

MODSIM III - A TUTORIAL

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ABSTRACT

This tutorial introduces the MODSIM III language, showing how its simulation "world view" together with its object-oriented architecture and built in graphics contribute to successful simulation model building.

1 WHAT IS MODSIM III?

Discrete systems simulation is one of the few truly new capabilities offered by the computing revolution. Computer simulation models provides us with a fascinating means to develop insight into the behaviors of the complex non-deterministic systems which surround us - in communications networks, transportation logistics, business and manufacturing processes, to name a few. These systems are costly to develop and modify. Feasibility analysis and performance prediction through simulation can greatly reduce the risk of failure or wasteful expense.

Simulation is an exploratory technique. We develop a model which represents our best understanding of a proposed system or modification. We run the model in the hope that it will confirm our design intuition. If it does not we endeavor to understand why, and use this knowledge to refine the model. Ultimately, we will use the model to explain and justify decisions affecting the real-world system.

So, simulation serves three principal roles: to help us articulate a coherent description of a system; to validate its dynamic behavior to our satisfaction; and, then to communicate this to colleagues and decision makers. These steps are commonly iterative. It is usually wise to begin with a high-level abstraction of the system, allowing the model to evolve as we gain greater understanding of system behavior. Furthermore, the system itself may change in this rapidly changing environment, requiring changes to the model.

For the simulation study to be effective, the model behavior should be presented in an understandable way, typically using animation. Ideally, domain experts should be involved in construction and validation of the

model. Finally, the whole exercise must be completed within a useful time-frame, or it will serve little purpose.

Before embarking on model development, it may be prudent to look for a suitable, off-the-shelf, domain-specific simulator. Frequently, however, unique characteristics or fidelity requirements dictate the need for a custom model. The characteristics of simulation modeling, then, make some special demands of the model development environment. The modeler needs help in the conceptualization of systems with dynamic, interacting, probabilistic behaviors. The model should be understandable, maintainable, and should lend itself to incremental addition of detail. The environment should support graphical interaction for scenario development and animated model execution.

This tutorial will introduce the benefits of using an object oriented language specially developed for simulation, and enhanced with comprehensive graphics support. MODSIM III combines CACI's experience with simulation programming over three decades with advances in software engineering to offer the most productive environment for the development of large, complex, evolutionary, custom models.

Examples of MODSIM III's simulation features, and the benefits of object-oriented architecture, are demonstrated below using code fragments from a hypothesized airport/airspace planning model. Such a model might be concerned with the representation of aircraft, flight duration, air traffic controllers, runway allocation procedures, and so on. To be of any interest, such a model must represent multiple aircraft in flight concurrently, and delays due to contending requests for resources, such as runways.

2 DEFINITION BLOCK-AN INTERFACE DESCRIPTION

In support of modular program construction, objects in MODSIM III are described in two separate blocks of code. The Definition block describes the object type by declaring its variables and methods. This is the object description as it will be referred to by other objects in

the simulation, and it provides the formal interface specification. An example of a Definition block for an aircraft object is shown below.

```
Aircraft = OBJECT;
  BestCruise : INTEGER;
  InFlight    : Boolean;
  ASK METHOD SetCruise (IN speed:INTEGER;
  TELL METHOD FlyDistance (IN
distance:INTEGER);
  END OBJECT;
```

The Definition block for an aircraft object declares the variables and methods that aircraft objects use in the simulation model. The information the aircraft knows is contained in its variables. In this simple case, the aircraft is responsible for the management of two variables, which represent its state:

* BestCruise-the optimal speed to cruise at for given conditions

* InFlight-whether or not the aircraft is actually in flight.

