GT4 GridFTP for Developers: The New GridFTP Server

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Overview

- **Introduction to GridFTP**
- Overview of asynchronous programming
- The server Data Storage Interface (DSI)
- GridFTP Client Library (Time Permitting)

What is GridFTP?

- A secure, robust, fast, efficient, standards based, widely accepted data transfer protocol
- A Protocol
  - Multiple independent implementations can interoperate
    - This works. Both the Condor Project at Uwis and Fermi Lab have home grown servers that work with ours.
    - Lots of people have developed clients independent of the Globus Project.
- We also supply a reference implementation:
  - Server
  - Client tools (globus-url-copy)
  - Development Libraries

GridFTP: The Protocol

- FTP protocol is defined by several IETF RFCs
- Start with most commonly used subset
  - Standard FTP: get/put etc., 3rd-party transfer
- Implement standard but often unused features
  - GSS binding, extended directory listing, simple restart
- Extend in various ways, while preserving interoperability with existing servers
  - Striped/parallel data channels, partial file, automatic & manual TCP buffer setting, progress monitoring, extended restart

GridFTP: The Protocol (cont)

- Existing standards
  - RFC 959: File Transfer Protocol
  - RFC 2228: FTP Security Extensions
  - RFC 2389: Feature Negotiation for the File Transfer Protocol
  - Draft: FTP Extensions
  - GridFTP: Protocol Extensions to FTP for the Grid
    - Grid Forum Recommendation
    - GFD.20
    - http://www.ggf.org/documents/GWD-R/GFD-R.020.pdf

wuftpd based GridFTP

Functionality prior to GT3.2

- Security
- Reliability / Restart
- Parallel Streams
- Third Party Transfers
- Manual TCP Buffer Size
- Partial File Transfer
- Large File Support
- Data Channel Caching
- Integrated Instrumentation
- De facto standard on the Grid

New Functionality in 3.2

- Server Improvements
  - Structured File Info
    - MLST, MLSD
  - checksum support
  - chmod support (client)
- globus-url-copy changes
  - File globbing support
  - Recursive dir moves
  - RFC 1738 support
  - Control of restart
  - Control of DC security

New GT4 GridFTP Implementation

- NOT based on wuftpd
- 100% Globus code. No licensing issues.
- GT3.9.4 (released in Dec.) has a very solid alpha. It will be in the GT4.0 Final scheduled for 2Q2005.
- wuftpd specific functionality, such as virtual domains, will NOT be present
- Has IPV6 support included (EPRT, EPSV), but we have limited environment for testing.
- Based on XIO
- Extremely modular to allow integration with a variety of data sources (files, mass stores, etc.)
- Striping will also be present in 4.0

Extensible IO (XIO) system

- Provides a framework that implements a Read/Write/Open/Close Abstraction
- Drivers are written that implement the functionality (file, TCP, UDP, GSI, etc.)
- Different functionality is achieved by building protocol stacks
- GridFTP drivers will allow 3rd party applications to easily access files stored under a GridFTP server
- Other drivers could be written to allow access to other data stores.
- Changing drivers requires minimal change to the application code.

