1 Preliminaries – what the reader will have seen already

Listing 1: FunctionExample.script

```
%  Create a s/c
Create Spacecraft Sat;

Create ForceModel Prop_FModel;
GMAT Prop_FModel.PrimaryBodies = {Earth};

Create Propagator Prop;
GMAT Prop.FM = Prop_FModel;

% Variables and arrays needed in calculations
Create Variable SMA ECC RAAN;
Create Variable r v pi2 mu d2r Energy;
Create Variable SMAError ECCError RAANError;
Create Array rv[3,1] vv[3,1] ev[3,1] nv[3,1];

%  Create a report to output error data
Create ReportFile Cart2KepConvert;
GMAT Cart2KepConvert.Filename = FunctDiffs.report;
GMAT Cart2KepConvert.ZeroFill = On;

mu = 398600.4415;
pi2 = 6.283185307179586232;
d2r = 0.01745329251994329509

While Sat.ElapsedDays < 1

   Propagate Prop(Sat)

   % Put the state data into some data structures
   [rv, vv, r, v] = LoadCartState(Sat);

   % Calculate the Energy and SMA
   Energy = v^2/2 - mu/r;
   SMA = -mu/2/Energy;

   % Eccentricity built from the eccentricity vector
   ev = cross(vv, cross(rv, vv)) / mu - rv / r;
   [ECC] = magnitude(ev);
   % Next the ascending node, using the node vector
   nv(1,1)  =  x*vz-z*vx;
   nv(2,1)  =  y*vz-z*vy;
   nv(3,1)  =  0;
   [n] = magnitude(nv);
   RAAN = acos( nv(1,1)/n );
   If nv(2,1) < 0;
      RAAN = (pi2 - RAAN) / d2r;
   EndIf;

   SMAError  = Sat.SMA  - SMA;
   ECCError  = Sat.ECC  - ECC;
   RAANError = Sat.RAAN - RAAN;

   Report Cart2KepConvert Sat.SMA SMA SMAError ...
      Sat.ECC ECC ECCError Sat.RAAN RAAN RAANError;
EndWhile
```

Listing 2: LoadCartState.gmf

```
function [rv, vv, r, v] = LoadCartState(Sat);
% This function fills some arrays and variables with
% Cartesian state data
Create Variable r v
Create Array rv[3,1] vv[3,1]

rv(1,1) = Sat.X;
rv(1,2) = Sat.Y;
rv(1,3) = Sat.Z;
vv(1,1) = Sat.VX;
vv(1,2) = Sat.VY;
vv(1,3) = Sat.VZ;

[r] = magnitude(rv);

[v] = magnitude(vv);
```

Listing 3: magnitude.gmf

```
function [val] = magnitude(vec1)

% This function takes a 3-vector in a GMAT array and
% calculates its magnitude
```

```
Create Variable val
val = sqrt(dot(vec1, vec1));
```

Listing 4: dot.gmf

```
function [val] = dot(vec1, vec2)

% This function takes two 3-vectors in a GMAT array and
% constructs their dot product
Create Variable val
val = vec1(1,1) * vec2(1,1) + vec1(2,1) * vec2(2,1) +...
         vec1(3,1) * vec2(3,1);
```

Listing 5: cross.gmf

```
function [vec3] = cross(vec1, vec2)

% This function takes two 3-vectors in a GMAT array and
% constructs their cross product
Create Array vec3[3,1]

vec3(1,1) = vec1(2,1) * vec2(3,1) - vec1(3,1) * vec2(2,1);
vec3(2,1) = vec1(3,1) * vec2(1,1) - vec1(1,1) * vec2(3,1);
vec3(3,1) = vec1(1,1) * vec2(2,1) - vec1(2,1) * vec2(1,1);
```

2 Steps Followed for the Sample Script

In this section we will look at the script (shown in Listing 1) along with the four functions used by this script (listings 2 through 5), and examine the behavior of the Mission Control Sequence, Function Control Sequences, Configuration, Sandbox, Sandbox Object Map, Global Object Store, and Function Control Stores as the script is loaded, executed, and removed from memory. This discussion will be broken into four distinct processes:

1. Script Parsing – the process of reading the script in Listing 1 and building the resources and Mission Control Sequence.
2. Initialization – The process of passing the configuration and MCS into the Sandbox.
3. Execution – The process of running the MCS, including calls to the functions.
4. Finalization – Steps taken when the run is complete.

As we will see, each of these steps can be further subdivided to a discrete set of substeps. We'll begin by examining what happens when the script is first read into memory.

2.1 Script Parsing

The details of script parsing are described fully in Chapter 16 (“Script Reading and Writing”). That chapter discusses the modes that the interpreter goes through when reading a script file, starting with the object property mode, moving through the command mode, and finishing with the final pass through the mission resources. You should review the relevant sections of that chapter if this terminology confuses you.

Table 1 shows the state of the components of the engine at the start of script reading. This table does not include any elements specific to the Sandbox, because the Sandbox in in an idle state at this point. When the Sandbox elements become relevant, they will be added to the tables summarizing the state of the system.

Table 1: Status at Start of Script Parsing

Configuration	MCS	Interpreter Mode	Sandbox
Empty	Empty	Object Property	Idle

The Script Interpreter remains in Object Property mode until the first command is encountered in the script. That means that the following lines are all parsed in Object Property mode:

```
%  Create a s/c
Create Spacecraft Sat;

Create ForceModel Prop_FModel;
GMAT Prop_FModel.PrimaryBodies = {Earth};

Create Propagator Prop;
GMAT Prop.FM = Prop_FModel;

% Variables and arrays needed in calculations
Create Variable SMA ECC RAAN;
Create Variable r v pi2 mu d2r Energy;
Create Variable SMAError ECCError RAANError;
Create Array rv[3,1] vv[3,1] ev[3,1] nv[3,1];

%  Create a report to output error data
Create ReportFile Cart2KepConvert;
GMAT Cart2KepConvert.Filename = FunctDiffs.report;
GMAT Cart2KepConvert.ZeroFill = On;

mu = 398600.4415;
pi2 = 6.283185307179586232;
```

```
    d2r = 0.01745329251994329509
```

After these lines have been parsed, the table of objects looks like this:

Table 2: Status after Parsing the Objects

Configuration		MCS	Interpreter Mode	Sandbox
Type	*Name*	Empty	Object Property	Idle
Spacecraft	Sat			
ForceModel	Prop_FModel			
Propagator	Prop			
Variable	SMA			
Variable	ECC			
Variable	RAAN			
Variable	r			
Variable	v			
Variable	pi2			
Variable	mu			
Variable	d2r			
Variable	Energy			
Variable	SMAError			
Variable	ECCError			
Variable	RAANError			
Array	rv			
Array	vv			
Array	ev			
Array	nv			
ReportFile	Cart2KepConvert			

At this point, the configuration is complete. The objects contained in the configuration all have valid data values; those that are not set explicitly in the script are given default values, while those that are explicitly set contain the specified values.

Note that at this point, the configuration does not contain any functions. GMAT functions are added to the configuration when they are encountered, as we'll see when we encounter a script line that includes a GMAT function. The next line of the script contains a command:

```
    While Sat.ElapsedDays < 1
```

When the Script Interpreter encounters this line, it toggles into command mode. Once this line of script has been parsed, the state of the engine looks like this (note that I'm abbreviating the configuration here – it still contains all of the objects listed above):

Table 3: Status after Parsing the First Command

Configuration		MCS	Interpreter Mode	Sandbox
Type	*Name*	While	Command	Idle
Spacecraft	Sat			
ForceModel	Prop_FModel			
Propagator	Prop			
Variable	SMA			
...	...			
Array	nv			
ReportFile	Cart2KepConvert			

The Script Interpreter parses the next line (a Propagate line) as expected, giving this state:

Table 4: Status after Parsing the Propagate Command

Configuration		MCS	Interpreter Mode	Sandbox
Type	*Name*	While	Command	Idle
Spacecraft	Sat	+ Propagate		
ForceModel	Prop_FModel			
Propagator	Prop			
Variable	SMA			
...	...			
Array	nv			
ReportFile	Cart2KepConvert			

The next script line is a function call:

```
        [rv, vv, r, v] = LoadCartState(Sat);
```

When the Script Interpreter encounters this function call, several things happen:

1. The line is decomposed into three sets of elements: outputs (rv, vv, r, and v), the function name (LoadCartState), and inputs (Sat)
2. The Script Interpreter builds a CallFunction command.
3. The Script Interpreter sends a request to the Moderator for a function named LoadCartState. The Moderator sends the request to the Configuration Manager. Since the configuration does not contain a function with this name, the Configuration Manager returns a NULL pointer, which is returned to the ScriptInterpreter.
4. The Script Interpreter sees the NULL pointer, and calls the Moderator to construct a GmatFunction object named LoadCartState. The Moderator calls the Factory Manager requesting this object. It is constructed in a function factory, and returned through the Moderator to the Script Interpreter. The

Moderator also adds the function to the Configuration.

5. The Script Interpreter passes the GmatFunction into the CallFunction command.
6. The CallFunction command sends the GmatFunction to its FunctionManager.
7. The Script Interpreter passes the list of input and output parameters to the CallFunction.
8. The CallFunction passes the list of input and output parameters to its FunctionManager.

This completes the parsing step for the CallFunction line. Note that (1) the Function Control Sequence is not yet built, and (2) the function file has not yet been located in the file system. These steps are performed later. At this point, the system has this state:

Table 5: Status after Parsing the CallFunction Command

Configuration		**MCS**	**Interpreter Mode**	**Sandbox**
Type Spacecraft ForceModel Propagator Variable ... Array ReportFile GmatFunction	*Name* Sat Prop_FModel Prop SMA ... nv Cart2KepConvert LoadCartState (FCS is empty)	While + Propagate + CallFunction	Command	Idle

Now that we've encountered the first function in the script, it is useful to start watching the data structures for the function. We'll do this in a separate table:

Table 6: Function Properties after Parsing the First CallFunction

Function	**Caller**[1]	**FunctionManager**			**Function Properties**		
		inputs, outputs lists	**Function Object Store**	**Global Object Store**	**inputs**	**outputs**	**FCS**
LoadCartState	CallFunction	input and output names set	Empty	NULL	Empty	Empty	Empty

One feature that it is worth noting at this point is that there are two locations used

1 "Caller" in this context is the type of object – a CallFunction or a FunctionRunner – that is used to execute the function in this example. It is possible that a function could be called from both types of object in the same script.

for input and output arguments. The list managed in the FunctionManager tracks the parameters as listed in the function call in the control sequence that is calling the function. These parameters are listed in the order found in the call. Thus for this CallFunction, the StringArrays containing the arguments in the FunctionManager contain these data:

```
inputNames = {  Sat  }

outputNames = {  rv  ,   vv  ,   r  ,   v  }
```

The inputs and outputs maps in the Function object map the names used in the function to the associated objects. Since the function itself has not been built at this stage, these maps are empty, and will remain empty until the function file is parsed.

The Function Object Store itself is empty at this point. It provides a mapping between the function scope object names and the objects. Since the function has not yet been parsed, this object store remains empty.

