Swift User Guide

REVISION HISTORY			
NUMBER	DATE	DESCRIPTION	NAME

Contents

1 Overview

This manual provides reference material for Swift: the Swift language and the Swift runtime system. For introductory material, consult the Swift tutorial http://www.ci.uchicago.edu/swift/guides/tutorial.php.

Swift is a data-oriented coarse grained scripting language that supports dataset typing and mapping, dataset iteration, conditional branching, and procedural composition.

Swift programs (or workflows) are written in a language called Swift scripts.

Swift scripts are dataflow oriented - they are primarily concerned with processing (possibly large) collections of data files, by invoking programs to do that processing. Swift handles execution of such programs on remote sites by choosing sites, handling the staging of input and output files to and from the chosen sites and remote execution of program code.

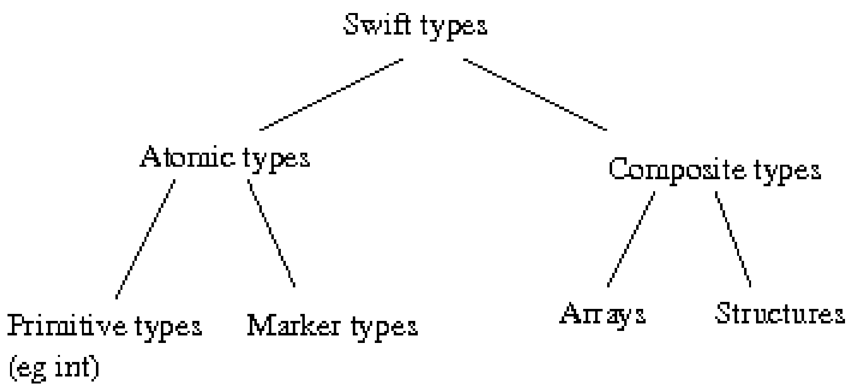
2 The Swift scripting Language

2.1 Language basics

A Swift script describes data, application components, invocations of applications components, and the inter-relations (data flow) between those invocations.

Data is represented in a script by strongly-typed single-assignment variables. The syntax superficially resembles C and Java. For example, { and } characters are used to enclose blocks of statements.

Types in Swift can be atomic or composite. An atomic type can be either a primitive type or a mapped type. Swift provides a fixed set of primitive types, such as integer and string. A mapped type indicates that the actual data does not reside in CPU addressable memory (as it would in conventional programming languages), but in POSIX-like files. Composite types are further subdivided into structures and arrays. Structures are similar in most respects to structure types in other languages. In Swift, structures are defined using the *type* keyword (there is no struct keyword). Arrays use numeric indices, but are sparse. They can contain elements of any type, including other array types, but all elements in an array must be of the same type. We often refer to instances of composites of mapped types as datasets.



Atomic types such as string, int, float and double work the same way as in C-like programming languages. A variable of such atomic types can be defined as follows:

```
string astring = "hello";
```

A struct variable is defined using the *type* keyword as discussed above. Following is an example of a variable holding employee data:

```
type Employee{
    string name;
    int id;
    string loc;
}
```

The members of the structure defined above can be accessed using the dot notation. An example of a variable of type Employee is as follows:

```
Employee emp;
emp.name="Thomas";
emp.id=2222;
emp.loc="Chicago";
```

Arrays of structures are allowed in Swift. A convenient way of populating structures and arrays of structures is to use the *readData()* function.

Mapped type and composite type variable declarations can be annotated with a mapping descriptor indicating the file(s) that make up that dataset. For example, the following line declares a variable named photo with type image. It additionally declares that the data for this variable is stored in a single file named shane.jpg.

```
image photo <"shane.jpg">;
```

Component programs of scripts are declared in an app declaration, with the description of the command line syntax for that program and a list of input and output data. An app block describes a functional/dataflow style interface to imperative components.

For example, the following example lists a procedure which makes use of the ImageMagick http://www.imagemagick.org/- convert command to rotate a supplied image by a specified angle:

```
app (image output) rotate(image input) {
  convert "-rotate" angle @input @output;
}
```

A procedure is invoked using the familiar syntax:

```
rotated = rotate(photo, 180);
```

While this looks like an assignment, the actual unix level execution consists of invoking the command line specified in the app declaration, with variables on the left of the assignment bound to the output parameters, and variables to the right of the procedure invocation passed as inputs.

The examples above have used the type image without any definition of that type. We can declare it as a marker type which has no structure exposed to Swift script:

```
type image;
```

This does not indicate that the data is unstructured; but it indicates that the structure of the data is not exposed to Swift. Instead, Swift will treat variables of this type as individual opaque files.

With mechanisms to declare types, map variables to data files, and declare and invoke procedures, we can build a complete (albeit simple) script:

```
type image;
image photo <"shane.jpg">;
image rotated <"rotated.jpg">;

app (image output) rotate(image input, int angle) {
   convert "-rotate" angle @input @output;
}

rotated = rotate(photo, 180);
```

This script can be invoked from the command line:

```
  $ ls *.jpg
  shane.jpg
  $ swift example.swift
  ...
  $ ls *.jpg
  shane.jpg rotated.jpg
```

This executes a single convert command, hiding from the user features such as remote multisite execution and fault tolerance that will be discussed in a later section.

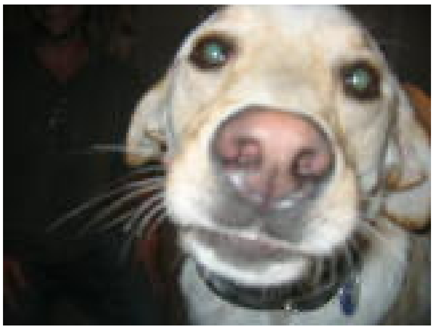


Figure 1. shane.jpg

Figure 2. rotated.jpg

2.2 Arrays and Parallel Execution

Arrays of values can be declared using the [] suffix. Following is an example of an array of strings:

```
string pets[] = ["shane", "noddy", "leo"];
```

An array may be mapped to a collection of files, one element per file, by using a different form of mapping expression. For example, the filesys_mapper maps all files matching a particular unix glob pattern into an array:

```
file frames[] <filesys_mapper; pattern="*.jpg">;
```

The foreach construct can be used to apply the same block of code to each element of an array:

```
foreach f,ix in frames {
  output[ix] = rotate(f, 180);
```

Sequential iteration can be expressed using the iterate construct:

```
step[0] = initialCondition();
iterate ix {
  step[ix] = simulate(step[ix-1]);
}
```

This fragment will initialise the 0-th element of the step array to some initial condition, and then repeatedly run the simulate procedure, using each execution's outputs as input to the next step.

2.3 Associative Arrays

By default, array keys are integers. However, other primitive types are also allowed as array keys. The syntax for declaring an array with a key type different than the default is:

```
<valueType>[<keyType>] array;
```

For example, the following code declares and assigns items to an array with string keys and float values:

```
float[string] a;
a["one"] = 0.2;
a["two"] = 0.4;
```

In addition to primitive types, a special type named **auto** can be used to declare an array for which an additional **append** operation is available:

```
int[auto] array;

foreach i in [1:100] {
   array << (i*2)
}

foreach v in array {
  trace(v);
}
```

Items in an array with **auto** keys cannot be accessed directly using a primitive type. The following example results in a compile-time error:

```
int[auto] array;
array[0] = 1;
```

However, it is possible to use **auto** key values from one array to access another:

```
int[auto] a;
int[auto] b;

a << 1;
a << 2;

foreach v, k in a {
  b[k] = a[k] * 2;
}
```

2.4 Ordering of execution

Non-array variables are single-assignment, which means that they must be assigned to exactly one value during execution. A procedure or expression will be executed when all of its input parameters have been assigned values. As a result of such execution, more variables may become assigned, possibly allowing further parts of the script to execute.

In this way, scripts are implicitly parallel. Aside from serialisation implied by these dataflow dependencies, execution of component programs can proceed in parallel.

In this fragment, execution of procedures p and q can happen in parallel:

```
y=p(x);
z=q(x);
```

while in this fragment, execution is serialised by the variable y, with procedure p executing before q.

```
y=p(x);
z=q(y);
```

Arrays in Swift are more monotonic - a generalisation of being assignment. Knowledge about the content of an array increases during execution, but cannot otherwise change. Each element of the array is itself single assignment or monotonic (depending on its type). During a run all values for an array are eventually known, and that array is regarded as closed.

Statements which deal with the array as a whole will often wait for the array to be closed before executing (thus, a closed array is the equivalent of a non-array type being assigned). However, a foreach statement will apply its body to elements of an array as they become known. It will not wait until the array is closed.

Consider this script:

```
file a[];
file b[];
foreach v,i in a {
  b[i] = p(v);
}
a[0] = r();
a[1] = s();
```

Initially, the foreach statement will have nothing to execute, as the array a has not been assigned any values. The procedures r and s will execute. As soon as either of them is finished, the corresponding invocation of procedure p will occur. After both r and s have completed, the array a will be closed since no other statements in the script make an assignment to a.

2.5 Compound procedures

As with many other programming languages, procedures consisting of Swift script can be defined. These differ from the previously mentioned procedures declared with the app keyword, as they invoke other Swift procedures rather than a component program.

```
(file output) process (file input) {
  file intermediate;
  intermediate = first(input);
  output = second(intermediate);
}

file x <"x.txt">;
file y <"y.txt">;
y = process(x);
```

This will invoke two procedures, with an intermediate data file named anonymously connecting the first and second procedures.

Ordering of execution is generally determined by execution of app procedures, not by any containing compound procedures. In this code block:

```
(file a, file b) A() {
  a = A1();
  b = A2();
}
file x, y, s, t;
(x,y) = A();
s = S(x);
t = S(y);
```

then a valid execution order is: A1 S(x) A2 S(y). The compound procedure A does not have to have fully completed for its return values to be used by subsequent statements.

2.6 More about types

Each variable and procedure parameter in Swift script is strongly typed. Types are used to structure data, to aid in debugging and checking program correctness and to influence how Swift interacts with data.

The image type declared in previous examples is a marker type. Marker types indicate that data for a variable is stored in a single file with no further structure exposed at the Swift script level.

Arrays have been mentioned above, in the arrays section. A code block may be applied to each element of an array using foreach; or individual elements may be references using [] notation.

There are a number of primitive types:

type	contains
int	integers
string	strings of text
float	floating point numbers, that behave the same as Java doubles
boolean	true/false

Complex types may be defined using the type keyword:

```
type headerfile;
type voxelfile;
type volume {
  headerfile h;
  voxelfile v;
}
```

Members of a complex type can be accessed using the . operator:

```
volume brain;
o = p(brain.h);
```

Sometimes data may be stored in a form that does not fit with Swift's file-and-site model; for example, data might be stored in an RDBMS on some database server. In that case, a variable can be declared to have external type. This indicates that Swift should use the variable to determine execution dependency, but should not attempt other data management; for example, it will not perform any form of data stage-in or stage-out it will not manage local data caches on sites; and it will not enforce component program atomicity on data output. This can add substantial responsibility to component programs, in exchange for allowing arbitrary data storage and access methods to be plugged in to scripts.

```
type file;

app (external o) populateDatabase() {
  populationProgram;
}

app (file o) analyseDatabase(external i) {
  analysisProgram @o;
}

external database;
file result <"results.txt">;

database = populateDatabase();
result = analyseDatabase(database);
```

Some external database is represented by the database variable. The populateDatabase procedure populates the database with some data, and the analyseDatabase procedure performs some subsequent analysis on that database. The declaration of database contains no mapping; and the procedures which use database do not reference them in any way; the description of database is entirely outside of the script. The single assignment and execution ordering rules will still apply though; populateDatabase will always be run before analyseDatabase.

2.7 Data model

Data processed by Swift is strongly typed. It may be take the form of values in memory or as out-of-core files on disk. Language constructs called mappers specify how each piece of data is stored.

2.8 Mappers

When a DSHandle represents a data file (or container of datafiles), it is associated with a mapper. The mapper is used to identify which files belong to that DSHandle.

A dataset's physical representation is declared by a mapping descriptor, which defines how each element in the dataset's logical schema is stored in, and fetched from, physical structures such as directories, files, and remote servers.

Mappers are parameterized to take into account properties such as varying dataset location. In order to access a dataset, we need to know three things: its type, its mapping, and the value(s) of any parameter(s) associated with the mapping descriptor. For example, if we want to describe a dataset, of type imagefile, and whose physical representation is a file called "file1.bin" located at "/home/yongzh/data/", then the dataset might be declared as follows:

```
imagefile f1<single_file_mapper;file="/home/yongzh/data/file1.bin">
```

The above example declares a dataset called f1, which uses a single file mapper to map a file from a specific location.

Swift has a simplified syntax for this case, since single_file_mapper is frequently used:

```
binaryfile f1<"/home/yongzh/data/file1.bin">
```

Swift comes with a number of mappers that handle common mapping patterns. These are documented in the mappers section of this guide.

