "c17", "kg");

  END ModelObjects;


  PROCEDURE ActivateLarchLBMModel;
  BEGIN
    IF NOT curActive THEN
       DeclM(m, discreteTime, Initialize, NoInput, Output, Dynamic, NoTerminate,
ModelObjects,
         "Larch Bud Moth model b1 V3.0 (Larch-Larch bud moth relationship)",
         "LWMod3 b1", NoAbout);
       SetSimTime(FLOAT(kmin),FLOAT(kmax));
      curActive:= TRUE
    END(*IF*);
  END ActivateLarchLBMModel;

  PROCEDURE DeactivateLarchLBMModel;
  BEGIN
    IF curActive THEN RemoveM(m); curActive:= FALSE END(*IF*);
  END DeactivateLarchLBMModel;

  PROCEDURE LarchLBMModelIsActive(): BOOLEAN;
  BEGIN
    RETURN curActive
  END LarchLBMModelIsActive;

BEGIN
  curActive := FALSE;
END LBMMod.
```

The module *LBMObs* provides a parallel submodel of the measured larval densities of the larch bud moth (observations) made in the field while studying the larch bud moth system in the Upper Engadine valley in Switzerland from 1949 till the presence (BALTENSWEILER & FISCHLIN, 1988). This allows to compare the observations with simulated values. At the begin of the simulation session this parallel model simply reads the observations stored in the data file into an array and will assign the measured values during any simulations to a monitoring variable, which the simulationist can display from within the simulation environment.

In case the simulationist should set the global simulation time such that it lies outside the range 1949 and 1988, the values produced by this module are no longer valid. The module has been programmed such that it visualizes missing values in the graph by letting portions of the curve(s) disappear. This is accomplished by setting the curve attribute to invisble as soon as values have become undefined, yet the legend is drawn with the attributes normally used if values are available.

The next three listings show the definition and the implementation parts of the module *LBMObs* which reads the data from the text file *LBMObsUE.DAT*:

```
DEFINITION MODULE LBMObs;

  (*
    Module  LBMObs

    Purpose Simulates the real larch bud moth system in the
```

```
             Upper Engadine Valley as a parallel model.

    Method  Observed larval densities in larvae/kg larch
             branches as sampled from the Upper Engadine Valley
             are simulated by means of a ModelWorks submodel.
             Data from Fischlin, A. 1982.  Analyse
             eines Wald-Insekten-Systems: Der subalpine
             Lärchen-Arvenwald und der graue Lärchenwickler
             Zeiraphera diniana Gn. (Lep., Tortricidae).
             Diss. ETH Nr. 6977. Swiss Federal Institute of
             Technology Zürich, Switzerland, 294pp, page 90,
             Table 10 and from Baltensweiler, W. and Fischlin, A.
             1987, The larch bud moth in the European Alps, In
             Berryman, A.A. (ed.), Population Dynamics of Forest-
             Insect Systems, Plenum Press, in print.

    Remark  The data are read from a file only once at model
             declaration and are loaded into memory for subsequent
            usage.
             This program module contains the model which runs
             under the simulation environment ModelWorks V0.5

    Programming  A.Fischlin, Systems Ecology, ETHZ, 01/05/87

  *)


  CONST
    kmin = 1949; (*first year sampled*)
    kmax = 1986; (*last year sampled*)
    limkmax = 1978; (* beyond limkmax yminDash, ymaxDash no longer available *)
    yLL =   0.0; (*minimum used on graph scale for larval densities *)
    yUL = 600.0; (*maximum used on graph scale for larval densities *)
    negLogDelta = 0.01; (*offset used to plot log scale if values <= 0*)


  (* The following variables may be freely used in another submodel,
  typically to compare simulation results of a simulation model
  with the observed values *)

  VAR
    yminDash: REAL;   (* minimum annual value found in anyone site *)
    ymeanDash: REAL;  (* average annual value for whole valley *)
    ymaxDash: REAL;   (* maximum annual value found in anyone site *)
    yminDashLn: REAL;    (* ln of minimum annual value found in anyone site *)
    ymeanDashLn: REAL;  (* ln of average annual value for whole valley *)
    ymaxDashLn: REAL;    (* ln of maximum annual value found in anyone site *)

  PROCEDURE ActivateLBMObsModel;
  PROCEDURE DeactivateLBMObsModel;
  PROCEDURE LBMObsModelIsActive(): BOOLEAN;

END LBMObs.


IMPLEMENTATION MODULE LBMObs;

  (*

        Revision history:
        =================

        Author  Date        Description
        ------  ----        -----------

        af       01/05/87    First implementation
        af       12/05/90    - ModelWorks 2.0 adaptation, now
                               dynamic model activation and de-
                               activation supported
                             - Curve attributes set, in particular
                               if no observations available
                               lineStyle is set to invisible

  *)


  FROM SimBase IMPORT
    Model, DeclM, IntegrationMethod,
    DeclSV, DeclMV, StashFiling, Tabulation, Graphing,
    CurrentTime, SetSimTime, GetGlobSimPars,
    NoInitialize, NoInput, NoOutput, NoDynamic, NoTerminate, NoAbout,
    RemoveM, SetDefltCurveAttrForMV, SetCurveAttrForMV, Stain, LineStyle;

  FROM DMFiles IMPORT Response, TextFile, Lookup, Reset, Close,
    EOF, GetCardinal, GetReal, legalNum;
```

```
FROM DMAlerts IMPORT WriteMessage, ShowAlert;

FROM DMConversions IMPORT CardToString;

FROM MathLib IMPORT Ln;


VAR
  (*storage for observations*)
  yminD, ymeanD, ymaxD: ARRAY [kmin..kmax] OF REAL;
  obsMod: Model;
  (*current larval densities used as a state variables:
  yminDash1,ymeanDash1,ymaxDash1: REAL;*)
  k: CARDINAL; curVar: ARRAY [0..20] OF CHAR; (*used for error messages*)
  curActive: BOOLEAN;


PROCEDURE DataFileNotOk;
BEGIN
  WriteMessage(2,3,"Data file with observations");
  WriteMessage(3,3,"could not be opened");
END DataFileNotOk;

PROCEDURE NotEnoughDataInFile;
BEGIN
  WriteMessage(2,3,"Not enough data in observation file");
END NotEnoughDataInFile;

PROCEDURE WrongNum;
  VAR numStr: ARRAY [0..3] OF CHAR;
BEGIN
  WriteMessage(2,3,"Illegal number found:  year = ");
  CardToString(k,numStr,0);
  WriteMessage(2,3+30,numStr);
  WriteMessage(3,3,"Attempt to read");
  WriteMessage(3,3+10,curVar);
END WrongNum;

PROCEDURE InitData;
  VAR f: TextFile; r: Response; year: CARDINAL;
BEGIN
  Lookup(f,"LBMObsUE.DAT",FALSE);
  IF f.res=done THEN
    FOR k:= kmin TO kmax DO
  IF EOF(f) THEN ShowAlert(3,50,NotEnoughDataInFile); HALT END;
  GetCardinal(f,year);  curVar:= "year";
  IF NOT legalNum OR (k<>year) THEN ShowAlert(4,50,WrongNum) END;
  IF EOF(f) THEN ShowAlert(3,50,NotEnoughDataInFile); HALT END;
  GetReal(f,ymeanD[k]);  curVar:= "Ymean'";
  IF NOT legalNum THEN ShowAlert(4,50,WrongNum) END;
  IF EOF(f) THEN ShowAlert(3,50,NotEnoughDataInFile); HALT END;
  GetReal(f,yminD[k]);  curVar:= "Ymin'";
  IF NOT legalNum THEN ShowAlert(4,50,WrongNum) END;
  IF EOF(f) THEN ShowAlert(3,50,NotEnoughDataInFile); HALT END;
  GetReal(f,ymaxD[k]);  curVar:= "Ymax'";
  IF NOT legalNum THEN ShowAlert(4,50,WrongNum) END;
    END(*FOR*);
    Close(f);
  ELSE
     ShowAlert(4,40,DataFileNotOk);
  END(*IF*);
  curActive := FALSE;
END InitData;



PROCEDURE SetCurveAttrsForLegend;
BEGIN
  SetCurveAttrForMV (obsMod, yminDash,turquoise,spotted,0C);
  SetCurveAttrForMV (obsMod, ymeanDash,turquoise,dashSpotted,0C);
  SetCurveAttrForMV (obsMod, ymaxDash,turquoise,spotted,0C);
  SetCurveAttrForMV (obsMod, yminDashLn,turquoise,spotted,0C);
  SetCurveAttrForMV (obsMod, ymeanDashLn,turquoise,dashSpotted,0C);
  SetCurveAttrForMV (obsMod, ymaxDashLn,turquoise,spotted,0C);
END SetCurveAttrsForLegend;


PROCEDURE Output;
  VAR k: INTEGER; t0,tend,h,er,c,hm: REAL;
BEGIN
  k:= TRUNC(CurrentTime()+0.1)(*ensures correct rounding*);
  IF (k>=kmin) AND (k<=kmax) THEN
    yminDash :=  yminD[k];
    ymeanDash := ymeanD[k];
    ymaxDash :=  ymaxD[k];
    yminDashLn :=  Ln(negLogDelta+yminDash);
```

```
      ymeanDashLn := Ln(negLogDelta+ymeanDash);
      ymaxDashLn :=  Ln(negLogDelta+ymaxDash);
       SetCurveAttrForMV (obsMod, ymeanDash,turquoise,dashSpotted,0C);
       SetCurveAttrForMV (obsMod, ymeanDashLn,turquoise,dashSpotted,0C);
      IF k<=limkmax THEN
         SetCurveAttrForMV (obsMod, yminDash,turquoise,spotted,0C);
         SetCurveAttrForMV (obsMod, ymaxDash,turquoise,spotted,0C);
         SetCurveAttrForMV (obsMod, yminDashLn,turquoise,spotted,0C);
         SetCurveAttrForMV (obsMod, ymaxDashLn,turquoise,spotted,0C);
      ELSE
         SetCurveAttrForMV (obsMod, yminDash,turquoise,invisible,0C);
         SetCurveAttrForMV (obsMod, ymaxDash,turquoise,invisible,0C);
         SetCurveAttrForMV (obsMod, yminDashLn,turquoise,invisible,0C);
         SetCurveAttrForMV (obsMod, ymaxDashLn,turquoise,invisible,0C);
      END(*IF*);
    ELSE
       SetCurveAttrForMV (obsMod, yminDash,turquoise,invisible,0C);
       SetCurveAttrForMV (obsMod, ymeanDash,turquoise,invisible,0C);
       SetCurveAttrForMV (obsMod, ymaxDash,turquoise,invisible,0C);
       SetCurveAttrForMV (obsMod, yminDashLn,turquoise,invisible,0C);
       SetCurveAttrForMV (obsMod, ymeanDashLn,turquoise,invisible,0C);
       SetCurveAttrForMV (obsMod, ymaxDashLn,turquoise,invisible,0C);
      yminDash:=  MIN(REAL);  (* stands for undefined *)
      ymeanDash:= MIN(REAL);
      ymaxDash:=  MIN(REAL);
      yminDashLn:=  Ln(negLogDelta);
      ymeanDashLn:= Ln(negLogDelta);
      ymaxDashLn:=  Ln(negLogDelta);
    END(*IF*);
    (* test whether Output is called just before legend drawing, then
    make an exception and draw legend with curve attributes used for
    display when observations exist *)
    GetGlobSimPars (t0,tend,h,er,c,hm);
    IF TRUNC(t0+0.1) = k THEN SetCurveAttrsForLegend END;
  END Output;