The next two script lines do not make function calls, so they can be parsed and built using the features described in Chapter 16. After these two lines are built:

```
Energy = v^2/2 - mu/r;
SMA = -mu/2/Energy;
```

the state tables contain these data:

Table 7: Status after Parsing the next two Commands

Configuration		**MCS**	**Interpreter Mode**	**Sandbox**
Type Spacecraft ForceModel Propagator Variable ... Array ReportFile GmatFunction	*Name* Sat Prop_FModel Prop SMA ... nv Cart2KepConvert LoadCartState	While + Propagate + CallFunction + Assignment + Assignment	Command	Idle

and

Table 8: Function Properties after Parsing the First Two Assignment Lines

Function	**Caller**	**FunctionManager**			**Function Properties**		
		Lists of inputs & outputs	**Function Object Store**	**Global Object Store**	**inputs**	**outputs**	**FCS**
LoadCartState	CallFunction	input and output	Empty	NULL	Empty	Empty	Empty

		names set					

Both of the lines listed here generate Assignment commands. The right side of these assignments are MathTree elements, built using the inline math features described in Chapter 26. As you might expect, the Mission Control Sequence contains these new commands, but nothing else has changed at this level.

The next line also generates an Assignment line:

```
        ev = cross(vv, cross(rv, vv)) / mu - rv / r;
```

This line also builds a MathTree for the right side of the equation. The resulting tree contains two function calls, both made to the GMAT function named “cross.” The MathTree built from this Assignment line is shown in Figure 1.

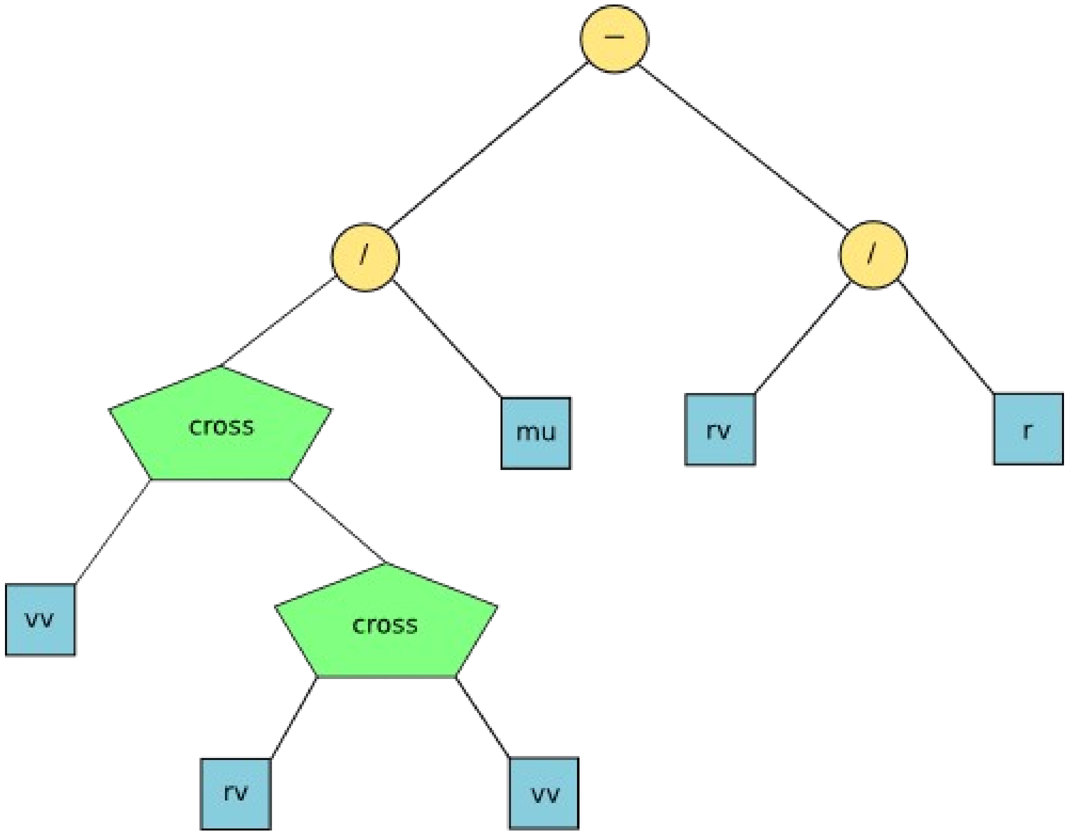


Figure 1: A MathTree with Two Function Calls

Once this command has been built, the state of the system can be tabulated as in Tables 9 and 10:

Table 9: Status after Parsing the Assignment Line containing Two Calls to the cross Function

Configuration	MCS	Interpreter	Sandbox

			Mode	
Type Spacecraft ForceModel Propagator Variable ... Array ReportFile GmatFunction GmatFunction	*Name* Sat Prop_FModel Prop SMA ... nv Cart2KepConvert LoadCartState cross	While + Propagate + CallFunction + Assignment + Assignment + Assignment	Command	Idle

and

Table 10: Function Properties after Parsing the cross Assignment Line

Function	**Caller**	**FunctionManager**			**Function Properties**		
		Lists of inputs & outputs	**Function Object Store**	**Global Object Store**	**inputs**	**outputs**	**FCS**
LoadCartState	CallFunction	input and output names set	Empty	NULL	Empty	Empty	Empty
cross	Function-Runner	input names set on both	Empty	NULL	Empty	Empty	Empty

There are two FunctionRunner nodes in the MathTree shown in Figure 1. Each one has its own FunctionManager. The inputs and outputs StringArrays have the following values for these FunctionManagers:

- Lower FunctionRunner MathNode

  ```
  inputNames = {  rv  ,   vv  }
  outputNames = {    }
  ```

- Upper FunctionRunner MathNode

  ```
  inputNames = {  vv  ,     }
  outputNames = {    }
  ```

Note that at this point in the process, the unnamed arguments are marked using empty strings in the StringArrays. This is a general feature of the argument arrays generated in a FunctionManager associated with a FunctionRunner: empty strings are used to indicate arguments that must exist, but that do not have names that can be looked up in the object stores. In general, these empty strings indicate either output data or results that come from lower calculations performed in the MathTree.

The next script line,

```
        [ECC] = magnitude(ev);
```

builds another function call using a CallFunction, this time to the magnitude function.

Table 11: Status after Parsing the Call to the magnitude Function

Configuration		MCS	Interpreter Mode	Sandbox
Type Spacecraft ForceModel Propagator Variable ... Array ReportFile GmatFunction GmatFunction GmatFunction	*Name* Sat Prop_FModel Prop SMA ... nv Cart2KepConvert LoadCartState cross magnitude	While + Propagate + CallFunction + Assignment + Assignment + Assignment + Assignment	Command	Idle

and

Table 12: Function Properties after Parsing the magnitude Line

Function	Caller	FunctionManager			Function Properties		
		Lists of inputs & outputs	Function Object Store	Global Object Store	inputs	outputs	FCS
LoadCartState	Call-Function	input and output names set	Empty	NULL	Empty	Empty	Empty
cross	Function-Runner	input names set on both	Empty	NULL	Empty	Empty	Empty
magnitude	Call-Function	input and output names set	Empty	NULL	Empty	Empty	Empty

This process continues through the remaining lines of the script:

```
        nv(1,1)  =  x*vz-z*vx;
        nv(2,1)  =  y*vz-z*vy;
        nv(3,1)  =  0;
        [n] = magnitude(nv);
        RAAN = acos( nv(1,1)/n );
        If nv(2,1) < 0;
           RAAN = (pi2 - RAAN) / d2r;
```

```
      EndIf;

      SMAError  = Sat.SMA  - SMA;
      ECCError  = Sat.ECC  - ECC;
      RAANError = Sat.RAAN - RAAN;

      Report Cart2KepConvert Sat.SMA SMA SMAError ...
         Sat.ECC ECC ECCError Sat.RAAN RAAN RAANError;
   EndWhile
```

The only line that calls a GMAT function here is the fourth line, a CallFunction command that again calls the magnitude function. At the end of parsing, our tables of object properties look like this:

Table 13: Status after Parsing the Script

Configuration		**MCS**	**Interpreter Mode**	**Sandbox**
Type	***Name***	While	Command	Idle
Spacecraft	Sat	+ Propagate		
ForceModel	Prop_FModel	+ CallFunction		
Propagator	Prop	+ Assignment		
Variable	SMA	+ Assignment		
Variable	ECC	+ Assignment		
Variable	RAAN	+ Assignment		
Variable	r	+ Assignment		
Variable	v	+ Assignment		
Variable	pi2	+ Assignment		
Variable	mu	+ CallFunction		
Variable	d2r	+ Assignment		
Variable	Energy	+ If		
Variable	SMAError	+ + Assignment		
Variable	ECCError	+ EndIf		
Variable	RAANError	+ Assignment		
Array	rv	+ Assignment		
Array	vv	+ Assignment		
Array	ev	+ Report		
Array	nv	EndWhile		
ReportFile	Cart2KepConvert			
GmatFunction	LoadCartState			
GmatFunction	cross			
GmatFunction	magnitude			

and

Table 14: Function Properties after Parsing the magnitude Line

Function	**Caller**	**FunctionManager**			**Function Properties**		
		Lists of	**Function**	**Global**	**inputs**	**outputs**	**FCS**

		inputs & outputs	**Object Store**	**Object Store**			
LoadCartState	CallFunction	input and output names set	Empty	NULL	Empty	Empty	Empty
cross	Function-Runner	input names set on both	Empty	NULL	Empty	Empty	Empty
magnitude	CallFunction	input and output names set	Empty	NULL	Empty	Empty	Empty

At this point in the process, the Configuration and Mission Control Sequence have been populated, and three GMAT functions have been identified but not yet located. The ScriptInterpreter has finished parsing the script, but has not yet made its final pass through the objects created during parsing.

During the final pass, object pointers and references are set and validated. the ScriptInterpreter uses the final pass to locate the function files for all of the GmatFunction objects built during parsing. The path to each function is set at this time. The ScriptInterpreter makes a call, through the Moderator, and locates the function file on the GmatFunctionPath. The file must be named identically to the name of the function, with a file extension of “.gmf” – so, for example, the function file for the magnitude function must be named “magnitude.gmf”. These file names are case sensitive; a file named “Magnitude.gmf” will not match the “magnitude” function. If there is no matching file for the function, the ScriptInterpreter throws an exception.

