Integrating Analysis and Computation with Trios Services

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Trilinos User Group Meeting

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Exceptional service in the national interest

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Some I/O Issues for Exascale

- Storage systems are the slowest, most fragile, part of an HPC system
  - Scaling to extreme client counts is challenging
  - POSIX semantics gets in the way, …
- Current usage models not appropriate for Petascale, much less Exascale
  - Checkpoints are a ***HUGE*** concern for I/O…currently primary focus of FS
  - App workflow uses storage as a communication conduit
    - Simulate, ***store***, analyze, ***store***, refine, ***store***, … most of the data is transient
- One way to reduce I/O pressure on the FS is to inject nodes between app and FS
  1. Reduce the "effective" I/O cost through data staging (a.k.a. ***Burst Buffer***)
  2. Reduce amount of data written to storage (integrated analysis, data services)
  3. Present FS with fewer clients (IO forwarding)

"Trios Services" enable application control of these nodes

Trios Data Services

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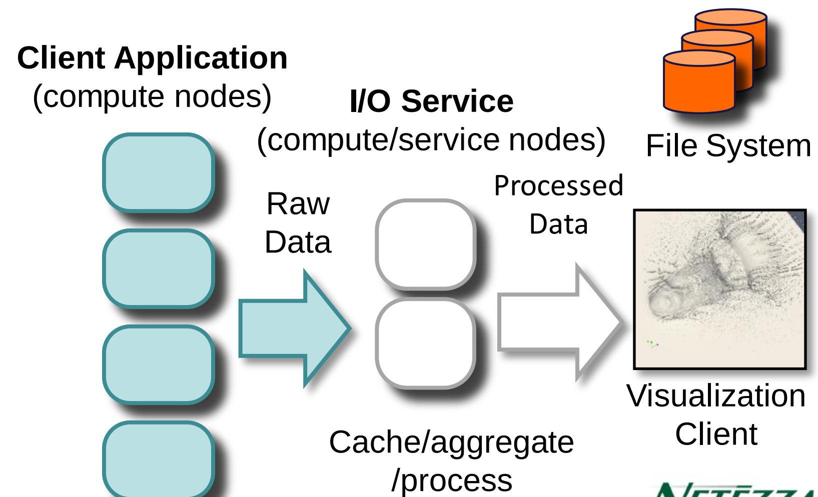
Approach

- Leverage available compute/service node resources for I/O caching and data processing

Application-Level I/O Services

- PnetCDF staging service
- CTH real-time analysis
- SQL Proxy (for NGC)
- Interactive sparse-matrix visualization
- In-memory key-value (in development)



NETEZZA

LexisNexis

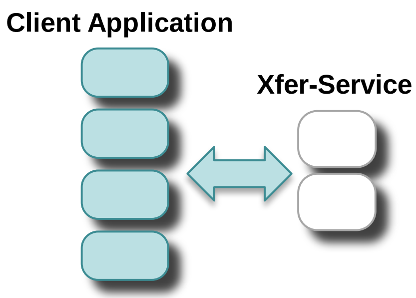
Nessie

- Framework for developing data services
- Portable API for inter-app comm (NNTI)
- Client and server libs, cmake macros, utilities
- Originally developed for LWFS

Example: A Simple Transfer Service

Trilinos/packages/trios/examples/xfer-service

- Used to test Nessie API
  - ***xfer_write_rdma***: server pulls raw data using RDMA get
  - ***xfer_read_rdma***: server transfers data to client using RDMA put
- Used for performance evaluation
  - Test low-level network protocols
  - Test overhead of XDR encoding
  - Tests async and sync performance
- Creating the Transfer Service
  - Define the XDR data structs and API arguments
  - Implement the client stubs
  - Implement the server




```
/* Data structure to transfer */
struct data_t {
   int int_val;        /* 4 bytes */
   float float_val;    /* 4 bytes */
   double double_val;  /* 8 bytes */
};

/* Array of data structures */
typedef data_t data_array_t<>;

/* Arguments for xfer_write_encode */
struct xfer_write_encode_args {
   data_array_t array;
};

/* Arguments for xfer_write_rdma */
struct xfer_write_rdma_args {
   int len;
};

...
```