  PROCEDURE Terminate;
  BEGIN
    SetCurveAttrsForLegend;
  END Terminate;

  PROCEDURE ModelObjects;
  BEGIN
    DeclMV(yminDash, yLL, yUL,
       "Minimum larval density per site", "Ymin'",
       "larvae/kg branches",
       notOnFile, notInTable, notInGraph);
    SetDefltCurveAttrForMV (obsMod, yminDash,turquoise,spotted,0C);
    DeclMV(ymeanDash, yLL, yUL,
       "Average larval density in valley", "Y'",
       "larvae/kg branches",
       notOnFile, writeInTable, notInGraph);
    SetDefltCurveAttrForMV (obsMod, ymeanDash,turquoise,dashSpotted,0C);
    DeclMV(ymaxDash, yLL, yUL,
       "Maximum larval density per site", "Ymax'",
       "larvae/kg branches",
       notOnFile, notInTable, notInGraph);
    SetDefltCurveAttrForMV (obsMod, ymaxDash,turquoise,spotted,0C);
    DeclMV(yminDashLn, Ln(negLogDelta), Ln(yUL),
       "Ln of minimum larval density per site", "Ln(Ymin')",
       "larvae/kg branches",
       notOnFile, notInTable, notInGraph);
    SetDefltCurveAttrForMV (obsMod, yminDashLn,turquoise,spotted,0C);
    DeclMV(ymeanDashLn, Ln(negLogDelta), Ln(yUL),
       "Ln of average larval density in valley", "Ln(Y')",
       "larvae/kg branches",
       notOnFile, notInTable, isY);
    SetDefltCurveAttrForMV (obsMod, ymeanDashLn,turquoise,dashSpotted,0C);
    DeclMV(ymaxDashLn, Ln(negLogDelta), Ln(yUL),
       "Ln of maximum larval density per site", "Ln(Ymax')",
       "larvae/kg branches",
       notOnFile, notInTable, notInGraph);
    SetDefltCurveAttrForMV (obsMod, ymaxDashLn,turquoise,spotted,0C);
  END ModelObjects;



  PROCEDURE ActivateLBMObsModel;
  BEGIN
    IF NOT curActive THEN
      DeclM(obsMod, discreteTime,
      NoInitialize, NoInput, Output, NoDynamic, Terminate, ModelObjects,
      "Observations from the Upper Engadine Valley", "Obs UE",
      NoAbout);
       SetSimTime(FLOAT(kmin),FLOAT(kmax));
      curActive:= TRUE
    END(*IF*);
  END ActivateLBMObsModel;


  PROCEDURE DeactivateLBMObsModel;
  BEGIN
    IF curActive THEN RemoveM(obsMod); curActive:= FALSE END(*IF*);
  END DeactivateLBMObsModel;


  PROCEDURE LBMObsModelIsActive (): BOOLEAN;
  BEGIN
    RETURN curActive
  END LBMObsModelIsActive;


BEGIN
  InitData;
END LBMObs.
```

Excerpt (middle portion missing) from data file *LBMObsUE.DAT* accessed by module *LBMObs*:

```
Year        y'          y'MIN       y'MAX
1949        0.018       0.006       0.041
1950        0.082       0.006       0.232
1951        0.444       0.001       1.266
1952        4.174       0.191       10.464
1953        68.797      16.667      128.490
1954        331.760     163.340     933.524
1955        126.541     25.048      317.868
1956        21.280      9.888       41.974
1957        2.246       1.330       4.538
1958        0.085       0.000       0.359
…
…
…
1985        0.120       N           N
1986        0.690       N           N
1987        2.279       0.445       4.866
1988        39.029      4.149       88.146

Legend
y'          mean observed larval density
y'MIN       minimum observed larval density
y'MAX       maximum observed larval density
```

The following module is the main program module *LBM*. Its sole purpose is to start the simulation environment (procedure *RunSimMaster*) and to install a menu (procedure *InstallMenus*) which gives access to the actual models. The latter menu contains a command which asks the simulationist which submodel(s) he/she wishes to load (activate) or to remove (deactivate) (procedure *Choose*). The master module imports from the modules *LBMMod* (population model) and *LBMObs* (exports the parallel observation model) the procedures *ActivateLarchLBMModel* and *DeactivateLarchLBMModel* resp. *ActivateLBMObsModel* and *DeactivateLBMObsModel*. These procedures will declare or remove the desired models, thus allowing the simulationist to drop or load a model anytime during the simulation session.

```
MODULE LBM;  (* af 1/5/87; 12/5/90 *)

  (*
     Module LBM  (Larch Bud Moth)

     Purpose    master module modeling the larch bud moth system
        by means of ModelWorks V0.3 simulating the system
        behavior for the Upper Engadine Valley

     References Fischlin, A. 1982.  Analyse eines Wald-Insekten-
        Systems: Der subalpine Lärchen-Arvenwald und der
        graue Lärchenwickler Zeiraphera diniana Gn. (Lep.,
        Tortricidae).  Diss. ETH Nr 6977. Swiss Federal
        Institute of Technology Zürich, Switzerland, 294pp.
  *)


  FROM DMLanguage IMPORT
```

```
    Language, SetLanguage, CurrentLanguage;
  FROM DMMenus IMPORT Menu, Command, AccessStatus, Marking,
    InstallMenu, InstallCommand, InstallAliasChar;
  FROM DMEntryForms IMPORT FormFrame, WriteLabel, DefltUse,
    CheckBox, UseEntryForm;
  FROM SimMaster IMPORT RunSimMaster;
  FROM SimBase IMPORT DoNothing;

  FROM LBMMod IMPORT ActivateLarchLBMModel, DeactivateLarchLBMModel,
    LarchLBMModelIsActive;
  FROM LBMObs IMPORT ActivateLBMObsModel, DeactivateLBMObsModel,
    LBMObsModelIsActive;


  VAR
    modM: Menu; modActCmd: Command;

  PROCEDURE Choose;
    CONST lm = 6; VAR bf: FormFrame; ok, modCB, obsCB: BOOLEAN; cl: INTEGER;
  BEGIN
    cl := 2; WriteLabel(cl,lm-1,"Check models to be activated:"); INC(cl);
    obsCB := LBMObsModelIsActive();
    modCB := LarchLBMModelIsActive();
    CheckBox(cl,lm,"Observations - Parallel Model Upper Engadine",obsCB); INC(cl);
    CheckBox(cl,lm,"Larch - Larch Bud Moth Model (b1)",modCB); INC(cl);
    bf.x:= 0; bf.y:= -1 (*display dialog window in middle of screen*);
    bf.lines:= cl+1; bf.columns:= 50;
    UseEntryForm(bf,ok);
    IF ok THEN
      IF modCB THEN ActivateLarchLBMModel ELSE DeactivateLarchLBMModel END;
      IF obsCB THEN ActivateLBMObsModel ELSE DeactivateLBMObsModel END;
    END(*IF*);
  END Choose;

  PROCEDURE InstallMenus;
  BEGIN
    InstallMenu(modM,"Models", enabled);
    InstallCommand(modM, modActCmd,"Activation…",
                   Choose, enabled, unchecked);
    InstallAliasChar(modM, modActCmd,"L");
  END InstallMenus;

BEGIN
  RunSimMaster( InstallMenus );
END LBM.
```

I Quick References

I.1 *DIALOG MACHINE*

For details on how to work with the Dialog Machine see this appendix the section above *How to Work With the Dialog Machine*. The following Dialog Machine version 2.0 is currently only available on the Macintosh. For the IBM PC the newest version is DM/PC V1.6 and its differences to DM 2.0 are explained in a separate documentation[1].

```
Dialog Machine Version 2.0 (January 1990)    © 1990 Andreas Fischlin, CELTIA, and Swiss Federal Institute of Technology
Zurich

(===========================================               K E R N E L
=============================================)

(*******************************************                DMConversions             *******************************************

   TYPE RealFormat = (FixedFormat, ScientificNotation);

   PROCEDURE StringToCard(str: ARRAY OF CHAR; VAR card: CARDINAL; VAR done: BOOLEAN);
   PROCEDURE CardToString(card: CARDINAL; VAR str: ARRAY OF CHAR; length: CARDINAL);
   PROCEDURE StringToLongCard(str: ARRAY OF CHAR; VAR lcard: LONGCARD; VAR done: BOOLEAN);
   PROCEDURE LongCardToString(lcard: LONGCARD; VAR str: ARRAY OF CHAR; length: CARDINAL);
   PROCEDURE StringToInt(str: ARRAY OF CHAR; VAR int: INTEGER; VAR done: BOOLEAN);
   PROCEDURE IntToString(int: INTEGER; VAR str: ARRAY OF CHAR; length: CARDINAL);
   PROCEDURE StringToLongInt(str: ARRAY OF CHAR; VAR lint: LONGINT; VAR done: BOOLEAN);
   PROCEDURE LongIntToString(lint: LONGINT; VAR str: ARRAY OF CHAR; length: CARDINAL);
   PROCEDURE StringToReal(str:ARRAY OF CHAR; VAR real: REAL; VAR done: BOOLEAN);
   PROCEDURE StringToLongReal(Str:ARRAY OF CHAR; VAR longReal: LONGREAL; VAR done: BOOLEAN);
   PROCEDURE RealToString(real: REAL; VAR str: ARRAY OF CHAR; length, dec: CARDINAL; f: RealFormat);
   PROCEDURE LongRealToString(longreal: LONGREAL; VAR str: ARRAY OF CHAR; length, dec: CARDINAL; f: RealFormat);
   PROCEDURE HexStringToBytes(hstr: ARRAY OF CHAR; VAR x: ARRAY OF BYTE; VAR done: BOOLEAN);
|  PROCEDURE BytesToHexString(x: ARRAY OF BYTE; VAR hstr: ARRAY OF CHAR);     PROCEDURE SetHexDigitsUpperCase( upperC:
BOOLEAN );
|  PROCEDURE IllegalSyntaxDetected(): BOOLEAN;

(*******************************************                DMErrorMsgs               *******************************************

   TYPE ErrMsgDispProc = PROCEDURE (CARDINAL, ARRAY OF CHAR, ARRAY OF CHAR, ARRAY OF CHAR);

   PROCEDURE DispError(nr: CARDINAL; modIdent, procIdent, inserts: ARRAY OF CHAR);
   PROCEDURE AssignErrMsgProducer(emdp: ErrMsgDispProc);
   PROCEDURE GetErrMsgProducer(VAR emdp: ErrMsgDispProc);
   PROCEDURE DfltErrMsgProducer(nr: CARDINAL; modIdent, procIdent, inserts: ARRAY OF CHAR);

(*******************************************                DMLanguage                *******************************************

   TYPE Language = (English, German, French, Italian, MyLanguage1, MyLanguage2);

|  VAR okButtonText, cancelButtonText: ARRAY [0..15] OF CHAR;

   PROCEDURE SetLanguage(l: Language);
   PROCEDURE CurrentLanguage(): Language;

(*******************************************                DMMaster                  *******************************************

   TYPE MouseHandlers = (WindowContent, BringToFront, RemoveFromFront, RedefWindow, CloseWindow);
     MouseHandler = PROCEDURE (Window);
     Status = (normal, abnormal);

   VAR DMMasterDone: BOOLEAN;