Striped Server

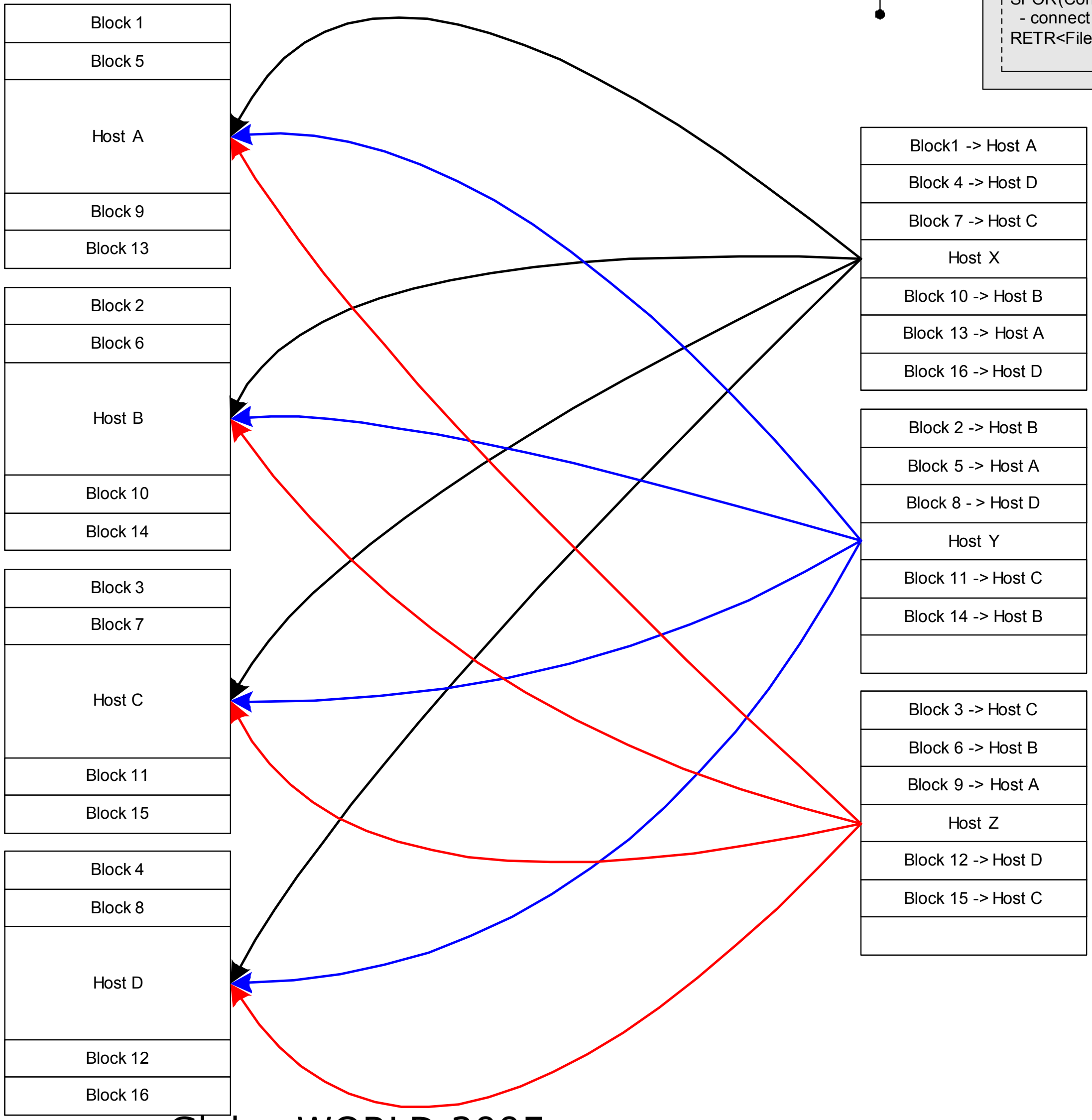
- Multiple nodes work together and act as a single GridFTP server
- An underlying parallel file system allows all nodes to see the same file system and must deliver good performance (usually the limiting factor in transfer speed)
  - I.e., NFS does not cut it
- Each node then moves (reads or writes) only the pieces of the file that it is responsible for.
- This allows multiple levels of parallelism, CPU, bus, NIC, disk, etc.
  - Critical if you want to achieve better than 1 Gbs without breaking the bank

18-Nov-03

GridFTP Striped Transfer

MODE E
SPAS (Listen)
- returns list of host:port pairs
STOR<FileName>

MODE E
SPOR(Connect)
- connect to the host-port pairs
RETR<FileName>



Block 1
Block 5
Host A
Block 9
Block 13

Block 2
Block 6
Host B
Block 10
Block 14

Block 3
Block 7
Host C
Block 11
Block 15

Block 4
Block 8
Host D
Block 12
Block 16

Block1 -> Host A
Block 4 -> Host D
Block 7 -> Host C
Host X
Block 10 -> Host B
Block 13 -> Host A
Block 16 -> Host D