3 IMPLEMENTATION BLOCK-WHAT THE METHODS DO

The aircraft behaviors are described in its methods. These methods are named in the object description provided by the Definition block. The logic of what they do and how they affect the state variables of the object are described in the Implementation block, shown below.

```
OBJECT AircraftObj;
```

```
ASK METHOD SetCruise (IN speed:INTEGER);
  BEGIN
  BestCruise := speed;
  END METHOD;
```

```
TELL METHOD FlyDistance (IN distance;INTEGER);
  BEGIN
  InFlight := TRUE
  WAIT DURATION distance/BestCruise;
  END WAIT;
  InFlight:=FALSE;
  OUTPUT ("Arrived Safely at",SimTime);
  END METHOD;
```

```
END OBJECT;
```

The behaviors that objects can perform are the methods described in the Implementation block. In this case the aircraft is capable of the behaviors described in the following two methods:

* ASK METHOD SetCruise-When the aircraft is requested to perform this behavior, it registers the new value for its optimal cruising speed, instantaneously, that is, simulation time does not elapse.

* TELL METHOD FlyDistance-When requested to perform this behavior, the aircraft calculates the required flight time to cover this distance at its cruising speed. This particular activity then pauses in execution until this period of time has elapsed within the simulation model, before completing the remainder of the behavior-in this case printing a notification that it has arrived safely. Unlike ASK methods, TELL methods are used to describe behaviors that elapse simulation time. While this method is paused, waiting for time to pass, other methods of other objects may be executing.

A key benefit of using MODSIM III in building complex simulations is the easy modeling of these behaviors. In a large model, many objects will have behaviors that must take account of the passage of time. Often, these behaviors will be concurrent, or overlapping in time. For example, our model will want to represent multiple "instances" of the aircraft object type. These instances can be created as needed; each can be given its own identifier, has its own state variables and can execute its methods as requested.

For a simple example of concurrent behaviors, let's look at how an aircraft dispatcher in our model might order two aircraft to fly to different destinations:

```
...
ASK JumboJet TO SetCruise(600);
TELL JumboJet TO FlyDistance(3000);

ASK Biplane TO SetCruise(100);
TELL Biplane TO FlyDistance(200)IN 1.0;
```

Using TELL methods, the flight times of both the JumboJet and Biplane aircraft can be modeled concurrently.

In this example, the aircraft object named JumboJet will elapse 5 hours flying a distance of 3000 miles at 600 mph. One hour after the JumboJet takes off (... IN 1.0), the Biplane aircraft will take off and fly 200 miles at 100 mph. It will complete its flight two hours before the JumboJet arrives at its destination. MODSIM III is responsible for sequencing the execution of the methods of both object instances, including the pauses to represent the flight times, so that the events of taking off and landing are played out in the correct order in the model. ASKING the object does not elapse any simulation time.

4 TIMING AND INTERACTION

Besides executing concurrently, time elapsing behaviors may interact. To make the model more realistic, we want to consider the effect of changing the cruising

speed of an aircraft while it is in flight—perhaps in response to a change in weather conditions. Such a change invalidates the original computation of flight time, and a new arrival time must be determined based on the new cruising speed and the distance remaining. Let's look at how the logic, or implementation, of the methods of our aircraft objects can be refined to incorporate this modified behavior. The method which is responsible for registering a change in cruising speed can INTERRUPT the time-elapsing method, FlyDistance if appropriate. On recognition of this INTERRUPT, the remaining time to WAIT is reevaluated. To see the changes that we've made, compare this code with the original Implementation block for the aircraft object, presented earlier.

```
OBJECT AircraftObj;

ASK METHOD SetCruise(IN speed:INTEGER);
  BEGIN
  BestCruise := speed;
  IF InFlight
    INTERRUPT SELF FlyDistance;
  END IF;
END METHOD;

  TELL METHOD FlyDistance (IN
distance;INTEGER);
  BEGIN
  InFlight := TRUE
  WHILE distance > 0.0
    speed := BestCruise;
    start := SimTime;
    WAIT DURATION distance/BestCruise;
    ON INTERRUPT
      elapsed := SimTime-start;
      distance := distance-(elapsed*speed);
    END WAIT;
  END WHILE;
  InFlight:=FALSE;
  OUTPUT ("Arrived Safely at",SimTime);
End METHOD;
```

The aircraft's CruiseSpeed can now be changed while in flight—the arrival time will be recomputed each time this occurs.

Look at how the FlyDistance method describes the entire flight from take off to landing, allowing multiple speed change events, in a logical activity description. Contrast this with multiple, disconnected, event subroutines in a conventional programming language which does not support the concept of time-elapsing behaviors.