   PROCEDURE InstallSetUpProc(suP: PROC);          PROCEDURE GetSetUpProc(VAR suP: PROC);
   PROCEDURE InstallMouseHandler(which: MouseHandlers; mhP: MouseHandler);
   PROCEDURE GetMouseHandler(which: MouseHandlers; VAR mhP: MouseHandler);
   PROCEDURE InstallKeyboardHandler(khP: PROC);
   PROCEDURE GetKeyboardHandler(VAR khP: PROC);
   PROCEDURE Read(VAR ch: CHAR);          PROCEDURE BusyRead(VAR ch: CHAR);
   PROCEDURE CmdKeyPressed(): BOOLEAN;    PROCEDURE OptKeyPressed(): BOOLEAN;    PROCEDURE ShiftKeyPressed(): BOOLEAN;
|  PROCEDURE DoTillKeyReleased(p: PROC);

   PROCEDURE ShowWaitSymbol;              PROCEDURE HideWaitSymbol;
|  PROCEDURE SoundBell;                   PROCEDURE Wait(nrTicks: LONGCARD); (* 1 tick = 1/60 second *)

   PROCEDURE InitDialogMachine;
   PROCEDURE RunDialogMachine;
   PROCEDURE DialogMachineIsRunning(): BOOLEAN;
   PROCEDURE DialogMachineTask;
   PROCEDURE CallSubProg(module: ARRAY OF CHAR; VAR status: Status);
   PROCEDURE QuitDialogMachine;
   PROCEDURE AbortDialogMachine;

(*******************************************                MathLib                   *******************************************

   PROCEDURE Sqrt   (x: REAL):     REAL;
   PROCEDURE Exp    (x: REAL):     REAL;
   PROCEDURE Ln     (x: REAL):     REAL;
   PROCEDURE Sin    (x: REAL):     REAL;
   PROCEDURE Cos    (x: REAL):     REAL;
   PROCEDURE ArcTan(x: REAL):      REAL;
   PROCEDURE Real   (x: INTEGER): REAL;
```

[1] Available from the following address: Projekt-Zentrum IDA, re Dialog Machine, Swiss Federal Institute of Technology ETHZ, ETH-Zentrum, CH-8092 Zürich, Switzerland

```
  PROCEDURE Entier(x: REAL):     INTEGER;

(*******************************************               DMMenus              *******************************************)

  TYPE Menu;    Command;
     AccessStatus = (enabled, disabled);    Marking = (checked, unchecked);    Separator = (line, blank);
     QuitProc = PROCEDURE(VAR BOOLEAN);

  VAR MenusDone: BOOLEAN;

  PROCEDURE InstallAbout(s: ARRAY OF CHAR; w,h: CARDINAL; p: PROC);
  PROCEDURE NoDeskAccessories;
  PROCEDURE InstallMenu(VAR m: Menu; menuText: ARRAY OF CHAR; ast: AccessStatus);
| PROCEDURE InstallSubMenu (inm: Menu; VAR subm: Menu; menuText: ARRAY OF CHAR; ast: AccessStatus);
  PROCEDURE InstallCommand(m: Menu; VAR c: Command; cmdText: ARRAY OF CHAR; p: PROC; ast: AccessStatus; chm: Marking);
| PROCEDURE RemoveCommand(m: Menu; cmd: Command);
  PROCEDURE InstallAliasChar(m: Menu; c: Command; ch: CHAR);
| PROCEDURE InstallSeparator(m: Menu; s: Separator);      PROCEDURE RemoveSeparator(m: Menu; s: CARDINAL);
  PROCEDURE InstallQuitCommand(s: ARRAY OF CHAR; p: QuitProc; aliasChar: CHAR);
  PROCEDURE UseMenu(m: Menu);                              PROCEDURE UseMenuBar;
  PROCEDURE RemoveMenu(VAR m: Menu);                       PROCEDURE RemoveMenuBar;
  PROCEDURE EnableDeskAccessories;                          PROCEDURE DisableDeskAccessories;
  PROCEDURE EnableMenu(m: Menu);                            PROCEDURE DisableMenu(m: Menu);
  PROCEDURE EnableCommand(m: Menu; c: Command);            PROCEDURE DisableCommand(m: Menu; c: Command);
  PROCEDURE CheckCommand(m: Menu; c: Command);             PROCEDURE UncheckCommand(m: Menu; c: Command);
| PROCEDURE SetCheckSym(ch: CHAR);
  PROCEDURE ChangeCommandText(m: Menu; c: Command; newCmdText: ARRAY OF CHAR);
  PROCEDURE ChangeAliasChar(m: Menu; c: Command; newCh: CHAR);
  PROCEDURE ExecuteCommand(m: Menu; c: Command);

(*********************************************             DMStorage            *******************************************)

| PROCEDURE Allocate(VAR p: ADDRESS; size: LONGINT);
| PROCEDURE AllocateOnLevel(VAR adr: ADDRESS; size: LONGINT; level: INTEGER);
| PROCEDURE Deallocate(VAR p: ADDRESS);
| PROCEDURE ALLOCATE (VAR p: ADDRESS; size: CARDINAL); (* IBM PC DM compatibility *)
| PROCEDURE DEALLOCATE (VAR p: ADDRESS; size: CARDINAL); (* IBM PC DM compatibility *)

(*******************************************              DMStrings             *******************************************)

  TYPE  String;

  PROCEDURE NewString(VAR s: ARRAY OF CHAR): String;
  PROCEDURE GetString(strRef: String; VAR s: ARRAY OF CHAR);
  PROCEDURE PutString(VAR strRef: String; VAR s: ARRAY OF CHAR);
  PROCEDURE DisposeString(VAR strRef: String);
  PROCEDURE ConcatString(VAR strRef: String; s: ARRAY OF CHAR);
  PROCEDURE ConcatChar(VAR strRef: String; ch: CHAR);
  PROCEDURE Length(VAR string: ARRAY OF CHAR): INTEGER;
  PROCEDURE Concat(VAR dest: ARRAY OF CHAR; source: ARRAY OF CHAR);
  PROCEDURE ConcatCh(VAR dest: ARRAY OF CHAR; ch: CHAR);
  PROCEDURE AssignString(source: ARRAY OF CHAR; VAR d: ARRAY OF CHAR);
| PROCEDURE ExtractSubString(VAR curPosInSrcS: INTEGER; VAR srcS,destS: ARRAY OF CHAR; delimiter: CHAR);
  PROCEDURE LoadString(fileName: ARRAY OF CHAR; stringID: INTEGER; VAR string: ARRAY OF CHAR);
  PROCEDURE StoreString(fileName: ARRAY OF CHAR; VAR stringID: INTEGER; string: ARRAY OF CHAR);
  PROCEDURE GetRString(stringID: INTEGER; VAR str: ARRAY OF CHAR);
| PROCEDURE Concatenate(first,second: ARRAY OF CHAR; VAR result: ARRAY OF CHAR);   (* IBM PC DM compatibility *)
| PROCEDURE Copy(from: ARRAY OF CHAR; startIndex, nrOfChars: INTEGER; VAR to: ARRAY OF CHAR);

(*******************************************              DMSystem              *******************************************)

  CONST startUpLevel = 1;    maxLevel = 5;

  PROCEDURE CurrentDMLevel(): CARDINAL;     PROCEDURE LevelisDMLevel(l: CARDINAL): BOOLEAN;
| PROCEDURE TopDMLevel(): CARDINAL;          PROCEDURE DoOnSubProgLevel(l: CARDINAL; p: PROC);

| PROCEDURE InstallInitProc(ip: PROC; VAR done: BOOLEAN);       PROCEDURE ExecuteInitProcs;
| PROCEDURE InstallTermProc(tp: PROC; VAR done: BOOLEAN);       PROCEDURE ExecuteTermProcs;

| PROCEDURE MainScreen(): INTEGER;
  PROCEDURE MenuBarHeight() : INTEGER;   PROCEDURE TitleBarHeight(): INTEGER;     PROCEDURE ScrollBarWidth(): INTEGER;
  PROCEDURE ScreenWidth(): INTEGER;       PROCEDURE ScreenHeight(): INTEGER;       PROCEDURE NumberOfColors(): INTEGER;
| PROCEDURE HowManyScreens(): INTEGER;
| PROCEDURE GetScreenSize(screen: INTEGER; VAR x,y,w,h: INTEGER);
| PROCEDURE NumberOfColorsOnScreen(screen: INTEGER): INTEGER;
| PROCEDURE SuperScreen(VAR whichScreen, x,y,w,h, nrOfColors: INTEGER; colorPriority: BOOLEAN);

  CONST unknown = 0;
|   Mac512      =  1;    MacIIx       =  5;    MacIIci     =  9;    SUN  = 101;    IBMPC  = 201;
|   MacPlus     =  2;    MacIIcx      =  6;    MacIIxi     = 10;    SUN3 = 102;    IBMAT  = 202;
|   MacSE       =  3;    MacSE30      =  7;                         SUN3 = 102;    IBMS2  = 203;
|   MacII       =  4;    MacPortable =  8;

  PROCEDURE ComputerSystem(): INTEGER;

  CONST CPU68000     =   1;       CPU8088      = 201;      CPU8186      = 203;
        CPU68010     =   2;       CPU8086      = 202;      CPU8286      = 204;
        CPU68020     =   3;                                CPU8386      = 205;
|       CPU68030     =   4;                                CPU8486      = 206;
|       CUP68040     =   5;
  PROCEDURE CPU(): INTEGER;       PROCEDURE FPU() : BOOLEAN;

| CONST MacKeyboard  = 1;       AExtendKbd         = 4;     StandPortableISOKbd = 7;
|       MacKbdAndPad = 2;       ADBKeyboard        = 5;     EastwoodISOKbd      = 8;
|       MacPlusKbd   = 3;       StandPortableKbd = 6;       SaratogaISOKbd      = 9;
  PROCEDURE Keyboard(): INTEGER;

| CONST  rom64k = 1;       rom128k = 2;       rom256k = 3;       rom512k = 4;
  PROCEDURE RomVersion(): INTEGER;        PROCEDURE SystemVersion(): REAL;

(*******************************************              DMWindowIO            *******************************************)

  TYPE MouseModifiers = (regular, cmded, opted, shifted);         ClickKind = SET OF MouseModifiers;
     DragProc = PROCEDURE (INTEGER, INTEGER);

  VAR WindowIODone: BOOLEAN;

  PROCEDURE PointClicked(x,y: INTEGER; maxDist: INTEGER): BOOLEAN;
  PROCEDURE RectClicked(rect: RectArea): BOOLEAN;
  PROCEDURE PointDoubleClicked(x,y: INTEGER; maxDist: INTEGER): BOOLEAN;
  PROCEDURE RectDoubleClicked(rect: RectArea): BOOLEAN;
| PROCEDURE GetLastClick(VAR x,y: INTEGER; VAR click: ClickKind): BOOLEAN;
| PROCEDURE GetLastDoubleClick(VAR x,y: INTEGER; VAR click: ClickKind): BOOLEAN;
  PROCEDURE GetCurMousePos(VAR x,y: INTEGER);
  PROCEDURE GetLastMouseClick(VAR x,y: INTEGER; VAR click: ClickKind);
```