2.9 More technical details about Swift script

The syntax of Swift script has a superficial resemblance to C and Java. For example, { and } characters are used to enclose blocks of statements.

A Swift script consists of a number of statements. Statements may declare types, procedures and variables, assign values to variables, and express operations over arrays.

2.9.1 Variables

Variables in Swift scripts are declared to be of a specific type. Assignments to those variables must be data of that type. Swift script variables are single-assignment - a value may be assigned to a variable at most once. This assignment can happen at declaration time or later on in execution. When an attempt to read from a variable that has not yet been assigned is made, the code performing the read is suspended until that variable has been written to. This forms the basis for Swift's ability to parallelise execution - all code will execute in parallel unless there are variables shared between the code that cause sequencing.

2.9.2 Variable Declarations

Variable declaration statements declare new variables. They can optionally assign a value to them or map those variables to on-disk files.

Declaration statements have the general form:

```
typename variablename (<mapping> | = initialValue ) ;
```

The format of the mapping expression is defined in the Mappers section. initialValue may be either an expression or a procedure call that returns a single value.

Variables can also be declared in a multivalued-procedure statement, described in another section.

2.9.3 Assignment Statements

Assignment statements assign values to previously declared variables. Assignments may only be made to variables that have not already been assigned. Assignment statements have the general form:

```
variable = value;
```

where value can be either an expression or a procedure call that returns a single value.

Variables can also be assigned in a multivalued-procedure statement, described in another section.

2.10 Procedures

There are two kinds of procedure: An atomic procedure, which describes how an external program can be executed; and compound procedures which consist of a sequence of Swift script statements.

A procedure declaration defines the name of a procedure and its input and output parameters. Swift script procedures can take multiple inputs and produce multiple outputs. Inputs are specified to the right of the function name, and outputs are specified to the left. For example:

```
(type3 out1, type4 out2) myproc (type1 in1, type2 in2)
```

The above example declares a procedure called myproc, which has two inputs in1 (of type type1) and in2 (of type type2) and two outputs out1 (of type type3) and out2 (of type type4).

A procedure input parameter can be an optional parameter in which case it must be declared with a default value. When calling a procedure, both positional parameter and named parameter passings can be passed, provided that all optional parameters are declared after the required parameters and any optional parameter is bound using keyword parameter passing. For example, if myproc1 is defined as:

```
(binaryfile bf) myproc1 (int i, string s="foo")
```

Then that procedure can be called like this, omitting the optional

```
parameter s:
binaryfile mybf = myproc1(1);
```

or like this supplying a value for the optional parameter s:

```
binaryfile mybf = myproc1 (1, s="bar");
```

2.10.1 Atomic procedures

An atomic procedure specifies how to invoke an external executable program, and how logical data types are mapped to command line arguments.

Atomic procedures are defined with the app keyword:

```
app (binaryfile bf) myproc (int i, string s="foo") {
    myapp i s @filename(bf);
}
```

which specifies that myproc invokes an executable called myapp, passing the values of i, s and the filename of bf as command line arguments.

2.10.2 Compound procedures

A compound procedure contains a set of Swift script statements:

```
(type2 b) foo_bar (type1 a) {
    type3 c;
    c = foo(a);    // c holds the result of foo
    b = bar(c);    // c is an input to bar
}
```

2.11 Control Constructs

Swift script provides if, switch, foreach, and iterate constructs, with syntax and semantics similar to comparable constructs in other high-level languages.

2.11.1 foreach

The foreach construct is used to apply a block of statements to each element in an array. For example:

```
check_order (file a[]) {
    foreach f in a {
        compute(f);
    }
}
```

foreach statements have the general form:

```
foreach controlvariable (,index) in expression {
    statements
}
```

The block of statements is evaluated once for each element in expression which must be an array, with controlvariable set to the corresponding element and index (if specified) set to the integer position in the array that is being iterated over.

2.11.2 if

The if statement allows one of two blocks of statements to be executed, based on a boolean predicate. if statements generally have the form:

```
if(predicate) {
    statements
} else {
    statements
}
```

where predicate is a boolean expression.

2.11.3 switch

switch expressions allow one of a selection of blocks to be chosen based on the value of a numerical control expression. switch statements take the general form:

```
switch(controlExpression) {
    case n1:
        statements2
    case n2:
        statements2
```

```
    [...]
    default:
        statements
}
```

The control expression is evaluated, the resulting numerical value used to select a corresponding case, and the statements belonging to that case block are evaluated. If no case corresponds, then the statements belonging to the default block are evaluated.

Unlike C or Java switch statements, execution does not fall through to subsequent case blocks, and no break statement is necessary at the end of each block.

2.11.4 iterate

iterate expressions allow a block of code to be evaluated repeatedly, with an iteration variable being incremented after each iteration.

The general form is:

```
iterate var {
    statements;
} until (terminationExpression);
```

Here *var* is the iteration variable. Its initial value is 0. After each iteration, but before *terminationExpression* is evaluated, the iteration variable is incremented. This means that if the termination expression is a function of only the iteration variable, the body will never be executed while the termination expression is true.

Example:

```
iterate i {
    trace(i); // will print 0, 1, and 2
} until (i == 3);
```

Variables declared inside the body of *iterate* can be used in the termination expression. However, their values will reflect the values calculated as part of the last invocation of the body, and may not reflect the incremented value of the iteration variable:

```
iterate i {
    trace(i);
    int j = i; // will print 0, 1, 2, and 3
} until (j == 3);
```

2.12 Operators

The following infix operators are available for use in Swift script expressions.

operator	purpose
+	numeric addition; string concatenation
-	numeric subtraction
*	numeric multiplication
/	floating point division
%/	integer division
%%	integer remainder of division
== !=	comparison and not-equal-to
< > ⇐ >=	numerical ordering
&& ||	boolean and, or
!	boolean not

2.13 Global constants

At the top level of a Swift script program, the global modified may be added to a declaration so that it is visible throughout the program, rather than only at the top level of the program. This allows global constants (of any type) to be defined. (since Swift 0.10)

2.14 Imports

The import directive can be used to import definitions from another Swift file.

For example, a Swift script might contain this:

```
import "defs";
file f;
```

which would import the content of defs.swift:

```
type file;
```

Imported files are read from two places. They are either read from the path that is specified from the import command, such as:

```
import "definitions/file/defs";
```

or they are read from the environment variable SWIFT_LIB. This environment variable is used just like the PATH environment variable. For example, if the command below was issued to the bash shell:

```
export SWIFT_LIB=${HOME}/Swift/defs:${HOME}/Swift/functions
```

then the import command will check for the file defs.swift in both "${HOME}/Swift/defs" and "${HOME}/Swift/functions" first before trying the path that was specified in the import command.

Other valid imports:

```
import "../functions/func"
import "/home/user/Swift/definitions/defs"
```

There is no requirement that a module is imported only once. If a module is imported multiple times, for example in different files, then Swift will only process the imports once.

Imports may contain anything that is valid in a Swift script, including the code that causes remote execution.

3 Mappers

Mappers provide a mechanism to specify the layout of mapped datasets on disk. This is needed when Swift must access files to transfer them to remote sites for execution or to pass to applications.

Swift provides a number of mappers that are useful in common cases. This section details those mappers. For more complex cases, it is possible to write application-specific mappers in Java and use them within a Swift script.

3.1 The single file mapper

The single_file_mapper maps a single physical file to a dataset.

Swift variable	Filename
f	myfile
f [0]	INVALID
f.bar	INVALID

parameter	meaning
file	The location of the physical file including path and file name.

Example:

```
file f <single_file_mapper;file="plot_outfile_param">;
```

There is a simplified syntax for this mapper:

```
file f <"plot_outfile_param">;
```

3.2 The simple mapper

The simple_mapper maps a file or a list of files into an array by prefix, suffix, and pattern. If more than one file is matched, each of the file names will be mapped as a subelement of the dataset.

Parameter	Meaning
location	A directory that the files are located.
prefix	The prefix of the files
suffix	The suffix of the files, for instance: ".txt"
padding	The number of digits used to uniquely identify the mapped file. This is an optional parameter which defaults to 4.
pattern	A UNIX glob style pattern, for instance: "*foo*" would match all file names that contain foo. When this mapper is used to specify output filenames, pattern is ignored.

```
type file;
file f <simple_mapper;prefix="foo", suffix=".txt">;
```

The above maps all filenames that start with foo and have an extension .txt into file f.

Swift variable	Filename
f	foo.txt

```
type messagefile;

(messagefile t) greeting(string m) {.
    app {
        echo m stdout=@filename(t);
    }
}

messagefile outfile <simple_mapper;prefix="foo",suffix=".txt">;

outfile = greeting("hi");
```

This will output the string *hi* to the file foo.txt.

The simple_mapper can be used to map arrays. It will map the array index into the filename between the prefix and suffix.

```
type messagefile;

(messagefile t) greeting(string m) {
    app {
        echo m stdout=@filename(t);
```

```
    }
}

messagefile outfile[] <simple_mapper;prefix="baz",suffix=".txt", padding=2>;

outfile[0] = greeting("hello");
outfile[1] = greeting("middle");
outfile[2] = greeting("goodbye");
```

Swift variable	Filename
outfile[0]	baz00.txt
outfile[1]	baz01.txt
outfile[2]	baz02.txt

simple_mapper can be used to map structures. It will map the name of the structure member into the filename, between the prefix and the suffix.

```
type messagefile;

type mystruct {
  messagefile left;
  messagefile right;
};

(messagefile t) greeting(string m) {
    app {
        echo m stdout=@filename(t);
    }
}

mystruct out <simple_mapper;prefix="qux",suffix=".txt">;

out.left = greeting("hello");
out.right = greeting("goodbye");
```

This will output the string "hello" into the file qux.left.txt and the string "goodbye" into the file qux.right.txt.

Swift variable	Filename
out.left	quxleft.txt
out.right	quxright.txt

3.3 concurrent mapper

The concurrent_mapper is almost the same as the simple mapper, except that it is used to map an output file, and the filename generated will contain an extract sequence that is unique. This mapper is the default mapper for variables when no mapper is specified.

Parameter	Meaning
location	A directory that the files are located.
prefix	The prefix of the files
suffix	The suffix of the files, for instance: ".txt" pattern A UNIX glob style pattern, for instance: "*foo*" would match all file names that contain foo. When this mapper is used to specify output filenames, pattern is ignored.

Example:

```
file f1;
file f2 <concurrent_mapper;prefix="foo", suffix=".txt">;
```

The above example would use concurrent mapper for f1 and f2, and generate f2 filename with prefix "foo" and extension ".txt"

3.4 File system mapper

The filesys_mapper is similar to the simple mapper, but maps a file or a list of files to an array. Each of the filename is mapped as an element in the array. The order of files in the resulting array is not defined.

TODO: note on difference between location as a relative vs absolute path w.r.t. staging to remote location - as mihael said: It's because you specify that location in the mapper. Try location="." instead of location="/sandbox/. . . "

parameter	meaning
location	The directory where the files are located.
prefix	The prefix of the files
suffix	The suffix of the files, for instance: ".txt"
pattern	A UNIX glob style pattern, for instance: "*foo*" would match all file names that contain foo.

Example:

```
file texts[] <filesys_mapper;prefix="foo", suffix=".txt">;
```

The above example would map all filenames that start with "foo" and have an extension ".txt" into the array texts. For example, if the specified directory contains files: foo1.txt, footest.txt, foo__1.txt, then the mapping might be:

Swift variable	Filename
texts[0]	footest.txt
texts[1]	foo1.txt
texts[2]	foo__1.txt

3.5 fixed array mapper

The fixed_array_mapper maps from a string that contains a list of filenames into a file array.

parameter	Meaning
files	A string that contains a list of filenames, separated by space, comma or colon

Example:

```
file texts[] <fixed_array_mapper;files="file1.txt, fileB.txt, file3.txt">;
```

would cause a mapping like this:

Swift variable	Filename
texts[0]	file1.txt
texts[1]	fileB.txt
texts[2]	file3.txt

3.6 array mapper

The array_mapper maps from an array of strings into a file

parameter	meaning
files	An array of strings containing one filename per element

Example:

```
string s[] = [ "a.txt", "b.txt", "c.txt" ];

file f[] <array_mapper;files=s>;
```

This will establish the mapping:

Swift variable	Filename
f[0]	a.txt
f[1]	b.txt
f[2]	c.txt

3.7 regular expression mapper

The regexp_mapper transforms one file name to another using regular expression matching.

parameter	meaning
source	The source file name
match	Regular expression pattern to match, use
()	to match whatever regular expression is inside the parentheses, and indicate the start and end of a group; the contents of a group can be retrieved with the
\\number	special sequence (two backslashes are needed because the backslash is an escape sequence introducer)
transform	The pattern of the file name to transform to, use \number to reference the group matched.

Example:

```
string s = "picture.gif";
file f <regexp_mapper;
  source=s,
  match="(.*)gif",
  transform="\\1jpg">;
```

This example transforms a string ending gif into one ending jpg and maps that to a file.