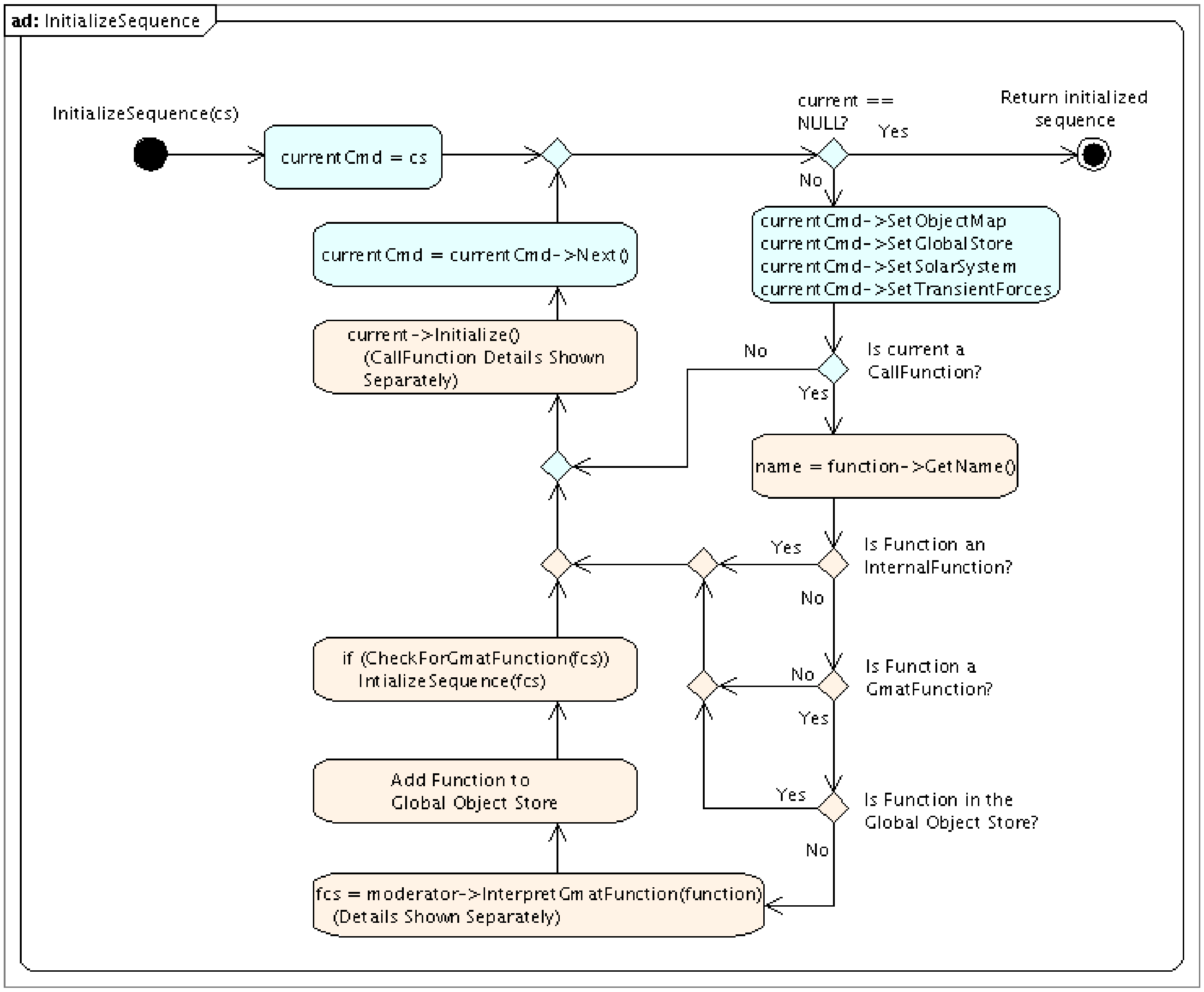
Once this final pass is complete, script parsing has finished, and the ScriptInterpreter returns to an idle state.

2.2 Initialization in the Sandbox

The steps followed to parse the Mission Control Sequence, described above, give GMAT enough information to fully populate the GUI so that it can present users with a view of the mission contained in the script. At this point, GMAT knows about the functions described in the Mission Control Sequence, but has not yet constructed any of these functions. That step is performed when the mission is passed into the Sandbox and initialized. The basic initialization process is described in Chapters 3 and 5 of the Architectural specification. The process followed can be described in three stages:

1. The objects in GMAT's configuration are cloned into the Sandbox Object Map, and the Mission Control Sequence is set.
2. The objects in the Sandbox Object Map are initialized.
3. Global objects are moved into the Global Object Store.

4. Automatic globals are moved from the Sandbox Object Map into the Sandbox's Global Object Store.
5. The Mission Control Sequence is initialized.


ad: InitializeSequence
InitializeSequence(cs)
currentCmd = cs
current == NULL?
Yes
No
Return initialized sequence
currentCmd->SetObjectMap
currentCmd->SetGlobalStore
currentCmd->SetSolarSystem
currentCmd->SetTransientForces
currentCmd = currentCmd->Next()
current->Initialize() (CallFunction Details Shown Separately)
Is current a CallFunction?
No
Yes
name = function->GetName()
Is Function an InternalFunction?
Yes
No
Is Function a GmatFunction?
No
Yes
if (CheckForGmatFunction(fcs)) IntializeSequence(fcs)
Add Function to Global Object Store
Is Function in the Global Object Store?
Yes
No
fcs = moderator->InterpretGmatFunction(function) (Details Shown Separately)

Outside of the cloning process, the GMAT function objects are not affected by the first two of these steps. Figure 2[2], copied from the Architectural Specification, shows the steps followed in the third step to initialize the Mission Control Sequence.Figure 2: Initializing a Control Sequence

Before going into the details of Figure2, I'll describe the activities performed in the first two steps.

2.2.1 Initialization Step 1: Passing Objects to the Sandbox

The first step in initialization is cloning the objects in the configuration into the Sandbox. At the start of this step, the system status looks like Table 15. The

2 This figure needs some modification based on the text in the rest of this document.

Interpreter subsystem will not play a role in this part of the initialization process – the Interpreters remain idle – so I will remove that column for the time being in subsequent tables.

One feature of GMAT's design that can be overlooked is that there is a separate Mission Control Sequence for each Sandbox, and there is a one-to-one relationship between the Mission Control Sequences and the Sandbox instances. What that means for this discussion is that the Mission Control Sequence shown in the table already belongs to the Sandbox shown there. The Mission Control Sequence is not cloned into the Sandbox[3].

Table 15: Status Immediately Before Initialization Starts

Configuration		**MCS**	**Interpreter Mode**	**Sandbox**
Type	*Name*			
Spacecraft ForceModel Propagator Variable Variable Variable Variable Variable Variable Variable Variable Variable Variable Variable Variable Array Array Array Array ReportFile GmatFunction GmatFunction GmatFunction	Sat Prop_FModel Prop SMA ECC RAAN r v pi2 mu d2r Energy SMAError ECCError RAANError rv vv ev nv Cart2KepConvert LoadCartState cross magnitude	While + Propagate + CallFunction + Assignment + Assignment + Assignment + Assignment + Assignment + Assignment + Assignment + CallFunction + Assignment + If + + Assignment + EndIf + Assignment + Assignment + Assignment + Report EndWhile	Idle	Idle, Sandbox Object Map is Empty

3 This relationship between the Mission Control Sequences and the array of Sandboxes is managed in the Moderator. The behavior described here is the default behavior, and is the behavior used in current implementations of GMAT. Implementations that use multiple Sandboxes – particularly when used in a distributed manner – will implement a different relationship between the Mission Control Sequence viewed by the user and the Mission Control Sequences in the Sandboxes.

The objects in the configuration, on the other hand, are contained in GMAT's engine, outside of the Sandbox. The Moderator accesses these configured objects by type, and passes each into the Sandbox for use in the mission. The Sandbox makes copies of these objects using the object's Clone() method. These clones are stored in the Sandbox Object Map. The clones contain identical data to the objects in the configuration; making clones at this stage preserves the user's settings on the configured objects while providing working copies that are used to run the mission.

Table 16 shows the status of the system after the Moderator has passed the objects into the Sandbox. The Sandbox Object Map is a mapping between a text name and a pointer to the associated object. Since the map is from the name to the object, the Sandbox Object Map in the table lists the name first.

Table 16: Status Immediately After Cloning into the Sandbox

Configuration		**Sandbox**		
Type	**Name**	**MCS**	**Sandbox Object Map**	
			Name	**Type**
Spacecraft	Sat	While	Sat	Spacecraft*
ForceModel	Prop_FModel	+ Propagate	Prop_FModel	ForceModel*
Propagator	Prop	+ CallFunction	Prop	PropSetup*
Variable	SMA	+ Assignment	SMA	Variable*
Variable	ECC	+ Assignment	ECC	Variable*
Variable	RAAN	+ Assignment	RAAN	Variable*
Variable	r	+ Assignment	r	Variable*
Variable	v	+ Assignment	v	Variable*
Variable	pi2	+ Assignment	pi2	Variable*
Variable	mu	+ Assignment	mu	Variable*
Variable	d2r	+ CallFunction	d2r	Variable*
Variable	Energy	+ Assignment	Energy	Variable*
Variable	SMAError	+ If	SMAError	Variable*
Variable	ECCError	+ + Assignment	ECCError	Variable*
Variable	RAANError	+ EndIf	RAANError	Variable*
Array	rv	+ Assignment	rv	Array*
Array	vv	+ Assignment	vv	Array*
Array	ev	+ Assignment	ev	Array*
Array	nv	+ Report	nv	Array*
ReportFile	Cart2KepConvert	EndWhile	Cart2KepConvert	ReportFile*
GmatFunction	LoadCartState		LoadCartState	GmatFunction*
GmatFunction	cross		cross	GmatFunction*
GmatFunction	magnitude		magnitude	GmatFunction*
CoordinateSys[4]	EarthMJ2000Eq		EarthMJ2000Eq	CoordinateSys*
CoordinateSys	EarthMJ2000Ec		EarthMJ2000Ec	CoordinateSys*
CoordinateSys	EarthFixed		EarthFixed	CoordinateSys*

Once the Moderator has passed the Configuration into the Sandbox, the mission run no longer depends on the Configuration. For that reason, most of the tables

4 The 3 coordinate systems listed at the end of the configuration table are automatically created by the Moderator

shown in the rest of this document will not include a list of the contents of the configuration. If needed, the Configuration will be displayed separately.

2.2.2 Initialization Step 2: Object Initialization

Now that the Sandbox has been populated with the configured objects and the Mission Control Sequence, the Moderator can pass control to the Sandbox to continue the initialization process. This hand off is made through a call to the Sandbox::Initialize method. The Sandbox initializes objects in the following order:

1. CoordinateSystem
2. Spacecraft
3. All others except Parameters and Subscribers
4. System Parameters
5. Other Parameters
6. Subscribers

The initialization of these objects follows this basic algorithm:

- Send the Sandbox's solar system to the object
- Set pointers for all of objects referenced by this object
- call the object's Initialize() method

The basic initialization for Function objects are part of element 3 in the list above. At that point in the initialization process, the Function objects are not yet populated, so this step does not perform any substantive action. The Sandbox checks each GmatFunction to ensure that the path to the function file is not empty as part of this initialization.

2.2.3 Initialization Step 3: Global Object Management

Once the objects in the Sandbox Object Map are initialized, the objects flagged as global objects are moved from the Sandbox Object Map into the Global Object Store. The Sandbox does this by checking the object's isGlobal flag, a new attribute of the GmatBase class added for global object management.

Some object types are automatically marked as global objects. All instances of the PropSetup class, Function classes, and coordinate system classes fall into this category, and are built with the isGlobal flag set.