```
   PROCEDURE DoTillMButReleased(p: PROC);
   PROCEDURE Drag(duringDragP,afterDragP: DragProc);
   PROCEDURE SetContSize(u: Window; contentRect: RectArea);     PROCEDURE GetContSize(u: Window; VAR contentRect: RectArea)
   PROCEDURE SetScrollStep(u: Window; xStep,yStep: INTEGER);   PROCEDURE GetScrollStep(u: Window; VAR xStep, yStep: INTEGE
   PROCEDURE GetScrollBoxPos(u: Window; VAR posX,posY: INTEGER);
|  PROCEDURE SetScrollBoxPos(u: Window; posX,posY: INTEGER);
   PROCEDURE GetScrollBoxChange(u: Window; VAR changeX,changeY: INTEGER);
   PROCEDURE AutoScrollProc(u: Window);
   PROCEDURE SetScrollProc(u: Window; scrollP: RestoreProc);   PROCEDURE GetScrollProc(u: Window; VAR scrollP: RestoreProc
   PROCEDURE ScrollContent(u: Window; dx,dy: INTEGER);          PROCEDURE MoveOriginTo(u: Window; x0,y0: INTEGER);
   PROCEDURE SelectForOutput(u: Window);                        PROCEDURE CurrentOutputWindow(): Window;

   TYPE PaintMode = (replace, paint, invert, erase);
     Hue = [0..359];      GreyContent = (light, lightGrey, grey, darkGrey, dark);          Saturation = [0..100];
     Color = RECORD hue: Hue; greyContent: GreyContent; saturation: Saturation; END;
     PatLine = BYTE;      Pattern = ARRAY [0..7] OF PatLine;

   VAR pat: ARRAY [light..dark] OF Pattern;      black, white, red, green, blue, cyan, magenta, yellow : Color;

   PROCEDURE SetMode(mode: PaintMode);                      PROCEDURE GetMode(VAR mode: PaintMode);
   PROCEDURE SetBackground(c: Color; pat: Pattern);        PROCEDURE GetBackground(VAR c: Color; VAR pat: Pattern);
   PROCEDURE SetColor(c: Color);                            PROCEDURE GetColor(VAR c: Color);
   PROCEDURE SetPattern(p: Pattern);                        PROCEDURE GetPattern(VAR p: Pattern);
   PROCEDURE IdentifyPos(x,y: INTEGER; VAR line,col: CARDINAL);
   PROCEDURE IdentifyPoint(line,col: CARDINAL; VAR x,y: INTEGER);
   PROCEDURE MaxCol(): CARDINAL;                            PROCEDURE MaxLn(): CARDINAL;
   PROCEDURE CellWidth(): INTEGER;                          PROCEDURE CellHeight(): INTEGER;
   PROCEDURE BackgroundWidth(): INTEGER;                    PROCEDURE BackgroundHeight(): INTEGER;
   PROCEDURE SetEOWAction(u: Window; action: PROC);        PROCEDURE GetEOWAction(u: Window; VAR action: PROC);
   PROCEDURE EraseContent;                                  PROCEDURE RedrawContent;
   PROCEDURE SetClipping(cr: RectArea);                     PROCEDURE GetClipping(VAR cr: RectArea);
   PROCEDURE RemoveClipping;

   TYPE WindowFont = (Chicago, Monaco, Geneva, NewYork);            FontStyles = (bold, italic, underline);
|    LaserFont = (Times, Helvetica, Courier, Symbol);               FontStyle  = SET OF FontStyles;

   PROCEDURE AssignWindowFont(f: WindowFont; size: CARDINAL);
   PROCEDURE SetWindowFont(wf: WindowFont; size: CARDINAL; style: FontStyle);
   PROCEDURE GetWindowFont(VAR wf: WindowFont; VAR size: CARDINAL; VAR style: FontStyle);
|  PROCEDURE SetLaserFont(lf: LaserFont; size: CARDINAL; style: FontStyle);
|  PROCEDURE GetLaserFont(VAR lf: LaserFont; VAR size: CARDINAL; VAR style: FontStyle);
   PROCEDURE SetPos(line,col: CARDINAL);                    PROCEDURE GetPos(VAR line,col: CARDINAL);
   PROCEDURE ShowCaret(on: BOOLEAN);                        PROCEDURE Invert(on: BOOLEAN);
   PROCEDURE Write(ch: CHAR);                               PROCEDURE WriteString(s: ARRAY OF CHAR);         PROCEDURE WriteL
|  PROCEDURE WriteCard(c,n: CARDINAL);                      PROCEDURE WriteLongCard(lc: LONGCARD; n: CARDINAL);
|  PROCEDURE WriteInt(c: INTEGER; n: CARDINAL);             PROCEDURE WriteLongInt(li: LONGINT; n: CARDINAL);
   PROCEDURE WriteReal(r: REAL; n,dec: CARDINAL);           PROCEDURE WriteRealSci(r: REAL; n,dec: CARDINAL);
|  PROCEDURE WriteLongReal(lr:LONGREAL; n,dec:CARDINAL);  PROCEDURE WriteLongRealSci(lr: LONGREAL; n,dec: CARDINAL);
   PROCEDURE SetPen(x,y: INTEGER);                          PROCEDURE GetPen(VAR x,y: INTEGER);
|  PROCEDURE SetBrushSize(width,height: INTEGER);           PROCEDURE GetBrushSize(VAR width,height: INTEGER);
   PROCEDURE Dot(x,y: INTEGER);                             PROCEDURE LineTo(x,y: INTEGER);
   PROCEDURE Circle(x,y: INTEGER; radius: CARDINAL; filled: BOOLEAN; fillpat: Pattern);
   PROCEDURE Area(r: RectArea; pat: Pattern);               PROCEDURE CopyArea(sourceArea: RectArea; dx,dy: INTEGER);
   PROCEDURE MapArea(sourceArea,destArea: RectArea);
   PROCEDURE DisplayPredefinedPicture(fileName: ARRAY OF CHAR; pictureID: INTEGER; f: RectArea);
   PROCEDURE StartPolygon;                                   PROCEDURE CloseAndFillPolygon(pat: Pattern);
|  PROCEDURE DrawAndFillPoly( nPoints: CARDINAL; VAR x, y: ARRAY OF INTEGER; VAR withEdge: ARRAY OF BOOLEAN;
                              VAR edgeColors: ARRAY OF Color; isFilled: BOOLEAN; fillColor: Color; fillPattern: Pattern )
   TYPE QDVHSelect = (v,h);  QDVHSelectR = [v..h];
     QDPoint = RECORD CASE :INTEGER OF 0: v,h: INTEGER; | 1: vh: ARRAY QDVHSelectR OF INTEGER; END; END;
     QDRect = RECORD CASE :INTEGER OF 0: top,left,bottom,right: INTEGER; | 1: topLeft,botRight: QDPoint; END; END;

   PROCEDURE XYToQDPoint(x,y: INTEGER; VAR p: QDPoint);            PROCEDURE RectAreaToQDRect(r: RectArea; VAR qdr: QDRect)
   PROCEDURE SelectRestoreCopy(u: Window);                          PROCEDURE SetRestoreCopy(u: Window; rcp: ADDRESS);
   PROCEDURE Turn(angle: INTEGER);         PROCEDURE TurnTo(angle: INTEGER);         PROCEDURE Move(distance: CARDINAL);
   PROCEDURE ScaleUC(r: RectArea; xmin,xmax,ymin,ymax: REAL);      PROCEDURE GetUC(VAR r: RectArea; VAR xmin,xmax,ymin,ymax
REAL);
   PROCEDURE ConvertPointToUC(x,y: INTEGER; VAR xUC,yUC: REAL);   PROCEDURE ConvertUCToPoint(xUC,yUC: REAL; VAR x,y:
INTEGER);
   PROCEDURE UCFrame;              PROCEDURE EraseUCFrame;            PROCEDURE EraseUCFrameContent;
   PROCEDURE SetUCPen(xUC,yUC: REAL);                                 PROCEDURE GetUCPen(VAR xUC,yUC: REAL);
   PROCEDURE UCDot(xUC,yUC: REAL);                                    PROCEDURE UCLineTo(xUC,yUC: REAL);
   PROCEDURE PlotSym(ch: CHAR);

(******************************************                DMWindows              ******************************************

   CONST nonexistent = NIL;

   TYPE Window;      WindowKind = (GrowOrShrinkOrDrag, FixedSize, FixedLocation, FixedLocTitleBar);
|     ModalWindowKind = (DoubleFrame, SingleFrameShadowed);
      ScrollBars = (WithVerticalScrollBar, WithHorizontalScrollBar, WithBothScrollBars, WithoutScrollBars);
      CloseAttr = (WithCloseBox, WithoutCloseBox);
      ZoomAttr = (WithZoomBox, WithoutZoomBox);
      RectArea = RECORD x,y,w,h: INTEGER END;
      WindowFrame = RectArea;
      WFFixPoint = (bottomLeft, topLeft);
      RestoreProc = PROCEDURE (Window);
      CloseProc = PROCEDURE (Window, VAR BOOLEAN);
      WindowProc = PROCEDURE (Window);

   VAR background: Window; WindowsDone: BOOLEAN;

   PROCEDURE NoBackground;
   PROCEDURE OuterWindowFrame(innerf: WindowFrame; wk: WindowKind; s: ScrollBars; VAR outerf: RectArea);
   PROCEDURE InnerWindowFrame(outerf: WindowFrame; wk: WindowKind; s: ScrollBars; VAR innerf: RectArea);
   PROCEDURE CreateWindow(VAR u: Window; wk: WindowKind; s: ScrollBars; c: CloseAttr; z: ZoomAttr;
                          fixPoint: WFFixPoint; f: WindowFrame; title: ARRAY OF CHAR; Repaint: RestoreProc);
|  PROCEDURE CreateModalWindow(VAR u: Window; wk: ModalWindowKind; s: ScrollBars; f: WindowFrame; Repaint: RestoreProc);
   PROCEDURE UsePredefinedWindow(VAR u: Window; fileName: ARRAY OF CHAR; windowID: INTEGER; fixPoint: WFFixPoint; Repaint
RestoreProc);
   PROCEDURE RedefineWindow(u: Window; f: WindowFrame);              PROCEDURE RedrawTitle(u: Window; title: ARRAY OF CHAR);
   PROCEDURE DummyRestoreProc(u: Window);                             PROCEDURE AutoRestoreProc(u: Window);
   PROCEDURE SetRestoreProc(u: Window; r: RestoreProc);              PROCEDURE GetRestoreProc(u: Window; VAR r: RestoreProc);
   PROCEDURE StartAutoRestoring(u:Window; r: RectArea);              PROCEDURE StopAutoRestoring(u: Window);
   PROCEDURE AutoRestoring(u: Window): BOOLEAN;                       PROCEDURE GetHiddenBitMapSize(u: Window; VAR r: RectArea
   PROCEDURE UpdateWindow(u: Window);                                 PROCEDURE InvalidateContent(u: Window);
   PROCEDURE SetCloseProc(u: Window; cp: CloseProc);                 PROCEDURE GetCloseProc(u: Window; VAR cp: CloseProc);
   PROCEDURE GetWindowFrame(u: Window; VAR f: WindowFrame);          PROCEDURE GetWFFixPoint(u: Window; VAR loc: WFFixPoint);
   PROCEDURE DoForAllWindows(action: WindowProc);
|  PROCEDURE UseWindowModally(u: Window; VAR terminateModalDialog, cancelModalDialog: BOOLEAN);
   PROCEDURE PutOnTop(u: Window);                                     PROCEDURE FrontWindow(): Window;
   PROCEDURE RemoveWindow(VAR u: Window);                             PROCEDURE RemoveAllWindows;
   PROCEDURE WindowExists(u: Window): BOOLEAN;
|  PROCEDURE AttachWindowObject(u: Window; obj: ADDRESS);            PROCEDURE WindowObject(u: Window): ADDRESS;
```