Swift variable	Filename
f	picture.jpg

3.8 structured regular expression mapper

The structured_regexp_mapper is similar to the regexp_mapper. The structured_regexp_mapper can be applied to lists while the regexp_mapper cannot.

parameter	meaning
source	The source file name

parameter	meaning
match	Regular expression pattern to match, use
()	to match whatever regular expression is inside the parentheses, and indicate the start and end of a group; the contents of a group can be retrieved with the
\\number	special sequence (two backslashes are needed because the backslash is an escape sequence introducer)
transform	The pattern of the file name to transform to, use \number to reference the group matched.

Example:

```
string s[] = ["picture.gif", "hello.gif", "world.gif"];
file f[] <structured_regexp_mapper;
          source=s,
          match="(.*)gif",
          transform="\\1jpg">;
```

This example transforms all strings in a list that end in gif to end in jpg and maps the list to those files.

3.9 csv mapper

The csv_mapper maps the content of a CSV (comma-separated value) file into an array of structures. The dataset type needs to be correctly defined to conform to the column names in the file. For instance, if the file contains columns: name age GPA then the type needs to have member elements like this:

```
type student {
  file name;
  file age;
  file GPA;
}
```

If the file does not contain a header with column info, then the column names are assumed as column1, column2, etc.

Parameter	Meaning
file	The name of the CSV file to read mappings from.
header	Whether the file has a line describing header info; default is
true	
skip	The number of lines to skip at the beginning (after header line); default is 0.
hdelim	Header field delimiter; default is the value of the
delim	parameter
delim	Content field delimiters; defaults are space, tab and comma

Example:

```
student stus[] <csv_mapper;file="stu_list.txt">;
```

The above example would read a list of student info from file "stu_list.txt" and map them into a student array. By default, the file should contain a header line specifying the names of the columns. If stu_list.txt contains the following:

```
name,age,gpa
101-name.txt, 101-age.txt, 101-gpa.txt
name55.txt, age55.txt, age55.txt
q, r, s
```

then some of the mappings produced by this example would be:

stus[0].name	**101-name.txt**
stus[0].age	101-age.txt
stus[0].gpa	101-gpa.txt
stus[1].name	name55.txt
stus[1].age	age55.txt
stus[1].gpa	gpa55.txt
stus[2].name	q
stus[2].age	r
stus[2].gpa	s

3.10 external mapper

The external mapper, ext maps based on the output of a supplied Unix executable.

parameter	meaning
exec	The name of the executable (relative to the current directory, if an absolute path is not specified)
*	Other parameters are passed to the executable prefixed with a - symbol

The output (stdout) of the executable should consist of two columns of data, separated by a space. The first column should be the path of the mapped variable, in Swift script syntax (for example [2] means the 2nd element of an array) or the symbol $ to represent the root of the mapped variable. The following table shows the symbols that should appear in the first column corresponding to the mapping of different types of swift constructs such as scalars, arrays and structs.

Swift construct	first column	second column
scalar	$	file_name
anarray[]	[]	file_name
2dimarray[][]	[][]	file_name
astruct.fld	fld	file_name
astructarray[].fldname	[].fldname	file_name

Example: With the following in mapper.sh,

```
#!/bin/bash
echo "[2] qux"
echo "[0] foo"
echo "[1] bar"
```

then a mapping statement:

```
student stus[] <ext;exec="mapper.sh">;
```

would map

Swift variable	**Filename**
stus[0]	foo
stus[1]	bar
stus[2]	qux

Advanced Example: The following mapper.sh is an advanced example of an external mapper that maps a two-dimensional array to a directory of files. The files in the said directory are identified by their names appended by a number between 000 and 099. The first index of the array maps to the first part of the filename while the second index of the array maps to the second part of the filename.

```
#!/bin/sh

#take care of the mapper args
while [ $# -gt 0 ]; do
  case $1 in
    -location)          location=$2;;
    -padding)           padding=$2;;
    -prefix)            prefix=$2;;
    -suffix)            suffix=$2;;
    -mod_index)         mod_index=$2;;
    -outer_index)       outer_index=$2;;
    *) echo "$0: bad mapper args" 1>&2
       exit 1;;
  esac
  shift 2
done

for i in `seq 0 ${outer_index}`
do
 for j in `seq -w 000 ${mod_index}`
 do
  fj=`echo ${j} | awk '{print $1 +0}'` #format j by removing leading zeros
  echo "["${i}"]["${fj}"]" ${location}"/"${prefix}${j}${suffix}
 done
done
```

The mapper definition is as follows:

```
file_dat dat_files[][] < ext;
                              exec="mapper.sh",
                              padding=3,
                              location="output",
                              prefix=@strcat( str_root, "_" ),
                              suffix=".dat",
                              outer_index=pid,
                              mod_index=n >;
```

Assuming there are 4 files with name aaa, bbb, ccc, ddd and a mod_index of 10, we will have 4x10=40 files mapped to a two-dimensional array in the following pattern:

Swift variable	Filename
stus[0][0]	output/aaa_000.dat
stus[0][1]	output/aaa_001.dat
stus[0][2]	output/aaa_002.dat
stus[0][3]	output/aaa_003.dat
...	...
stus[0][9]	output/aaa_009.dat
stus[1][0]	output/bbb_000.dat
stus[1][1]	output/bbb_001.dat
...	...
stus[3][9]	output/ddd_009.dat

4 Commands

The commands detailed in this section are available in the bin/ directory of a Swift installation and can by run from the commandline if that directory is placed on the PATH.

4.1 swift

The swift command is the main command line tool for executing Swift scripts.

4.1.1 Command-line Syntax

The swift command is invoked as follows: swift [options] Swifti script [Swift-arguments]* with options taken from the following list, and Swift script arguments made available to the Swift script through the @arg function.

Swift command-line options

-help or -h

```
Display usage information
```

-typecheck

```
Does a typecheck of a Swift script, instead of executing it.
```

-dryrun

```
Runs the Swift script without submitting any jobs (can be
used to get a graph)
```

-monitor

```
Shows a graphical resource monitor
```

-resume file

```
Resumes the execution using a resume-log file .rlog
```

-config file

```
Indicates the Swift configuration file to be used for this run.
Properties in this configuration file will override the default
properties. If individual command line arguments are used for
properties, they will override the contents of this file.
```

-verbose | -v

```
Increases the level of output that Swift produces on the console to
include more detail about the execution
```

-debug | -d

```
Increases the level of output that Swift produces on the console to
include lots of detail about the execution
```

-logfile file

```
Specifies a file where log messages should go to. By default Swift
uses the name of the program being run and a numeric index (e.g.
myworkflow.1.log)
```

-runid identifier

```
Specifies the run identifier. This must be unique for every
invocation and is used in several places to keep files from
different executions cleanly separated. By default, a datestamp and
random number are used to generate a run identifier. When using this
parameter, care should be taken to ensure that the run ID remains
unique with respect to all other run IDs that might be used,
irrespective of (at least) expected execution sites, program or user.
```

-tui

```
Displays an interactive text mode monitor during a run. (since Swift
0.9)
```

In addition, the following Swift properties can be set on the command line:

- caching.algorithm
- clustering.enabled
- clustering.min.time
- clustering.queue.delay
- ip.address
- kickstart.always.transfer
- kickstart.enabled
- lazy.errors
- pgraph
- pgraph.graph.options
- pgraph.node.options
- sitedir.keep
- sites.file
- tc.file
- tcp.port.range

4.1.2 Return codes

The swift command may exit with the following return codes:

value	meaning
0	success
1	command line syntax error or missing project name
2	error during execution
3	error during compilation
4	input file does not exist

4.1.3 Environment variables

The swift is influenced by the following environment variables:

GLOBUS_HOSTNAME, GLOBUS_TCP_PORT_RANGE - set in the environment before running Swift. These can be set to inform Swift of the configuration of your local firewall. More information can be found in the Globus firewall How-to http://dev.globus.org/wiki/FirewallHowTo.

COG_OPTS - set in the environment before running Swift. Options set in this variable will be passed as parameters to the Java Virtual Machine which will run Swift. The parameters vary between virtual machine imlementations, but can usually be used to alter settings such as maximum heap size. Typing *java -help* will sometimes give a list of commands. The Sun Java 1.4.2 command line options are documented here http://java.sun.com/j2se/1.4.2/docs/tooldocs/windows/java.html.

4.2 swift-osg-ress-site-catalog

The swift-osg-ress-site-catalog command generates a site catalog based on OSG http://www.opensciencegrid.org/'s ReSS information system (since Swift 0.9)

Usage: **swift-osg-ress-site-catalog [options]**

--help

```
Show help message
```

--vo=[name]

```
Set what VO to query ReSS for
```

--engage-verified

```
Only retrieve sites verified by the Engagement VO site verification
tests This can not be used together with |--vo|, as the query will
only work for sites advertising support for the Engagement VO.

This option means information will be retrieved from the Engagement
collector instead of the top-level ReSS collector.
```

--out=[filename]

```
Write to [filename] instead of stdout
```

--condor-g

```
Generates sites files which will submit jobs using a local Condor-G
installation rather than through direct GRAM2 submission. (since
Swift 0.10)
```

4.3 swift-plot-log

swift-plot-log generates summaries of Swift run log files.

Usage: swift-plot-log [logfile] [targets]

When no targets are specified, swift-plog-log will generate an HTML report for the run. When targets are specified, only those named targets will be generated.

5 Executing app procedures

This section describes how Swift executes app procedures, and requirements on the behaviour of application programs used in app procedures. These requirements are primarily to ensure that the Swift can run your application in different places and with the various fault tolerance mechanisms in place.

5.1 Mapping of app semantics into unix process execution semantics

This section describes how an app procedure invocation is translated into a (remote) unix process execution. It does not describe the mechanisms by which Swift performs that translation; that is described in the next section.

In this section, this example Swift script is used for reference:

```
type file;

app (file o) count(file i) {
  wc @i stdout=@o;
}

file q <"input.txt">;
file r <"output.txt">;
```

The executable for wc will be looked up in tc.data.

This unix executable will then be executed in some application procedure workspace. This means:

Each application procedure workspace will have an application workspace directory. (TODO: can collapse terms application procedure workspace and application workspace directory ?

This application workspace directory will not be shared with any other application procedure execution attempt; all application procedure execution attempts will run with distinct application procedure workspaces. (for the avoidance of doubt: If a Swift script procedure invocation is subject to multiple application procedure execution attempts (due to Swift-level restarts, retries or replication) then each of those application procedure execution attempts will be made in a different application procedure workspace.)

The application workspace directory will be a directory on a POSIX filesystem accessible throughout the application execution by the application executable.

Before the application executable is executed:

- The application workspace directory will exist.
- The input files will exist inside the application workspace directory (but not necessarily as direct children; there may be subdirectories within the application workspace directory).
- The input files will be those files mapped to input parameters of the application procedure invocation. (In the example, this means that the file input.txt will exist in the application workspace directory)
- For each input file dataset, it will be the case that @filename or @filenames invoked with that dataset as a parameter will return the path relative to the application workspace directory for the file(s) that are associated with that dataset. (In the example, that means that @i will evaluate to the path input.txt)
- For each file-bound parameter of the Swift procedure invocation, the associated files (determined by data type?) will always exist.
- The input files must be treated as read only files. This may or may not be enforced by unix file system permissions. They may or may not be copies of the source file (conversely, they may be links to the actual source file).

During/after the application executable execution, the following must be true:

- If the application executable execution was successful (in the opinion of the application executable), then the application executable should exit with unix return code 0; if the application executable execution was unsuccessful (in the opinion of the application executable), then the application executable should exit with unix return code not equal to 0.
- Each file mapped from an output parameter of the Swift script procedure call must exist. Files will be mapped in the same way as for input files.
- The output subdirectories will be precreated before execution by Swift if defined within a Swift script such as the location attribute of a mapper. App executables expect to make them if they are referred to in the wrapper scripts.
- Output produced by running the application executable on some inputs should be the same no matter how many times, when or where that application executable is run. *The same* can vary depending on application (for example, in an application it might be acceptable for a PNG→JPEG conversion to produce different, similar looking, output jpegs depending on the environment)

Things to not assume:

- Anything about the path of the application workspace directory
- That either the application workspace directory will be deleted or will continue to exist or will remain unmodified after execution has finished
- That files can be passed between application procedure invocations through any mechanism except through files known to Swift through the mapping mechanism (there is some exception here for external datasets - there are a separate set of assertions that hold for external datasets)
- That application executables will run on any particular site of those available, or than any combination of applications will run on the same or different sites.

5.2 How Swift implements the site execution model

This section describes the implementation of the semantics described in the previous section.

Swift executes application procedures on one or more sites.