Transfer Service

Implementing the Client Stubs

- Interface between scientific app and service
- Steps for client stub
  - Initialize the remote method arguments, in this case, it's just the length of the array
  - Call the rpc function. The RPC function includes method arguments (*args*), and a pointer to the data available for RDMA (*buf*)
- The RPC is asynchronous
  - The client checks for completion by calling nssi_wait(&req);

```
int xfer_write_rdma(
  const nssi_service *svc,
  const data_array_t *arr,
  nssi_request *req)
{
  xfer_write_rdma_args args;
  int nbytes;

  /* the only arg is size of array */
  args.len = arr->data_array_t_len;

  /* the RDMA buffer */
  const data_t *buf=array->data_array_t_val;

  /* size of the RDMA buffer */
  nbytes = args.len*sizeof(data_t);

  /* call the remote methods */
  nssi_call_rpc(svc, XFER_PULL,
    &args, (char *)buf, nbytes,
    NULL, req);
}
```

Transfer Service

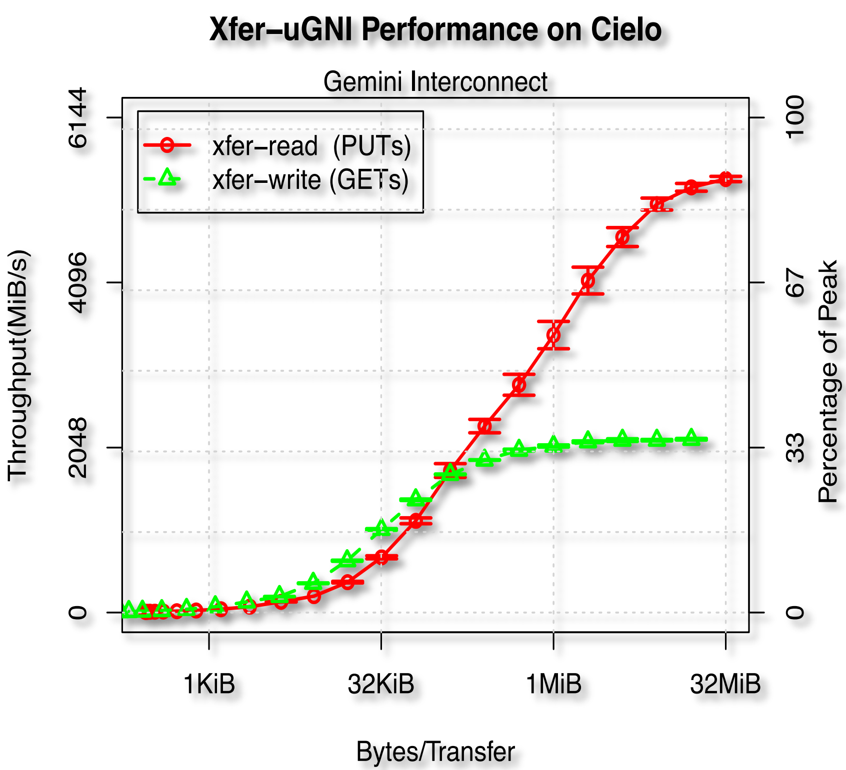