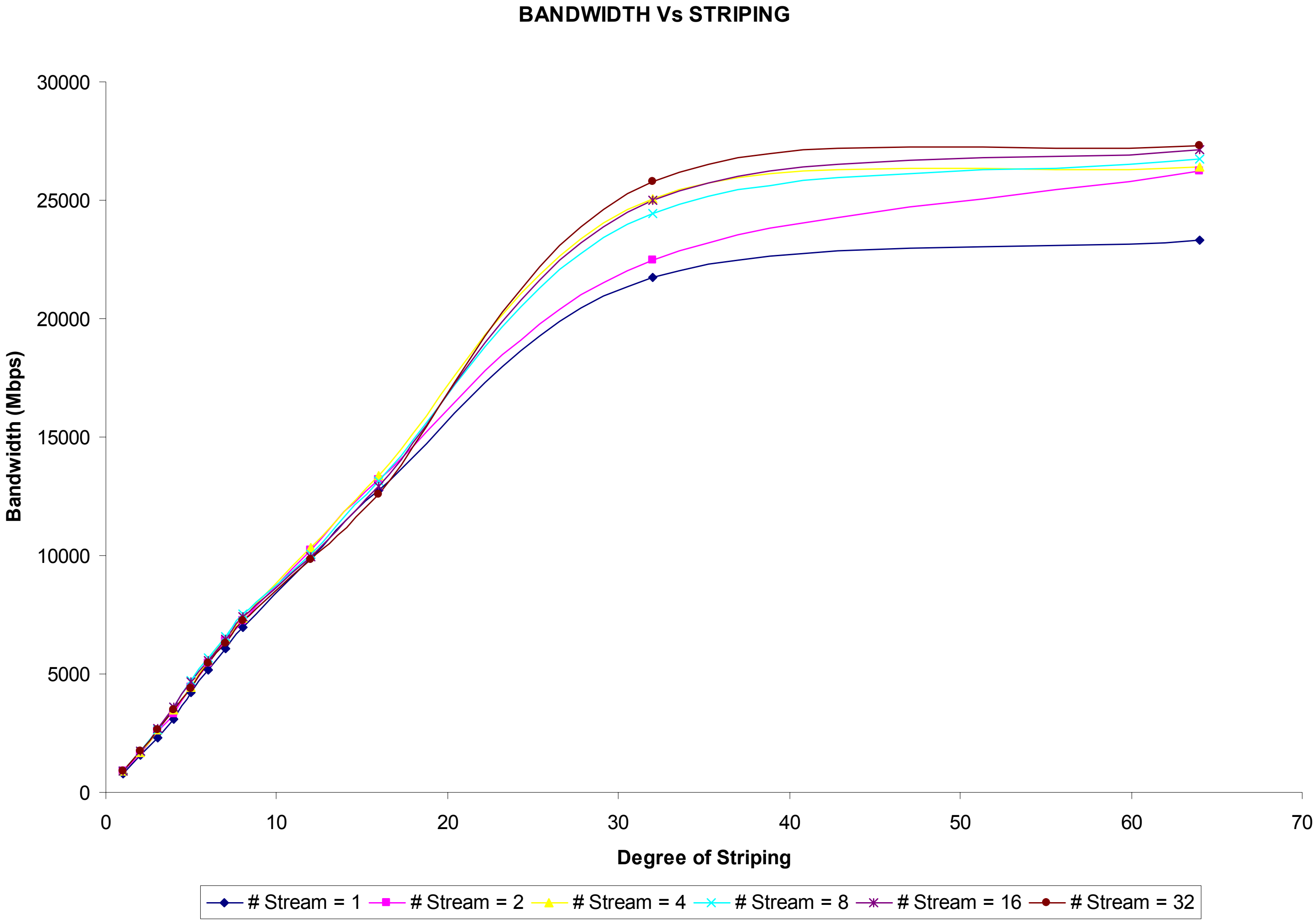
Block 2 -> Host B
Block 5 -> Host A
Block 8 - > Host D
Host Y
Block 11 -> Host C
Block 14 -> Host B

Block 3 -> Host C
Block 6 -> Host B
Block 9 -> Host A
Host Z
Block 12 -> Host D
Block 15 -> Host C