2.2.4 Initialization Step 4: Control Sequence Initialization

The final step in Sandbox initialization is initialization of the Mission Control Sequence. This step in the initialization process includes construction of the Function Control Sequences, and does the first portion of initialization that is needed before the Function Control Sequence can be executed. At this stage in the initialization process, the Sandbox Object Map contains clones of all of the configured objects, the Global Object Store is empty, and the GmatFunction objects know the locations of the function files. The Function Control Sequences are all empty, and the system has not identified any functions called from inside of functions that are not also called in the Mission Control Sequence. The objects in the Sandbox Object Map have the connections to referenced objects set, and are ready for use in the Mission Control Sequence.

So far, we have encountered three GmatFunctions, shown in Table 17 with their data structures:

Table 17: GmatFunction Status at the Start of Control Sequence Initialization

Function	Function Object Store	Global Object Store	inputs	outputs	Function Control Sequence	Call Stack
LoadCartState	empty	NULL	empty	empty	empty	empty
cross	empty	NULL	empty	empty	empty	empty
magnitude	empty	NULL	empty	empty	empty	empty

As we will see, the call stack, implemented as the "objectStack" attribute in the GmatFunction class, remains empty throughout the initialization process.

Before initializing the Mission Control Sequence, the Sandbox walks through the Sandbox Object Map and places the pointer to each coordinate system, propagator, and function into the Global Object Store. This initial population of the Global Object Store ensures that the automatic globals cloned from the configuration can be accessed when they are needed.

The Sandbox initialized the Mission Control Sequence by walking through the list of commands in the sequence, and performing the following tasks on each:

- Send the pointers to the Sandbox Object Map and the Global Object Map to the command
- Set the solar system pointer for the command
- Set the transient force vector for the command
- If the command uses a GmatFunction. build that function as described below
- Call the command's Initialize() method

In order to see how these actions work with GmatFunctions, we'll continue walking through the sample script. For clarity's sake, it is useful to have a complete picture of the contents of the Mission Control Sequence. The Mission Control Sequence, listed by node type and script line, and numbered for reference, can be written like this:

1 While `While Sat.ElapsedDays < 1`

```
      1.1 Propagate          Propagate Prop(Sat)
      1.2 CallFunction       [rv, vv, r, v] = LoadCartState(Sat);
      1.3 Assignment         Energy = v^2/2 - mu/r;
      1.4 Assignment         SMA = -mu/2/Energy;
      1.5 Assignment         ev = cross(vv,cross(rv, vv))/mu - rv/r;
      1.6 Assignment         [ECC] = magnitude(ev);
      1.7 Assignment         nv(1,1)  =  x*vz-z*vx;
      1.8 Assignment         nv(2,1)  =  y*vz-z*vy;
      1.9 Assignment         nv(3,1)  =  0;
      1.10 CallFunction      [n] = magnitude(nv);
      1.11 Assignment        RAAN = acos( nv(1,1)/n );
      1.12 If                If nv(2,1) < 0;
         1.12.1 Assignment   RAAN = (pi2 - RAAN) / d2r;
      1.13 EndIf             EndIf;
      1.14 Assignment        SMAError  = Sat.SMA  - SMA;
      1.15 Assignment        ECCError  = Sat.ECC  - ECC;
      1.16 Assignment        RAANError = Sat.RAAN - RAAN;
      1.17 Report            Report Cart2KepConvert Sat.SMA SMA SMAError
                                Sat.ECC ECC ECCError Sat.RAAN RAAN
                                RAANError
   2  EndWhile               EndWhile
```

The line of script associated with each node is shown on the right in this list.

At the start of the Mission Control Sequence initialization, the Sandbox Object Map and Global Object Store contain the following items:

Table 18: The Sandbox Maps

Sandbox Object Map		Global Object Store	
Name	**Type**	**Name**	**Type**
Sat	Spacecraft*	Prop	PropSetup*
Prop_FModel	ForceModel*	EarthMJ2000Eq	CoordinateSystem*
Prop	PropSetup*	EarthMJ2000Ec	CoordinateSystem*
SMA	Variable*	EarthFixed	CoordinateSystem*
ECC	Variable*	LoadCartState	GmatFunction*
RAAN	Variable*	cross	GmatFunction*
r	Variable*	magnitude	GmatFunction*
v	Variable*		
pi2	Variable*		
mu	Variable*		

d2r	Variable*	
Energy	Variable*	
SMAError	Variable*	
ECCError	Variable*	
RAANError	Variable*	
rv	Array*	
vv	Array*	
ev	Array*	
nv	Array*	
Cart2KepConvert	ReportFile*	
LoadCartState	GmatFunction*	
cross	GmatFunction*	
magnitude	GmatFunction*	
EarthMJ2000Eq	CoordinateSystem*	
EarthMJ2000Ec	CoordinateSystem*	
EarthFixed	CoordinateSystem*	

These maps stay the same until either a Global command is encountered or a Create command is encountered that creates an object that is automatically global.

The steps listed above for command initialization are performed for the first two commands in the list, items 1 and 1.1, without changing any of the object maps or function attributes. Item 1.2:

```
        [rv, vv, r, v] = LoadCartState(Sat);
```

is a CallFunction that initializes a GmatCommand, so we need to look more closely at the initialization for this line.

The CallFunction at this point has a FunctionManager which contains the name of a GmatFunction object and StringArrays for the inputs and outputs. The StringArrays contain the following data:

```
     inputNames = {  Sat  }
     outputNames = {  rv  ,   vv  ,   r  ,   v  }
```

The Sandbox passes the pointers for the Sandbox Object Map and the Global Object Store to the CallFunction command. Once the CallFunction has received the Global Object Store, it uses that mapping to locate the function needed by the Function Manager, and passes the pointer to that function into the FunctionManager. The FunctionManager determines the type of the function – in this example, the function is a GmatFunction. The function attributes at this point are shown in Table 19.

Table 19: GmatFunction Status after Setting the GOS and SOM

Function	Function Object Store	Global Object Store	inputs	outputs	Function Control Sequence	Call Stack
LoadCartState	empty	Set	empty	empty	empty	empty
cross	empty	NULL	empty	empty	empty	empty
magnitude	empty	NULL	empty	empty	empty	empty

The Sandbox then passes in the pointers to the solar system and transient force vector, which the CallFunction passes into the FunctionManager. Since the function in the FunctionManager is a GmatFunction, these pointers will be needed later in initialization and execution, so the FunctionManager passes these pointers into the function for later use. (If the function in the FunctionManger was not a GmatFunction, the pointers would have been discarded.)

At this point, all of the items needed to build the Function Control Sequence exist. The Sandbox retrieves the pointer for the GmatFunction from the CallFunction command. It checks to see if the function's Function Control Sequence has been built. If the Function Control Sequence is NULL, the Sandbox calls the Moderator::InterpretGmatFunction() method to construct the Function Control Sequence, which in turn calls the ScriptInterpreter::InterpretGmatFunction() method. Both of these calls take the function pointer as input arguments. so that the interpreter has the local Sandbox instance of the GmatFunction that is uses to build the Function Control Sequence. The ScriptInterpreter::InterpretGmatFunction() method builds the Function Control Sequence and returns it, through the Moderator, to the Sandbox.

The LoadCartState GmatFunction that is constructed here is built from this scripting:

```
function [rv, vv, r, v] = LoadCartState(Sat);
% This function fills some arrays and variables with
% Cartesian state data
Create Variable r v
Create Array rv[3,1] vv[3,1]

rv(1,1) = Sat.X;
rv(1,2) = Sat.Y;
rv(1,3) = Sat.Z;
vv(1,1) = Sat.VX;
vv(1,2) = Sat.VY;
vv(1,3) = Sat.VZ;
```

```
[r] = magnitude(rv);

[v] = magnitude(vv);
```

The process followed in the ScriptInterpreter::InterpretGmatFunction() method will be described below. Upon return from this function call, the functions contain the attributes shown in Table 20.

Table 20: GmatFunction Status after Building the LoadCartState FCS

Function	Function Object Store	Global Object Store	inputs	outputs	Function Control Sequence	Call Stack
LoadCartState	empty	Set	'Sat' -> NULL	'rv' -> NULL 'vv' -> NULL 'r' -> NULL 'v' -> NULL	Create Create Assignment Assignment Assignment Assignment Assignment Assignment CallFunction CallFunction	empty
cross	empty	NULL	empty	empty	empty	empty
magnitude	empty	NULL	empty	empty	empty	empty

The Sandbox then checks the Function Control Sequence generated in the ScriptInterpreter, and checks to see if that sequence contains a GmatFunction. If it does, then for each GmatFunction encountered, the process is repeated.

The Sandbox checks the Function Control Sequence by starting at the first node, and checking each Assignment and CallFunction command in that control sequence to see if it references a GmatFunction. Our example script does contain such a call to a GmatFunction – it calls the magnitude function twice, in the last two CallFunction commands in the Function Control Sequence. Each of the FunctionManagers associated with these CallFunction commands have StringArrays containing the names of the input and output objects that will be used during execution – more specifically, the FunctionManager associated with the first CallFunction has these StringArrays:

```
inputNames = {  rv  }
outputNames = {  r  }
```

while the second has these:

```
inputNames = {  vv  }
outputNames = {  v  }
```

When the Sandbox detects the GmatFunction in the first CallFunction command, it performs the same tasks as were performed on the CallFunction in the Mission Control Sequence – more specifically:

1 The Sandbox passes the pointer for the Global Object Store to the CallFunction command. (Note that the Sandbox does not pass in the Sandbox Object Map; the Sandbox Object Map is only used in commands in the Mission Control Sequence.)

2 Once the CallFunction has received the Global Object Store, it uses that mapping to locate the function needed by the FunctionManager.

   - If the function was found, the CallFunction passes the pointer to that function into the FunctionManager

   - If the function was not found, the pointer referenced by the Function Manager remains NULL.

3 The FunctionManager determines the type of the function. If the function is not a GmatFunction, the process ends.

4 The Sandbox passes the pointers to the solar system and transient force vector, to the CallFunction, which passes them into the FunctionManager.

5 The FunctionManager passes these pointers into the function for later use.

At this point, all of the items needed to build the nested Function Control Sequence exist. Returning to our example, the state of the function object attributes at this point is shown in Table 21.

Table 21: GmatFunction Status after Detecting the First Nested CallFunction

Function	Function Object Store	Global Object Store	inputs	outputs	Function Control Sequence	Call Stack
LoadCartState	empty	Set	'Sat' -> NULL	'rv' -> NULL 'vv' -> NULL 'r' -> NULL 'v' -> NULL	Create Create Assignment Assignment Assignment Assignment Assignment Assignment CallFunction CallFunction	empty
cross	empty	NULL	empty	empty	empty	empty
magnitude	empty	Set	empty	empty	empty	empty

The Sandbox then calls the Moderator::InterpretGmatFunction() method to build the Function Control Sequence for the magnitude command. The magnitude function is scripted like this:

```
function [val] = magnitude(vec1)
```

```
% This function takes a 3-vector in a GMAT array and
% calculates its magnitude
Create Variable val
val = sqrt(dot(vec1, vec1));
```

so the resulting Function Control Sequence and other attributes have the values shown in Table 22 when the Moderator returns control to the Sandbox.