Implementing the Server

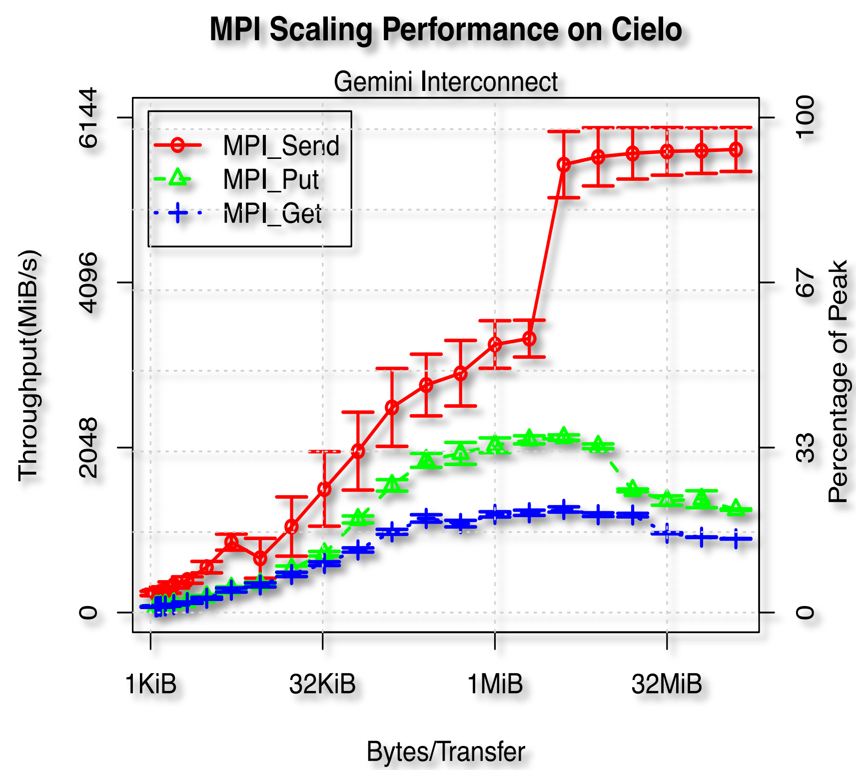
- Implement server stubs
  - Using standard stub args
  - For **xfer_write_rdma_srvr**, the server pulls data from client
- Implement server executable
  - Initialize Nessie
  - Register server stubs/callbacks
  - Start the server thread(s)

```
int xfer_write_rdma_srvr(
        const unsigned long request_id,
        const NNTI_peer_t *caller,
        const xfer_pull_args *args,
        const NNTI_buffer_t *data_addr,
        const NNTI_buffer_t *res_addr)
{
  const int len = args->len;
  int nbytes = len*sizeof(data_t);

  /* allocate space for the buffer */
  data_t *buf = (data_t *)malloc(nbytes);

  /* fetch the data from the client */
  nssi_get_data(caller, buf, nbytes, data_addr);

  /* send the result to the client */
  rc = nssi_send_result(caller, request_id,
          NSSI_OK, NULL, res_addr);

  /* free buffer */
  free(buf);
}
```

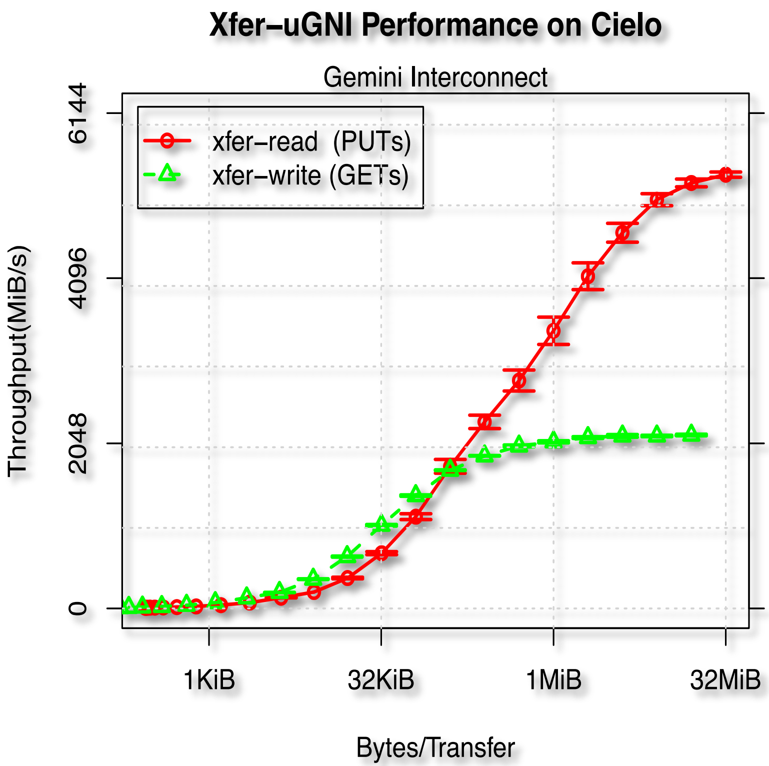
Transfer Service Evaluation:

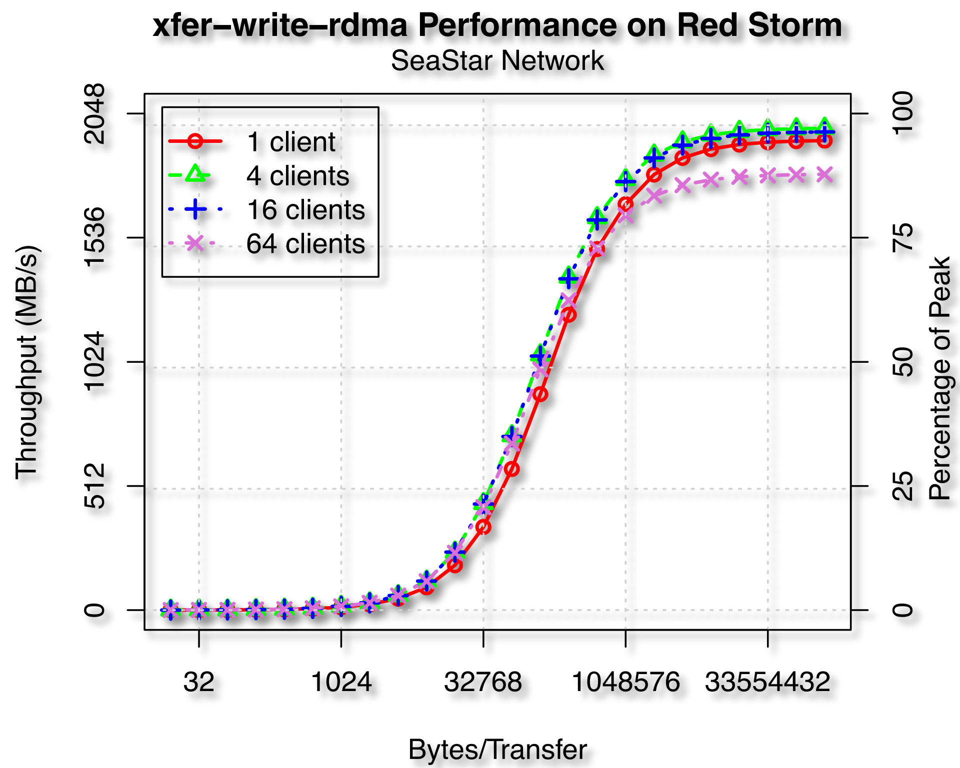
Put/Get Performance





Transfer Service Evaluation:
Put/Get Performance





Trios Services for Analysis

CTH Analysis using ParaView

Motivation

- Analysis code may not scale as well as HPC code
- Direct integration may be fragile (e.g., large binaries)
- "Fat" nodes may be available on Exascale architectures for buffering and analysis