```
(======================================       O P T I O N A L    M O D U L E S
=========================================)

(******************************************             DM2DGraphs              ******************************************)

  TYPE Graph;    Curve;
     LabelString    = ARRAY[0..255] OF CHAR;
    GridFlag        = ( withGrid, withoutGrid) ;
    ScalingType    = ( lin, log, negLog );
     PlottingStyle = ( solid, slash, slashDot, dots, hidden, wipeout );
    Range = RECORD  min,max : REAL  END;
     AxisType = RECORD range: Range; scale: ScalingType; dec: CARDINAL; tickD: REAL; label: LabelString; END;
     GraphProc = PROCEDURE(Graph);

   VAR DM2DGraphsDone: BOOLEAN;

   PROCEDURE DefineGraph(VAR g: Graph; u: Window; r: RectArea; xAxis, yAxis: AxisType; grid: GridFlag);
   PROCEDURE SetNegLogMin(nlm: REAL);
   PROCEDURE DefineCurve(g: Graph; VAR c: Curve; col: Color; style: PlottingStyle; sym: CHAR);
   PROCEDURE RedefineGraph(g: Graph; r: RectArea; xAxis,yAxis :AxisType; grid: GridFlag);
   PROCEDURE RedefineCurve(c: Curve; col: Color; style: PlottingStyle; sym: CHAR);
   PROCEDURE ClearGraph(g: Graph);
   PROCEDURE DrawGraph(g: Graph);
   PROCEDURE DoForAllGraphs(u: Window; gp: GraphProc);
   PROCEDURE DrawLegend(c: Curve; x,y: INTEGER; comment: ARRAY OF CHAR);
  PROCEDURE RemoveGraph(VAR g: Graph);                    PROCEDURE RemoveAllGraphs(u: Window);
   PROCEDURE RemoveCurve(VAR c: Curve);
   PROCEDURE Plot(curve: Curve;   newX,newY: REAL);
   PROCEDURE Move(c: Curve; x,y: REAL);
   PROCEDURE PlotSym(g: Graph; x,y: REAL; sym: CHAR);
   PROCEDURE ConvertToPoint(g: Graph; xReal,yReal: REAL; VAR xInt,yInt: INTEGER);
   PROCEDURE PlotCurve(c: Curve; nrOfPoints: CARDINAL; x,y: ARRAY OF REAL);
   PROCEDURE WindowToGraphPoint( g: Graph;  xInt,yInt: INTEGER; VAR xReal,yReal: REAL );
  PROCEDURE GraphExists( g: Graph ) : BOOLEAN;            PROCEDURE CurveExists( g: Graph;  c: Curve ) : BOOLEAN;

(******************************************              DMAlerts               ******************************************)

   PROCEDURE WriteMessage(line,col: CARDINAL; msg: ARRAY OF CHAR);
   PROCEDURE ShowAlert(height,width: CARDINAL; WriteMessages: PROC);
   PROCEDURE ShowPredefinedAlert(fileName: ARRAY OF CHAR; alertID: INTEGER; str1,str2,str3,str4: ARRAY OF CHAR);

(******************************************             DMClipboard             ******************************************)

   TYPE EditCommands = ( undo, cut, copy, paste, clear );

|  VAR ClipboardDone: BOOLEAN;

   PROCEDURE InstallEditMenu ( UndoProc, CutProc, CopyProc, PasteProc, ClearProc: PROC );
  PROCEDURE EnableEditMenu;                                        PROCEDURE DisableEditMenu;
   PROCEDURE EnableEditCommand( whichone : EditCommands);          PROCEDURE DisableEditCommand( whichone : EditCommands);

|  PROCEDURE  PutPictureIntoClipboard;
|  PROCEDURE  GetPictureFromClipboard (simultaneousDisplay: BOOLEAN; destRect: RectArea);
|  PROCEDURE  PutTextIntoClipboard;
|  PROCEDURE  GetTextFromClipboard (simultaneousDisplay: BOOLEAN; destRect: RectArea; fromLine: LONGINT);

(******************************************             DMEditFields            ******************************************)

   CONST nonexistent = NIL;

   TYPE EditItem;          RadioBut;        EditHandler = PROCEDURE(EditItem);
      ItemType = (charField, stringField, textField, cardField, intField, realField,
                  pushButton, radioButtonSet, checkBox, scrollBar);
     Direction = (horizontal, vertical);

   VAR EditFieldsDone: BOOLEAN;

   PROCEDURE CharField(u: Window; VAR ei: EditItem; x,y: INTEGER; ch: CHAR; charset: ARRAY OF CHAR);
   PROCEDURE StringField(u: Window; VAR ei: EditItem; x,y: INTEGER; fw: CARDINAL; string: ARRAY OF CHAR);
   PROCEDURE TextField(u: Window; VAR ei: EditItem; x,y: INTEGER; fw,lines: CARDINAL; string: ARRAY OF CHAR);
   PROCEDURE CardField(u: Window; VAR ei: EditItem; x,y: INTEGER; fw: CARDINAL; card: CARDINAL; minCard,maxCard: CARDINAL);
|  PROCEDURE LongCardField(u: Window; VAR ei: EditItem; x,y: INTEGER; fw: CARDINAL; card: LONGCARD; minCard,maxCard:
LONGCARD);
   PROCEDURE IntField(u: Window; VAR ei: EditItem; x,y: INTEGER; fw: CARDINAL; int: INTEGER; minInt,maxInt: INTEGER);
|  PROCEDURE LongIntField(u: Window; VAR ei: EditItem; x,y: INTEGER; fw: CARDINAL; int: LONGINT; minInt,maxInt: LONGINT);
   PROCEDURE RealField(u: Window; VAR ei: EditItem; x,y: INTEGER; fw: CARDINAL; real: REAL; minReal,maxReal: REAL);
|  PROCEDURE LongRealField(u: Window; VAR ei: EditItem; x,y: INTEGER; fw: CARDINAL; real: LONGREAL; minReal,maxReal:
LONGREAL);
   PROCEDURE PushButton(u: Window; VAR ei: EditItem; x,y: INTEGER; buttonWidth: CARDINAL; buttonText: ARRAY OF CHAR;
                        pushButtonAction: PROC);
|  PROCEDURE  UseAsDefaultButton(pushButton: EditItem);
   PROCEDURE BeginRadioButtonSet(u: Window; VAR ei: EditItem);
   PROCEDURE RadioButton(VAR radButt: RadioBut; x,y: INTEGER; text: ARRAY OF CHAR);
    PROCEDURE  EndRadioButtonSet(checkedRadioButton: RadioBut);
   PROCEDURE CheckBox(u: Window; VAR ei: EditItem; x,y: INTEGER; text: ARRAY OF CHAR; boxChecked: BOOLEAN);
   PROCEDURE ScrollBar(u: Window; VAR ei: EditItem; x, y, length: INTEGER; sbd: Direction; minVal,maxVal: REAL;
                        smallStep, bigStep: REAL; curVal: REAL; actionProc: PROC);

   PROCEDURE  SetChar(ei: EditItem; newCh:CHAR);
   PROCEDURE  SetString(ei: EditItem; newStr: ARRAY OF CHAR);
|  PROCEDURE SetText(ei: EditItem; VAR text: ARRAY OF CHAR);
|  PROCEDURE SetCardinal(ei: EditItem;  newValue: CARDINAL);      PROCEDURE  SetLongCardinal(ei: EditItem;   newValue:
LONGCARD);
|  PROCEDURE SetInteger(ei: EditItem;   newValue: INTEGER);        PROCEDURE  SetLongInteger(ei: EditItem;   newValue: LONGINT);
|  PROCEDURE SetReal(ei: EditItem; newValue: REAL);                 PROCEDURE  SetLongReal(ei: EditItem; newValue: LONGREAL);
    PROCEDURE  SetRadioButtonSet(ei: EditItem; checkedRadioButton: RadioBut);
   PROCEDURE  SetCheckBox(ei: EditItem; boxChecked: BOOLEAN);
|  PROCEDURE  SetScrollBar(ei: EditItem; newValue: REAL);

   PROCEDURE  IsChar(ei: EditItem; VAR ch:CHAR): BOOLEAN;
   PROCEDURE  GetString(ei: EditItem; VAR str: ARRAY OF CHAR);
|  PROCEDURE GetText(ei: EditItem; VAR text: ARRAY OF CHAR);
|  PROCEDURE IsCardinal(ei: EditItem; VAR c: CARDINAL): BOOLEAN; PROCEDURE  IsLongCardinal(ei: EditItem; VAR c: LONGCARD):
BOOLEAN;
|  PROCEDURE IsInteger(ei: EditItem; VAR i: INTEGER): BOOLEAN;    PROCEDURE  IsLongInteger(ei: EditItem; VAR i: LONGINT):
BOOLEAN;
```

```
| PROCEDURE IsReal(ei: EditItem; VAR r: REAL): BOOLEAN;           PROCEDURE IsLongReal(ei: EditItem; VAR r: LONGREAL):
BOOLEAN;
   PROCEDURE GetRadioButtonSet(ei: EditItem; VAR checkedRadioButton: RadioBut);
   PROCEDURE GetCheckBox(ei: EditItem; VAR boxChecked: BOOLEAN);
| PROCEDURE GetScrollBar(ei: EditItem; VAR r: REAL);

| PROCEDURE InstallEditHandler(u: Window; eh: EditHandler);       PROCEDURE GetEditHandler(u: Window; VAR eh: EditHandler)
| PROCEDURE SelectField(ei: EditItem);                              PROCEDURE ClearFieldSelection (u: Window);

| PROCEDURE EnableItem(ei: EditItem);    PROCEDURE DisableItem(ei: EditItem);      PROCEDURE IsEnabled(ei: EditItem): BOOLE

  PROCEDURE EditItemExists(ei: EditItem) : BOOLEAN;                PROCEDURE GetEditItemType(ei: EditItem; VAR it: ItemType
  PROCEDURE RemoveEditItem(VAR ei: EditItem);                      PROCEDURE RemoveAllEditItems(u: Window);
| PROCEDURE AttachEditFieldObject(ei: EditItem; obj: ADDRESS);   PROCEDURE EditFieldObject(ei: EditItem): ADDRESS;

(*****************************************              DMEntryForms            *****************************************

   VAR FieldInstalled: BOOLEAN;

   TYPE FormFrame = RECORD x,y: INTEGER; lines,columns: CARDINAL END;   DefltUse = (useAsDeflt, noDeflt);    RadioButtonID;