Because MODSIM III provides you with a rich set of features to manage the complex scheduling, interaction and synchronizing of time-elapsing behaviors, you get

increased readability and consistency in your models, factors that translate directly to increased productivity and maintainability.

Unlike making calls on a subroutine library, MODSIM III understands the meaning of these simulation features. Thus it can diagnose inadvertent misuse early—for example, WAIT statements are not allowed in ASK methods that are always instantaneous. Not only does such checking save time in building and running a model, but it can help avoid debugging subtle logic errors in simulations with complex interactions.

These specialized features for modeling concurrent and interacting behaviors distinguish MODSIM III as a simulation model development tool. In addition, MODSIM III includes a rich collection of simulation building block objects. These library objects are designed to fulfill many common simulation modeling requirements. MODSIM III uses the power of object oriented software architecture to allow these pre-built library objects to be readily adapted to special needs.

Consider contention for resources, an issue which is at the heart of many discrete system simulations. Specific allocation policies are a basis for common behavior. Objects incur delays in competing for resources; they queue for resources on some priority basis; they may choose to abandon requests after a time-out interval. Every simulation model will want to report to some degree on measurements of resource utilization, waiting time statistics, and so on.

MODSIM III provides a prebuilt Resource object as one of many objects in its simulation support libraries. In our airport model, for example, runways are clearly a resource. We could use an instance of ResourceObj taken directly from MODSIM III's library to model runway allocation, enqueueing and dequeueing the aircraft on a first-come-first-served basis, and recording statistics.

We need to make one important change, however. To avoid the danger of wake turbulence effects, it is important that a light aircraft not use a runway immediately following a large aircraft; it should delay a short time to allow wake vortices in the air to dissipate. This is where inheritance comes in. It allows us to describe a Runway object in terms of the existing ResourceObj provided by MODSIM III. We only need to specify the differences between the new RunwayObj and ResourceObj.

Inheritance is one of the chief benefits of object oriented software construction, and the basis for providing libraries of useful objects which can be readily adapted to specialized needs.

In the example below, we have imported a resource management object from the MODSIM III library, defined an enumerated variable called AircraftCategory and show the Definition block for Runway. By declaring

our Runway object to be derived from the library-supplied resource management object, it inherits all the built-in capabilities for enqueueing requests and maintaining utilization statistics. The Give method is declared as overridden, meaning that a different implementation, for just this method, will be substituted in the Implementation block (not shown). The Runway object also has an extra variable to 'remember' the last aircraft type. Our specialized implementation logic can now be designed to impose appropriate delays before giving the runway to aircraft of different categories.

```
FROM ResMod IMPORT ResourceObj;
TYPE
  AircraftCategory = (Light, Heavy);
...
Runway = OBJECT(ResourceObj);
  lastuse : AircraftCategory;
OVERRIDE
  TELL METHOD Give(IN number : INTEGER);
END OBJECT;
...
```

The Runway object, derived from MODSIM III's resource management object has been customized to meet special modeling requirements.

Inheritance provides a disciplined way to selectively modify and extend object characteristics. As a specification mechanism, it maintains a clear distinction between those properties which continue to be available unchanged, and those enhancements designed to meet special needs-this is very valuable as software evolves through versions and upgrades.

New object types, derived through inheritance from existing objects, continue to conform to common interfaces, but incorporate additional capability. This is an excellent match to the evolutionary nature of successful simulation models; with increasing understanding of the system comes a desire to add details in areas of special focus.

The reuse of libraries of pre-built objects holds out the promise of real productivity gains in software development. Without a means to adapt such objects to special needs, this promise is rarely fulfilled. The extensibility offered by inheritance, coupled with the modular separation of interface definitions from actual implementation code are the mechanisms needed to support practical reuse of object libraries.

Object orientation offers other benefits to model development. The controlled access to object data structures through the object methods is just what is needed to build robust objects which can be the basis of reuse. Look back at the modified aircraft object implementation: any request to change the aircraft speed can now ensure a reevaluation of the flight time-which is faithful to the way things happen in the real world.