Each site consists of:

- worker nodes. There is some execution mechanism through which the Swift client side executable can execute its wrapper script on those worker nodes. This is commonly GRAM or Falkon or coasters.
- a site-shared file system. This site shared filesystem is accessible through some file transfer mechanism from the Swift client side executable. This is commonly GridFTP or coasters. This site shared filesystem is also accessible through the posix file system on all worker nodes, mounted at the same location as seen through the file transfer mechanism. Swift is configured with the location of some site working directory on that site-shared file system.

There is no assumption that the site shared file system for one site is accessible from another site.

For each workflow run, on each site that is used by that run, a run directory is created in the site working directory, by the Swift client side.

In that run directory are placed several subdirectories:

- shared/ - site shared files cache
- kickstart/ - when kickstart is used, kickstart record files for each job that has generated a kickstart record.
- info/ - wrapper script log files
- status/ - job status files
- jobs/ - application workspace directories (optionally placed here - see below)

Application execution looks like this:

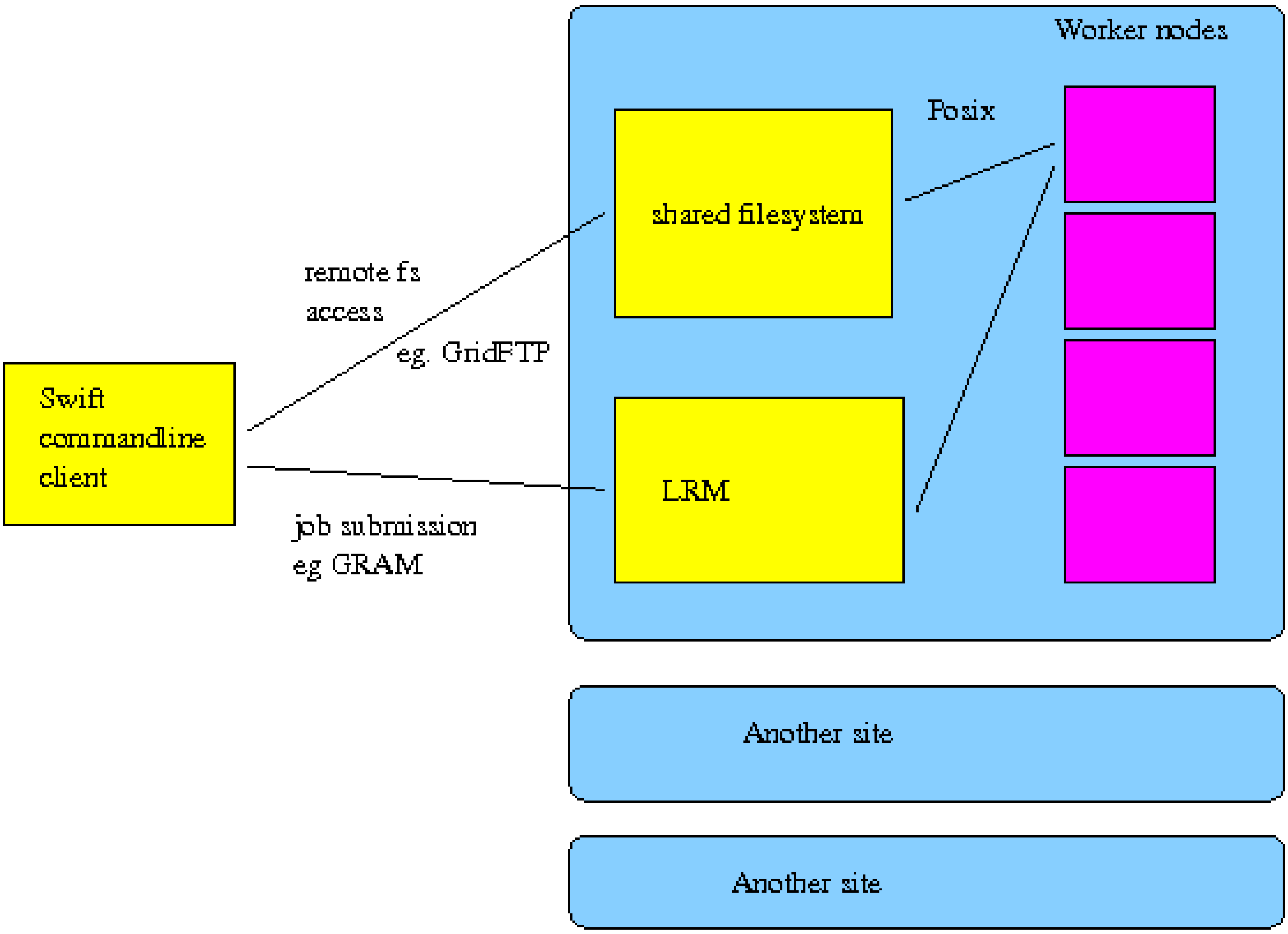
For each application procedure call:

The Swift client side selects a site; copies the input files for that procedure call to the site shared file cache if they are not already in the cache, using the file transfer mechanism; and then invokes the wrapper script on that site using the execution mechanism.

The wrapper script creates the application workspace directory; places the input files for that job into the application workspace directory using either cp or ln -s (depending on a configuration option); executes the application unix executable; copies output files from the application workspace directory to the site shared directory using cp; creates a status file under the status/ directory; and exits, returning control to the Swift client side. Logs created during the execution of the wrapper script are stored under the info/ directory.

The Swift client side then checks for the presence of and deletes a status file indicating success; and copies files from the site shared directory to the appropriate client side location.

The job directory is created (in the default mode) under the jobs/ directory. However, it can be created under an arbitrary other path, which allows it to be created on a different file system (such as a worker node local file system in the case that the worker node has a local file system).



6 Technical overview of the Swift architecture

This section attempts to provide a technical overview of the Swift architecture.

6.1 Execution layer

The execution layer causes an application program (in the form of a unix executable) to be executed either locally or remotely.

The two main choices are local unix execution and execution through GRAM. Other options are available, and user provided code can also be plugged in.

The kickstart utility can be used to capture environmental information at execution time to aid in debugging and provenance capture.

6.2 Swift script language compilation layer

Step i: text to XML intermediate form parser/processor. parser written in ANTLR - see resources/VDL.g. The XML Schema Definition (XSD) for the intermediate language is in resources/XDTM.xsd.

Step ii: XML intermediate form to Karajan workflow. Karajan.java - reads the XML intermediate form. compiles to karajan workflow language - for example, expressions are converted from Swift script syntax into Karajan syntax, and function invocations become karajan function invocations with various modifications to parameters to accomodate return parameters and dataset handling.

6.3 Swift/karajan library layer

Some Swift functionality is provided in the form of Karajan libraries that are used at runtime by the Karajan workflows that the Swift compiler generates.

7 Ways in which Swift can be extended

Swift is extensible in a number of ways. It is possible to add mappers to accomodate different filesystem arrangements, site selectors to change how Swift decides where to run each job, and job submission interfaces to submit jobs through different mechanisms.

A number of mappers are provided as part of the Swift release and documented in the mappers section. New mappers can be implemented in Java by implementing the org.griphyn.vdl.mapping.Mapper interface. The Swift tutorial http://www.ci.uchicago.edu/-swift/guides/tutorial.php contains a simple example of this.

Swift provides a default site selector, the Adaptive Scheduler. New site selectors can be plugged in by implementing the org.globus.cog.karajan.scheduler.Scheduler interface and modifying libexec/scheduler.xml and etc/karajan.properties to refer to the new scheduler.

Execution providers and filesystem providers, which allow to Swift to execute jobs and to stage files in and out through mechanisms such as GRAM and GridFTP can be implemented as Java CoG kit providers.

8 Function reference

This section details functions that are available for use in the Swift scripting language.

8.1 @arg

Takes a command line parameter name as a string parameter and an optional default value and returns the value of that string parameter from the command line. If no default value is specified and the command line parameter is missing, an error is generated. If a default value is specified and the command line parameter is missing, @arg will return the default value.

Command line parameters recognized by @arg begin with exactly one hyphen and need to be positioned after the script name.

For example:

```
trace(@arg("myparam"));
trace(@arg("optionalparam", "defaultvalue"));
```

```
$ swift arg.swift -myparam=hello
Swift v0.3-dev r1674 (modified locally)

RunID: 20080220-1548-ylc4pmda
Swift trace: defaultvalue
Swift trace: hello
```

8.2 @extractInt

@extractInt(file) will read the specified file, parse an integer from the file contents and return that integer.

8.3 @filename

@filename(v) will return a string containing the filename(s) for the file(s) mapped to the variable v. When more than one filename is returned, the filenames will be space separated inside a single string return value.

8.4 @filenames

@filenames(v) will return multiple values (!) containing the filename(s) for the file(s) mapped to the variable v. (compare to @filename)

8.5 @regexp

@regexp(input,pattern,replacement) will apply regular expression substitution using the Java java.util.regexp API http://java.sun.com/-j2se/1.4.2/docs/api/java/util/regex/Pattern.html. For example:

```
string v =  @regexp("abcdefghi", "c(def)g","monkey");
```

will assign the value "abmonkeyhi" to the variable v.

8.6 @sprintf

@sprintf(spec, variable list) will generate a string based on the specified format.

```
Example: string s = @sprintf("\t%s\n", "hello");
```

Format specifiers

%%	% sign
%M	Filename output (waits for close)
%p	Format variable according to an internal format
%b	Boolean output
%f	Float output
%i	int output
%s	String output
%k	Variable sKipped, no output
%q	Array output

8.7 @strcat

@strcat(a,b,c,d,. . .) will return a string containing all of the strings passed as parameters joined into a single string. There may be any number of parameters.

The + operator concatenates two strings: @strcat(a,b) is the same as a + b

8.8 @strcut

@strcut(input,pattern) will match the regular expression in the pattern parameter against the supplied input string and return the section that matches the first matching parenthesised group.

For example:

```
string t = "my name is John and i like puppies.";
string name = @strcut(t, "my name is ([^ ]*) ");
string out = @strcat("Your name is ",name);
trace(out);
```

This will output the message: Your name is John.

8.9 @strjoin

@strjoin(array, delimiter) will combine the elements of an array into a single string separated by a given delimiter. The array passed to @strjoin must be of a primitive type (string, int, float, or boolean). It will not join the contents of an array of files.

Example:

```
string test[] = ["this", "is", "a", "test" ];
string mystring = @strjoin(test, " ");
tracef("%s\n", mystring);
```

This will print the string "this is a test".

8.10 @strsplit

@strsplit(input,pattern) will split the input string based on separators that match the given pattern and return a string array.

Example:

```
string t = "my name is John and i like puppies.";
string words[] = @strsplit(t, "\\s");
foreach word in words {
    trace(word);
}
```

This will output one word of the sentence on each line (though not necessarily in order, due to the fact that foreach iterations execute in parallel).

8.11 @toInt

@toInt(input) will parse its input string into an integer. This can be used with @arg to pass input parameters to a Swift script as integers.

8.12 @toFloat

@toFloat(input) will parse its input string into a floating point number. This can be used with @arg to pass input parameters to a Swift script as floating point numbers.

8.13 @toString

@toString(input) will parse its input into a string. Input can be an int, float, string, or boolean.

8.14 @length

@length(array) will return the length of an array in Swift. This function will wait for all elements in the array to be written before returning the length.

8.15 @java

@java(class_name, static_method, method_arg) will call a java static method of the class class_name.

9 Built-in procedure reference

This section details built-in procedures that are available for use in the Swift scripting language.

9.1 readData

readData will read data from a specified file and assign it to Swift variable. The format of the input file is controlled by the type of the return value. For scalar return types, such as int, the specified file should contain a single value of that type. For arrays of scalars, the specified file should contain one value per line. For complex types of scalars, the file should contain two rows. The first row should be structure member names separated by whitespace. The second row should be the corresponding values for each structure member, separated by whitespace, in the same order as the header row. For arrays of structs, the file should contain a heading row listing structure member names separated by whitespace. There should be one row for each element of the array, with structure member elements listed in the same order as the header row and separated by whitespace. The following example shows how readData() can be used to populate an array of Swift struct-like complex type:

```
type Employee{
    string name;
    int id;
    string loc;
}

Employee emps[] = readData("emps.txt");
```

Where the contents of the "emps.txt" file are:

```
name id address
Thomas 2222 Chicago
Gina 3333 Boston
Anne 4444 Houston
```

This will result in the array "emps" with 3 members. This can be processed within a Swift script using the foreach construct as follows:

```
foreach emp in emps{
    tracef("Employee %s lives in %s and has id %d", emp.name, emp.loc, emp.id);
}
```

9.2 readStructured

readStructured will read data from a specified file, like readdata, but using a different file format more closely related to that used by the ext mapper.

