From Legion to Avaki: The Persistence of Vision Part 1

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Introduction

- Grids Are Here
- Grid Architecture Requirements
- Legion Principles and Philosophy
- Using Legion in Day-to-Day Operations
- The Legion Grid Architecture: Under the Covers
- Core Legion Objects
- The Transformation From Legion to Avaki

Grids Are Here

- Avaki (Commercial ventures)
  - Has its roots in Legion, a Grid project at the University of Virginia begun in 1993
- The near future
  - No longer be executed on supercomputers and single workstations using local data sources
  - => Users will be presented the illusion of a single, very powerful computer
  - The system will schedule application components on processors, manage data transfer, and provide communication and synchronization

Grid Architecture Requirements

- Definitions
  - Grid system
    - A collection of distributed resources connected by a network
  - Grid application
    - Operates in a Grid environment or is “on” a Grid system
  - Grid software
    - Facilitates writing Grid Applications and manages the underlying Grid infrastructure

Grid Architecture Requirements

- Requirements (1/3)
  - *Security:* A Grid system must have mechanisms that allow users and resource owners to select policies that fit particular security and performance needs
  - *Global name space:* All Grid objects must be able to access any other Grid object *transparently* without regard to location or replication
  - *Fault tolerance:* Hosts, networks, disks and applications frequently fail, restart, disappear and behave otherwise unexpectedly

Grid Architecture Requirements

- Requirements (2/3)
  - *Accommodating heterogeneity:* A Grid system must support interoperability between heterogeneous hardware and software platforms
  - *Binary management:* The underlying system should keep track of executables and libraries, knowing which ones are current
  - *Multi-language support:* Fortran or C
  - *Scalability:* The service demanded of any given component must be independent of the number of components in the system => distributed systems principle
  - *Persistence:* I/O and the ability to read and write persistent data are critical in order to communicate between applications and to save data

Grid Architecture Requirements

- Requirements (3/3)
  - *Extensibility:* Grid systems must be flexible enough to satisfy current user demands and unanticipated future needs => value-added services
  - *Site autonomy:* For each resource the owner must be able to limit or deny use by particular users, specify when it can be used
  - *Complexity management:* Providing the programmer and system administrator with clean abstractions is critical to reducing the cognitive burden

Legion Principles and Philosophy

- The Design principles and philosophy
  - Provide a single-system view
    - To reduce the complexity of the overall system and provides a single namespace
  - Provide transparency as a means of hiding detail
    - Users and programmers should not have to know where an object is located in order to use it
  - Provide flexible semantics
  - By default the user should not have to think about plumbing or infrastructure
  - Reduce "activation energy"
  - Do not change host operating systems
  - Do not change network interfaces
  - Do not require Grids to run in privileged mode
    - Require Grid software to run with the lowest possible privileges

Using Legion in Day-to-Day Operations

- A compute Grid and a data Grid of Legion
  - Allowing processing power to be shared
  - A virtual single set of files that can be accessed without regard to location or platform
- A typical scenario
  - A user sits down at a terminal, authenticates to Legion (logs in) and runs the command
    - *legion_run my_application my_data*

Using Legion in Day-to-Day Operations

- A typical scenario (cont.)
  - Determine the binaries available
  - Find and select a host on which to execute *my_application*
  - Manage the secure transport of credentials
  - Interact with the local operating environment on the selected host (SGE queue)
  - Create accounting records
  - Check to see if the current version of the application has been installed
  - Move all of the data around as necessary
  - Return the results to the user

Using Legion in Day-to-Day Operations

- Key features
  - Global name space
    - Names everything: processors, applications, queues, data files and directories
  - Wide-area access to data
    - All of the named entities are mapped into the local file system directory structure of her workstation, making access to the Grid transparent
  - Access to distributed and heterogeneous computing resources – binary availabilty/versions
  - Single sign-on
  - Policy-based administration of the resource base
  - Accounting both for resource usage information and auditing purposes
  - Find-grained security that protects both her resources and those of others
  - Failure detection and recovery

Creating and Administering a Legion Grid

- Once a Grid is created, users can think of it as <u>one computer</u> with <u>one directory structure</u> and <u>one batch processing protocol</u>
- Two administrative ways
  - As a single administrative domain: When all resources on the Grid are owned or controlled by single department or division
  - As a federation of multiple administrative domains: When resources are part of multiple administrative domains
    - Administrators define which of their resources are made available to the Grid and who has access