Table 22: GmatFunction Status after Parsing the First Nested CallFunction

Function	Function Object Store	Global Object Store	inputs	outputs	Function Control Sequence	Call Stack
LoadCartState	empty	Set	'Sat' -> NULL	'rv' -> NULL 'vv' -> NULL 'r' -> NULL 'v' -> NULL	Create Create Assignment Assignment Assignment Assignment Assignment Assignment CallFunction CallFunction	empty
cross	empty	NULL	empty	empty	empty	empty
magnitude	empty	Set	'vec1' -> NULL	'val' -> NULL	Create Assignment	empty

The Assignment command in the newly created Function Control Sequence is particularly interesting, because it contains inline mathematics, which use a previously unencountered GmatFunction named dot. The MathTree for this Assignment command is shown in Figure 3.

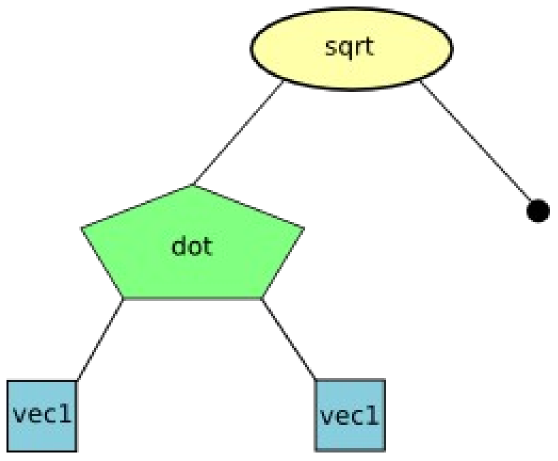


Figure 3: The MathTree for the Assignment command in the magnitude GmatFunction

Note that while the dot GmatFunction has been identified as a needed element for the Assignment line, there is not yet an instance of a GmatFunction object that is associated with the dot function, even though the MathTree shown in Figure 3 has a FunctionRunner MathNode that requires it. This issue will be resolved shortly.

The Sandbox takes this new Function Control Sequence, and checks it for the presence of a GmatFunction by walking through the list of commands in the control sequence. When it checks the Assignment command, it finds that there is a function dependency, and that the associated function does not exist in either the Global Object Store or in the Sandbox Object Map. Since all function types except for GmatFunctions must be created before they can be used, the Sandbox assumes that the needed function is a GmatFunction and asks the Moderator to create an unnamed GmatFunction[5].

The Moderator calls the Factory Manager to create the function, and returns the pointer of the new function to the Sandbox. The Sandbox then sets its name to be "dot" and adds it to the Sandbox Object Map and the Global Object Store[6]. The Sandbox also performs the preinitialization steps described above: it sets the solar system pointer on the function, sets any pointers referenced by the function, and calls the function's Initialize() method. Finally, the Sandbox calls the Moderator to locate the function file for the GmatFunction and sets the path to the file, completing this piece of the initialization. The Sandbox then passes the function pointer to the Assignment command, which passes it, in turn, into the FunctionRunner node. At this point, the Sandbox can continue initializing the Assignment command. The GmatFunction data is set as shown in Table 23.

Table 23: GmatFunction Status after Creating the dot Function

Function	Function Object Store	Global Object Store	inputs	outputs	Function Control Sequence	Call Stack
LoadCartState	empty	Set	'Sat' -> NULL	'rv' -> NULL 'vv' -> NULL 'r' -> NULL 'v' -> NULL	Create Create Assignment Assignment Assignment Assignment Assignment Assignment CallFunction CallFunction	empty
cross	empty	NULL	empty	empty	empty	empty
magnitude	empty	Set	'vec1' -> NULL	'val' -> NULL	Create Assignment	empty

5 The GmatFunction is unnamed so that it will not be passed to the configuration.

6 GmatFunctions are always added to the Sandbox Object Map so that they are ensured of proper cleanup when the Sandbox cleans up memory. Other objects created inside of functions are not handled this way, because they have an associated Create command that can manage memory for these local objects.

dot	empty	NULL	empty	empty	empty	empty

Recall that we are at the point in the initialization where the Sandbox is checking the Function Control Sequence for the magnitude GmatFunction for internal function calls. The Sandbox found the dot function as an internal dependency, and built the corresponding GmatFunction. The final step performed by the Sandbox at this point is to build the Function Control Sequence for the dot command. The text of the dot file looks like this:

```
function [val] = dot(vec1, vec2)

% This function takes two 3-vectors in a GMAT array and
% constructs their dot product
Create Variable val
val = vec1(1,1) * vec2(1,1) + vec1(2,1) * vec2(2,1) +...
         vec1(3,1) * vec2(3,1);
```

The Sandbox calls the Moderator::InterpretGmatFunction() method to build the control sequence for the dot function. Upon return, the function attribute table has the contents shown in Table 24.

Table 24: GmatFunction Status after Interpreting the dot Function

Function	Function Object Store	Global Object Store	inputs	outputs	Function Control Sequence	Call Stack
LoadCartState	empty	Set	'Sat' -> NULL	'rv' -> NULL 'vv' -> NULL 'r' -> NULL 'v' -> NULL	Create Create Assignment Assignment Assignment Assignment Assignment Assignment CallFunction CallFunction	empty
cross	empty	NULL	empty	empty	empty	empty
magnitude	empty	Set	'vec1' -> NULL	'val' -> NULL	Create Assignment	empty
dot	empty	Set	'vec1' -> NULL 'vec2' -> NULL	'val' -> NULL	Create Assignment	empty

The Sandbox takes the Function Control Sequence built for the dot function, and checks it for internal function calls. There is an Assignment command in this control sequence that references inline mathematics, but the corresponding MathTree does not contain any functions. Therefore, the initialization for the dot function is complete, and the method that built it returns control to the calling method.

In this case, the calling method is actually the same method – the call was a recursive call, because we were checking the Function Control Sequence for the dot function, which was called part way through the check of the Function Control Sequence for the magnitude function. That call was made for the Assignment command in the magnitude function. The check for the magnitude Assignment command has now built all of the functions it needs, so control is returned to the method that was performing the check on the magnitude function.

Again, the calling method is the method that checks for function calls, this time for the first CallFunction in the LoadCartState function. All of the function references in that CallFunction have been resolved and initialized, so the function check method moves to the second CallFunction. That CallFunction makes a call to the magnitude function. All of the internal structures needed to execute the magnitude function have been built, following the procedures discussed above. The check for this CallFunction does detect that there is a GmatFunction in the call – a call to the magnitude function. It then checks the magnitude GmatFunction, and finds that it has been initialized, so it proceeds to the next command in the LoadCartState Function Control Sequence. Since this second CallFunction was the last command in that Function Control Sequence, the LoadCartState function control sequence is now fully initialized and ready to execute.

We have now initialized all of the system except for the cross function. The Sandbox is partway through the check on the Mission Control Sequence for function calls – all of the preceding GmatFunction initialization was performed to fully initialize the CallFunction command in the Mission Control Sequence. The next function encountered in the main script is in the third Assignment command. That command was generated by the script line

```
     ev = cross(vv, cross(rv, vv)) / mu - rv / r;
```

When the Sandbox checks that line, it finds that there are two FunctionRunner nodes in the associated MathTree. The first of these nodes requires an initialized cross function, so the Sandbox follows the process described above to build the Function Control Sequence for the cross function. Once this first node has been handled by the Sandbox, the function attribute table looks like Table 25.

Table 25: GmatFunction Status after Interpreting the cross Function

Function	Function Object Store	Global Object Store	inputs	outputs	Function Control Sequence	Call Stack
LoadCartState	empty	Set	'Sat' -> NULL	'rv' -> NULL 'vv' -> NULL 'r' -> NULL 'v' -> NULL	Create Create Assignment Assignment Assignment Assignment	empty

					Assignment Assignment CallFunction CallFunction	
cross	empty	Set	'vec1' -> NULL 'vec2' -> NULL	'vec3'-> NULL	Create Assignment Assignment Assignment	empty
magnitude	empty	Set	'vec1' -> NULL	'val' -> NULL	Create Assignment	empty
dot	empty	Set	'vec1' -> NULL 'vec2' -> NULL	'val' -> NULL	Create Assignment	empty

The Sandbox then checks the second FunctionRunner node, and finds that it uses a function that has already been built – the cross function – so no further action is necessary for this Assignment command. It moves to the next command in the Mission Control Sequence, and finds that that command – a CallFunction that uses the magnitude GmatFunction – is also ready to execute. This process continues through all of the remaining commands in the Mission Control Sequence. All of the commands and called functions have been initialized, so the commands and functions used in the Sandbox have now been fully prepared for the mission run.

2.2.5 Additional Notes on Initialization

2.2.5.1 Function and FunctionManager Status Summary

The scripting in our example generates seven specific places where a FunctionManager interface is built in order to implement the structure needed to run a GmatFunction. Table 26 shows each of these interfaces, along with the string descriptors that are set in the interface tables for each of these instances. The actual data structures that contain the input and output objects are not set during initialization; they are built the first time the function is called during execution of the Mission Control Sequence. That process is described in the execution section of this text.

Table 26: Summary of the Function Interfaces

Script Line	**Interface Type**	**FunctionManager**		**Function**		
		inputNames	*outputNames*	*name*	*inputs*	*outputs*
[rv, vv, r, v] = LoadCartState(Sat)	Call-Function	'Sat'	'rv' 'vv' 'r' 'v'	LoadCartState	'Sat' -> NULL	'rv' -> NULL 'vv' -> NULL 'r' -> NULL 'v' -> NULL
ev = cross(vv, cross(rv, vv)) /	Function-Runner	'rv' 'vv'	''	cross (inner	'vec1' -> NULL	'vec3'-> NULL

mu - rv / r;	(Two instances)			instance)	'vec2' -> NULL	
		'vv' ''	''	cross (outer instance)	'vec1' -> NULL 'vec2' -> NULL	'vec3'-> NULL
[ECC] = magnitude(ev)	Call-Function	'ev'	'ECC'	magnitude	'vec1' -> NULL	'val' -> NULL
[n] = magnitude(nv)	Call-Function	'ev'	'n'	magnitude	'vec1' -> NULL	'val' -> NULL
[r] = magnitude(rv)	Call-Function	'rv'	'r'	magnitude	'vec1' -> NULL	'val' -> NULL
[v] = magnitude(vv)	Call-Function	'vv'	'v'	magnitude	'vec1' -> NULL	'val' -> NULL
val = sqrt(dot(vec1, vec1));	Function-Runner	'vec1' 'vec1'	''	dot	'vec1' -> NULL 'vec2' -> NULL	'val' -> NULL

Before we examine execution, a few items should be mentioned about the work performed in the ScriptInterpreter when the InterpretGmatFunction() method is invoked.

2.2.5.2 Details of the ScriptInterpreter::InterpretGmatFunction() Method

The Interpreter::InterpretGmatFunction()[7] method is very similar to the ScriptInterpreter::Interpret() method. The differences arise in the Interpreter state, the parsing for the function line in the function file, and the management of the commands created during the parsing of the function file.