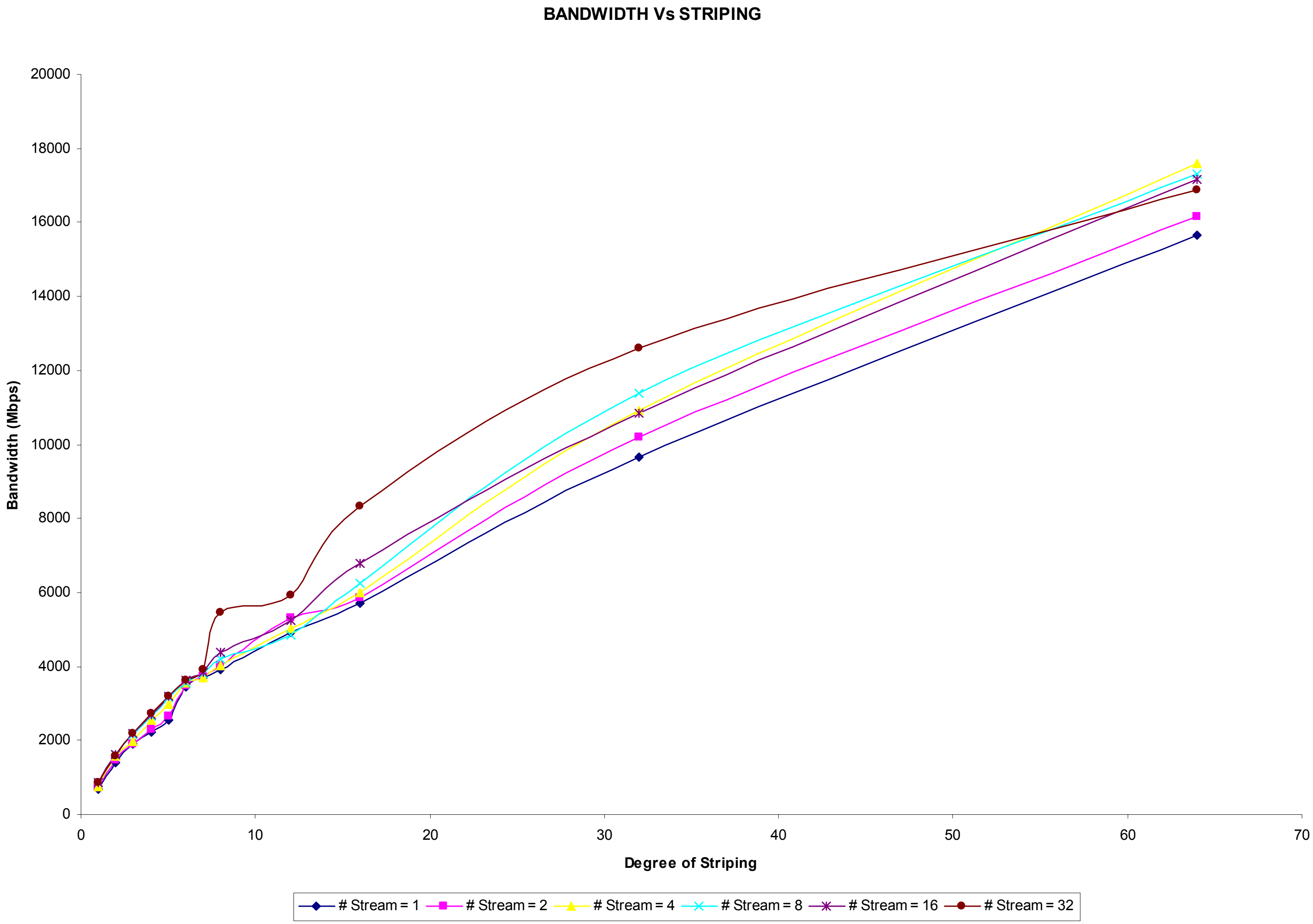
TeraGrid Striping results

- Ran varying number of stripes
- Ran both memory to memory and disk to disk.
- Memory to Memory gave extremely high linear scalability (slope near 1).
- We achieved 27 Gbs on a 30 Gbs link (90% utilization) with 32 nodes.
- Disk to disk we were limited by the storage system, but still achieved 17.5 Gbs

Memory to Memory Striping Performance



Disk to Disk Striping Performance



GridFTP: Caveats

- Protocol requires that the sending side do the TCP connect (possible Firewall issues)
- Client / Server
  - Currently, no simple encapsulation of the server side functionality (need to know protocol), therefore Peer to Peer type apps VERY difficult
    - A library with this encapsulation is on our radar, but no timeframe.
  - Generally needs a pre-installed server
    - Looking at a “dynamically installable” server

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Asynchronous Programming

- There are 3 basic event models
  - Blocking: Code does not make progress until event handling is finished.
  - Non-blocking: Code can make progress, but there is typically a large case or if structure.
  - Asynchronous: No in-line path of execution. Event handlers are registered and executed as needed.

Asynch Programming is complicated

- There is no in-line logic that can be easily looked at and understood.
- All state needs to be packaged up in a structure and passed through.
- You need to be careful of race conditions.
- The event handling system is not really “visible” so it seems like there is some “magic” involved.

The callback is everything

- The term callback may be a bit confusing, because it does not necessarily “call back” to some other process.
- Think of it as “Now that I am done, what should happen next?”

```
main()
{
    1();
    2();
    3();
}
```

```
2(cb=3) { … return()};
3(cb=done) {… return()};
main()
{
    1(cb =2);
}
```

Example Code

```
In main():
bytes_read = fread(buffer, 1, MAX_BUFFER_SIZE, fd);
globus_ftp_client_register_write(&handle, buffer, bytes_read, global_offset,
                                 feof(fd), data_cb, (void *) fd);

In data_cb():
        if(!feof(fd))
        {
           bytes_read = fread(buffer, 1, MAX_BUFFER_SIZE, fd);
           if (ferror(fd))
           {
               printf("Read error in function data_cb; errno = %d\n", errno);
               globus_mutex_unlock(&lock);
               return;
           }
           globus_ftp_client_register_write(
              handle,
              buffer,
              bytes_read,
              global_offset,
              feof(fd),
              data_cb,
              (void *) fd);
           cb_ref_count++;
           global_offset += bytes_read;
         }
```

Globus Thread Abstraction

- With Globus libraries, you write threaded and non-threaded code the same way.
- use globus_cond_wait and globus_cond_signal
    - in a threaded build they translate to the standard pthread calls
    - in a non-threaded they translate to globus_poll_blocking and globus_signal_poll
- This allows the same code to be built either threaded or non-threaded.