Creating and Administering a Legion Grid

- Legion provides features for the convenience of administrators
  - Monitoring load, idle time, etc
  - Add/remove resources
  - Dynamic reconfiguration based on policy
  - Logging
  - Collection of resource usage information

Legion Data Grid

- Concepts of Legion data Grid
  - Users access files by name – typically a pathname in the Legion virtual directory
  - There is no need to know the physical location of the files
  - How the data is accessed, and how the data is included into the Grid

Legion Data Grid

- Data Access
  - DAP Access (a Legion-aware NFS server)
    - Provides a standards-based mechanism to access a Legion Data Grid
    - Differences
      - It has no actual disk or file system behind it
      - It supports the Legion security mechanisms
      - It caches data aggressively
    - Can have DAP per site or per host
  - Command Line Access
    - A set of command line tools that mimic the Unix file system commands such as *ls, cat*, etc -> legion_ls, etc
  - I/O Libraries
    - A set of I/O libraries that mimic that *stdio* libraries

Legion Data Grid

- Data Inclusion
  - "copy"
    - Copy of the file is made in the grid
    - "legion_cp" command
  - "container"
    - Copy of the file is made in a container on the grid
    - Reduces the overhead associated with having one service per file
  - "share"
    - The data continues to reside on the original machine
    - "legion_export_dir" command starts a daemon that maps a file or rooted directory in Unix or Windows NT

Distributed Processing

- In a typical network
  - The user must know where the file is, where the application is, and whether the resources are sufficient to complete the work
- With Legion
  - Users have a single point of access to an entire Grid
  - Users log in, define application parameters and submit a program to run on available resources
  - Input data is read securely from distributed sources without necessarily being copied to a local disk

Distributed Processing

- Automated Resource Matching and File Staging
  - Administrative controls and predefined policies
  - Matches applications with queues in different ways
  - Through access controls: a user and application may or may not have access to a specific queue
  - Through matching of application requirements and host characteristics: a specific operating system/library
  - Through prioritization: based on policies and load conditions
- Support for Legacy Applications – No Modification Necessary
  - Applications can run anywhere at all on the Grid without regard to location or platform as long as resources are available that match the application' needs

Distributed Processing

- Batch Processing – Queues and Scheduling
  - Users can execute applications interactively or submit them to a queue
  - Queues
    - Shared processing power
    - Sequence jobs based on business priorities
    - Distribute jobs to available resources
    - Permit allocation of resources to groups of users
  - Administrator tasks
    - Monitor usage from anywhere on the network
    - Preempt jobs, re-prioritize and re-queue jobs
    - Establish policies based on time windows, load conditions or job limits

Security

- Security of Legion
  - Designed in the Legion architecture and implementation from the beginning
  - Authentication, authorization and data integrity
    - See references 7 and 9 in Chapter

Automatic Failure Detection and Recovery

- Fault-tolerant of Legion
  - If a computer goes down, Legion can migrate applications to other computers based on predefined deployment policies as long as resources are available that match application requirements
- Legion provides fat, transparent recovery from outages
  - Hosts, jobs and queues automatically back up their current state, enabling them to restart with minimal loss of information
- Systems can be reconfigured dynamically
  - Processing continues using other resources without interrupting operations
- Legion migrates jobs and files as needed
  - The job is automatically migrated to another host and restarted

The Legion Grid Architecture: Under the Covers

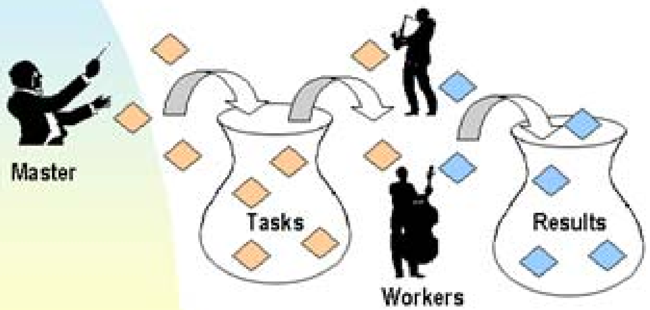
- Legion
  - An object-based system comprised of independent objects
- Legion class interfaces
  - Interface Description Language (IDL)
    - CORBA IDL, MPL, BFS
  - Communication
    - Supported for parallel applications (MPI libraries)
    - Supports cross-platform, cross-site MPI applications
- All legion objects
  - Name, state (which may or may not persist), Meta-data (<name, valueset> tuples) associated with their stat and an interface
  - Similar to OGSA