The InterpretGmatFunction() method has this signature:

```
GmatCommand* Interpreter::InterpretGmatFunction(Function *funct)
```

The InterpretGmatFunction() method does not manage state in the same sense as the Interpret() method. At the point that the InterpretGmatFunction() method is invoked, there is no longer a sense of “object mode” and “command mode,” because every executable line in a GmatFunction file has an associated command – in other words, there is no “object mode” at this point in the process. Since there is no sense in tracking state, the Interpreter treats the entire time spent reading and building the GmatFunction as if it were in Command mode.

When the InterpretGmatFunction() method is invoked, it takes the Function pointer from the function's argument list and retrieves the function file name and path from that object. It opens the referenced file, and uses the

7 While this method is most naturally assigned to the ScriptInterpreter – since it is interpreting a text file describing the function – the method itself is found in the Interpreter base class.

ScriptReadWriter and TextParser helper classes to parse the function file, one logical block at a time.

The first logical block in a GmatFunction file defines the function, and must start with the “function” keyword. An example of this line can be see in the first line of the cross function in Listing 5:

```
    function [vec3] = cross(vec1, vec2)
```

If the keyword “function” is not encountered as the first element in the command section of the the first logical block in the file, the method throws an exception stating that the Interpreter expected a GmatFunction file, but the function definition line is missing.

The remaining elements in this logical block are used to check the function name for a match to the expected name, and to set the input and output argument lists for the function. The list contained in square brackets is sent, one element at a time, into the function as the output elements using the SetStringParameter() method. Similarly, the function arguments in parentheses following the function name generate calls to the SetStringParameter() method, setting the names for the input arguments. Thus, for example, the function definition line above for the cross function generates the following calls into the GmatFunction object that was passed into the InterpretGmatFunction() method:

```
    // Calls that are made to the cross function.  These are not
    // intended to be actual code; they are representative calls.
    // The actual code will loop through the argument lists rather
    // than perform the linear process shown here.


    // Given these values from the TextParser:
    //       inputList = {  vec1  ,   vec2  }
    //       functionName =   cross
    //       outputList = {  vec3  }

    // First check the name
    if (functionName != funct->GetName())
       throw CommandException(  The GmatFunction \     +
          funct->GetName() +   \   in the file \     +
          funct->GetStringParameter(  Filename  ) +
            \   does not match the function identifier in the file.  );

    // Next set the input argument(s)
    funct->SetStringParameter(INPUTPARAM_ID, inputList[0]);
    funct->SetStringParameter(INPUTPARAM_ID, inputList[1]);

    // And the output argument(s):
    funct->SetStringParameter(OUTPUTPARAM_ID, outputList[0]);
```

(Of course, the exception message should be changed to conform to GMAT's usual message formats.) The code in the GmatFunction is built to receive these values, and populate the internal data structures accordingly. This, for example, when the line

```
funct->SetStringParameter(INPUTPARAM_ID, inputList[0]);
```

is executed, the GmatFunction checks the inputs map and, if the input value is not in the map, adds it to the map, something like this:

```
// on this call: SetStringParameter(INPUTPARAM_ID,   vec1  ),
// the GmatFunction does this:

if (inputs.find(  vec1  ) == inputs.end())
   inputs[  vec1  ] = NULL;
else
   throw FunctionException(  Invalid operation: an attempt was
         made to add an input argument named \     +   vec1   +
        \  , but an argument with that name already exists.  );
```

Once the function definition line has been parsed, the process followed to build the Function Control Sequence begins. The Function Control Sequence is built using the same process as is followed for the Mission Control Sequence: the function file is read one logical block at a time, the command corresponding to that logical block is constructed, and the command is appended to the control sequence. The only difference for this phase of initialization is this: when GMAT is building a Mission Control Sequence, the sequence that receives the new commands is the Mission Control Sequence associated with the current Sandbox. For GmatFunction, the control sequence is the Function Control Sequence associated with the current function.

2.3 GmatFunction Execution

Once the Mission Control Sequence and all referenced Function Control Sequences have been initialized, they are ready for execution in the Sandbox. The Moderator launches execution by calling the Sandbox::Execute() method. When this method is called, the Sandbox sets an internal pointer to the first command in the Mission Control Sequence, and then enters a loop that walks through the Mission Control Sequence one command at a time. For each command in the Mission Control Sequence, the Sandbox performs the following actions:

1. Check to see if a user interrupt has occurred, and if so, respond to it.
2. Call the Execute() method on the current command.
3. Set the current command pointer to the command returned by calling GetNext() on the command that just executed.
4. If the new current command pointer is not NULL, loop to step 1; otherwise,

the Mission Control Sequence is finished executing and control returns to the Moderator.

In this section, we will examine the behavior of the execution of the commands that reference GmatFunctions exclusively. Readers interested in the general execution of the Mission Control Sequence are referred to Chapters 3 through 5 and Chapter 23 of the GMAT Architectural Specification.

The first command that references a GmatFunction is the command near the top of the While loop which was generated by this text:

```
[rv, vv, r, v] = LoadCartState(Sat);
```

This script line generates a CallFunction command. That CallFunction has a FunctionManager that references the LoadCartState GmatFunction. The first time Execute() is called for this CallFunction, these objects have the attributes shown in Table 27. (For the CallFunction, only the pointers needed in this discussion are shown in the object stores. The example used here does not use any global objects, so just the Global Object Store status is indicated.)

Table 27: CallFunction Attributes Prior to First Execution

CallFunction		**FunctionManager**			**LoadCartState function**			
Sandbox Object Store	*Global Object Store*	*input-Names*	*output-Names*	*Function Object Store*	*inputs*	*outputs*	*Function Object Store*	*Global Object Store*
Sat rv vv r v	set	'Sat'	'rv' 'vv' 'r' 'v'	empty	Sat->NULL	rv->NULL vv->NULL r->NULL v->NULL	NULL	NULL

The first time a CallFunction or FunctionRunner is executed, the final piece of initialization is performed so that all of the data structures used for the execution are set and the Function Control Sequence is fully initialized. Subsequent calls into the same CallFunction or FunctionRunner updates the data used in the function calls by copying the data into the Function Object Store using the object's assignment operator. Both of these processes are described below, and illustrated using our sample functions.

2.3.1 Steps Performed on the First Execution

The first time a CallFunction or FunctionRunner executes, the following processes are performed:

1. The CallFunction tells the FunctionManager to build the Function Object Store. The FunctionManager performs the following actions in response:
    - First the input arguments are set up:
        - The FunctionManager finds each input object listed in the inputNames

    StringArray
    - The input object is cloned , using its Clone() method
    - The Function is queried for the name of the matching input argument
    - The clone is set in the Function Object Store, using the function's argument name as the map key
    - An ElementWrapper is built for the clone
    - The ElementWrapper is passed to the Function as the input argument
  - Then the output arguments are set up:
    - The FunctionManager finds each output object listed in the outputNames StringArray
    - The output object is stored in an ObjectArray for later use
  - If this process fails for any input or output object, an exception is thrown and the process terminates.
  - The Function Object Store and Global Object Store are passed into the Function

At this point, the objects managed by this CallFunction have the attributes shown in Table 28.

Table 28: CallFunction Attributes After Building the Function Object Store

CallFunction		**FunctionManager**			**LoadCartState function**			
Sandbox Object Store	*Global Object Store*	*input-Names*	*output-Names*	*Function Object Store*	*inputs*	*outputs*	*Function Object Store*	*Global Object Store*
Sat rv vv r v	set	'Sat'	'rv' 'vv' 'r' 'v'	'Sat' -> Sat clone	Sat->clone wrapper	rv->NULL vv->NULL r->NULL v->NULL	set	set

2. Initialize the Function by calling Function->Initialize(). This call makes the Function complete initialization for each command in the Function Control Sequence. Each command in the Function Control Sequence (1) receives the pointer to the Function Object Store, Global Object Store, and Solar System, and then (2) calls the Initialize() method on the command.
3. Execute the Function Control Sequence by walking through the linked list of commands in the sequence, calling Execute() on each commands in the sequence and using the command's GetNext() method to access the next command that is executed. Some details are provided below for the behavior of CallFunction commands and FunctionRunner MathNodes encountered during this process.

Create commands encountered during this execution sequence add their objects to the Function Object Store. Global commands add the identified objects to the Global Object Store as well. At the end of the execution step, the attributes for the CallFunction example are listed in Table 29. Note that the pointers in the outputs attribute have not been set yet.

Table 29: CallFunction Attributes After Building the Function Object Store

CallFunction		**FunctionManager**			**LoadCartState function**			
Sandbox Object Store	*Global Object Store*	*input-Names*	*output-Names*	*Function Object Store*	*inputs*	*outputs*	*Function Object Store*	*Global Object Store*
Sat rv vv r v	set	'Sat'	'rv' 'vv' 'r' 'v'	'Sat' -> Sat clone 'rv'->rv 'vv'->vv 'r'->r 'v'->v	Sat->clone wrapper	rv->NULL vv->NULL r->NULL v->NULL	set	set

4. Retrieve the output data generated from the execution, and use it to set data in the output arguments that were stored in step 1. The output arguments are retrieved through a call to Function::GetOutputArgument(Integer argNumber), which finds the output argument at the indicated location and returns it
5. Reset the Function Control Sequence so it is ready for subsequent calls to this function. The final state of the function attributes is shown in Table 30.

Table 30: CallFunction Attributes After Execution

CallFunction		**FunctionManager**			**LoadCartState function**			
Sandbox Object Store	*Global Object Store*	*input-Names*	*output-Names*	*Function Object Store*	*inputs*	*outputs*	*Function Object Store*	*Global Object Store*
Sat rv vv r v	set	'Sat'	'rv' 'vv' 'r' 'v'	'Sat' -> Sat clone 'rv'->rv 'vv'->vv 'r'->r 'v'->v	Sat->NULL	'rv' -> rv 'vv' -> vv 'r' -> r 'v' -> v	NULL	set

2.3.2 Steps Performed on the Subsequent Executions

Subsequent calls into a CallFunction or FunctionRunner that has executed once have a simplified first step, because the structures in the FunctionManager are initialized in the first call. Subsequent calls follow the following procedure:

1. The CallFunction tells the FunctionManager to refresh the Function Object Store. The FunctionManager performs the following actions in response:
    - The input arguments are updated using the assignment operator to set the clones equal to the original objects.
    - The Function Object Store is passed into the Function.

At this point, the objects managed by this CallFunction have the attributes shown in Table 31.

Table 31: CallFunction Attributes After Building the Function Object Store

CallFunction		**FunctionManager**			**LoadCartState function**			
Sandbox Object Store	*Global Object Store*	*input-Names*	*output-Names*	*Function Object Store*	*inputs*	*outputs*	*Function Object Store*	*Global Object Store*
Sat rv vv r v	set	'Sat'	'rv' 'vv' 'r' 'v'	'Sat' -> Sat clone	Sat->clone wrapper	rv->NULL vv->NULL r->NULL v->NULL	set	set

2. Initialize the Function by calling Function->Initialize(). This call makes the Function complete initialization for each command in the Function Control Sequence. Each command in the Function Control Sequence (1) receives the pointer to the Function Object Store, Global Object Store, and Solar System, and then (2) calls the Initialize() method on the command. (This repetition of step 2 is required because the same function can be called from multiple locations, with different input objects, so the object pointers in the Function Control Sequence have to be refreshed each time a function is entered.)
3. Execute the Function Control Sequence by walking through the linked list of commands in the sequence, calling Execute() on each command in the sequence and using the command's GetNext() method to access the next command that is executed.
4. Retrieve the output data generated from the execution, and use it to set data in the output arguments.
5. Reset the Function Control Sequence so it is ready for subsequent calls to this function.