Input files should list, one per line, a path into a Swift structure, and the value for that position in the structure:

```
rows[0].columns[0] = 0
rows[0].columns[1] = 2
rows[0].columns[2] = 4
rows[1].columns[0] = 1
rows[1].columns[1] = 3
rows[1].columns[2] = 5
```

which can be read into a structure defined like this:

```
type vector {
        int columns[];
}

type matrix {
        vector rows[];
}

matrix m;

m = readStructured("readStructured.in");
```

(since Swift 0.7, was readData2(deprecated))

9.3 trace

trace will log its parameters. By default these will appear on both stdout and in the run log file. Some formatting occurs to produce the log message. The particular output format should not be relied upon. (since Swift 0.4)

9.4 tracef

`tracef(`*`spec, variable list`*`)` will log its parameters as formatted by the formatter *spec*. *spec* must be a string. Checks the type of the specifiers arguments against the variable list and allows for certain escape characters.

Example:

```
int i = 3;
tracef("%s: %i\n", "the value is", i);
```

Specifiers:

%s
: Format a string.

%i
: Format a number as an integer.

%f
: Format a number as a floating point number.

%q
: Format an array.

%M
Format a mapped variable's filename.

%k
Wait for the given variable but do not format it.

%p
Format variable according to an internal format.

Escape sequences:

\n
Produce a newline.

\t
Produce a tab.

Known issues:
Swift does not correctly scan certain backslash sequences such as `\\`.

9.5 writeData

writeData will write out data structures in the format described for readData

10 Swift configuration properties

Various aspects of the behavior of the Swift Engine can be configured through properties. The Swift Engine recognizes a global, per installation properties file which can found in etc/swift.properties in the Swift installation directory and a user properties file which can be created by each user in ~/.swift/swift.properties. The Swift Engine will first load the global properties file. It will then try to load the user properties file. If a user properties file is found, individual properties explicitly set in that file will override the respective properties in the global properties file. Furthermore, some of the properties can be overridden directly using command line arguments to the **swift** command.

Swift properties are specified in the following format:

<name>=<value>

The value can contain variables which will be expanded when the properties file is read. Expansion is performed when the name of the variable is used inside the standard shell dereference construct: configuration file:

Swift Configuration Variables

swift.home

```
Points to the Swift installation directory ($SWIFT_HOME). In
general, this should not be set as Swift can find its own
installation directory, and incorrectly setting it may impair the
correct functionality of Swift.
```

user.name

```
The name of the current logged in user.
```

user.home

```
The user's home directory.
```

The following is a list of valid Swift properties:

Swift Properties

caching.algorithm

```
Valid values: LRU

Default value: LRU

Swift caches files that are staged in on remote resources, and files
that are produced remotely by applications, such that they can be
re-used if needed without being transfered again. However, the
amount of remote file system space to be used for caching can be
limited using the swift:storagesize profile entry in the sites.xml file. Example:
```

```
<pool handle="example" sysinfo="INTEL32::LINUX">
<gridftp url="gsiftp://example.org" storage="/scratch/swift" major="2" minor="4" patch ←
    ="3"/>
<jobmanager universe="vanilla" url="example.org/jobmanager-pbs" major="2" minor="4" patch ←
    ="3"/>
<workdirectory>/scratch/swift</workdirectory>
<profile namespace="SWIFT" key="storagesize">20000000</profile>
</pool>
```

```
The decision of which files to keep in the cache and which files to
remove is made considering the value of the caching.algorithm
property. Currently, the only available value for this property is
LRU, which would cause the least recently used files to be deleted
first.
```

clustering.enabled

```
Valid values: true, false

Default value: false

Enables clustering.
```

clustering.min.time

```
Valid values: <int>

Default value: 60

Indicates the threshold wall time for clustering, in seconds. Jobs
that have a wall time smaller than the value of this property will
be considered for clustering.
```

clustering.queue.delay

```
Valid values: <int>

Default value: 4
```

This property indicates the interval, in seconds, at which the clustering queue is processed.

execution.retries

Valid values: positive integers

Default value: 2

The number of time a job will be retried if it fails (giving a maximum of 1 + execution.retries attempts at execution)

foreach.max.threads

Valid values: positive integers

Default value: 1024

Limits the number of concurrent iterations that each foreach statement can have at one time. This conserves memory for swift programs that have large numbers of iterations (which would otherwise all be executed in parallel). (since Swift 0.9)

ip.address

Valid values: <ipaddress>

Default value: N/A

The Globus GRAM service uses a callback mechanism to send notifications about the status of submitted jobs. The callback mechanism requires that the Swift client be reachable from the hosts the GRAM services are running on. Normally, Swift can detect the correct IP address of the client machine. However, in certain cases (such as the client machine having more than one network interface) the automatic detection mechanism is not reliable. In such cases, the IP address of the Swift client machine can be specified using this property. The value of this property must be a numeric address without quotes.

This option is deprecated and the hostname property should be used instead.

kickstart.always.transfer

Valid values: true, false

Default value: false

This property controls when output from Kickstart is transfered back to the submit site, if Kickstart is enabled. When set to false, Kickstart output is only transfered for jobs that fail. If set to true, Kickstart output is transfered after every job is completed or failed.

kickstart.enabled

Valid values: true, false, maybe

Default value: maybe

This option allows controlling of when Swift uses Kickstart. A value of false disables the use of Kickstart, while a value of true enables the use of Kickstart, in which case sites specified in the sites.xml file must have valid gridlaunch attributes. The maybe value will enable the use of Kickstart only on sites that have the gridlaunch attribute specified.

lazy.errors

Valid values: true, false

Default value: false

Swift can report application errors in two modes, depending on the value of this property. If set to false, Swift will report the first error encountered and immediately stop execution. If set to true, Swift will attempt to run as much as possible from a Swift script before stopping execution and reporting all errors encountered.

When developing Swift scripts, using the default value of false can make the program easier to debug. However in production runs, using true will allow more of a Swift script to be run before Swift aborts execution.

pgraph

Valid values: true, false, <file>

Default value: false

Swift can generate a Graphviz <http://www.graphviz.org/> file representing the structure of the Swift script it has run. If this property is set to true, Swift will save the provenance graph in a file named by concatenating the program name and the instance ID (e.g. helloworld-ht0adgi315l61.dot).

If set to false, no provenance graph will be generated. If a file name is used, then the provenance graph will be saved in the specified file.

The generated dot file can be rendered into a graphical form using Graphviz <http://www.graphviz.org/>, for example with a command-line such as:

```
$ swift -pgraph graph1.dot q1.swift
$ dot -ograph.png -Tpng graph1.dot
```

pgraph.graph.options

```
Valid values: <string>

Default value: splines="compound", rankdir="TB"

This property specifies a Graphviz <http://www.graphviz.org>
specific set of parameters for the graph.
```

pgraph.node.options

```
Valid values: <string>

Default value: color="seagreen", style="filled"

Used to specify a set of Graphviz <http://www.graphviz.org> specific
properties for the nodes in the graph.
```

provenance.log

```
Valid values: true, false

Default value: false

This property controls whether the log file will contain provenance
information enabling this will increase the size of log files,
sometimes significantly.
```

replication.enabled

```
Valid values: true, false

Default value: false

Enables/disables replication. Replication is used to deal with jobs
sitting in batch queues for abnormally large amounts of time. If
replication is enabled and certain conditions are met, Swift creates
and submits replicas of jobs, and allows multiple instances of a job
to compete.
```

replication.limit

```
Valid values: positive integers

Default value: 3

The maximum number of replicas that Swift should attempt.
```

sitedir.keep

Valid values: true, false

Default value: false

Indicates whether the working directory on the remote site should be left intact even when a run completes successfully. This can be used to inspect the site working directory for debugging purposes.

sites.file

Valid values: <file>

Default value: ${swift.home}/etc/sites.xml

Points to the location of the site catalog, which contains a list of all sites that Swift should use.

status.mode

Valid values: files, provider

Default value: files

Controls how Swift will communicate the result code of running user programs from workers to the submit side. In files mode, a file indicating success or failure will be created on the site shared filesystem. In provider mode, the execution provider job status will be used.

provider mode requires the underlying job execution system to correctly return exit codes. In at least the cases of GRAM2, and clusters used with any provider, exit codes are not returned, and so files mode must be used in those cases. Otherwise, provider mode can be used to reduce the amount of filesystem access. (since Swift 0.8)

tc.file

Valid values: <file>

Default value: ${swift.home}/etc/tc.data

Points to the location of the transformation catalog file which contains information about installed applications. Details about the format of the transformation catalog can be found here <http://vds.uchicago.edu/vds/doc/userguide/html/H_TransformationCatalog.html>.

tcp.port.range

Valid values: <start>,<end> where start and end are integers

Default value: none

A TCP port range can be specified to restrict the ports on which GRAM callback services are started. This is likely needed if your submit host is behind a firewall, in which case the firewall should be configured to allow incoming connections on ports in the range.

throttle.file.operations

Valid values: <int>, off

Default value: 8

Limits the total number of concurrent file operations that can happen at any given time. File operations (like transfers) require an exclusive connection to a site. These connections can be expensive to establish. A large number of concurrent file operations may cause Swift to attempt to establish many such expensive connections to various sites. Limiting the number of concurrent file operations causes Swift to use a small number of cached connections and achieve better overall performance.

throttle.host.submit

Valid values: <int>, off

Default value: 2

Limits the number of concurrent submissions for any of the sites Swift will try to send jobs to. In other words it guarantees that no more than the value of this throttle jobs sent to any site will be concurrently in a state of being submitted.

throttle.score.job.factor

Valid values: <int>, off

Default value: 4

The Swift scheduler has the ability to limit the number of concurrent jobs allowed on a site based on the performance history of that site. Each site is assigned a score (initially 1), which can increase or decrease based on whether the site yields successful or faulty job runs. The score for a site can take values in the (0.1, 100) interval. The number of allowed jobs is calculated using the following formula:

2 + score*throttle.score.job.factor

This means a site will always be allowed at least two concurrent jobs and at most 2 + 100*throttle.score.job.factor. With a default of 4 this means at least 2 jobs and at most 402.

This parameter can also be set per site using the jobThrottle profile key in a site catalog entry.

throttle.submit

Valid values: <int>, off

Default value: 4

Limits the number of concurrent submissions for a run. This throttle only limits the number of concurrent tasks (jobs) that are being sent to sites, not the total number of concurrent jobs that can be run. The submission stage in GRAM is one of the most CPU expensive stages (due mostly to the mutual authentication and delegation). Having too many concurrent submissions can overload either or both the submit host CPU and the remote host/head node causing degraded performance.

throttle.transfers

Valid values: <int>, off

Default value: 4

Limits the total number of concurrent file transfers that can happen at any given time. File transfers consume bandwidth. Too many concurrent transfers can cause the network to be overloaded preventing various other signaling traffic from flowing properly.

ticker.disable

Valid values: true, false

Default value: false

When set to true, suppresses the output progress ticker that Swift sends to the console every few seconds during a run (since Swift 0.9)

wrapper.invocation.mode

Valid values: absolute, relative

Default value: absolute

Determines if Swift remote wrappers will be executed by specifying an absolute path, or a path relative to the job initial working directory. In most cases, execution will be successful with either option. However, some execution sites ignore the specified initial working directory, and so absolute must be used. Conversely on some sites, job directories appear in a different place on the worker node file system than on the filesystem access node, with the execution system handling translation of the job initial working directory. In such cases, relative mode must be used. (since Swift 0.9) wrapper.parameter.mode

```
Controls how Swift will supply parameters to the remote wrapper
script. args mode will pass parameters on the command line. Some
execution systems do not pass commandline parameters sufficiently
cleanly for Swift to operate correctly. files mode will pass
parameters through an additional input file (since Swift 0.95). This
provides a cleaner communication channel for parameters, at the
expense of transferring an additional file for each job invocation.
```

wrapperlog.always.transfer

```
Valid values: true, false
```

```
Default value: false
```

```
This property controls when output from the Swift remote wrapper is
transfered back to the submit site. When set to false, wrapper
logs are only transfered for jobs that fail. If set to true,
wrapper logs are transfered after every job is completed or failed.
```

Example:

```
sites.file=${vds.home}/etc/sites.xml
tc.file=${vds.home}/etc/tc.data
ip.address=192.168.0.1
```

11 Profiles

Profiles influence the behaviour of Swift when running an `app` task. They are configuration parameters than can be specified for sites, for transformation catalog entries, or on a task-by-task as a dynamic profile.

Profile entries for a site are specified in the site catalog. Profile entries for specific procedures are specified in the transformation catalog. Profile entries for a given task are specified in the `app` definition as a dynamic profile.