Legion

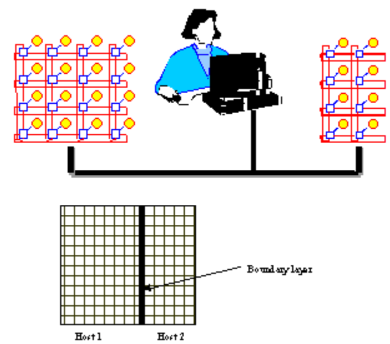
Parallel Processing

- Bag-of-tasks
  - Parameter space studies
  - Monte Carlos
  - Simple data-parallel
- Stencils (regular)
  - Ocean codes
  - PPM

Bag of Tasks



Wide-area parallel processing

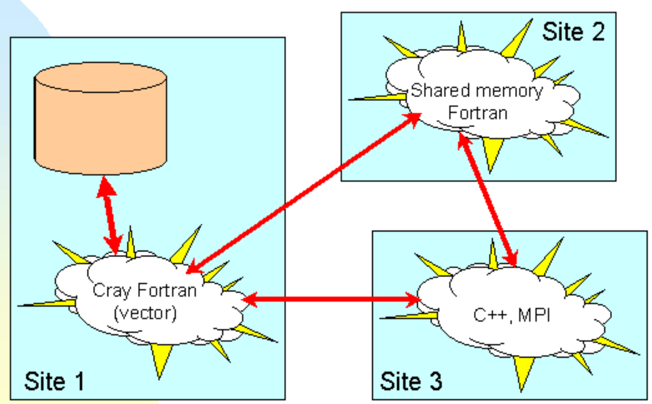


May be heterogeneous hosts

Meta-applications

A meta-application may be constructed from multiple components - each of which was previously a single application.

Meta-application example



Characteristics of Meta-applications

- Multiple components
  - modeling different physical components
  - written by different groups
  - historically separate applications
  - possibly written in different languages
  - with internal parallelism (task and data)
  - some have sub-components or sub-models
  - possibly executing on different scales

Architecture and Object Model

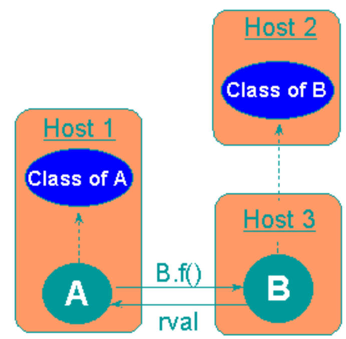
System architecture is key to the success of metasystems.

Legion is object-based

- Everything is an object
- Legion's core "system" objects
  - Hosts
  - Vaults
  - Classes - LegionClass
- All system objects can be replaced
- Classes are objects

The object model

- Legion objects
  - belong to classes
  - are logically independent, address-space-disjoint
  - communicate via non-blocking method calls
  - are *Active* or *Inert*
  - export *object-mandatory* member functions
  - are named using LOIDs



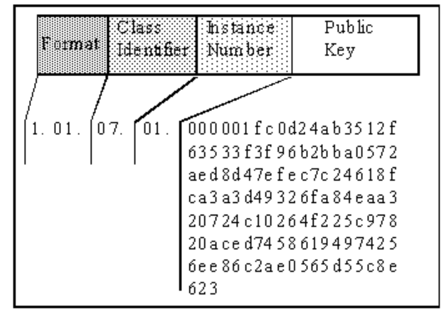
Legion Object Identifiers (LOIDs)

- LOIDs name objects and are location independent strings of bits
- LOIDs have many fields (arbitrary)
- Basic LOIDs have
  - type
  - “domain”
  - class id (integer)
  - instance id (integer)
  - public key (RSA)

Secure communication without trusted 3rd part

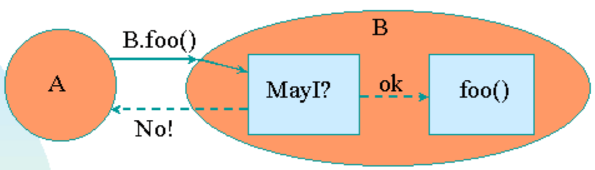
Dotted-hex notation

The Legion LOID



1.01.07.01000000.000001fc0ce16fe5110ac2a6051c70191b05c42
4d3bb6c18a8de593a32ac18f1e3d410a4636cb39edd281cf6eb264
758710c7609497003db974aeccc0a23ffeabdb87d8b