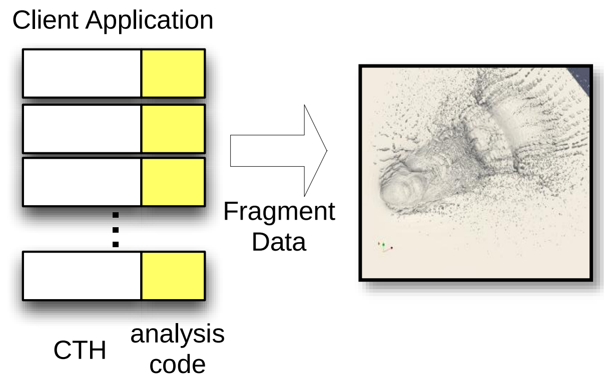
CTH fragment detection service

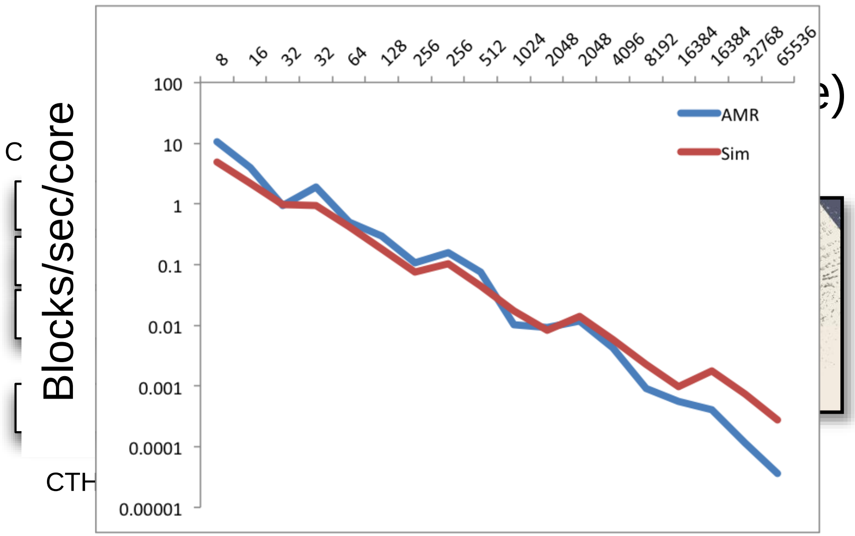
- Extra nodes provide in-line processing (overlap fragment detection with time step calculation)
- Only output results to storage (reduce I/O)
- Non-intrusive – Looks like in-situ (pvspy API)

Issues to Address

- Number of nodes for service
  - Based on memory requirements
  - Based on computational requirements
- Placement of nodes
- Resilience