Taken together, support for object modeling concepts, along with concurrent time based behaviors, are what make MODSIM III an effective simulation productivity tool.

5 GRAPHICS AND SIMULATION

Through inheritance, the objects in your simulation can acquire a rich set of graphical properties and behaviors. You can use this to provide an interactive, graphically managed model that speeds up analyses and produces easy-to-understand results. Adding graphics is easy. You use a graphical editor to configure the appearance of [A1] icons, menus, dialog boxes and presentation charts. Minimal code then connects these to the entities and variables in the model. Adding graphics can enhance the appeal of a model in three principal areas:

5.1 GRAPHICAL SCENARIO LAYOUT

Interactive graphical editing lets you define a scenario to simulate by selecting icons from the palette, positioning them on the screen, and configuring parameters through dialog boxes.

5.2 Dynamic Analysis

With a scenario on the screen, you can begin the simulation and see an animated picture of the system under study. In addition, you can study plots that are drawn while the simulation is running. You can pan and zoom on areas of special interest. These results, shown dynamically, will suggest alternatives that can be tried immediately. Interacting with the model in this way increases understanding of the system under study and speeds your analysis. Often errors that may have otherwise been difficult to find, will be obvious. Dynamic analysis contrasts sharply with the old iterative approach to simulation, where the following steps were repeated: prepare data, simulate, examine results, modify data, simulate, ...

5.3 Communication of Results

Through animation, you can dramatize the effect of alternative system configurations, spot unexpected behavior, and back up your recommendations. It's the best way to sell your ideas.

6 DEVELOPMENT ENVIRONMENT

MODSIM is a complete development environment. The MODSIM III simulation support, Compilation Manager, Object Manager and the Debugging Manager provide a

complete environment for the successful development of advanced models.

6.1 Compilation Manager

The MODSIM compilation manager automatically determines which modules have been edited since the last compilation and recompiles only those modules and any other modules that depend on them. No make files are required.

6.2 Object Manager

MODSIM III provides a browsing tool for MODSIM III objects, variables and procedures. The Object Manager provides a concise representation of complex objects including aggregation of fields and methods and inheritance diagrams. For object types, all the fields and methods are displayed. Methods are followed by a condensed parameter list; fields have their types indicated. You can see all the attributes and capabilities this object has either defined or acquired through inheritance.

Further detail is provided by an inheritance diagram of this object, the module in which it is defined, any replaceable types it has declared and any type substitutions that have been made in ancestor objects. Clicking on a displayed ancestor selects this object type for browsing. A record is kept of all objects visited, making it easy to return to a previously browsed object. Browsing methods show you which ancestor originally defined the method, which ancestor implementation the object will invoke and a full parameter list.

6.3 Debugging Manager

Selective runtime checking of object referencing, invalid parameters, array bounds, and memory use are invaluable aids to software development. Models are large, complex programs, and debugging support for both simulation and programming errors are crucial to success. With debugging support enabled, a runtime error automatically drops you into debugging mode, allowing you to see where the error occurred and letting you examine variables. A traceback shows you the calling chain that led to the current method or procedure, so you can browse up and down the execution stack examining the sequence of procedure and method calls that preceded the error. The debugger supports a wide range of capabilities that are essential to interactive symbolic debugging. In addition it has special knowledge of MODSIM III's simulation constructs and can display the pending list, simulation time, and memory usage information.

7 MODSIM III AVAILABILITY

MODSIM III is developed and supported by CACI Products Company. MODSIM III is available to your organization for a free trial in your environment, on your computer. We provide everything you need for a complete evaluation at your site: training, software, documentation, sample models and immediate support when you need it. In addition, CACI regularly offers time-tested training courses.

AUTHOR BIOGRAPHY

JOHN GOBLE is the Vice President of Decision Support Products for CACI Products Company in La Jolla, CA. He holds a MSc degree in Industrial Engineering from the University of Nebraska. Prior to coming to CACI he worked with Motorola as a simulation developer in the Cellular Infrastructure area. His efforts at CACI are being directed towards making SIMPROCESS an industry standard for business process simulation.