   PROCEDURE WriteLabel(line,col: CARDINAL; text: ARRAY OF CHAR);
   PROCEDURE CharField(line,col: CARDINAL; VAR ch: CHAR; du: DefltUse; charset: ARRAY OF CHAR);
   PROCEDURE StringField(line,col: CARDINAL; fw: CARDINAL; VAR string: ARRAY OF CHAR; du: DefltUse);
   PROCEDURE CardField(line,col: CARDINAL; fw: CARDINAL; VAR card: CARDINAL; du: DefltUse; minCard,maxCard: CARDINAL);
| PROCEDURE LongCardField (line,col: CARDINAL; fw: CARDINAL; VAR longCard: LONGCARD; du: DefltUse; minLCard,maxLCard:
LONGCARD);
   PROCEDURE IntField(line,col: CARDINAL; fw: CARDINAL; VAR int: INTEGER; du: DefltUse; minInt,maxInt: INTEGER);
| PROCEDURE LongIntField (line,col: CARDINAL; fw: CARDINAL; VAR longInt: LONGINT; du: DefltUse; minLInt,maxLInt: LONGINT
   PROCEDURE RealField(line,col: CARDINAL; fw: CARDINAL; VAR real: REAL; du: DefltUse; minReal,maxReal: REAL);
| PROCEDURE LongRealField (line,col: CARDINAL; fw,dig: CARDINAL; fmt: RealFormat; VAR longReal: LONGREAL; du: DefltUse;
                          minLReal,maxLReal: LONGREAL);
   PROCEDURE PushButton(line,col: CARDINAL; buttonText: ARRAY OF CHAR; buttonWidth: CARDINAL; pushButtonAction: PROC);
   PROCEDURE DefineRadioButtonSet(VAR radioButtonVar: RadioButtonID);
   PROCEDURE RadioButton(VAR radButt: RadioButtonID; line,col: CARDINAL; text: ARRAY OF CHAR);
   PROCEDURE CheckBox(line,col: CARDINAL; text: ARRAY OF CHAR; VAR checkBoxVar: BOOLEAN);
   PROCEDURE UseEntryForm(bf: FormFrame; VAR ok: BOOLEAN);

(*****************************************                DMFiles              *****************************************

  CONST EOL = 36C;

   TYPE Response = (done, filenotfound, volnotfound, cancelled, unknownfile, toomanyfiles, diskfull, memfull, notdone);
     HiddenFileInfo;               IOMode = (reading, writing);
     TextFile = RECORD
                  res:        Response;
                   filename:   ARRAY [0..255] OF CHAR;
                  path:        ARRAY [0..63] OF CHAR;
                  curIOMode:  IOMode;
                  curChar:    CHAR;
                   fhint: HiddenFileInfo;
               END;

   VAR legalNum: BOOLEAN;

   PROCEDURE GetExistingFile(VAR f: TextFile; prompt: ARRAY OF CHAR);
| PROCEDURE SetFileFilter(f1,f2,f3,f4: ARRAY OF CHAR);                     PROCEDURE GetFileFilter(VAR f1,f2,f3,f4: ARRAY O
CHAR);
   PROCEDURE CreateNewFile(VAR f: TextFile; prompt, defaultName: ARRAY OF CHAR);
   PROCEDURE Lookup(VAR f: TextFile; filename: ARRAY OF CHAR; new: BOOLEAN);
| PROCEDURE Close(VAR f: TextFile);                                        PROCEDURE IsOpen(VAR f: TextFile): BOOLEAN;

  PROCEDURE Delete(VAR f: TextFile);                                        PROCEDURE Rename(VAR f: TextFile; filename: ARRA
OF CHAR);
  PROCEDURE Reset(VAR f: TextFile);                                        PROCEDURE Rewrite(VAR f: TextFile);
| PROCEDURE Append(VAR f: TextFile);                                        PROCEDURE FileSize(VAR f: TextFile): LONGINT;

   PROCEDURE EOF(VAR f: TextFile): BOOLEAN;
  PROCEDURE ReadByte(VAR f: TextFile; VAR b: BYTE);                       PROCEDURE WriteByte(VAR f: TextFile; b: BYTE);
  PROCEDURE ReadChar(VAR f: TextFile; VAR ch: CHAR);                      PROCEDURE WriteChar(VAR f: TextFile; ch: CHAR);
   PROCEDURE WriteEOL(VAR f: TextFile);
   PROCEDURE ReadChars(VAR f: TextFile; VAR string: ARRAY OF CHAR);       PROCEDURE WriteChars(VAR f: TextFile; string: AR
OF CHAR);
  PROCEDURE SkipGap(VAR f: TextFile);                                      PROCEDURE Again(VAR f: TextFile);
  PROCEDURE GetCardinal(VAR f: TextFile; VAR c: CARDINAL);                PROCEDURE GetLongCard(VAR f: TextFile; VAR c:
LONGCARD);
   PROCEDURE PutCardinal(VAR f: TextFile; c: CARDINAL; n: CARDINAL);      PROCEDURE PutLongCard(VAR f: TextFile; lc:
LONGCARD; n: CARDINAL);
  PROCEDURE GetInteger(VAR f: TextFile; VAR i: INTEGER);                  PROCEDURE GetLongInt(VAR f: TextFile; VAR i:
LONGINT);
   PROCEDURE PutInteger(VAR f: TextFile; i: INTEGER; n: CARDINAL);        PROCEDURE PutLongInt(VAR f: TextFile; li: LONGIN
n: CARDINAL);
  PROCEDURE GetReal(VAR f: TextFile; VAR x: REAL);                        PROCEDURE GetLongReal(VAR f: TextFile; VAR x:
LONGREAL);
  PROCEDURE PutReal(VAR f: TextFile; x: REAL; n, dec: CARDINAL);         PROCEDURE PutRealSci(VAR f: TextFile; x: REAL; n
CARDINAL);
   PROCEDURE PutLongReal(VAR f: TextFile; lr: LONGREAL; n,dec: CARDINAL);
   PROCEDURE PutLongRealSci(VAR f: TextFile; lr: LONGREAL; n,dec: CARDINAL);

(*****************************************              DMPrinting          *****************************************)

| TYPE PrinterFont = (chicago, newYork, geneva, monaco, times, helvetica, courier, symbol);

   PROCEDURE PageSetup;                               PROCEDURE SetHeaderText(h: ARRAY OF CHAR);
   PROCEDURE SetSubHeaderText(sh: ARRAY OF CHAR); PROCEDURE SetFooterText(f: ARRAY OF CHAR);
   PROCEDURE PrintPicture;
| PROCEDURE PrintText(font: PrinterFont; fontSize: INTEGER; tabwidth: INTEGER;);

(********************************************            DMPTFiles          *****************************************)

| VAR PTFileDone: BOOLEAN;

| PROCEDURE DumpPicture(VAR f: TextFile);
| PROCEDURE LoadPicture (VAR f: TextFile; simulDisplay: BOOLEAN; destRect: RectArea);
| PROCEDURE DumpText(VAR f: TextFile);
| PROCEDURE LoadText (VAR f: TextFile; simulDisplay: BOOLEAN; destRect: RectArea; fromLine: LONGINT);

(********************************************            DMQuestions        *****************************************)

| PROCEDURE Ask(question: ARRAY OF CHAR; butTexts: ARRAY OF CHAR; butWidth: CARDINAL; VAR answer: INTEGER);
| PROCEDURE ShowPredefinedQuestion(fileName: ARRAY OF CHAR; alertID: INTEGER;
                               str1,str2,str3,str4: ARRAY OF CHAR; VAR answer: INTEGER);

(********************************************             DMTextFields       *****************************************)
```

```
| TYPE TextPointer = POINTER TO TextSegment;   TextSegment = ARRAY [0..32000] OF CHAR;

| PROCEDURE RedefineTextField(textField: EditItem; wf: WindowFrame; withFrame: BOOLEAN);
| PROCEDURE WrapText(textField: EditItem; wrap: BOOLEAN);
| PROCEDURE CopyWTextIntoTextField(textField: EditItem; VAR done: BOOLEAN);
| PROCEDURE CopyTextFromFieldToWText(textField: EditItem);

| PROCEDURE SetSelection(textField: EditItem; beforeCh,afterCh: INTEGER);
| PROCEDURE GetSelection(textField: EditItem; VAR beforeCh,afterCh: INTEGER);
| PROCEDURE GetSelectedChars(textField: EditItem; VAR text: ARRAY OF CHAR);
| PROCEDURE DeleteSelection(textField: EditItem);
| PROCEDURE InsertBeforeCh(textField: EditItem; VAR text: ARRAY OF CHAR; beforeCh: INTEGER);

| PROCEDURE GetTextSizes(textField: EditItem; VAR curTextLength, nrLns, charHeight, firstLnVis,lastLnVis: INTEGER);
| PROCEDURE GrabText(textField: EditItem; VAR txtbeg: TextPointer; VAR curTextLength: INTEGER);
| PROCEDURE ReleaseText(textField: EditItem);
| PROCEDURE FindInText(textField: EditItem; stringToFind: ARRAY OF CHAR; VAR firstCh,lastCh: INTEGER): BOOLEAN;
| PROCEDURE ScrollText(textField: EditItem; dcols,dlines: INTEGER);
| PROCEDURE ScrollTextWithWindowScrollBars(textField: EditItem);
| PROCEDURE AddScrollBarsToText(textField: EditItem; withVerticalScrollBar, withHorizontalScrollBar: BOOLEAN);

(*******************************************           DMWPictIO           *******************************************)

  PROCEDURE StartPictureSave;                                                        PROCEDURE StopPictureSave;
  PROCEDURE PausePictureSave;                                                        PROCEDURE ResumePictureSave;
| PROCEDURE DisplayPicture(ownerWindow: Window; destRect: RectArea);                 PROCEDURE DiscardPicture;

  PROCEDURE SetPictureArea(r: RectArea);                                   PROCEDURE GetPictureArea(VAR r: RectArea);
| PROCEDURE SetHairLineWidth(f: REAL);                                     PROCEDURE GetHairLineWidth(VAR f: REAL);

(*******************************************           DMWTextIO           *******************************************)

| PROCEDURE StartTextSave;                                                           PROCEDURE StopTextSave;
| PROCEDURE PauseTextSave;                                                           PROCEDURE ResumeTextSave;
| PROCEDURE DisplayText(ownerWindow: Window; destRect: RectArea; fromLine: LONGINT);   PROCEDURE DiscardText;

| PROCEDURE GrabWText(VAR txtbeg: ADDRESS; VAR curTextLength: LONGINT);    PROCEDURE ReleaseWText;
| PROCEDURE AppendWText(txtbeg: ADDRESS; length: LONGINT);                   PROCEDURE SetWTextSize(newTextLength: LONGINT);

(==================================================         - E N D -
==================================================)

The Dialog Machine may be freely copied but not for profit!                               | Different from Version
1.0
```

I.2 ModelWorks Client Interface and Optional Modules

he following listing of the client interface is identical for all ModelWorks versions (V2.0, V2.0/Reflex, V1.1/PC, and V2.0/II). For differences in behavior see part III *Reference*.

```
ModelWorks Version 2.0 (May 1990)          © 1989, 1990 Andreas Fischlin, Olivier Roth, Dimitrios Gyalistras, and Markus
Ulrich and
Swiss Federal Institute of Technology Zurich ETHZ, Switzerland.

