Moving from Extreme Scale Data to Extreme Scale Metadata Concerns: It’s About Time!

EMC3

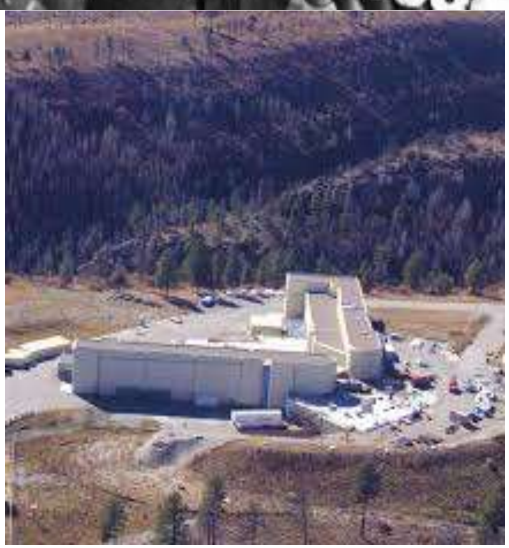
Gary Grider

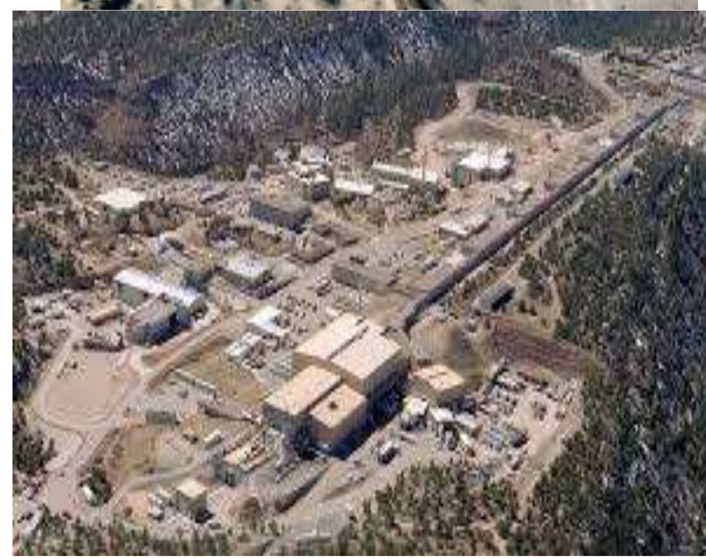
HPC Division Leader, LANL/US DOE

2018

Subset of LA-UR-18-24612

What is Los Alamos





Eight Decades of Production Weapons Computing to Keep the Nation Safe

Maniac

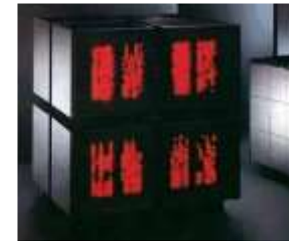
IBM Stretch

CDC

Cray 1

Cray X/Y

CM-2



CM-5

SGI Blue Mountain

DEC/HP Q

IBM Cell Roadrunner

Cray XE Cielo

Cray Intel KNL Trinity

Ising DWave

Cross Roads

CROSSROADS
An APEX Collaboration

LANL HPC History Project (80k artifacts) Joint work with U Minn Babbage Institute

TWX-910-988-17
[illegible]

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(CONTRACT W-7405-ENG-36)

DEPARTMENT OF SUPPLY AND PROPERTY

P. O. BOX 990
LOS ALAMOS
NEW MEXICO
87544

August 19, 1975

Mr. Seymour Cray
Cray Research, Inc.
P. O. Box 169
Chippewa Falls, WI 54729

Dear Mr. Cray:

This is to advise you that the Los Alamos Scientific Laboratory of the University of California is interested in acquiring the first Cray-1 computer, scheduled for delivery in November 1975, to handle calculational requirements beyond the capability of our presently-installed computers.