2.3.3 Functions within Functions

GmatFunctions can call other GmatFunctions, either in a nested manner, or by calling recursively into the same function. When a GmatFunction detects that it is about to call into a GmatFunction in this manner, it needs to preserve the current state of the function data so that, upon return from the nested call, the function can resume execution. This preservation of function data is accomplished using a call stack, implemented as the GmatFunction::objectStack data member.

An example of the use of the call stack can be seen in the example script that we've been working through. The first function call, made to the LoadCartState function, uses a CallFunction in the Mission Control Sequence. When the Sandbox calls this function, the steps outlined in the previous section are performed, initializing and setting the Function Object Store and Function Control Sequence, and then calling the Execute method on each command in the Function Control Sequence to run the function. The use of the call stack can be seen when we examine the details of this process, as we will do in the following paragraphs.

When the Sandbox receives a message to execute the Mission Control Sequence, it sets its state to "RUNNING" and sets the current command pointer to the first command in the Mission Control Sequence. For our example, that means the current pointer start out pointing to the While command generated by this line of script:

```
While Sat.ElapsedDays < 1
```

The command is executed, and control returned to the Sandbox. The Sandbox then calls the GetNext() method to determine the next command to execute. The command pointer returned from that call points back to the While command again, because the While command is a branch command. The Sandbox polls for a user interrupt, and then calls the Execute() method on the While command again. The While command begins the execution of the commands inside of the While loop by calling its ExecuteBranch() method. That call executes the first command in the while loop,

```
Propagate Prop(Sat)
```

which advances the spacecraft one step and returns control to the While command. The While command then calls GetNext() on the Propagate command that just executed, and sets its loop command pointer to the returned value – in this case, a pointer to the CallFunction command generated by this line:

```
   [rv, vv, r, v] = LoadCartState(Sat);
```

The While command then returns control to the Sandbox. The Sandbox calls GetNext() on the While command, and receives, again, a pointer back to the While command, since the While command is running the commands in the while loop. The Sandbox polls for interrupts, and then calls Execute() on the While command, which calls ExecuteBranch(), which, in turn, calls Execute() on the CallFunction command. The CallFunction command and FunctionManager have completed initialization of the GmatFunction as described above, and the CallFunction has made a call into the FunctionManager::Execute() method to run the function. The following discussion picks up at that point.   I'll refer to this long sequence of calls as the "Sandbox call chain" for the rest of this section – in other words, the

Sandbox call chain is the sequence

```
Sandbox::Execute() --> While::Execute()
                   --> While::ExecuteBranch()
                   --> CallFunction::Execute()
                   --> FunctionManager::Execute()
```

The function that is executing at this point is the LoadCartState GmatFunction, which has the Function Control Sequence, Function Object Store, and call stack shown in Table 32. The functions called during execution of this function are also listed in this table, along with their attributes. The pointer in the FCS column shows the next command that will be executed; for example, the first Create command in the LoadCartState will be executed at the point where we resume discussion of the actual process in the next paragraph.

Table 32: Attributes of the LoadCartState GmatFunction and Subfunctions

LoadCartState			**magnitude**			**dot**		
FCS	*FOS*	*Call Stack*	*FCS*	*FOS*	*Call Stack*	*FCS*	*FOS*	*Call Stack*
> Create Create Assignment Assignment Assignment Assignment Assignment Assignment CallFunction CallFunction	Sat clone	empty	Create Assignment	NULL	empty	Create Assignment	NULL	empty

The first call on the Sandbox call chain at this point executed the Create command

```
Create Variable r v
```

placing the variables r and v into the function object store, as is shown in Table 33.

Table 33: Attributes of the LoadCartState GmatFunction After the Executing the First
Create Command

LoadCartState			**magnitude**			**dot**		
FCS	*FOS*	*Call Stack*	*FCS*	*FOS*	*Call Stack*	*FCS*	*FOS*	*Call Stack*
Create > Create Assignment Assignment Assignment	Sat clone r v	empty	Create Assignment	NULL	empty	Create Assignment	NULL	empty

Assignment Assignment Assignment CallFunctio n CallFunctio n								

The next call executes the second Create command

```
Create Array rv[3,1] vv[3,1]
```

adding the rv and vv arrays to the Function Object Store. The next six calls execute the six assignment commands that are used to set the elements of the rv and vv arrays:

```
rv(1,1) = Sat.X;
rv(1,2) = Sat.Y;
rv(1,3) = Sat.Z;
vv(1,1) = Sat.VX;
vv(1,2) = Sat.VY;
vv(1,3) = Sat.VZ;
```

Once all of these commands have executed, the attributes contain the data shown in Table 34, the next command to be executed is the first CallFunction command, and the function is ready to call the first nested function.

Table 34: Attributes of the LoadCartState GmatFunction After the Executing the Six Assignment Commands

LoadCartState			**magnitude**			**dot**		
FCS	*FOS*	*Call Stack*	*FCS*	*FOS*	*Call Stack*	*FCS*	*FOS*	*Call Stack*
Create Create Assignment Assignment Assignment Assignment Assignment Assignment > CallFunction CallFunction	Sat clone r v rv vv	empty	Create Assignment	NULL	empty	Create Assignment	NULL	empty

The CallFunction that is about to be invoked was generated from the script line

```
[r] = magnitude(rv);
```

Whenever the Sandbox call chain invokes a command, the following actions occur in the FunctionManager::Execute() method:

1. The FunctionManager::Execute() method checks to see if the command that needs to be executed makes a function call. If it does:
    - A flag is set indicating that a nested function is being run. (This flag is used to prevent repetition of the following bullets when the FunctionManager::Execute() method is reentered after polling for a user interrupt.)
    - The Function Object Store is cloned.
    - The Function Object Store is placed on the call stack.
    - The nested function (or functions, if more than one function call is made) is initialized, using the clone of the Function Object Store for the arguments and nested Function Object Store that are passed to the nested function.
2. The Execute() method is called for the command.
3. The GetNext() method is called for the command.
4. Control is returned to the caller so that interrupt polling can occur.

Once this process is started, calls from the Sandbox call chain into the FunctionManager::Execute() method as the result of polling for user interrupts skip the first step.

For the CallFunction command under discussion here, the attribute table shown in Table 35 described the internal state of the data immediately following the initialization in step one.

Table 35: Attributes of the LoadCartState GmatFunction after Initializing the First CallFunction Command

LoadCartState			**magnitude**			**dot**		
FCS	*FOS*	*Call Stack*	*FCS*	*FOS*	*Call Stack*	*FCS*	*FOS*	*Call Stack*
Create Create Assignment Assignment Assignment Assignment Assignment Assignment > CallFunction CallFunction	Clones of: Sat clone r v rv vv	Original FOS	>Create Assignment	clone of vv clone	empty	Create Assignment	NULL	empty

The magnitude GmatFunction is now ready to be run through the LoadCartState function. The next call through the Sandbox call chain invokes a call to the magnitude function's Create() command, which builds a variable named val. Table 36 shows the attributes after running this command.

Table 36: Attributes of the LoadCartState GmatFunction After Running the First magnitude Command

LoadCartState			**magnitude**			**dot**		
FCS	*FOS*	*Call Stack*	*FCS*	*FOS*	*Call Stack*	*FCS*	*FOS*	*Call Stack*
Create Create Assignment Assignment Assignment Assignment Assignment Assignment > CallFunction CallFunction	Clones of: Sat clone r v rv vv	Original FOS: Sat clone r v rv vv	Create >Assignment	'vec1'-> clone of vv clone val	empty	Create Assignment	NULL	empty

The next call through the Sandbox call chain invokes the magnitude function's Assignment command, built off of this line of script:

```
val = sqrt(dot(vec1, vec1));
```

The right side of this equation generates a MathTree. One node of that MathTree is a FunctionRunner, constructed to run the dot GmatFunction. Hence the check performed by the FunctionManager that is running the magnitude function detects that there is a nested function call in its Assignment command. Accordingly, when it is time to evaluate the MathTree, the controlling FunctionManager passes a pointer to itself into the MathTree, which passes that pointer to each FunctionRunner node in the tree. Then when the MathTree makes the call to evaluate the FunctionRunner node, the FunctionRunner starts by calling the controlling FunctionManager::PushToStack() method, which clones its local Function Object Store, places the original on its call stack, and build the Function Object Store for the nested function. It then sets the clone as the Function Object Store for the FunctionManager inside of the FunctionRunner, and calls that FunctionManager's Evaluate() method. The Evaluate method starts by initializing the function, using the newly cloned Function Object Store as the source for the objects needed for initialization. The resulting attributes are shown in Table 37.

Table 37: Attributes of the LoadCartState GmatFunction After Running the First magnitude Command

LoadCartState			**magnitude**			**dot**		
FCS	*FOS*	*Call Stack*	*FCS*	*FOS*	*Call Stack*	*FCS*	*FOS*	*Call Stack*
Create Create Assignment Assignment Assignment Assignment	Clones of: Sat clone r v	Original FOS: Sat clone r v	Create >Assignment	Clones of: 'vec1'-> clone of	Origina l FOS: 'vec1'-> clone of	>Create Assignment	'vec1'-> clone of clone of vv	empty

Assignment Assignment > CallFunction CallFunction	rv vv	rv vv		vv clone val	vv clone val		clone 'vec2'-> clone of clone of vv clone	

The dot function can now be run. This execution is made by calling the Evaluate() method on the FunctionRunner. In turn, the FunctionRunner executes the function. Fortunately, this function does not call another. Upon completion of the execution of the dot function, the attributes have the values shown in Table 38.

Table 38: Attributes of the LoadCartState GmatFunction After Evaluating the dot Command in the magnitude Function

LoadCartState			**magnitude**			**dot**		
FCS	*FOS*	*Call Stack*	*FCS*	*FOS*	*Call Stack*	*FCS*	*FOS*	*Call Stack*
Create Create Assignment Assignment Assignment Assignment Assignment Assignment > CallFunction CallFunction	Clones of: Sat clone r v rv vv	Original FOS: Sat clone r v rv vv	Create >Assignment	Clones of: 'vec1'-> clone of vv clone val	Original FOS: 'vec1'-> clone of vv clone val	Create Assignment	'vec1'-> clone of clone of vv clone 'vec2'-> clone of clone of vv clone val	empty

At this point we can start unwinding the call stack. The Function Object Store for the dot function includes a Variable, val, that has the scalar product of the vv Array with itself. Once the dot function has completed execution, the FunctionManager retrieves this value, and saves it so that it can be passed to the MathTree as the result of the Evaluate() call on the FunctionRunner node. The FunctionManger then finalizes the dot function, clearing the Function Object Store pointer in the dot function. The FunctionRunner then calls the controlling FunctionManager's PopFromStack() method, which deletes the cloned call stack and restores the Function Object Store that was on the call stack. The MathTree completes its evaluation, retrieving the values obtained from the dot function, and using that value to build the resultant needed by the Assignment command that contains the MathTree. The attributes at this point are shown in Table 39.