Non-Threaded

- During initialization the XIO select poller callback is registered in the callback library queue. It is always ready.
- Registering your callback places it in the same queue.
- globus_cond_wait calls globus_poll_blocking which initiates the callback library queue processing. This will not return (in general) until globus_cond_signal (globus_signal_poll) is called.
- Callbacks can be ready immediately or after a wait time, they can be one-shot or periodic.
- If nothing else is ready, XIO select poller determines how long before the next callback will be ready and sleeps till then.
- So callbacks get queued and executed from either the callback library or XIO select poller.

Threaded

- In this case, things work as expected ☺
- globus_cond_wait calls pthread_cond_wait and puts the main thread to sleep.
- The select loop runs in its own thread.
- globus_cond_signal calls pthread_cond_signal and wakes up the thread waiting on the cond (typically main).
  - Note that POSIX allows the thread to wake up aribitrarily and so the cond_wait should be enclosed in some sort of while (!done) loop

Lets look at the web examples

- http://www-unix.globus.org/toolkit/docs/3.2/developer/globus-async.html

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New Server Architecture

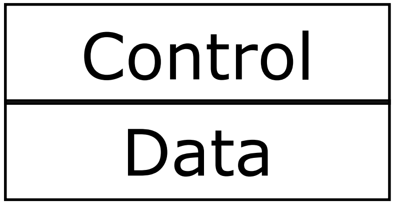
- GridFTP (and normal FTP) use (at least) two separate socket connections:
  - A control channel for carrying the commands and responses
  - A Data Channel for actually moving the data
- Control Channel and Data Channel can be (optionally) completely separate processes.
- A single Control Channel can have multiple data channels behind it.
  - This is how a striped server works.
  - In the future we would like to have a load balancing proxy server work with this.

New Server Architecture

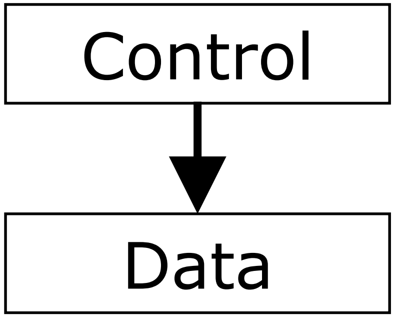
- Data Transport Process (Data Channel) is architecturally, 3 distinct pieces:
  - The protocol handler. This part talks to the network and understands the data channel protocol
  - The Data Storage Interface (DSI). A well defined API that may be re-implemented to access things other than POSIX filesystems
  - ERET/ESTO processing. Ability to manipulate the data prior to transmission.
    - currently handled via the DSI
    - In V4.2 we to support XIO drivers as modules and chaining
- Working with several groups to on custom DSIs
  - LANL / IBM for HPSS
  - UWis / Condor for NeST
  - SDSC for SRB