(===================      C L I E N T   I N T E R F A C E   M O D U L E S       ====================)

(****************************    SimBase  *********************************)

   (* Declaration of models and model objects: *)
   (* --------------------------------------    *)

   TYPE
     Model;
      IntegrationMethod = (Euler, Heun, RungeKutta4, RungeKutta45Var, stiff, discreteTime);
     RTCType = (rtc, noRtc);
      StashFiling = (writeOnFile, notOnFile);
      Tabulation = (writeInTable, notInTable);
     Graphing = (isX, isY, isZ, notInGraph);

   PROCEDURE DeclM(VAR m: Model; defaultMethod: IntegrationMethod;
                    initial, input, output, dynamic, terminal: PROC;
                   installModelObjects: PROC;
                    descriptor, identifier: ARRAY OF CHAR; about: PROC);
   PROCEDURE DeclSV(VAR s, ds: REAL; initial, minRange, maxRange: REAL;
                     descriptor, identifier, unit: ARRAY OF CHAR);
   PROCEDURE DeclP(VAR p: REAL; defaultVal, minVal, maxVal: REAL;
                   runTimeChange: RTCType;
                    descriptor, identifier, unit: ARRAY OF CHAR);
   PROCEDURE DeclMV(VAR mv: REAL; defaultScaleMin, defaultScaleMax: REAL;
                     descriptor, identifier, unit: ARRAY OF CHAR;
                      defaultSF: StashFiling; defaultT: Tabulation; defaultG: Graphing);
   PROCEDURE SelectM (m: Model; VAR done: BOOLEAN);
   PROCEDURE NoInitialize;
   PROCEDURE NoInput;
   PROCEDURE NoOutput;
   PROCEDURE NoDynamic;
   PROCEDURE NoTerminate;
   PROCEDURE NoModelObjects;
   PROCEDURE NoAbout;
   PROCEDURE DoNothing;

   (* Modifying of models and model objects: *)
   (* ------------------------------------    *)

   PROCEDURE GetDefltM (VAR m: Model; VAR defaultMethod: IntegrationMethod;
                         VAR initialize, input, output, dynamic, terminate: PROC;
                         VAR descriptor, identifier: ARRAY OF CHAR; VAR about: PROC);
   PROCEDURE SetDefltM (VAR m: Model; defaultMethod: IntegrationMethod;
                             initialize, input, output, dynamic, terminate: PROC;
                             descriptor, identifier: ARRAY OF CHAR; about: PROC);
   PROCEDURE GetDefltSV     (m: Model; VAR s: REAL; VAR defaultInit, minCurInit, maxCurInit: REAL;
                              VAR descriptor, identifier, unit: ARRAY OF CHAR);
   PROCEDURE SetDefltSV     (m: Model; VAR s: REAL; defaultInit, minCurInit, maxCurInit: REAL;
                                 descriptor, identifier, unit: ARRAY OF CHAR);
   PROCEDURE GetDefltP      (m: Model; VAR p: REAL; VAR defaultVal, minVal, maxVal: REAL;
                             VAR runTimeChange: RTCType;
                              VAR descriptor, identifier, unit: ARRAY OF CHAR);
   PROCEDURE SetDefltP      (m: Model; VAR p: REAL; defaultVal, minVal, maxVal: REAL;
                                 runTimeChange: RTCType;
                                  descriptor, identifier, unit: ARRAY OF CHAR);
   PROCEDURE GetDefltMV     (m: Model; VAR mv: REAL; VAR defaultScaleMin, defaultScaleMax: REAL;
                              VAR descriptor, identifier, unit: ARRAY OF CHAR;
                               VAR defaultSF: StashFiling; VAR defaultT: Tabulation;
                             VAR defaultG: Graphing);
   PROCEDURE SetDefltMV     (m: Model; VAR mv: REAL; defaultScaleMin, defaultScaleMax: REAL;
                                  descriptor, identifier, unit: ARRAY OF CHAR;
                                   defaultSF: StashFiling; defaultT: Tabulation;
                                 defaultG: Graphing);

  PROCEDURE GetM (VAR m: Model;                   VAR curMethod: IntegrationMethod);
  PROCEDURE SetM (VAR m: Model;                       curMethod: IntegrationMethod);
  PROCEDURE GetSV     (m: Model; VAR s:   REAL; VAR curInit: REAL);
  PROCEDURE SetSV     (m: Model; VAR s:   REAL;       curInit: REAL);
  PROCEDURE GetP      (m: Model; VAR p:   REAL; VAR curVal: REAL);
  PROCEDURE SetP      (m: Model; VAR p:   REAL;       curVal: REAL);
   PROCEDURE GetMV     (m: Model; VAR mv: REAL; VAR curScaleMin, curScaleMax: REAL;
                         VAR curSF: StashFiling; VAR curT: Tabulation; VAR curG: Graphing);
  PROCEDURE SetMV     (m: Model; VAR mv: REAL;       curScaleMin, curScaleMax: REAL;
                           curSF: StashFiling;      curT: Tabulation;      curG: Graphing);


   (* Removing of models and model objects:   *)
   (* ------------------------------------    *)

  PROCEDURE RemoveM       (VAR m: Model);
  PROCEDURE RemoveSV     (m: Model; VAR s : REAL);
  PROCEDURE RemoveMV     (m: Model; VAR mv: REAL);
  PROCEDURE RemoveP      (m: Model; VAR p : REAL);
   PROCEDURE RemoveAllModels;


   (* Global simulation parameters and project description: *)
   (* -------------------------------------------------     *)

   PROCEDURE CurrentStep(): INTEGER;
   PROCEDURE CurrentTime(): REAL;

   PROCEDURE SetDefltGlobSimPars(      t0, tend, h, er, c, hm: REAL);
   PROCEDURE GetDefltGlobSimPars(VAR t0, tend, h, er, c, hm: REAL);
   PROCEDURE SetDefltProjDescrs(      title,remark,footer: ARRAY OF CHAR;
                                        wtitle,wremark,autofooter,
                                  recM, recSV, recP, recMV, recG: BOOLEAN);
PROCEDURE GetDefltProjDescrs(VAR title,remark,footer: ARRAY OF CHAR;
                              VAR wtitle,wremark,autofooter,
                                  recM, recSV, recP, recMV, recG: BOOLEAN);
PROCEDURE SetDefltIndepVarIdent(descr,ident,unit:    ARRAY OF CHAR);

     PROCEDURE SetMonInterval(hm: REAL); (* only for upward compatibility *)
     PROCEDURE SetIntegrationStep(h: REAL); (* only for upward compatibility *)
     PROCEDURE SetSimTime(t0,tend: REAL); (* only for upward compatibility *)

PROCEDURE SetGlobSimPars(    t0, tend, h, er, c, hm: REAL);
PROCEDURE GetGlobSimPars(VAR t0, tend, h, er, c, hm: REAL);
PROCEDURE SetProjDescrs(     title,remark,footer: ARRAY OF CHAR;
                             wtitle,wremark,autofooter,
                             recM, recSV, recP, recMV, recG: BOOLEAN);
PROCEDURE GetProjDescrs(VAR title,remark,footer: ARRAY OF CHAR;
                        VAR wtitle,wremark,autofooter,
                            recM, recSV, recP, recMV, recG: BOOLEAN);
PROCEDURE SetIndepVarIdent(descr,ident,unit:     ARRAY OF CHAR);

(* Control of simulation run conditions: *)
(* ----------------------------------   *)

TYPE TerminateConditionProcedure = PROCEDURE(): BOOLEAN;
   StartConsistencyProcedure = PROCEDURE(): BOOLEAN;

PROCEDURE InstallStartConsistency(sc: StartConsistencyProcedure);
PROCEDURE InstallTerminateCondition(tc: TerminateConditionProcedure);

(* Control of Display and Monitoring: *)
(* -------------------------------   *)

PROCEDURE TileWindows;
PROCEDURE StackWindows;

TYPE MWWindow = (MIOW, SVIOW, PIOW, MVIOW, TableW, GraphW, AboutMW);

PROCEDURE SetWindowPlace(mww: MWWindow;     x,y,w,h: INTEGER);
PROCEDURE GetWindowPlace(mww: MWWindow; VAR x,y,w,h: INTEGER; VAR isOpen : BOOLEAN);
PROCEDURE SetDefltWindowPlace(mww: MWWindow;     x,y,w,h: INTEGER);
PROCEDURE GetDefltWindowPlace(mww: MWWindow; VAR x,y,w,h: INTEGER; VAR enabled: BOOLEAN);
PROCEDURE CloseWindow(w: MWWindow);

TYPE
   IOWColsDisplay = RECORD
     descrCol, identCol : BOOLEAN;
     CASE iow: MWWindow OF
       MIOW  : m : RECORD
                    integMethCol: BOOLEAN;
                   END(*RECORD*);
     | SVIOW : sv: RECORD
                    unitCol, sVInitCol: BOOLEAN;
                    fw,dec: INTEGER;
                   END(*RECORD*);
     | PIOW  : p : RECORD
                    unitCol, pValCol, pRtcCol: BOOLEAN;
                    fw,dec: INTEGER;
                   END(*RECORD*);
     | MVIOW : mv: RECORD
                      unitCol, scaleMinCol, scaleMaxCol, mVMonSetCol: BOOLEAN;
                    fw,dec: INTEGER;
                   END(*RECORD*);
     END(*CASE*)
   END(*RECORD*);

PROCEDURE SetIOWColDisplay     (mww: MWWindow;     wd: IOWColsDisplay );
PROCEDURE GetIOWColDisplay     (mww: MWWindow; VAR wd: IOWColsDisplay );
PROCEDURE SetDefltIOWColDisplay(mww: MWWindow;     wd: IOWColsDisplay );
PROCEDURE GetDefltIOWColDisplay(mww: MWWindow; VAR wd: IOWColsDisplay );

PROCEDURE DisableWindow(w: MWWindow);
PROCEDURE EnableWindow (w: MWWindow);

PROCEDURE UseCurWSettingsAsDefault;

PROCEDURE SuppressMonitoring;
PROCEDURE ResumeMonitoring;
PROCEDURE DeclClientMonitoring(initmp, mp, termmp: PROC);

PROCEDURE StashFileName  (sfn:     ARRAY OF CHAR);
PROCEDURE SwitchStashFile(newsfn: ARRAY OF CHAR);

PROCEDURE Message(m: ARRAY OF CHAR);

TYPE
   Stain = (coal, snow, ruby, emerald, sapphire, turquoise, pink, gold, autoDefCol);
   LineStyle = (unbroken, broken, dashSpotted, spotted, invisible, purge, autoDefStyle);

CONST               autoDefSym = 200C;

PROCEDURE SetCurveAttrForMV(m: Model; VAR mv: REAL;
                              st: Stain; ls: LineStyle; sym: CHAR);
PROCEDURE GetCurveAttrForMV(m: Model; VAR mv: REAL;
                              VAR st: Stain; VAR ls: LineStyle; VAR sym: CHAR);
PROCEDURE SetDefltCurveAttrForMV(m: Model; VAR mv: REAL;
                                   st: Stain; ls: LineStyle; sym: CHAR);
PROCEDURE GetDefltCurveAttrForMV(m: Model; VAR mv: REAL;
                                   VAR st: Stain; VAR ls: LineStyle; VAR sym: CHAR);

PROCEDURE ClearGraph;
PROCEDURE DumpGraph;

(* Preferences and simulation environment modes: *)
(* ------------------------------------------   *)

PROCEDURE SetDocumentRunAlwaysMode( dra: BOOLEAN );
PROCEDURE GetDocumentRunAlwaysMode( VAR dra: BOOLEAN );

PROCEDURE SetRedrawTableAlwaysMode( rta: BOOLEAN );
PROCEDURE GetRedrawTableAlwaysMode( VAR rta: BOOLEAN );
PROCEDURE SetCommonPageUpRows( rows: CARDINAL );
PROCEDURE GetCommonPageUpRows( VAR rows: CARDINAL );

PROCEDURE SetRedrawGraphAlwaysMode( rga: BOOLEAN );
PROCEDURE GetRedrawGraphAlwaysMode( VAR rga: BOOLEAN );
```