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Some Storage Products You May Not Realize Were Funded/Heavily Influenced by DOE/LANL

panasas

lustre

CRAY
THE SUPERCOMPUTER COMPANY
Data Warp

HDF

IBM GPFS

UniTree software

pNFS

DataTree CFS

HPSS
High Performance Storage System

ceph

DDN STORAGE

INFINITE MEMORY ENGINE

IBM Photo-store

Tokutek

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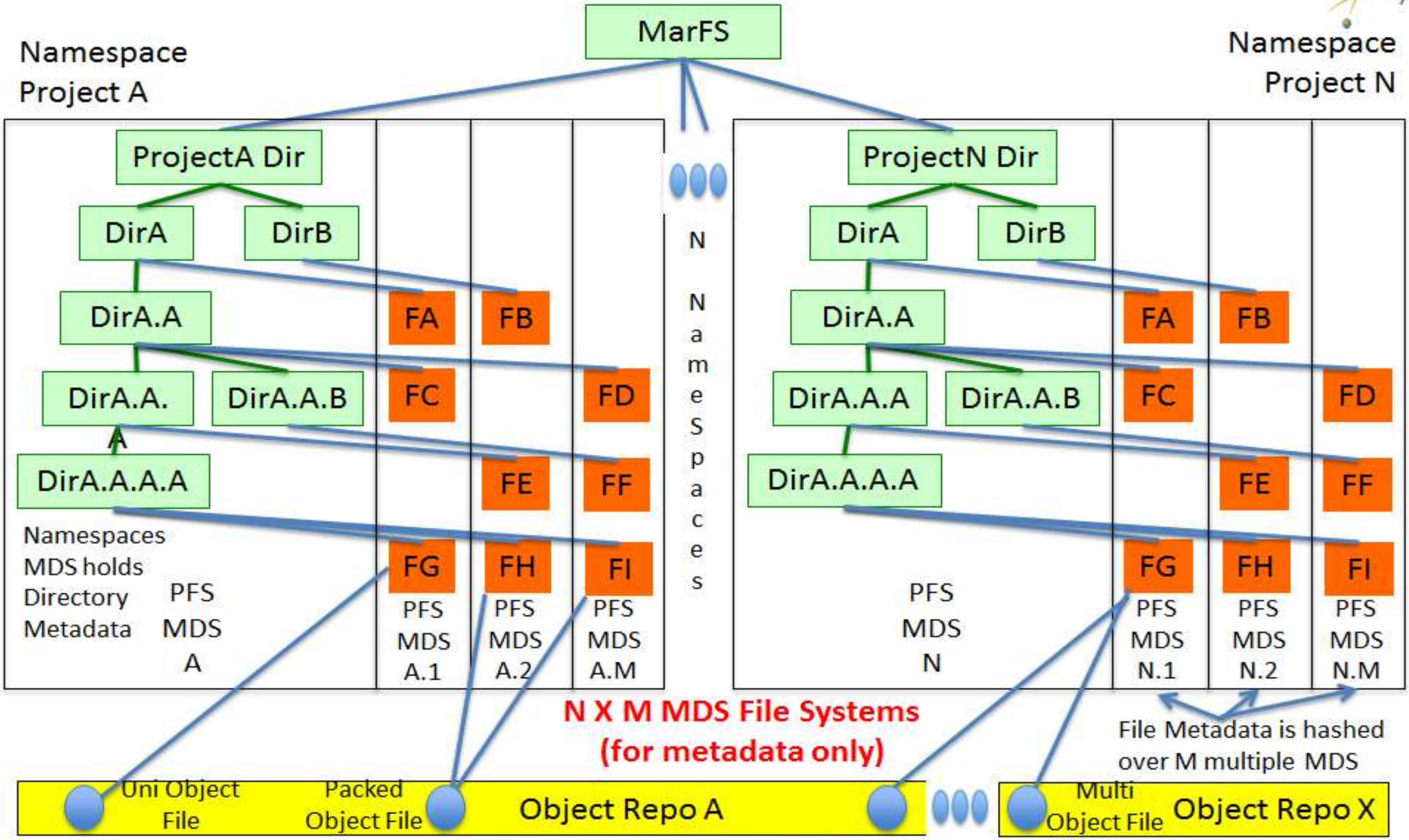
USRC