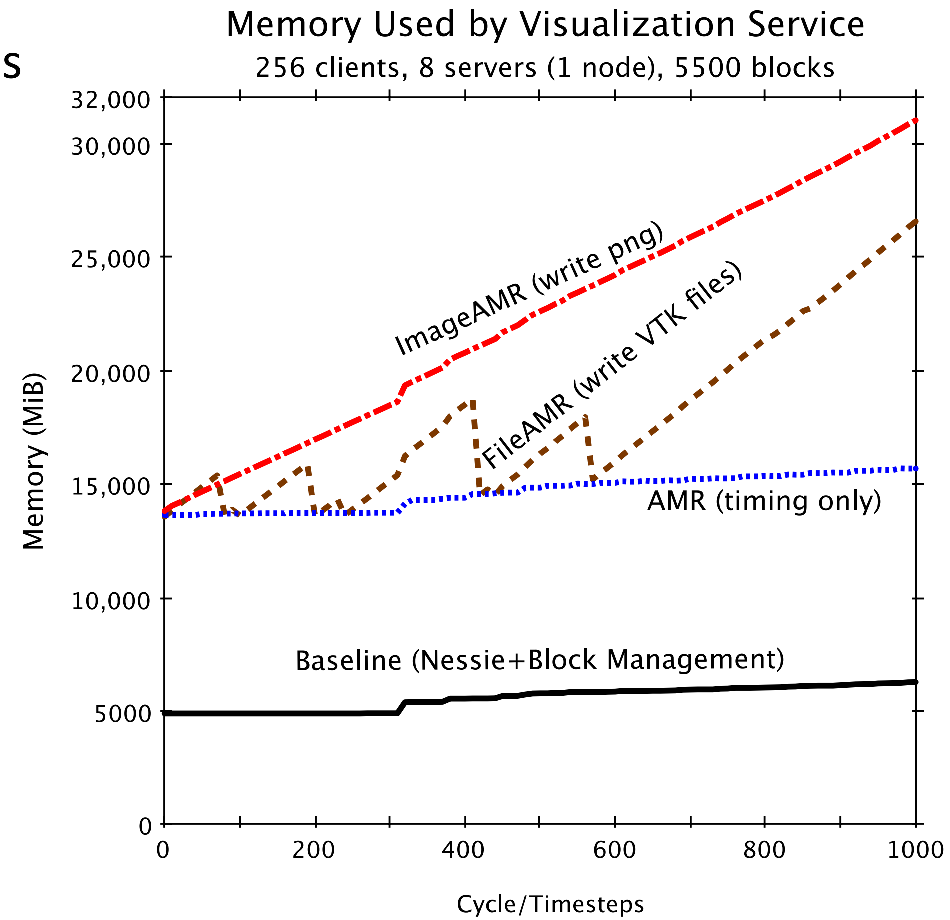
In-Situ Analysis





Memory Requirements for CTH Service

- Memory Analysis of ParaView Codes
  - Current implementation of analysis codes have problems…
- Constraints given 32 GiB/node
  - One node can manage/process ~16K AMR blocks from CTH.
  - 16:1 ratio of compute nodes to service nodes (based on our input decks)
- Our goal is to use less than 10% additional resources
  - In-situ viz adds ~10% overhead

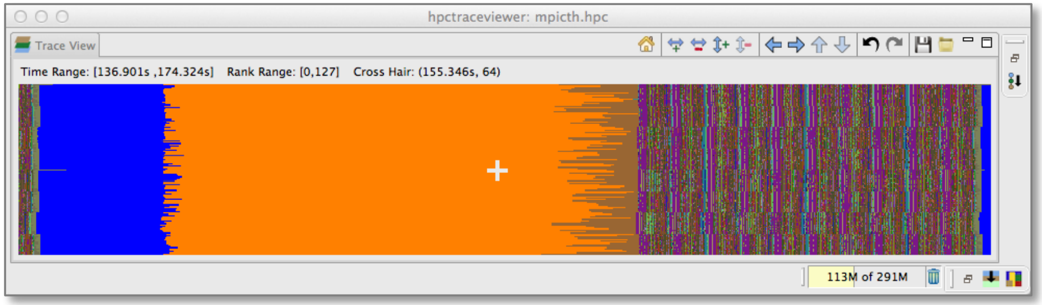


Load Balancing for CTH Service

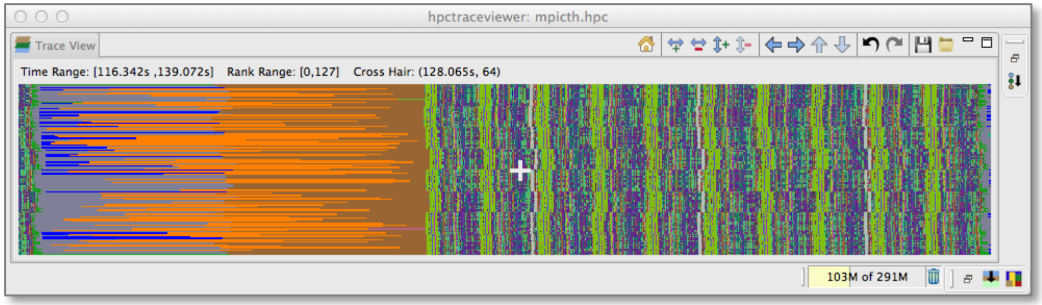
Ten Cycles of 128-core run (one server node)

Wait for Server   Transfer Data

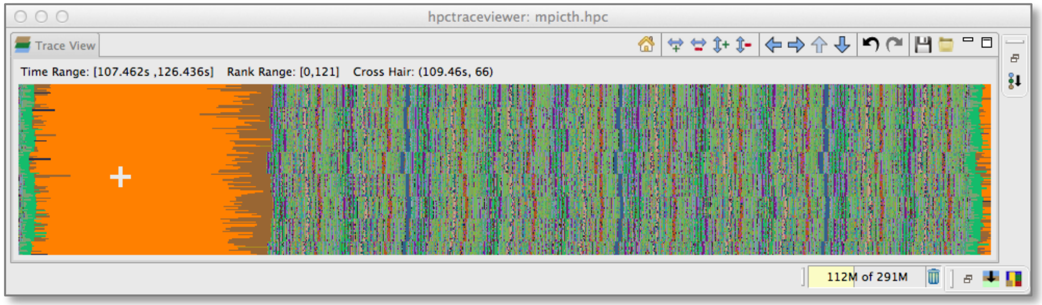
- 2 server cores – 64:1
  - 10 cycles in 37 secs
  - Client idle waiting for server to complete (also affects transfers)