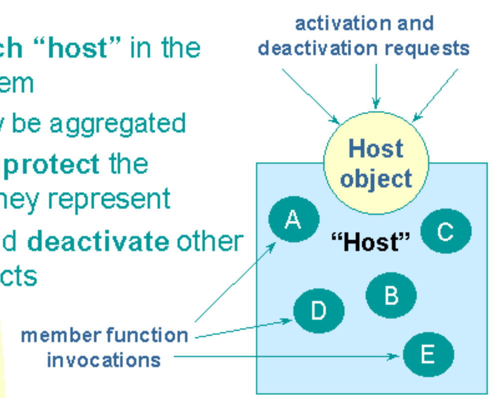
Access Control



- No single access control policy
  - Use a standard policy or define your own
- Security restricted to MayI function
  - Policies can replaced and verified
  - use a simple access control language

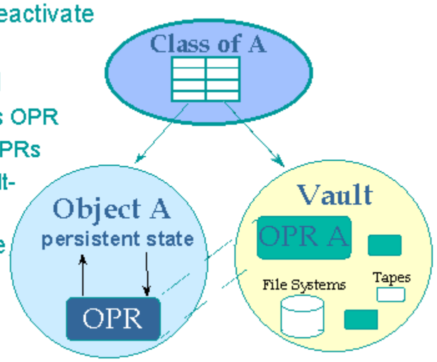
Host objects

- **Run on each “host”** in the Legion system
  - hosts may be aggregated
- **Guard and protect** the resources they represent
- **Activate** and **deactivate** other Legion objects



Vaults

- Objects will migrate, deactivate
  - State must persist
- Three objects involved
  - the object writes to its OPR
  - the Vault manages OPRs
  - Classes manage vault-object matching
- Vaults abstract storage

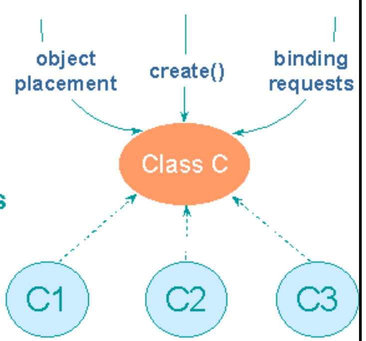


Vaults

- Are the **mechanism** for object persistence
  - "contain" inert Legion objects
  - keep the OPRs safe while an object is inert
  - are known by the class of the object
- Are **policy makers** (selected by the class)
  - how is the OPR maintained?
  - how is it kept "safe"?
  - many different implementations are possible
    - file system, DBMS, even shared memory
    - trust anyone, trust only the class, etc.

Class Objects

- Classes are **managers** that provide system-level services
  - creation
  - deletion
  - binding
  - keep track of binaries
- Classes are **policy makers**
  - placement and scheduling
  - fault-tolerance
  - instance implementation.



For example...

- Classes may desire
  - application-specific scheduling algorithms
  - to be part of a mandatory security protocol for all instances
  - to multiplex multiple instances within a single address space
  - to hand out different aliases for the same instance
  - to define and use special inheritance semantics
  - to manage changing instances

Binary Management

- User compiles code for each architecture of interest
- User registers binaries with a class object
- Class object, working with host object, ensures the right binaries are always used.

Implementation Objects

- Encapsulate Legion executables
- Write-once, read-many
- Typically contain code for single platform
- May be Java byte code, Perl scripts, or HLL that requires compilation
- Maintain a set of attributes
  - Type of executable, machine requirements, performance charactistics
- Class objects maintain list of acceptable implementa tion objects
- Allows multiple implementation with different time/ space trade-offs

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Implementation Caches

- Aviod storage & comm costs by caching implementai on
- Host object invoke cache objects to download imple mentation
- If Cache object does not have, it downloads and cac hes
- Invalidation of old versions easy
  - Class objects specify LOID of implementation
  - Need only change list of binaries
  - Future invocations will specify new binaries
  - Old versions will time out and be deleted from cache