11.1 Karajan namespace

maxSubmitRate limits the maximum rate of job submission, in jobs per second. For example:

```
<profile namespace="karajan" key="maxSubmitRate">0.2</profile>
```

will limit job submission to 0.2 jobs per second (or equivalently, one job every five seconds).

jobThrottle allows the job throttle factor (see Swift property throttle.score.job.factor to be set per site.

initialScore allows the initial score for rate limiting and site selection to be set to a value other than 0.

delayBase controls how much a site will be delayed when it performs poorly. With each reduction in a sites score by 1, the delay between execution attempts will increase by a factor of delayBase.

status.mode allows the status.mode property to be set per-site instead of for an entire run. See the Swift configuration properties section for more information. (since Swift 0.8)

11.2 swift namespace

storagesize limits the amount of space that will be used on the remote site for temporary files. When more than that amount of space is used, the remote temporary file cache will be cleared using the algorithm specified in the caching.algorithm property.

wrapperInterpreter - The wrapper interpreter indicates the command (executable) to be used to run the Swift wrapper script. The default is "/bin/bash" on Unix sites and "cscript.exe" on Windows sites.

wrapperInterpreterOptions - Allows specifying additional options to the executable used to run the Swift wrapper. The defaults are no options on Unix sites and "Nologo" on Windows sites.

wrapperScript - Specifies the name of the wrapper script to be used on a site. The defaults are "_swiftwrap" on Unix sites and "_swiftwrap.vbs" on Windows sites. If you specify a custom wrapper script, it must be present in the "libexec" directory of the Swift installation.

cleanupCommand Indicates the command to be run at the end of a Swift run to clean up the run directories on a remote site. Defaults are "/bin/rm" on Unix sites and "cmd.exe" on Windows sites

cleanupCommandOptions Specifies the options to be passed to the cleanup command above. The options are passed in the argument list to the cleanup command. After the options, the last argument is the directory to be deleted. The default on Unix sites is "-rf". The default on Windows sites is ["/C", "del", "/Q"].

11.3 Globus namespace

maxwalltime specifies a walltime limit for each job, in minutes.

The following formats are recognized:

- Minutes
- Hours:Minutes
- Hours:Minutes:Seconds

Example:

```
localhost       echo    /bin/echo       INSTALLED       INTEL32::LINUX  GLOBUS::maxwalltime ↩
    ="00:20:00"
```

When replication is enabled (see replication), then walltime will also be enforced at the Swift client side: when a job has been active for more than twice the maxwalltime, Swift will kill the job and regard it as failed.

When clustering is used, maxwalltime will be used to select which jobs will be clustered together. More information on this is available in the clustering section.

When coasters as used, maxwalltime influences the default coaster worker maxwalltime, and which jobs will be sent to which workers. More information on this is available in the coasters section.

queue is used by the PBS, GRAM2 and GRAM4 providers. This profile entry specifies which queue jobs will be submitted to. The valid queue names are site-specific.

host_types specifies the types of host that are permissible for a job to run on. The valid values are site-specific. This profile entry is used by the GRAM2 and GRAM4 providers.

condor_requirements allows a requirements string to be specified when Condor is used as an LRM behind GRAM2. Example:

```
<profile namespace="globus" key="condor_requirements">Arch == "X86_64" || Arch="INTEL"</ ↩
    profile>
```

slots When using coasters, this parameter specifies the maximum number of jobs/blocks that the coaster scheduler will have running at any given time. The default is 20.

jobsPerNode - This parameter determines how many coaster workers are started one each compute node. The default value is 1.

nodeGranularity - When allocating a coaster worker block, this parameter restricts the number of nodes in a block to a multiple of this value. The total number of workers will then be a multiple of workersPerNode * nodeGranularity. The default value is 1.

allocationStepSize - Each time the coaster block scheduler computes a schedule, it will attempt to allocate a number of slots from the number of available slots (limited using the above slots profile). This parameter specifies the maximum fraction of slots that are allocated in one schedule. Default is 0.1.

lowOverallocation - Overallocation is a function of the walltime of a job which determines how long (time-wise) a worker job will be. For example, if a number of 10s jobs are submitted to the coaster service, and the overallocation for 10s jobs is 10, the coaster scheduler will attempt to start worker jobs that have a walltime of 100s. The overallocation is controlled by manipulating the end-points of an overallocation function. The low endpoint, specified by this parameter, is the overallocation for a 1s job. The high endpoint is the overallocation for a (theoretical) job of infinite length. The overallocation for job sizes in the [1s, +inf) interval is determined using an exponential decay function: overallocation(walltime) = walltime * (lowOverallocation - highOverallocation) * exp(-walltime * overallocationDecayFactor) + highOverallocation The default value of lowOverallocation is 10.

highOverallocation - The high overallocation endpoint (as described above). Default: 1

overallocationDecayFactor - The decay factor for the overallocation curve. Default 0.001 (1e-3).

spread - When a large number of jobs is submitted to the a coaster service, the work is divided into blocks. This parameter allows a rough control of the relative sizes of those blocks. A value of 0 indicates that all work should be divided equally between the blocks (and blocks will therefore have equal sizes). A value of 1 indicates the largest possible spread. The existence of the spread parameter is based on the assumption that smaller overall jobs will generally spend less time in the queue than larger jobs. By submitting blocks of different sizes, submitted jobs may be finished quicker by smaller blocks. Default: 0.9.

reserve - Reserve time is a time in the allocation of a worker that sits at the end of the worker time and is useable only for critical operations. For example, a job will not be submitted to a worker if it overlaps its reserve time, but a job that (due to inaccurate walltime specification) runs into the reserve time will not be killed (note that once the worker exceeds its walltime, the queuing system will kill the job anyway). Default 10 (s).

maxnodes - Determines the maximum number of nodes that can be allocated in one coaster block. Default: unlimited.

maxtime - Indicates the maximum walltime, in seconds, that a coaster block can have. Default: unlimited.

remoteMonitorEnabled - If set to "true", the client side will get a Swing window showing, graphically, the state of the coaster scheduler (blocks, jobs, etc.). Default: false

internalhostname - If the head node has multiple network interfaces, only one of which is visible from the worker nodes. The choice of which interface is the one that worker nodes can connect to is a matter of the particular cluster. This must be set in the your sites file to clarify to the workers which exact interface on the head node they are to try to connect to.

11.4 env namespace

Profile keys set in the env namespace will be set in the unix environment of the executed job. Some environment variables influence the worker-side behaviour of Swift:

PATHPREFIX - set in env namespace profiles. This path is prefixed onto the start of the PATH when jobs are executed. It can be more useful than setting the PATH environment variable directly, because setting PATH will cause the execution site's default path to be lost.

SWIFT_JOBDIR_PATH - set in env namespace profiles. If set, then Swift will use the path specified here as a worker-node local temporary directory to copy input files to before running a job. If unset, Swift will keep input files on the site-shared filesystem. In some cases, copying to a worker-node local directory can be much faster than having applications access the site-shared filesystem directly.

SWIFT_EXTRA_INFO - set in env namespace profiles. If set, then Swift will execute the command specified in SWIFT_EXTRA_INFO on execution sites immediately before each application execution, and will record the stdout of that command in the wrapper info log file for that job. This is intended to allow software version and other arbitrary information about the remote site to be gathered and returned to the submit side. (since Swift 0.9)

SWIFT_GEN_SCRIPTS - set in the env namespace profiles. This variable just needs to be set, it doesn't matter what it is set to. If set, then Swift will keep the script that was used to execute the job in the job directory. The script will be called run.sh and will have the command line that Swift tried to execute with.

11.5 Dynamic profiles

To set a profile setting based on the value of a Swift variable, you must use dynamic profiles. This allows you to set profile settings in the `globus` namespace.

```
app (file o) c(file i, int p)
{
  profile "mpi.processes" = 2+p;
  profile "mpi.ppn" = 1;

  my_mpi_program @i @o;
}
```

This would be equivalent to the sites file settings:

```
<profile namespace="globus" key="mpi.processes">4</profile>
<profile namespace="globus" key="mpi.ppn">1</profile>
```

except, of course, the number of MPI processes may not be dynamically set by the value of Swift variable `p` in the sites file.

Additional beneficial use cases of dynamic profiles may be to set the `maxwalltime` or `queue` profile settings.

11.6 Profile debugging

Swift profiles, generally speaking, are converted into Java CoG "attributes", which are attached to each CoG task. Thus, when reading the log or debugging, look for messages regarding "attributes".

12 The Site Catalog - sites.xml

The site catalog lists details of each site that Swift can use. The default file contains one entry for local execution, and a large number of commented-out example entries for other sites.

By default, the site catalog is stored in etc/sites.xml. This path can be overridden with the sites.file configuration property, either in the Swift configuration file or on the command line.

The sites file is formatted as XML. It consists of <pool> elements, one for each site that Swift will use.

12.1 Pool element

Each pool element must have a handle attribute, giving a symbolic name for the site. This can be any name, but must correspond to entries for that site in the transformation catalog.

Optionally, the gridlaunch attribute can be used to specify the path to kickstart on the site.

Each pool must specify a file transfer method, an execution method and a remote working directory. Optionally, profile settings can be specified.

12.2 File transfer method

Transfer methods are specified with either the <gridftp> element or the <filesystem> element.

To use gridftp or local filesystem copy, use the <gridftp> element:

```
<gridftp  url="gsiftp://evitable.ci.uchicago.edu" />
```

The url attribute may specify a GridFTP server, using the gsiftp URI scheme; or it may specify that filesystem copying will be used (which assumes that the site has access to the same filesystem as the submitting machine) using the URI local://localhost.

Filesystem access using scp (the SSH copy protocol) can be specified using the <filesystem> element:

```
<filesystem url="www11.i2u2.org" provider="ssh"/>
```

For additional ssh configuration information, see the ssh execution provider documentation below.

Filesystem access using CoG coasters can be also be specified using the <filesystem> element. More detail about configuring that can be found in the CoG coasters section.

12.3 Execution method

Execution methods may be specified either with the <jobmanager> or <execution> element.

The <jobmanager> element can be used to specify execution through GRAM2. For example,

```
<jobmanager universe="vanilla" url="evitable.ci.uchicago.edu/jobmanager-fork" major="2" />
```

The universe attribute should always be set to vanilla. The url attribute should specify the name of the GRAM2 gatekeeper host, and the name of the jobmanager to use. The major attribute should always be set to 2.

The <execution> element can be used to specify execution through other execution providers:

To use GRAM4, specify the gt4 provider. For example:

```
<execution provider="gt4" jobmanager="PBS" url="tg-grid.uc.teragrid.org" />
```

The url attribute should specify the GRAM4 submission site. The jobmanager attribute should specify which GRAM4 jobmanager will be used.

For local execution, the local provider should be used, like this:

```
<execution provider="local" url="none" />
```

For PBS execution, the pbs provider should be used:

```
<execution provider="pbs" url="none" />
```

The GLOBUS::queue profile key can be used to specify which PBS queue jobs will be submitted to.

For execution through a local Condor installation, the condor provider should be used. This provider can run jobs either in the default vanilla universe, or can use Condor-G to run jobs on remote sites.

When running locally, only the <execution> element needs to be specified:

```
<execution provider="condor" url="none" />
```

When running with Condor-G, it is necessary to specify the Condor grid universe and the contact string for the remote site. For example:

```
 <execution provider="condor" />
 <profile namespace="globus" key="jobType">grid</profile>
 <profile namespace="globus" key="gridResource">gt2 belhaven-1.renci.org/jobmanager-fork</ ↩
    profile>
```

For execution through SSH, the ssh provider should be used:

```
<execution url="www11.i2u2.org" provider="ssh"/>
```

with configuration made in ~/.ssh/auth.defaults with the string *www11.i2u2.org* changed to the appropriate host name:

```
www11.i2u2.org.type=key
www11.i2u2.org.username=hategan
www11.i2u2.org.key=/home/mike/.ssh/i2u2portal
www11.i2u2.org.passphrase=XXXX
```

For execution using the CoG Coaster mechanism, the coaster provider should be used:

```
<execution provider="coaster" url="tg-grid.uc.teragrid.org"
    jobmanager="gt2:gt2:pbs" />
```

More details about configuration of coasters can be found in the section on coasters.

12.4 Work directory

The workdirectory element specifies where on the site files can be stored.

```
<workdirectory>/home/benc</workdirectory>
```

This file must be accessible through the transfer mechanism specified in the <gridftp> element and also mounted on all worker nodes that will be used for execution. A shared cluster scratch filesystem is appropriate for this.

12.5 Profiles

Profile keys can be specified using the <profile> element. For example:

```
<profile namespace="globus" key="queue">fast</profile>
```

The site catalog format is an evolution of the VDS site catalog format which is documented here http://vds.uchicago.edu/vds/-doc/userguide/html/H_SiteCatalog.html.

13 The Transformation Catalog - tc.data

The transformation catalog lists where application executables are located on remote sites.

By default, the site catalog is stored in etc/tc.data. This path can be overridden with the tc.file configuration property, either in the Swift configuration file or on the command line.

The format is one line per executable per site, with fields separated by tabs.

Some example entries:

```
localhost  echo    /bin/echo       INSTALLED       INTEL32::LINUX  null
TGUC       touch   /usr/bin/touch  INSTALLED       INTEL32::LINUX  GLOBUS::maxwalltime ↩
    ="0:1"
```

The fields are: site, transformation name, executable path, installation status, platform, and profile entries.

The site field should correspond to a site name listed in the sites catalog.

The transformation name should correspond to the transformation name used in a Swift script app procedure.

The executable path should specify where the particular executable is located on that site.

The installation status and platform fields are not used. Set them to INSTALLED and INTEL32::LINUX respectively.