- 4 server cores – 32:1
  - 10 cycles in 23 secs

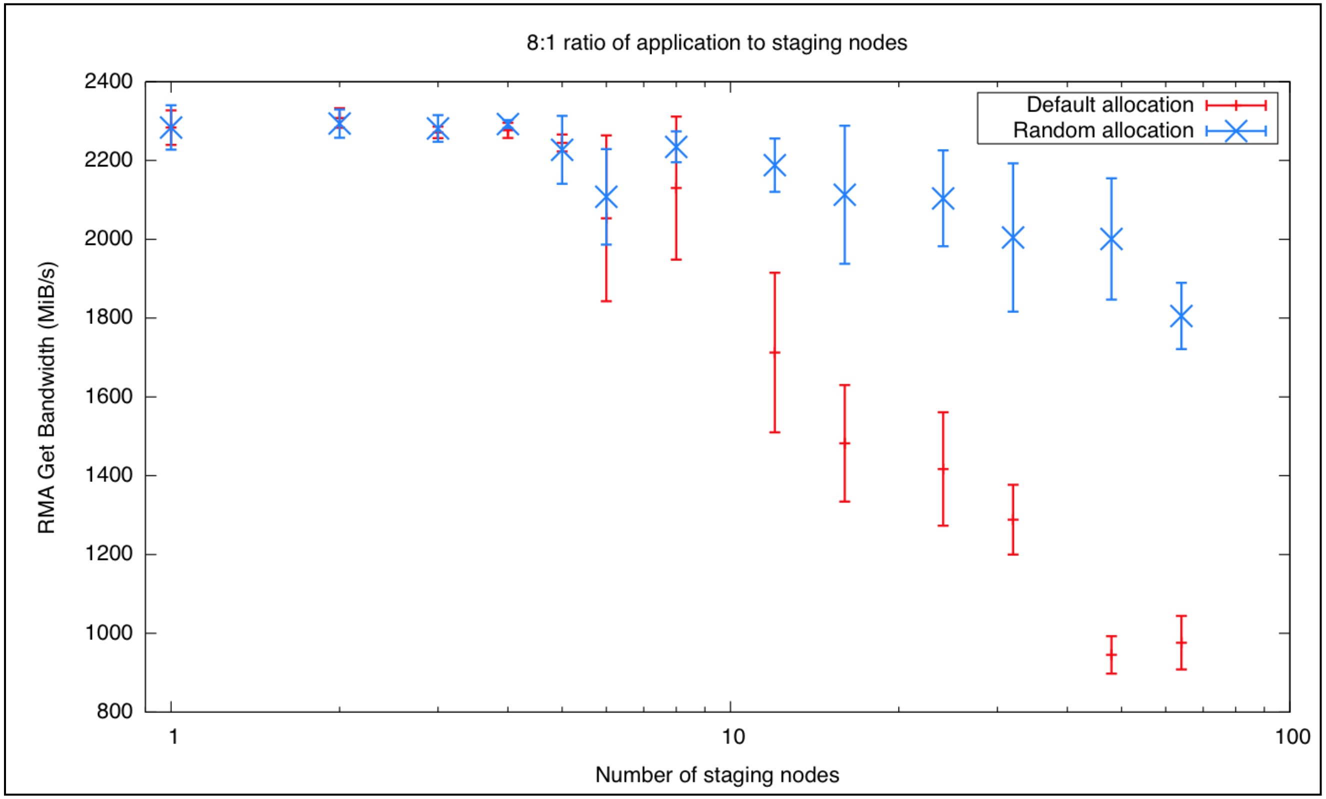


- 8 server cores – 16:1
  - 10 cycles in 19 secs
  - Less than 1% time waiting



Impact of Placement on Performance

- We know placement is important from previous study
- Goal is to place nodes within given allocation to avoid network contention
  - App-to-app (MPI), app-to-svc (NTTI), svc-to-svc (MPI), svc-to-storage (PFS)
  - Graph partitioning based on network topology and application network traffic (w/Pedretti)