Possible Configurations

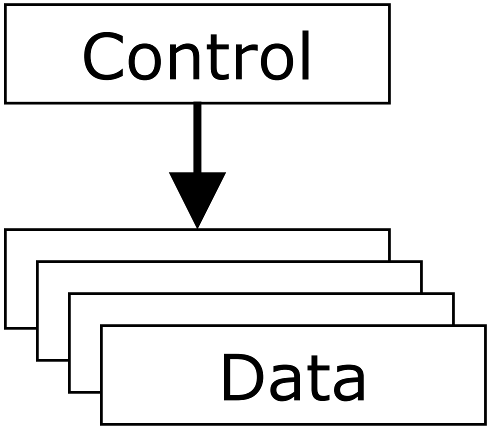
Typical Installation


Control
Data

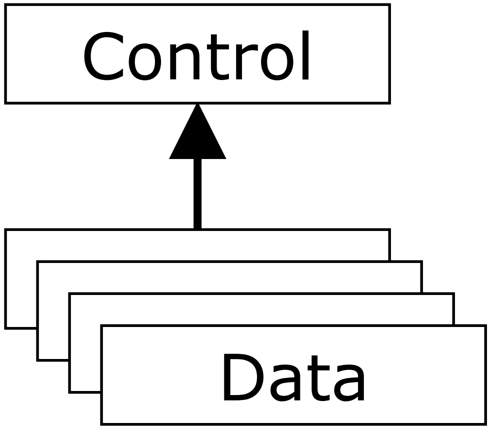
Separate Processes


Control
Data

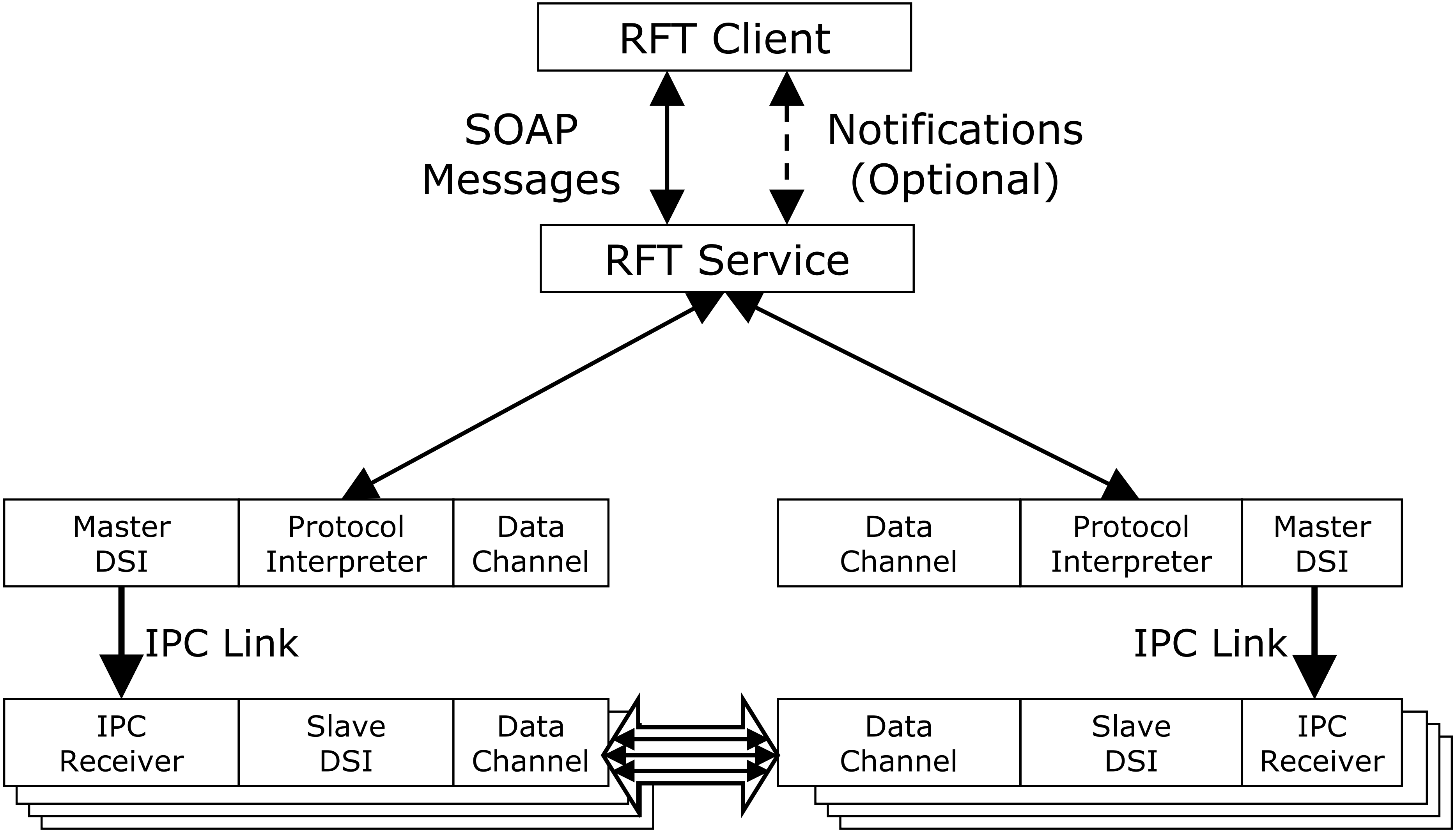
Striped Server


Control
Data

Striped Server (future)


Control
Data

Third Party Transfer



The Data Storage Interface (DSI)

- Unoriginally enough, it provides an interface to data storage systems.
- Typically, this data storage system is a file system accessible via the standard POSIX API, and we provide a driver for that purpose.
- However, there are many other storage systems that it might be useful to access data from, for instance HPSS, SRB, a database, non-standard file systems, etc..

The Data Storage Interface (DSI)

- Conceptually, the DSI is very simple.
- There are a few required functions (init, destroy)
- Most of the interface is optional, and you can only implement what is needed for your particular application.
- There are a set of API functions provided that allow the DSI to interact with the server itself.
- Note that the DSI could be given significant functionality, such as caching, proxy, backend allocation, etc..