The profiles field should be set to null if no profile entries are to be specified.

13.1 Setting Environment Variables

It is often useful to set environment variables when running an application. This can be accomplished using **env** in the profile entry. For example, the following application sets an environment variable called R_LIBS to /home/user/R_libs.

```
localhost      R      /usr/bin/R      INSTALLED      INTEL32::LINUX  env::R_LIBS=/home/ ↩
    user/r_libs
```

13.2 Setting Multiple Profiles

Multiple profile entries can be added by using a semicolon. The example below sets two environment variables: R_LIBS and R_HOME.

```
localhost       R       /usr/bin/R      INSTALLED       INTEL32::LINUX  env::R_LIBS=/home/ ←
    user/r_libs;env::R_HOME=/home/user/r
```

14 Build options

See the Swift download page http://www.ci.uchicago.edu/swift/downloads/ for instructions on downloading and building Swift from source. When building, various build options can be supplied on the ant commandline. These are summarised here:

with-provider-condor - build with CoG condor provider

with-provider-coaster - build with CoG coaster provider (see the section on coasters). Since 0.8, coasters are always built, and this option has no effect.

with-provider-deef - build with Falkon provider deef. In order for this option to work, it is necessary to check out the provider-deef code in the cog/modules directory alongside swift:

```
$ cd cog/modules
$ svn co https://svn.ci.uchicago.edu/svn/vdl2/provider-deef
$ cd ../swift
$ ant -Dwith-provider-deef=true redist
```

with-provider-wonky - build with provider-wonky, an execution provider that provides delays and unreliability for the purposes of testing Swift's fault tolerance mechanisms. In order for this option to work, it is necessary to check out the provider-wonky code in the |cog/modules| directory alongside swift:

```
$ cd cog/modules
$ svn co https://svn.ci.uchicago.edu/svn/vdl2/provider-wonky
$ cd ../swift
$ ant -Dwith-provider-wonky=true redist
```

no-supporting - produces a distribution without supporting commands such as grid-proxy-init. This is intended for when the Swift distribution will be used in an environment where those commands are already provided by other packages, where the Swift package should be providing only Swift commands, and where the presence of commands such as grid-proxy-init from the Swift distribution in the path will mask the presence of those commands from their true distribution package such as a Globus Toolkit package.

```
$ ant -Dno-supporting=true redist
```

15 Kickstart

Kickstart is a tool that can be used to gather various information about the remote execution environment for each job that Swift tries to run.

For each job, Kickstart generates an XML invocation record. By default this record is staged back to the submit host if the job fails.

Before it can be used it must be installed on the remote site and the sites file must be configured to point to kickstart.

Kickstart can be downloaded as part of the Pegasus *worker package* available from the worker packages section of the Pegasus download page http://pegasus.isi.edu/code.php.

Untar the relevant worker package somewhere where it is visible to all of the worker nodes on the remote execution machine (such as in a shared application filesystem).

Now configure the gridlaunch attribute of the sites catalog to point to that path, by adding a gridlaunch attribute to the pool element in the site catalog:

```
<pool handle="example" gridlaunch="/usr/local/bin/kickstart" sysinfo="INTEL32::LINUX">
...
</pool>
```

There are various kickstat.* properties, which have sensible default values. These are documented in the properties section.

16 Reliability mechanisms

This section details reliabilty mechanisms in Swift: retries, restarts and replication.

16.1 Retries

If an application procedure execution fails, Swift will attempt that execution again repeatedly until it succeeds, up until the limit defined in the execution.retries configuration property.

Site selection will occur for retried jobs in the same way that it happens for new jobs. Retried jobs may run on the same site or may run on a different site.

If the retry limit execution.retries is reached for an application procedure, then that application procedure will fail. This will cause the entire run to fail - either immediately (if the lazy.errors property is false) or after all other possible work has been attempted (if the lazy.errors property is true).

16.2 Restarts

If a run fails, Swift can resume the program from the point of failure. When a run fails, a restart log file will be left behind in a file named using the unique job ID and a .rlog extension. This restart log can then be passed to a subsequent Swift invocation using the -resume parameter. Swift will resume execution, avoiding execution of invocations that have previously completed successfully. The Swift source file and input data files should not be modified between runs.

Every run creates a restart log file with a named composed of the file name of the workflow being executed, an invocation ID, a numeric ID, and the .rlog extension. For example, example.swift, when executed, could produce the following restart log file: example-ht0adgi315l61.0.rlog. Normally, if the run completes successfully, the restart log file is deleted. If however the workflow fails, swift can use the restart log file to continue execution from a point before the failure occurred. In order to restart from a restart log file, the -resume logfile argument can be used after the Swift script file name. Example:

```
$ swift -resume example-ht0adgi315l61.0.rlog example.swift.
```

16.3 Replication

When an execution job has been waiting in a site queue for a certain period of time, Swift can resubmit replicas of that job (up to the limit defined in the replication.limit configuration property). When any of those jobs moves from queued to active state, all of the other replicas will be cancelled.

This is intended to deal with situations where some sites have a substantially longer (sometimes effectively infinite) queue time than other sites. Selecting those slower sites can cause a very large delay in overall run time.

Replication can be enabled by setting the replication.enabled configuration property to true. The maximum number of replicas that will be submitted for a job is controlled by the replication.limit configuration property.

When replication is enabled, Swift will also enforce the maxwalltime profile setting for jobs as documented in the profiles section.

17 Clustering

Swift can group a number of short job submissions into a single larger job submission to minimize overhead involved in launching jobs (for example, caused by security negotiation and queuing delay). In general, CoG coasters should be used in preference to the clustering mechanism documented in this section.

By default, clustering is disabled. It can be activated by setting the clustering.enabled property to true.

A job is eligible for clustering if the GLOBUS::maxwalltime profile is specified in the tc.data entry for that job, and its value is less than the value of the clustering.min.time property.

Two or more jobs are considered compatible if they share the same site and do not have conflicting profiles (e.g. different values for the same environment variable).

When a submitted job is eligible for clustering, it will be put in a clustering queue rather than being submitted to a remote site. The clustering queue is processed at intervals specified by the clustering.queue.delay property. The processing of the clustering queue consists of selecting compatible jobs and grouping them into clusters whose maximum wall time does not exceed twice the value of the clustering.min.time property.

18 Coasters

18.1 Introduction

Coasters are the Swift's implementation of *pilot job abstraction*.

In many applications, Swift performance can be greatly enhanced by the use of coasters. Coasters provide a low-overhead job submission and file transfer mechanism suited for the execution of jobs and the transfer of files for which other grid protocols such as GRAM and GridFTP are poorly suited.

18.2 Benefits

Much of the overhead associated with other grid protocols (such as authentication and authorization, and allocation of worker nodes by the site's local resource manager) is reduced, because that overhead is associated with the allocation of a coaster pilot or coaster worker, rather than with every Swift-level procedure invocation; potentially hundreds or thousands of Swift-level procedure invocations can be run through a single worker. Coasters can be configured for two purposes: job execution and file staging. In practice, the Swift script remains the same while working with coasters. A detailed description of coaster mechanism is explained in the next section.

18.3 Mechanism

Coasters run at the task management layer logically under the Swift script. The jobs and data movement requirements resulting after the interpretation of a Swift script are handled by the coasters. The coaster mechanism submits a pilot job using some other execution mechanism such as GRAM, SGE or PBS scheduler, and for each worker node that will be used in a remote cluster, it submits a worker job, again using some other execution mechanism such as GRAM. Details on the design of the coaster mechanism can be found here: http://wiki.cogkit.org/wiki/Coasters. The pilot job manages file transfers and the dispatch of execution jobs to workers.

18.4 Coasters How-to

To use for job execution, specify a sites.xml execution element like this:

```
<execution provider="coaster" jobmanager="gt2:gt2:pbs" url="grid.myhost.org">
```

The jobmanager string contains more detail than with other providers. It contains either two or three colon separated fields: 1:the provider to be use to execute the coaster pilot job - this provider will submit from the Swift client side environment. Commonly this will be one of the GRAM providers; 2: the provider to be used to execute coaster worker jobs. This provider will be used to submit from the coaster pilot job environment, so a local scheduler provider can sometimes be used instead of GRAM. 3: optionally, the jobmanager to be used when submitting worker job using the provider specified in field 2.

To use for file transfer, specify a sites.xml filesystem element like this:

```
<filesystem provider="coaster" url="gt2://grid.myhost.org" />
```

The url parameter should be a pseudo-URI formed with the URI scheme being the name of the provider to use to submit the coaster pilot job, and the hostname portion being the hostname to be used to execute the coaster pilot job. Note that this provider and hostname will be used for execution of a coaster pilot job, not for file transfer; so for example, a GRAM endpoint should be specified here rather than a GridFTP endpoint.

Coasters are affected by the following profile settings, which are documented in the Globus namespace profile section:

Profile key	Brief description
slots	How many maximum LRM jobs/worker blocks are allowed
jobsPerNode	How many coaster workers to run per execution node
nodeGranularity	Each worker block uses a number of nodes that is a multiple of this number
lowOverallocation	How many times larger than the job walltime should a block's walltime be if all jobs are 1s long
highOverallocation	How many times larger than the job walltime should a block's walltime be if all jobs are infinitely long
overallocationDecayFactor	How quickly should the overallocation curve tend towards the highOverallocation as job walltimes get larger
spread	By how much should worker blocks vary in worker size
jobsPerNode	How many coaster workers to run per execution node
reserve	How many seconds to reserve in a block's walltime for starting/shutdown operations
maxnodes	The maximum number of nodes allowed in a block
maxtime	The maximum walltime allowed for a block, in integer seconds
remoteMonitorEnabled	If true, show a graphical display of the status of the coaster service

18.5 Coaster config parameters and Job Quantities

This section presents information on coaster configuration parameters and their effect on application and scheduler jobs submitted by Swift. In order to achieve optimal performance, the number of application tasks must correspond to the total number of coaster workers. Coaster configuration parameters influence both application tasks and the LRM (Local Resource Manager) jobs that are submitted by Swift. Specifically, the following quantities are influenced by coasters configuration parameters:

- Number of application tasks Swift will pack in one "wave" to be executed in parallel depends on the `foreach.max.threads` and the `throttle` parameters. Furthermore, the number of `foreach` loops in a Swift script influences the aggregate `foreach.max.threads`. The relation between application tasks and the above mentioned quantities could be explained as follows:

```
app_tasks = min{nforeach X foreach.max.threads), (throttle X 100 +1)}
```

Where `nforeach` is the number of independent foreach loops appearing in a Swift script.

- Number of jobs Swift will submit via the LRM interface is determined by the `slots` configuration parameter in sites file.

```
LRM jobs = slots
```

- Size of each LRM job in terms of number of compute nodes per job is determined by the `maxnodes` and `nodegranularity` parameters. LRM jobs submitted by Swift will be of size spread between `nodegranularity` and `maxnodes` values.

```
nodegranularity <= LRM job size <= maxnodes
```

- Number of coaster workers to be run per LRM job on a target cluster is determined by the `jobspernode` parameter.

Considering the above factors, the following paramter expressions must match in order for a Swift run to be optimal:

```
min{nforeach X foreach.max.threads), (throttle X 100 +1)} ~=
            slots X avg(nodegranularity,maxnodes) X jobspernode
```

19 How-To Tips for Specific User Communities

19.1 Saving Logs - for UChicago CI Users

If you have a UChicago Computation Institute account, run this command in your submit directory after each run. It will copy all your logs and kickstart records into a directory at the CI for reporting, usage tracking, support and debugging.

```
rsync --ignore-existing *.log *.d login.ci.uchicago.edu:/disks/ci-gpfs/swift/swift-logs/ -- ↩
    verbose
```

19.2 Specifying TeraGrid allocations

TeraGrid users with no default project or with several project allocations can specify a project allocation using a profile key in the site catalog entry for a TeraGrid site:

```
<profile namespace="globus" key="project">TG-CCR080002N</profile>
```

More information on the TeraGrid allocations process can be found here http://www.teragrid.org/userinfo/access/allocations.php.

19.3 Launching MPI jobs from Swift

There are several ways to run MPI jobs under Swift. Two will be discussed here - calling mpiexec from a wrapper script, and using the MPICH/coasters interface.