Table 39: Attributes of the LoadCartState GmatFunction After Evaluating the magnitude
Assignment Command

LoadCartState	**magnitude**	**dot**

FCS	*FOS*	*Call Stack*	*FCS*	*FOS*	*Call Stack*	*FCS*	*FOS*	*Call Stack*
Create Create Assignment Assignment Assignment Assignment Assignment Assignment > CallFunction CallFunction	Clones of: Sat clone r v rv vv	Original FOS: Sat clone r v rv vv	Create Assignment	'vec1'-> clone of vv clone val	empty	Create Assignment	NULL	empty

The Assignment command that called into the dot function used the results of that function to set the value of the val Variable in the magnitude function's Function Object Store. That Assignment command was the last command in the magnitude function's Function Control Sequence, so the call to the magnitude function made from the LoadCartState function has completed execution. The FunctionManager for the LoadCartState function retrieves the output argument – in this case, the val Variable – from the magnitude function. It then deletes the cloned function object store, pops the Function Object Store off of the call stack, locates the object set to contain the output – that is, the r Variable – in this Function Object Store, and calls the assignment operator to set these two objects equal. That process is followed for all of the output arguments in the function call, and then the FunctionManager clears the magnitude function, completing the execution of the CallFunction command. These steps result in the attributes tabulated in Table 40.

Table 40: Attributes of the LoadCartState GmatFunction After Evaluating the Clearing the magnitude Function

LoadCartState			**magnitude**			**dot**		
FCS	*FOS*	*Call Stack*	*FCS*	*FOS*	*Call Stack*	*FCS*	*FOS*	*Call Stack*
Create Create Assignment Assignment Assignment Assignment Assignment Assignment CallFunction > CallFunction	Sat clone r v rv vv	empty	Create Assignment	NULL	empty	Create Assignment	NULL	empty

This process is repeated for the last CallFunction in the LoadCartState Function Control Sequence, resulting in calls that set the value of the v Variable in the

LoadCartState Function Object Store. Once this final CallFunction has been evaluated, the FunctionManager in the Mission Control Sequence CallFunction command that started this process – that is, the FunctionManager that is running the LoadCartState function -- retrieves the output objects, one at a time, and sets the objects in the Sandbox Object Map referenced by the CallFunction command equal to the objects found in the LoadCartState Function Object Store using the corresponding assignment operators. This completes the LoadCartState function execution, so the CallFunction FunctionManager finalizess the LoadCartState function, resulting in the attributes shown in Table 41. The LoadCartState function is now ready for a new call, should one be encountered later in the mission.

Table 40: Attributes after running the LoadCartState Function

LoadCartState			**magnitude**			**dot**		
FCS	*FOS*	*Call Stack*	*FCS*	*FOS*	*Call Stack*	*FCS*	*FOS*	*Call Stack*
Create Create Assignment Assignment Assignment Assignment Assignment Assignment CallFunction CallFunction	NULL	empty	Create Assignment	NULL	empty	Create Assignment	NULL	empty

2.4 Finalization

The final step in running scripts that use GMAT functions is the cleanup after the function has been run. The normal procedure followed in the Sandbox is to call RunComplete() on the Mission Control Sequence, which gives each command the opportunity to reset itself for a subsequent run. The CallFunction and Assignment commands that access GmatFunctions use this call to execute the RunComplete() method in the Function Control Sequences contained in those functions.

The Sandbox Object Map and Global Object Store are left intact when GMAT finishes a run. Subsequent runs in GMAT start by clearing and reloading these object stores. The preservation of the final states of the objects in the Sandbox makes it possible to query these objects for final state data after a run completes execution.

3 Global Data Handling: Another Short Example

In this section, we will examine another short sample to show how global data is managed in GMAT when functions are present. The main script that drives this example is shown here:

```
    Create ImpulsiveBurn globalBurn;
```

```
Create Spacecraft globalSat;
Create Variable index;

Create ForceModel fm
fm.PrimaryBodies = {Earth}
Create Propagator prop
prop.FM = fm

Create OpenGLPlot OGLPlot1;
GMAT OGLPlot1.Add = {globalSat, Earth};

Global globalBurn globalSat
Propagate prop(globalSat) {globalSat.Earth.Periapsis}
For index = 1 : 4
    RaiseApogee(index);
    Propagate prop(globalSat) {globalSat.Earth.Periapsis}
EndFor
```

The function called here, RaiseApogee, applies a maneuver to the spacecraft so that subsequent propagation moves the spacecraft on different trajectory. The function is defined like this:

```
function [] = RaiseApogee(burnSize)

Global globalBurn globalSat
globalBurn.Element1 = burnSize / 10.0;
Maneuver globalBurn(globalSat);
```

This function uses two objects that are not defined in the function, and that are also not passed in using arguments to the function. These objects are placed in the Sandbox's Global Object Store. In the next few pages we will examine this object repository during initialization, execution, and finalization.

3.1 Globals During Initialization

At the start of initialization in the Sandbox, the Global Object Store is empty, the Sandbox Object Map contains the objects from the Configuration, and the Mission Control Sequence has been built from parsing of the script. The state of the objects in the Sandbox immediately before the start of Mission Control Sequence initialization is shown in Table 41.

Table 41: The Objects in the Globals Example at the Start of Initialization

Mission Objects			**RaiseApogee Function**		
Sandbox Object Map	*Global Object Store*	*Mission Control Sequence*	*Function Object Store*	*Global Object Map*	*Function Control Sequence*
globalBurn globalSat	empty	Global Propagate	NULL	NULL	empty

index fm prop EarthMJ2000Eq EarthMJ2000Ec EarthFixedOGL Plot1 RaiseApogee		For CallFunction Propagate EndFor			

The first thing the Sandbox does after initializing the objects in the Sandbox Object Map is to collect the automatic global objects from the Sandbox Object Map and sets them in the Global Object Store. The Sandbox also finds all objects in the Sandbox Object Store that are marked as globals via the isGlobal flag, and moves those objects into the Global Object Store. These objects are set as globals using a check box on the GUI, or using the "MakeGlobal" object property in the script file. For this example, neither case is met, so the only global objects are the automatic globals – the Propagator and the Function found in the script. Table 42 shows the resulting rearrangement of objects.

Table 41: The Objects in the Globals Example at the Start of Initialization

Mission Objects			**RaiseApogee Function**		
Sandbox Object Map	*Global Object Store*	*Mission Control Sequence*	*Function Object Store*	*Global Object Map*	*Function Control Sequence*
globalBurn globalSat index fm OGLPlot1	prop EarthMJ2000Eq EarthMJ2000Ec EarthFixed RaiseApogee	Global Propagate For CallFunction Propagate EndFor	NULL	NULL	empty

Note that the global objects have been moved from the Sandbox Object Map into the Global Object Store. This feature – glossed over in the earlier discussion – makes memory management for the objects at the Sandbox level simple. When the Sandbox is cleared, all of the objects in the Sandbox Object Map and the Global Object Store are deleted.

This feature has implications for global objects created inside of functions as well. If an object created inside of a function is declared global, either explicitly using a Global command or implicitly by virtue of its type, the Sandbox checks the Global Object Store to see if an object of that name is already stored in it. If the object already exists in the Global Object Store, the types of the objects are compared, and if they do not match, an exception is thrown. Additional discussion of the interplay between the Create command and the Global command are provided in the design specifications for those commands.

Once the automatic globals have been moved into the Global Object Store, the Sandbox proceeds with initialization of the commands in the Mission Control

Sequence. This process follows the procedure described in the preceding sections, so the results are summarized here, with details related to global objects discussed more completely.

The first command of interest in this discussion is the Global command. At construction, this command was given the names of the global objects identified for the command. These names are stored in the command for use at execution time. No action is applied for this command during initialization.

The next command of interest is the CallFunction command. When the CallFunction command initializes, the Global Object Store pointer is passed into the function contained in the CallFunction – in this case, the RaiseApogee function. Then the solar system and transient force vector pointers are set in the function. The function is then retrieved by the Sandbox, and passed to the ScriptInterpreter::InterpretGmatFunction() method, which builds the Function Control Sequence. Upon return, the attributes are set as shown in Table 42.

Table 42: The Objects in the Globals Example on return from InterpretGmatFunction

Mission Objects			**RaiseApogee Function**		
Sandbox Object Map	*Global Object Store*	*Mission Control Sequence*	*Function Object Store*	*Global Object Map*	*Function Control Sequence*
globalBurn globalSat index fm OGLPlot1	prop EarthMJ2000Eq EarthMJ2000Ec EarthFixed RaiseApogee	Global Propagate For CallFunction Propagate EndFor	NULL	set	Global Assignment Maneuver

Like the Mission Control Sequence, the Function Control Sequence contains a Global command. The names of the global objects identified for this command are set in the InterpretGmatFunction() method when the GmatFunction is parsed. Nothing else happens for the Global command during the initialization that builds the Function Control Sequence.

The Sandbox continues initializing the commands in the Mission Control Sequence until they are all initialized, completing the process.

3.2 Globals During Execution

Next we will examine the behavior of the Global commands during execution of the Mission Control Sequence. The first command that is executed in the Mission Control Sequence is the Global command defined by the line

```
Global globalBurn globalSat
```

in the Function Control Sequence. This command contains a list of the global objects, specified as objects named “globalBurn” and “globalSat”. When the

Global::Execute() method is called, it takes this list and, for each element in the list, performs these actions:

1 Check the command's object map (in this case the Sandbox Object Store) for the named object.

2 If the object was found:

  2.1 Check the Global Object Store for an object with the same name.

  2.2 If no such object was found, remove the object from the object map and set it in the Global Object Store. Continue at step 4.

  2.3 If the object was found in the Global Object Store, throw an exception stating that an object was found in the Global Object Store with the same name as one that was being added, and terminate the run.

3 The object is not in the object map, so the Global command needs to verify that it was set by another process in the Global Object store. Looks for the object, and verify that it in the Global Object Store and that its pointer is not NULL. If the pointer is NULL, throw an exception and terminate the run.

4 Get the next name from the list of global objects. If the list is finished, exit, otherwise, return to step 1 to process the next global object.

The Global command in the Mission Control Sequence follows the process shown in step 2.2, moving the declared objects into the Global Object store, as shown in Table 43.

Table 43: The Objects in the Globals Example after Executing the Global Command in the Mission Control Sequence

Mission Objects			**RaiseApogee Function**		
Sandbox Object Map	*Global Object Store*	*Mission Control Sequence*	*Function Object Store*	*Global Object Map*	*Function Control Sequence*
index fm OGLPlot1	prop EarthMJ2000Eq EarthMJ2000Ec EarthFixed RaiseApogee globalBurn globalSat	Global Propagate For CallFunction Propagate EndFor	NULL	set	Global Assignment Maneuver

Execution of the Global command in the Mission Control Sequence simply verifies that the global objects are set as specified.