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Legion to Avaki

- Legion began 1993 – determining requirements, desi gning architecture, coding
- First funding and code 1996
- 1997 first deployment
  - Initially difficult to maintain MTBF > 20 hrs due to peculiar failure modes
  - By Nov 1998 MTBF > 1 month
- Always intended to move the software into mainstre am with commercial support
  - 2001 Avaki raised capital and relesase Avaki
  - Hardened, trimmed-down, commercially focussed version

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Avaki today

- Grid paradigm useful for dynamic business environment where companies regularly merge
  - May be geographically distributed, have heterogeneous architectures, require unified secure access
- What has changed from Legion to Avaki
  - Eliminates more esoteric features and functions
    - 2D files, heterogeneous MPI
  - Adds more stringent error-checking & recommends safer configurations
  - Increases usability through documentation, configuration guidelines, extra tools

Differences between Avaki & OGSA

- RPC model
  - Avaki intends to address by becoming Web Services compliant i.e supporting XML/SOAP & WDSL
- Naming model
  - OGSA names have no security information
  - Binding resolvers in OGSA are location and protocol specific
- No security model in OGSA

Users View

For more information including access to on-line tutorials see:

http://legion.virginia.edu

First steps

- Setup shell environment variables

(ksh or sh users)

```
export LEGION=<Legion root dir path>
export LEGION_OPR=<Legion OPR root path>
(suggested: $LEGION/../OPR)
. $LEGION/bin/legion_env.sh
. $LEGION_OPR/legion_context_env.sh
```

- Specifies where binaries can be found and sets root context

Authentication (login)

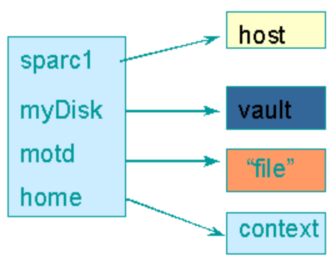
- legion_login <user id>
  - currently uses passwords - other mechanisms may be easily added
  - login object is the user's proxy to the world
  - login object generates a certificate
  - certificate identifies who you are

Legion (context) space

- Network-wide, transparent file system
- Programs can read/write files regardless of execution location
- Data files can easily be moved between Legion space and user's local file system
- I/O libraries for access
- All the usual utilities, legion_cat, legion_ls, legion_ln, legion_cp, ...

Contexts are more general than Unix directories

- Contexts map strings to LOIDs
- Directory-like - but can "point" to anything, not just other contexts and files
  - host objects
  - class objects
  - vaults
  - TTYs



Context Examples

```
$ legion_ls -l
.                  (context)
class              (context)
hosts              (context)
vaults             (context)
home               (context)
$ legion_context_create /tmp
Creating context "tmp" in parent ".".
New context LOID = "1.01.05.608.003..."
$ legion_set_context /tmp
$ legion_ls -la
.                  (context)
..                 (context)
```

```
$ legion_cp -localsource myfile /tmp/myfile

$ legion_ls -la
.                  (context)
..                 (context)
myfile             1564 bytes
$
$ legion_ln myfile /ln_to_myfile
$ legion_ls -la /
.                  (context)
class              (context)
hosts              (context)
vaults             (context)
home               (context)
tmp                (context)
ln_to_myfile       1564 bytes
```

```
$ legion_ls -la /hosts
.                              (context)
..                             (context)
BootstrapHost
bootstrap.host.DNS.name
stonesoup00.cs.virginia.edu
stonesoup03.cs.virginia.edu
```

Access Control

- MayI implements access control lists on a function basis
- Users are named by their login object
- Sets of users defined by contexts with links to users

```
$ legion_change_permissions [+-rwx] [-v] \
[-help] <group/user context path> \  <target
context path>

$legion_change_permissions +r /users/fred \
      /home/grimshaw/myfile
```

Access Control

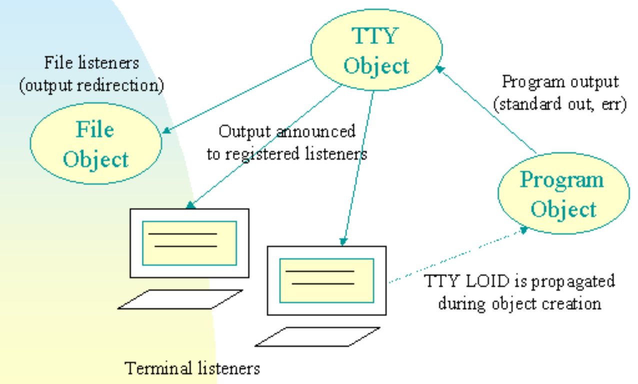
```
$legion_ls /users/grimshaw/mygroup
.
..
Tony
Sally
Tim

$legion_change_permissions +r \
      /home/grimshaw/mygroup \
      /home/grimshaw/myfile
```