Resilience for Trios Services

- Storage-efficient app resilience is still a problem after 20+ years of research
- Trios services use memory for transient data, how do we ensure resilience in such a model?
- We are exploring transaction-based methods
  - Goal is to provide assurances in multiple protection domains (e.g., the application, service 1, service 2,…)
  - Jay Lofstead (1423) has an LDRD to look at this issue.

Summary

- Data Services provide a new way to integrate analysis and computation
  - Particularly useful on deployments of "Burst Buffer" architectures
  - Other Labs are also looking into this type of approach (ANL:Gleam, ORNL:ADIOS, …)
  - Scheduling, programming models, security, and resilience need to better support data services. Lots of work to do!
- Nessie provides an effective framework for developing services
  - Client and server API, macros for XDR processing, utils for managing svcs
  - Supports most HPC interconnects (Seastar, Gemini, InfiniBand, IBM)
- Trilinos provides a great research vehicle
  - Common repository, testing support, broad distribution
- Trios Data Services Development Team (and current assignment)
  - Ron Oldfield: PI, CTH data service, Nessie development
  - Todd Kordenbrock: Nessie development, performance analysis
  - Gerald Lofstead: PnetCDF/Exodus, transaction-based resilience
  - Craig Ulmer: Data-service APIs for accelerators (GPU, FPGA)
  - Shyamali Mukherjee: Protocol performance evaluations, Nessie BG/P support

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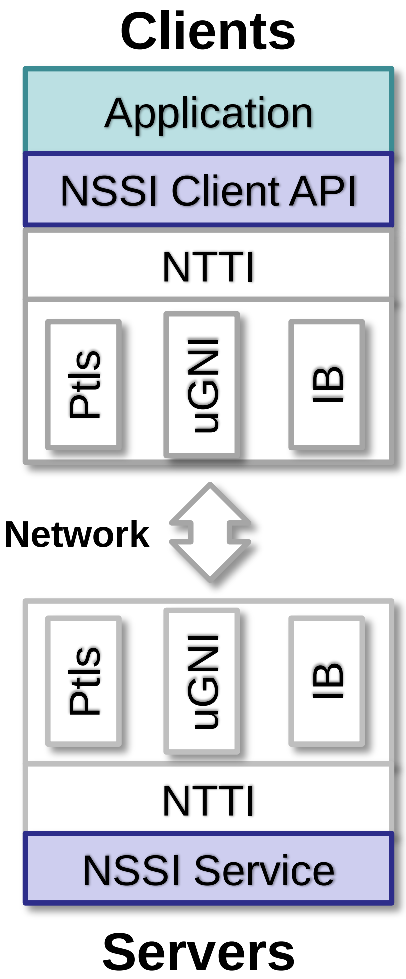
Extra Slides

Nessie Network Transport Interface (NNTI)

An abstract API for RDMA-based interconnects

- Portable methods for inter-application communication
- Basic functionality
  - Initialize/close the interface
  - Connect/disconnect to a peer
  - Register/deregister memory
  - Transport data (put, get, wait)
- Supported Interconnects
  - Seastar (Cray XT), InfiniBand, Gemini (Cray XE, XK), DCMF (IBM BG/P)
- Users
  - Nessie, ADIOS/DataStager (new), HDF5? , Ceph?



Trios Services for Staging

PnetCDF Data Staging – Application level Burst Buffer

- Motivation
  - Synchronous I/O libraries require app to wait until data is on storage device
  - Not enough cache on compute nodes to handle "**I/O bursts**"
  - NetCDF is basis of important I/O libs at Sandia (Exodus)
- PnetCDF Caching Service
  - Service aggregates/caches data and pushes data to storage
  - Async I/O allows overlap of I/O and computation
- Status
  - First described in MSST 2006 paper
  - Implemented in 2007
  - Presented at PDSW'11