Developer Implemented Functions

- Below is the structure used to hold the pointers to your functions.
- This can be found in <install>/source-trees/gridftp/server/src

```
typedef struct globus_gfs_storage_iface_s
{
    int                             descriptor;

    /* session initiating functions */
    globus_gfs_storage_init_t       init_func;
    globus_gfs_storage_destroy_t    destroy_func;

    /* transfer functions */
    globus_gfs_storage_transfer_t   list_func;
    globus_gfs_storage_transfer_t   send_func;
    globus_gfs_storage_transfer_t   recv_func;
    globus_gfs_storage_trev_t       trev_func;

    /* data conn funcs */
    globus_gfs_storage_data_t           active_func;
    globus_gfs_storage_data_t           passive_func;
    globus_gfs_storage_data_destroy_t   data_destroy_func;

    globus_gfs_storage_command_t        command_func;
    globus_gfs_storage_stat_t           stat_func;

    globus_gfs_storage_set_cred_t       set_cred_func;
    globus_gfs_storage_buffer_send_t    buffer_send_func;
} globus_gfs_storage_iface_t;
```

Master vs. Slave DSI

- If you wish to support striping, you will need two DSIs
- The Master DSI will be in the PI or front end. It must implement all functions (that you want to support).
    - Usually, this is relatively trivial and involves minor processing and then “passing” the command over the IPC channel to the slave DSI
- Any functions not implemented will be handled by the server if possible (non-filesystem, active, list)
- All DSI’s must implement the init_func and destroy_func functions.

Slave Functions

- The slave DSI does the real work. It typically implements the following functions:
  - send_func: This function is used to send data from the DSI to the server (get or RETR)
  - recv_func: This function is used to receive data from the server (put or STOR)
  - stat_func: This function performs a unix stat, i.e. it returns file info. Used by the list function
  - command_func: This function handles simple (succeed/fail or single line response) file system operations such as mkdir, site chmod, etc.

Slave Functions (cont)

- If you implement active/passive (you normally shouldn’t) you will need to implement data_destroy to free the data channel memory.
- The set_cred function normally does not need to be implemented.

Additional Master Functions

- As noted before, the master should (must?) implement all functions. Besides the sender functions, these include:
  - active_func: This is for when the DSI will be doing a TCP connect.
    - The master figures out who gets what IP/port info and then passes it through.
    - The slave should not need to implement this. The server can handle this for you.
  - passive_func: The counter-part to the active_func when the DSI will be the listener
  - list_func: This should be passed through and will handle LIST, NLST, MLST, etc..

Additional Master Functions

- There are also some utility functions the master should (must?) implement:
  - data_destroy_func: Frees the memory associated with the data channel. This should be a simple pass through, unless you implement your own active/passive functions.
  - trev_func: This handles the restart and performance markers, but should be a simple pass through
- If you choose not to implement any of these functions you need to have a good reason.

IPC Calls

- These calls are how the master DSI "passes" the call to the slave DSI
- The IPC calls are basically the same as the DSI calls.
  - globus_gfs_ipc_iface_stat_t   stat_func;
  - globus_gfs_storage_stat_t   stat_func;
- These calls implement an internal, binary protocol to transfer the necessary structures between the front end and the back end.
- The IPC receiver receives the message and then invokes the sender DSI. The sender DSI does not know, nor does it need to know, whether it is local or remote.

Helper Functions that should be used

- When implementing the DSI functions, the following helper functions should be called:
  - <function>_finished: This tells the server that a specific function (such as recv) has completed
    - all functions have finished functions. There is also a generic finished. The send and recv also have start calls.
  - register[read|write]: This is how file data is transferred between the DSI and the server.
  - bytes_written: This should be called anytime the DSI successfully completes a write to its own storage system. This allows performance and restart markers to be generated

Helper Functions that should be used

- get_concurrency: Tells you the number of outstanding reads or writes you should have based on the parallelism.
- get_blocksize: This indicates the buffer size that you should exchange with the server via the register_[read|write].
- get_[read|write]_range: This tells the DSI which data it should be sending.
  - This handles striping (this DSI only needs to send a portion of the file), restart (including “holey” transfers), and partial files.
  - read should be called repeatedly until it returns zero.
  - write is only a hint (you have to write where the offset tells you) and should only be called once.

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Writing a GridFTP Client

- Module Activation / Initialization
- Check Features
- Select Mode
- Set Attributes
- Enable any needed plug-ins
- Execute the operation
- Module Deactivation / Clean up

Initialization

- globus_module_activate(GLOBUS_FTP_CLIENT_MODULE)
- Must be called in any program that use the client library.
- Will automatically call module_activate for any required lower level modules (like globus_io)

Checking Features

- call globus_ftp_client_features_init
- then call globus_ftp_client_feat
  - this is a non-blocking call, so you will need to wait on it to finish.
  - you need only call this once
- Once globus_ftp_client_feat has returned, globus_ftp_client_is_feature_supported can be called as often as necessary for the various features.