Unified Console

- Run-time output can flow back to a central (or multiple) consoles
- Can dynamically connect and disconnect
- Faster, simpler debugging
- Easy monitoring of status, errors, etc.
- share console with others
- Commands:

```
legion_tty /mytty
legion_set_tty /mytty
legion_tty_watch /mytty &
```

TTY Objects in Action



Running sequential applications

Running sequential applications

- Can run Legion-aware or legacy programs
  - Primary distinction is the use of the Legion I/O and context Libraries.
- Register programs with a Legion class object
- Execute the program remotely using legion commands

Registering the binary

```
$ legion_register_program printLoc    \
      /bin/hostname linux
Creating class "printLoc"
Registering implementation for class "printLoc"
```

- Creates class, if necessary
- Register versions of program for multiple platforms with same class

Remote execution

```
legion_run [<options>] <prog_path> [<args>]
```

- non-Legion binaries and shell scripts
- selects a host for remote execution
- copies binary if necessary (system caches)
- copies files in and out as specified
- simplest way to do parameter space studies

Example 1

```
$ legion_tty myTTY

$ legion_run printLoc
stonesoup05.cs.virginia.edu

$ legion_run -h /hosts/stonesoup00 printLoc
stonesoup00.cs.virginia.edu

$ legion_run -a alpha_linux printLoc
centurion019.cs.virginia.edu
```

- Can select a host or platform type

Parameter space studies

- Perform multiple executions of a sequential program (e.g., simulation), each with different data
- E.g., examine changes in simulation results under different parameter values
- Simulation of each point in the parameter space can execute in parallel
- Natural application of Legion remote execution

legion_run_multi

```
legion_run_multi [<options>] -n <num nodes>
        -f <control_file> <prog_path> [<args>]
```

- Manages multiple legion_run sessions, providing easy-to-configure parameter space studies
- Control file uses simple language for specifying input/output file name patterns
- Provides support for directing scheduling of remote jobs

Example 1

- Run eight copies of my_prog on input files data.[1-8] producing output files results.[1-8]

```
$ legion_register_program my_prog my_prog sgi
$ cat dataset.cfg
      in data data.*
      out results
$ ls data.*
data.1 data.2 data.3 data.4
data.5 data.6 data.7 data.8
$ legion_run_multi -n 8 -f dataset.cfg          \
      my_prog data -o results
$ ls results.*
results.1 results.2 results.3 results.4
results.5 results.6 results.7 results.8
```

Example 2

- Wish to select the hosts to run on

```
$ cat hfile
/hosts/centurion001     3
/hosts/centurion002     3
/hosts/stonesoup01      1
/hosts/stonesoup02      1

$ legion_run_multi -s hfile -n 8 -f dataset.cfg \
      my_prog data -o results
```

- Place 3 tasks on each of the centurion hosts, and 1 on each of the stonesoup hosts.

Legion-aware sequential applications

- Can modify existing sequential applications to use Legion I/O and context libraries

Legion I/O

- A number of supported interfaces
  - C/C++ BasicFiles library interface
  - Fortran BasicFiles library interface
    - Simple copy-in/copy-out routines
    - Standard file access routines
  - C++ object-oriented interface
  - Java object-oriented interface

C interface example

```
long fd;
char buf[1024];

fd = BasicFiles_open(path, BASIC_FILE_O_CREAT |
            BASIC_FILE_O_TRUNC);


BasicFiles_write(fd, buf, 1024);

BasicFiles_seek(fd, BASIC_FILES_SEEK_BEGINNING, 512);
```

Linkage requirements

- Link against Legion libraries
- Sample makefile:

```
CFLAGS = -I$(LEGION)/include                          \
         -L$(LEGION)/lib/$LEGION_ARCH/$(CC)
LIB    = -lBasicFiles -lLegion
example: example.c
      $(CC) $(CFLAGS) example.c -o example $(LIB)
```

- or use legion_link:

```
CFLAGS = -I$(LEGION)/include
example: example.c
      $(CC) $(CFLAGS) -c example.c
      legion_link example.o -o example
```