19.3.1 Calling mpiexec

In this example, a single MPI program will run across two nodes. For this to happen, sites.xml must be configured to allocate two nodes but only run a single job on them. A wrapper script must then be used to call mpiexec.

sites.xml

First, we need to make sure that Swift will allocate exactly two nodes. This can be done with the maxnodes and nodegranularity settings.

```
<profile namespace="globus" key="nodeGranularity">2</profile>
<profile namespace="globus" key="maxnodes">2</profile>
```

Next, we want to make sure that the MPI program is called only once on those nodes. There are two settings we must set to get this behavior:

```
<profile namespace="globus" key="jobsPerNode">1</profile>
<profile namespace="globus" key="jobtype">single</profile>
```

tc.data

The app defined in tc.data should be a shell script wrapper to the actual program that is being called. Let's assume in this example that the MPI program we are using is called "mpitest", and the wrapper script will be called "mpitest.sh". The tc.data will look like this then:

```
host mpitest /path/to/mpitest.sh
```

Wrapper script

The wrapper script in this example, mpitest.sh, will call mpiexec and launch the real MPI program. Here is an example:

```
#!/bin/bash

mpiexec /path/to/mpitest "$@"
```

Swift then makes an invocation that does not look any different from any other invocation. In the code below, we pass one input file and get back one output file.

```
type file;

app (file output_file) mpitest (file input_file)
{
   mpitest @input_file @output_file;
}

file input <"input.txt">;
file output <"output.txt">;

output = mpitest(input);
```

19.3.2 MPICH/Coasters

In this case, the user desires to launch many MPI jobs within a single Coasters allocation, reusing Coasters workers for variable-sized jobs. The reuse of the Coasters workers allows the user to launch many MPI jobs in rapid succession with minimal overhead.

The user must access to MPICH compiled for sockets, with `mpiexec` in the `PATH` environment variable. Swift uses this MPICH installation to launch the user processes on the remote Coasters workers, which are able to connect back to `mpiexec` and coordinate the job launch. The infrastructure must allow the user MPI processes to find each other and communicate over sockets.

To configure the user MPI job, simply add `mpi.processes` and `mpi.ppn` to the profile in the `tc.file`:

```
pbs_site my_program  /path/to/program null null globus::mpi.processes=16;globus::mpi.ppn=8
```

Coasters must be set with `jobsPerNode=1`.

This runs `mpiexec` locally, and allocates 2 Coasters workers (2 nodes), each with 8 MPI processes. Thus, `MPI_COMM_WORLD` has size 16.

19.4 Running on Windows

Swift has the ability to run on a Windows machine, as well as the ability to submit jobs to a Windows site (provided that an appropriate provider is used).

In order to launch Swift on Windows, use the provided batch file (swift.bat). In certain cases, when a large number of jar libraries are present in the Swift lib directory and depending on the exact location of the Swift installation, the classpath environment variable that the Swift batch launcher tries to create may be larger than what Windows can handle. In such a case, either install Swift in a directory closer to the root of the disk (say, c:\swift) or remove non-essential jar files from the Swift lib directory.

Due to the large differences between Windows and Unix environments, Swift must use environment specific tools to achieve some of its goals. In particular, each Swift executable is launched using a wrapper script. This script is a Bourne Shell script. On Windows machines, which have no Bourne Shell interpreter installed by default, the Windows Scripting Host is used instead, and the wrapper script is written in VBScript. Similarly, when cleaning up after a run, the "/bin/rm" command available in typical Unix environments must be replaced by the "del" shell command.

It is important to note that in order to select the proper set of tools to use, Swift must know when a site runs under Windows. To inform Swift of this, specify the "sysinfo" attribute for the "pool" element in the site catalog. For example:

```
<pool handle="localhost" sysinfo="INTEL32::WINDOWS">
...
</pool>
```

20 Collective Data Management

20.1 Description

Collective Data Management (CDM) is a set of optimizations in Swift to improve data access patterns by Swift. In particular, it can be used to avoid data staging (extra file copies) on an HPC system or cluster with a shared file system.

20.2 Usage Overview

1. The user specifies a CDM policy in a file, customarily `fs.data`.
2. `fs.data` is given to Swift on the command line.
3. The Swift data module is informed of the CDM policy.
4. At job launch time, for each file, the Swift mechanics query the CDM file,
    a. altering the file staging phase, and
    b. sending `fs.data` to the compute site.
5. At job run time, the Swift wrapper script
    a. consults a Perl script to obtain policy from `fs.data`, and
    b. uses wrapper extensions to modify data movement.
6. Similarly, stage out can be changed.

Command line

```
$ swift -sites.file sites.xml -tc.file tc.data -cdm.file fs.data stream.swift
```

20.3 CDM policy file format

A CDM policy file contains four space separated fields as follows: . The keyword *rule* . The filename pattern expressed as a regexp . The rulename: DIRECT, GATHER, BROADCAST etc. . The path where to look for the files (optional)

20.3.1 Example

```
# Describe CDM for my job
property GATHER_LIMIT 1
rule .*input.txt DIRECT /gpfs/homes/wozniak/data
rule .*xfile*.data BROADCAST /dev/shm
rule .* DEFAULT
```

The lines contain:

1. A directive, either `rule` or `property`.
2. A rule has:
    a. A regular expression to match on the file name.
    b. A policy token.
    c. Additional policy-specific arguments.
3. A property has:
    a. A policy property token.
    b. The token value.
4. Comments with `#`.
5. Blank lines are ignored.

20.3.2 Notes

1. The policy file is used as a lookup database by Swift and Perl methods. Thus, one should only use basic features such as `.*` .
2. Swift treats file names as URLs, while the wrapper script treats them as Unix file names. Thus, one should use a wildcard in the beginning of each file name, as shown in the example.
3. For example, a lookup with the database above given the argument `input.txt` would result in the `DIRECT` policy.
4. Each rule is considered in the order given; the first match results in that policy line.
5. If the lookup does not succeed, the result is `DEFAULT`.

20.4 Policy Descriptions

20.4.1 DEFAULT

- Just use file staging as provided by Swift. Identical to behavior if no CDM file is given.

20.4.2 DIRECT

```
rule .*input.txt DIRECT /gpfs/scratch/wozniak/
```

- Allows for direct I/O to the parallel FS without staging.
- The input files matching the pattern must already exist in the given directory, a shared file system location. Links will be placed in the job directory.
- The output files matching the pattern will be stored in the given directory, with links in the job directory.
- Example: In the rule above, the Swift-generated file name `./data/input.txt` would be accessed by the user job in `/gpfs/homes/wozniak/data/input.txt`.

20.4.3 LOCAL

```
rule .*input.txt LOCAL dd /gpfs/homes/user/data obs=64K
```

- Allows for client-directed input copy to the compute node.
- The user may specify `cp` or `dd` as the input transfer program.
- The input files matching the pattern must already exist in the given directory, a shared file system location. Copies will be placed in the job directory for use by the user job.
- Argument list: [tool] [directory] [tool arguments]*

20.5 Specific use cases

20.5.1 Matching on all file names

To match all file names produced by Swift, simply use pattern `.*`

A common use case is to redirect all file operations to a given directory, say, `/fs/dir`. To do this, use a rule such as:

```
rule .* DIRECT /fs/dir
```

20.5.2 Absolute paths

If your Swift script operates on files with absolute path names such as:

```
file f<"/fs/dir/f.txt">;
```

use:

```
rule .*f.txt DIRECT /
```

20.5.3 Use of symbolic links

Swift may provide a symbolic link to the application, which the application may read and write normally. The application may not unlink these links; if it does, the application will not be able to find or create Swift-compatible data.

20.6 Debugging

To troubleshoot CDM, check the Swift log and the wrapper logs (`*-info` files). These will indicate the CDM policy that Swift finds for each file and resulting action, such as skipping stage in for DIRECT and the creation of links. Common errors include specifying the wrong directory which will result in an error that the file was not found, or that a link could not be created.

21 Log Processing

To properly generate log plots, you must enable VDL/Karajan logging. This can be done by putting the following lines in log4j.properties file found in the /etc directory of Swift installation:

```
log4j.logger.swift=DEBUG
log4j.logger.org.globus.cog.abstraction.coaster.service.job.manager.Cpu=DEBUG
log4j.logger.org.globus.cog.abstraction.coaster.service.job.manager.Block=DEBUG
```

All the executables, zsh and perl scripts mentioned in the following steps are available in the libexec/log-processing directory of your Swift installation.

21.1 Log plotting

21.1.1 Normalize event times in the log to the run start time

- Generate the normalized log, assuming the log is titled `swift-run.log`

```
./normalize-log.pl file.contains.start.time swift-run.log > swift-run.norm
```

TODO:In what format does the start time be in *file.contains.start.time*

21.1.2 Make a basic load plot from Coasters Cpu log lines

1. Normalize the log.
2. Build up a load data file:

   ```
   ./cpu-job-load.pl < swift-run.norm > load.data
   ```

3. Plot with the JFreeChart-based plotter in usertools/plotter:

   ```
   swift_plotter.zsh -s load.cfg load.eps load.data
   ```

Note: Th load.cfg is available from swift/libexec/log-processing/

21.1.3 Make a basic job completion plot from Coasters Cpu log lines

1. Normalize the log.
2. Build up a completed data file:

   ```
   ./cpu-job-completed.pl < swift-run.norm > completed.data
   ```

3. Plot with the JFreeChart-based plotter in usertools/plotter:

   ```
   swift_plotter.zsh -s completed.cfg completed.eps completed.data
   ```

21.1.4 Make a basic Block allocation plot from Coasters Block log lines

1. Normalize the log.
2. Build up a block allocation data file:

   ```
   ./block-level.pl < swift-run.norm > blocks.data
   ```

3. Plot with the JFreeChart-based plotter in usertools/plotter:

   ```
   swift_plotter.zsh -s blocks.{cfg,eps,data}
   ```

21.1.5 Make a job runtime distribution plot from Coasters Cpu log lines

1. Normalize the log.
2. Build up a job runtime file:

   ```
   ./extract-times.pl < swift-run.norm > times.data
   ```

3. Put the job runtimes into 1-second buckets:

   ```
   ./ buckets.pl 1 times.data > buckets.data
   ```

4. Plot with the JFreeChart-based plotter in usertools/plotter:

   ```
   swift_plotter.zsh -s buckets.cfg buckets.eps buckets.data
   ```

21.2 Meaning and interpretation of Swift log messages

A Swift log file is typically a text file with the name of the Swift run and its timestamp in the filename and an extension ".log". In addition, a ".rlog" file is Swift's resume log which is used by Swift when a run is resumed using the "-resume" option. The .rlog file is only for Swift's internal purpose and not to be interpreted by the user.

Each line in the log file typically consists of three parts. The first part is the timestamp, the second is the type of log message and the third is the message itself. The types of log messages follows the java log4j standard types of TRACE, DEBUG, INFO, WARN, ERROR and FATAL.

This section lists the various Swift log messages and explains the meaning and likely interpretation of those messages. Note that the list is not comprehensive at this time. Also note that we will ignore the timestamps here.

1. *DEBUG Loader arguments: [-sites.file, sites.xml, -config, cf, -tc.file, tc, postproc-gridftp.swift]* Swift commandline arguments
2. *DEBUG Loader Max heap: 5592449024* The java runtime heap size
3. *DEBUG textfiles BEGIN* A dump of config and source files associated with this run
4. *DEBUG VDL2ExecutionContext Stack dump*
5. *INFO SetFieldValue Set*
6. *INFO get*site STARTCOMPOUND thread=0-8 name=get*site*
7. *INFO vdl:execute START thread=0-8-0 tr=* Start execution of a thread associated with a job.
8. *INFO GlobalSubmitQueue No global submit throttle set. Using default (1024)*
9. *DEBUG vdl:execute2 THREAD_ASSOCIATION jobid=getsite-ymj72ook thread=0-8-0-1 host=localhost replicationGroup=xmj72* Thread id associated with jobid and target site.

10. *DEBUG vdl:execute2 JOB_START jobid=getsite-ymj72ook tr=getsite arguments=[644] tmpdir=postproc-gridftp-20120319-0942-adf1o1u2/jobs/y/getsite-ymj72ook host=localhost* Start of a job with job id, arguments and workdir

11. *INFO GridExec TASK_DEFINITION*

12. *WARN RemoteConfiguration Find: http://140.221.8.62:38260* Coaster service endpoint.

13. *INFO AbstractStreamKarajanChannel$Multiplexer Multiplexer 0 started*

14. *INFO AbstractStreamKarajanChannel$Multiplexer (0) Scheduling SC-null for addition*

15. *INFO AbstractStreamKarajanChannel Channel configured*

16. *INFO MetaChannel MetaChannel: 651528505[1478354072: {}] → null.bind → SC-null*

17. *INFO ReadBuffer Will ask for 1 buffers for a size of 6070*

18. *INFO ThrottleManager O maxBuffers=512, crtBuffers=0, allowedTransfers=256, active=0, suspended=0*

19. *INFO ThrottleManager mem=113.54 MB, heap=482.88 MB, maxHeap=5.21 GB* A running trace of available heap memory.

20. *INFO ThrottleManager I maxBuffers=512, crtBuffers=0, allowedTransfers=256, active=0, suspended=0*

21. *INFO PerformanceDiagnosticInputStream [MEM] Heap total: 482.88 MB, Heap used: 118.58 MB* Heap sizes for performance

22. *INFO vdl:execute END_SUCCESS thread=0-8-0 tr=getsite* The job ended successfully

23. *INFO WeightedHostScoreScheduler CONTACT_SELECTED host=localhost, score=99.854*

24. _