```
   PROCEDURE  SetColorVectorGraphSaveMode(cvgs:  BOOLEAN);
   PROCEDURE  GetColorVectorGraphSaveMode(VAR  cvgs:  BOOLEAN);

(*****************************    SimMaster    *********************************)

   PROCEDURE  RunSimMaster(md: PROC);   (*  must  always  be  called  *)
   PROCEDURE  DeclInitSimSession(issp:  PROC);

   PROCEDURE  SimRun;
   PROCEDURE  PauseRun;
   PROCEDURE  DeclExperiment(e:  PROC);
   PROCEDURE  CurrentSimNr():  INTEGER;

  TYPE
    MWState =
        (noSimulation,   (*no  simulation  going  on*)
        simulating,      (*during  simulation*)
        pause);           (*current  simulation  temporarily  halted*)
    MWSubState =
        (noRun,        (*  simulating  but  not  in  SimMaster.SimRun  *)
        running,       (*  simulating  but  in  SimMaster.SimRun  *)
        noSubState);  (*  state  <>  simulating  *)

   PROCEDURE  GetMWState(VAR  s:  MWState);
   PROCEDURE  GetMWSubState(VAR  ss:  MWSubState);

   PROCEDURE  ExperimentRunning():  BOOLEAN;
   PROCEDURE  ExperimentAborted():  BOOLEAN;


(===========================            O P T I O N A L    M O D U L E S          ===========================)

(*****************************     JulianDays      *********************************)

  CONST
    Jan = 1; Feb = 2; Mar = 3; Apr =  4; Mai =  5; Jun =  6;
    Jul = 7; Aug = 8; Sep = 9; Oct = 10; Nov = 11; Dec = 12;
    Sun = 1; Mon = 2; Tue = 3; Wed =  4; Thur = 5; Fri =  6; Sat =  7;

   PROCEDURE  DateToJulDay(day,month,year:  INTEGER):  LONGINT;
   PROCEDURE  JulDayToDate(julday:  LONGINT;  VAR  day,month,year,weekday:  INTEGER);
   PROCEDURE  LeapYear(yr:  INTEGER):  BOOLEAN;
   PROCEDURE  SetCalendarRange(firstYear,lastYear,firstSunday:  INTEGER);

(*****************************         RandGen      *********************************)

   PROCEDURE  SetSeeds(z0,z1,z2:  INTEGER);  (*defaults:  z0=1,  z1=10000,  z2=3000*)
   PROCEDURE  GetSeeds(VAR  z0,z1,z2:  INTEGER);
   PROCEDURE  Randomize;
   PROCEDURE  ResetSeeds;
   PROCEDURE  U():  REAL;  (*U~(0,1],  cycle  length  >≈  2.78  E13  ~  220  years  for  1000  U/sec*)

(*****************************     RandNormal      *********************************)

   TYPE  URandGen  =  PROCEDURE():  REAL;
   PROCEDURE  InstallU(U:  URandGen);  (*  do  always  call  *)
   PROCEDURE  SetPars(mu,stdDev:  REAL);  (*  defaults  μ  =  0,  stdDev  =  1  *)
   PROCEDURE  GetPars(VAR  mu,stdDev:  REAL);
   PROCEDURE  N():  REAL;  (*  N~(μ,stdDev)  *)
   PROCEDURE  ResetN;  (*  call  after  SetSeeds  for  full  reset  of  N  *)

(*****************************        ReadData      *********************************)

   FROM  DMStrings  IMPORT  String;
   FROM  DMFiles    IMPORT  TextFile;

   VAR  dataF:  TextFile;

   PROCEDURE  OpenADataFile(  VAR  fn:  ARRAY  OF  CHAR;   VAR  ok:  BOOLEAN  );  (*  always  with  dialog  *)
   PROCEDURE  OpenDataFile  (  VAR  fn:  ARRAY  OF  CHAR;   VAR  ok:  BOOLEAN  );  (*  normally  no  dialog  *)
   PROCEDURE  ReReadDataFile;  (*  performs  a  reset  *)
   PROCEDURE  CloseDataFile;

   PROCEDURE  SkipHeaderLine;
   PROCEDURE  ReadHeaderLine(VAR  labels:  ARRAY  OF  String;  VAR  nrVars:  INTEGER  );
                                (*  assign  NIL  to  labels  before  first  use!  *)
   PROCEDURE  ReadLn   (  VAR  txt:  ARRAY  OF  CHAR  );
   PROCEDURE  GetChars(  VAR  str:  ARRAY  OF  CHAR  );
   PROCEDURE  GetStr   (  VAR  str:  String  );
   PROCEDURE  SkipGapOrComment;  (*  skips  <=  "  "  and  "(*  .....  *)"  *)
   PROCEDURE  ReadCharsUnlessAComment(  VAR  string:  ARRAY  OF  CHAR  );

   (*  Used  for  error  messages  only:   desc  -  describes  the  item  to  be  read,
   loc  -  is  location  e.g.  a  line  #  where  error  was  encountered  *)
   PROCEDURE  GetInt  (  desc   :  ARRAY  OF  CHAR;   loc:  INTEGER;
                        VAR  x:  INTEGER;    min,  max:  INTEGER  );
   PROCEDURE  GetReal(  desc   :  ARRAY  OF  CHAR;  loc:   INTEGER;
                        VAR  x:  REAL;        min,  max:  REAL      );
   (*  values  used  if  measurement  is  missing:  *)
   PROCEDURE  SetMissingValCode(      missingValCode:  CHAR);  (*  default  "N";  used  in  dataF  *)
   PROCEDURE  GetMissingValCode(VAR  missingValCode:  CHAR);
   PROCEDURE  SetMissingReal     (      missingReal:  REAL);      (*  default  0.0;  value  used  for  a  real  *)
   PROCEDURE  GetMissingReal     (VAR  missingReal:  REAL);
   PROCEDURE  SetMissingInt      (      missingInt:  INTEGER);   (*  default  0;  value  used  for  an  integer  *)
   PROCEDURE  GetMissingInt      (VAR  missingInt:  INTEGER);

   (*  Segments  are  data  untis  separated  by  eosCode  *)
   PROCEDURE  SetEOSCode(      eosCode:  CHAR  );  (*  default  ASCII  us  (unit  seperator)  37C  *)
   PROCEDURE  GetEOSCode(VAR  eosCode:  CHAR  );
   PROCEDURE  FindSegment(segNr:  CARDINAL;  VAR  found:  BOOLEAN);  (*  first  segNr  =  1  *)
   PROCEDURE  SkipToNextSegment(VAR  done:  BOOLEAN);

   PROCEDURE  AtEOL():  BOOLEAN;
   PROCEDURE  AtEOS():  BOOLEAN;
   PROCEDURE  AtEOF():  BOOLEAN;
   PROCEDURE  TestEOF;  (*  use  only  where  you  don't  expect  EOF  (shows  alert)  *)

   TYPE  Relation  =  (  smaller,  equal,  greater  );
   PROCEDURE  Compare2Strings(  a,  b:  ARRAY  OF  CHAR  ):  Relation;

   CONST  negLogDelta  =  0.01;  (*offset  to  plot  log  scale  if  values  <=  0*)

(*****************************    SimGraphUtils    *********************************)

   FROM  SimBase      IMPORT  Model,  Stain,  LineStyle;
   FROM  DMWindowIO  IMPORT  Color;

   TYPE Curve;              VAR nonexistent : Curve;   (* read only! *)

   PROCEDURE  SelectForOutputGraph;
   PROCEDURE  DefineCurve(  VAR c: Curve;
                            st: Stain;  style: LineStyle;  sym: CHAR );
   PROCEDURE  RemoveCurve(  VAR c: Curve  );
   PROCEDURE  DrawLegend(  c: Curve;   x,  y: INTEGER;   comment: ARRAY OF CHAR );
   PROCEDURE  Plot(  c: Curve;   newX, newY: REAL  );
   PROCEDURE  Move(  c: Curve;   newX, newY: REAL  );
   PROCEDURE  PlotSym(  x,  y: REAL;   sym: CHAR  );
   PROCEDURE  PlotCurve(  c: Curve;  nrOfPoints: CARDINAL;  x,  y: ARRAY  OF  REAL  );
   PROCEDURE  GraphToWindowPoint(  xReal,  yReal: REAL;
                                  VAR xInt, yInt: INTEGER );
   PROCEDURE  WindowToGraphPoint(  xInt,  yInt: INTEGER;
                                  VAR xReal, yReal: REAL );
   PROCEDURE  TimeIsX()  : BOOLEAN;

   TYPE Abscissa = RECORD isMV: POINTER TO REAL; xMin,xMax: REAL END;
   PROCEDURE  CurrentAbscissa(VAR  a:  Abscissa);

   PROCEDURE  TranslStainToColor(  stain:  Stain;   VAR  color:  Color  );
   PROCEDURE  TranslColorToStain(  color:  Color;   VAR  stain:  Stain  );

   TYPE  DisplayTime  =  (  showAtInit,  showAtTerm,  noAutoShow  );
   VAR  timeIsIndep:  REAL;
   PROCEDURE  DeclDispData(  mDepVar      : Model;   VAR  mvDepVar   : REAL;
                            mIndepVar      : Model;   VAR mvIndepVar: REAL;
                         x, v,
                            vLo, vUp       : ARRAY OF REAL;
                           n           : INTEGER;
                            withErrBars: BOOLEAN;
                            dispTime       : DisplayTime      );
   PROCEDURE  DisplayDataNow(  mDepVar  :  Model;   VAR  mvDepVar   :  REAL  );
   PROCEDURE  DisplayAllDataNow;
   PROCEDURE  RemoveDispData(  mDepVar  :  Model;   VAR  mvDepVar   :  REAL  );

(*****************************    SimIntegrate    ********************************)

   PROCEDURE  Integrate  (  m:  Model;  from,  till:  REAL);

(*****************************    TabFunc  ********************************)

   TYPE  TabFUNC;

   PROCEDURE  DeclTabF(  VAR   t          : TabFUNC;
                       xx, yy        : ARRAY OF REAL;
                       NValPairs     : INTEGER;
                       modifiable    : BOOLEAN;
                       tabName,
                       xName, yName,
                        xUnit, yUnit : ARRAY OF CHAR;
                       xMin, xMax,
                       yMin, yMax    : REAL );

   PROCEDURE  SetTabF(  t               : TabFUNC;
                      xx, yy        : ARRAY OF REAL;
                      NValPairs     : INTEGER;
                      modifiable    : BOOLEAN;
                      tabName,
                      xName, yName,
                       xUnit, yUnit : ARRAY OF CHAR;
                      xMin, xMax,
                      yMin, yMax    : REAL );

   PROCEDURE  GetTabF(  t:  TabFUNC;
                      VAR xx, yy        : ARRAY OF REAL;
                      VAR NValPairs     : INTEGER;
                      VAR modifiable    : BOOLEAN;
                      VAR tabName,
                          xName, yName,
                           xUnit, yUnit : ARRAY OF CHAR;
                      VAR xMin, xMax,
                          yMin, yMax    : REAL );

   PROCEDURE  RemoveTabF(  VAR  t:  TabFUNC  );

   PROCEDURE  Yi  (  t:  TabFUNC;  x:  REAL  ):  REAL;  (*  interpolate  only  ELSE  HALT  *)
   PROCEDURE  Yie(  t:  TabFUNC;  x:  REAL  ):  REAL;  (*  inter-  and  extrapolate  *)

(========================================        - E N D -       ========================================)

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