Attributes

- Very powerful feature and control much of the functionality
- Two types of attributes:
  - Handle Attributes: Good for an entire session and independent of any specific Operation
  - Operation Attributes: Good for a single operation.
- Files:
  - globus_ftp_client_attr.c
  - globus_i_ftp_client.h

Attributes (Cont)

- Handle Attributes:
  - Initialize/Destroy/Copy Attribute Handle
  - Connection Caching: Either all, or URL by URL.
  - Plugin Management: Add/Remove Plugins

Attributes (Cont)

- Operation Attributes
  - Parallelism
  - Striped Data Movement
  - Striped File Layout
  - TCP Buffer Control
  - File Type
  - Transfer Mode
  - Authorization/Privacy/Protection
- Functions
  - globus_ftp_client_operationattr_set_<attribute>(&attr, &<attribute_struct>)
  - globus_ftp_client_operationattr_get_<attribute>(&attr, &<attribute_struct>)

Attributes (Cont)

- Example Code (structs and enums in globus_ftp_control.h):

```
globus_ftp_client_handle_t                handle;
globus_ftp_client_operationattr_t         attr;
globus_ftp_client_handleattr_t            handle_attr;
globus_size_t                             parallelism_level = 4;
globus_ftp_control_parallelism_t          parallelism;
globus_ftp_control_layout_t               layout;

globus_module_activate(GLOBUS_FTP_CLIENT_MODULE);
globus_ftp_client_handleattr_init(&handle_attr);
globus_ftp_client_operationattr_init(&attr);
parallelism.mode = GLOBUS_FTP_CONTROL_PARALLELISM_FIXED;
parallelism.fixed.size = parallelism_level;
globus_ftp_client_operationattr_set_mode(&attr,
        GLOBUS_FTP_CONTROL_MODE_EXTENDED_BLOCK);
globus_ftp_client_operationattr_set_parallelism(&attr, &parallelism);
globus_ftp_client_handle_init(&handle,  &handle_attr);
```

Mode S versus Mode E

- Mode S is stream mode as defined by RFC 959.
  - No advanced features accept simple restart
- Mode E enables advanced functionality
  - Adds 64 bit offset and length fields to the header.
  - This allows discontiguous, out-of-order transmission and along with the SPAS and SPOR commands, enable parallelism and striping.
- Command:

```
globus_ftp_client_operationattr_set_mode(&attr, GLOBUS_FTP_CONTROL_MODE_EXTENDED_BLOCK);
```

Plug-Ins

- Interface to one or more plug-ins:
  - Callouts for all interesting protocol events
    - Allows monitoring of performance and failure
  - Callins to restart a transfer
    - Can build custom restart logic
- Included plug-ins:
  - Debug: Writes event log
  - Restart: Parameterized automatic restart
    - Retry N times, with a certain delay between each try
    - Give up after some amount of time
  - Performance: Real time performance data

Plug-Ins (Cont.)

- Coding:
  - globus_ftp_client_plugin_t *plugin;
  - globus_ftp_client_plugin_set_<type>_func
    - Macro to make loading the struct easier
  - globus_ftp_client_handleattr_add_plugin(attr, plugin)
- Files:
  - globus_ftp_client_plugin.h
  - globus_ftp_client.h
  - globus_ftp_client_plugin.c
  - Also some internal .h files

Plug-Ins (Cont.)

- A plugin is created by defining a globus_ftp_client_plugin_t which contains the function pointers and plugin-specific data needed for the plugin's operation. It is recommended that a plugin define a a globus_module_descriptor_t and plugin initialization functions, to ensure that the plugin is properly initialized.
- Every plugin must define copy and destroy functions. The copy function is called when the plugin is added to an attribute set or a handle is initialized with an attribute set containing the plugin. The destroy function is called when the handle or attribute set is destroyed.

Plug-Ins (Cont.)

- Essentially filling in a structure of function pointers:
  - Operations (Put, Get, Mkdir, etc)
  - Events (command, response, fault, etc)
- Called only if both the operation and event have functions defined
- Filtered based on command_mask

High Level Calls

- globus_ftp_client_put/get/3rd Party
- Function signature:

```
globus_result_t globus_ftp_client_get
  (globus_ftp_client_handle_t *handle,
   const char *url,
  globus_ftp_client_operationattr_t *attr,
  globus_ftp_client_restart_marker_t *restart,
  globus_ftp_client_complete_callback_t
  complete_callback,
   void *callback_arg)
```

Example: globus_ftp_client_put_test.c

Parallel Put/Get

- Parallelism is hidden. You are not required to do anything other than set the attributes, though you may want to for performance reasons.
- Doc needs to be updated. Does not have enums or structures. Look in globus_ftp_control.h

Deactivate / Cleanup

- Free any memory that *you* allocated
- Call the necessary destroy and deactivate functions:

```
globus_ftp_client_handleattr_destroy(&handle_attr);
globus_ftp_client_operationattr_destroy(&operation_attr);
globus_ftp_client_handle_destroy(&handle);
globus_module_deactivate(GLOBUS_FTP_CLIENT_MODULE);
```