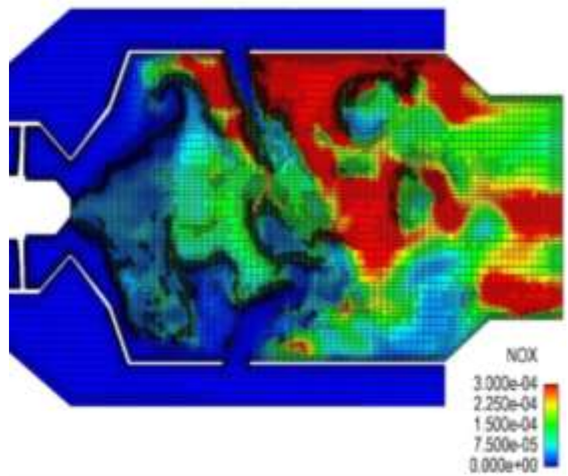
An example of metadata scaling: MarFS Scaling



Scaling test on our retired Cielo machine:
835M File Inserts/sec Stat single file < 1 millisecond
> 1 trillion files in the same directory

Striping across 1 to X
Object Repos

Hopefully we have whipped the scalable parallel data into submission on to Metadata pursuits



DeltaFS

A File System Service for Simulation Science

Best Paper SC18

HXHIM

Indexing for Scientific Data

GUFI

Fast Userspace Metadata Query

R&D100 Award Disruptor

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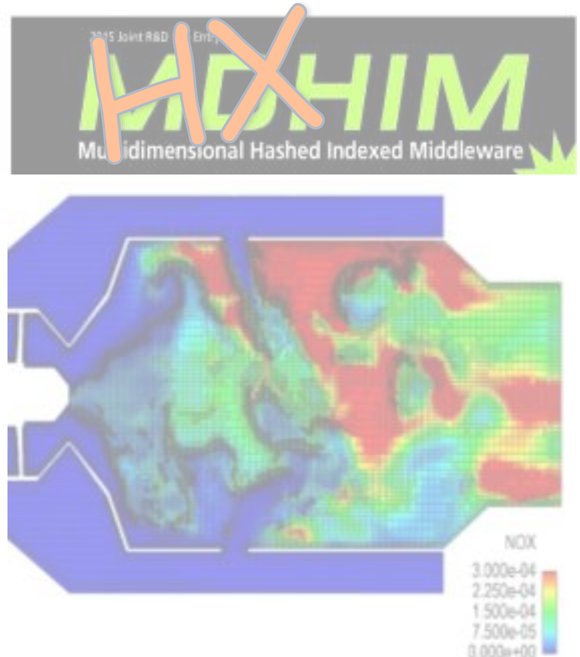
A dynamically loadable namespace – DeltaFS
Lets make metadata scale with the application!

DeltaFS

A File System Service for Simulation Science



HXHIM

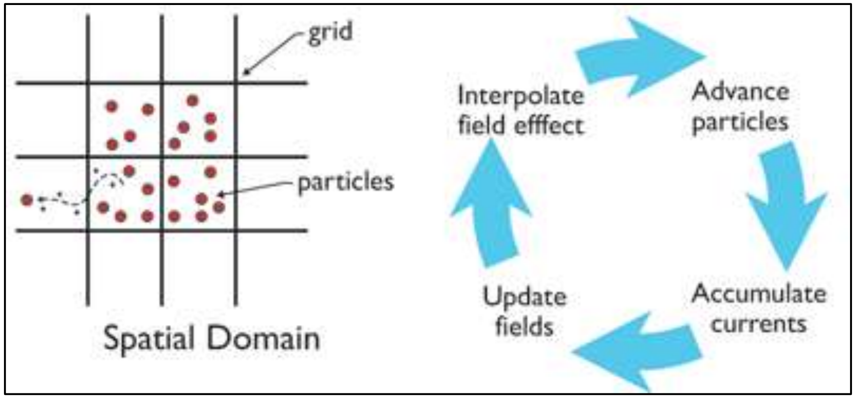
Indexing for Scientific Data

GUFI

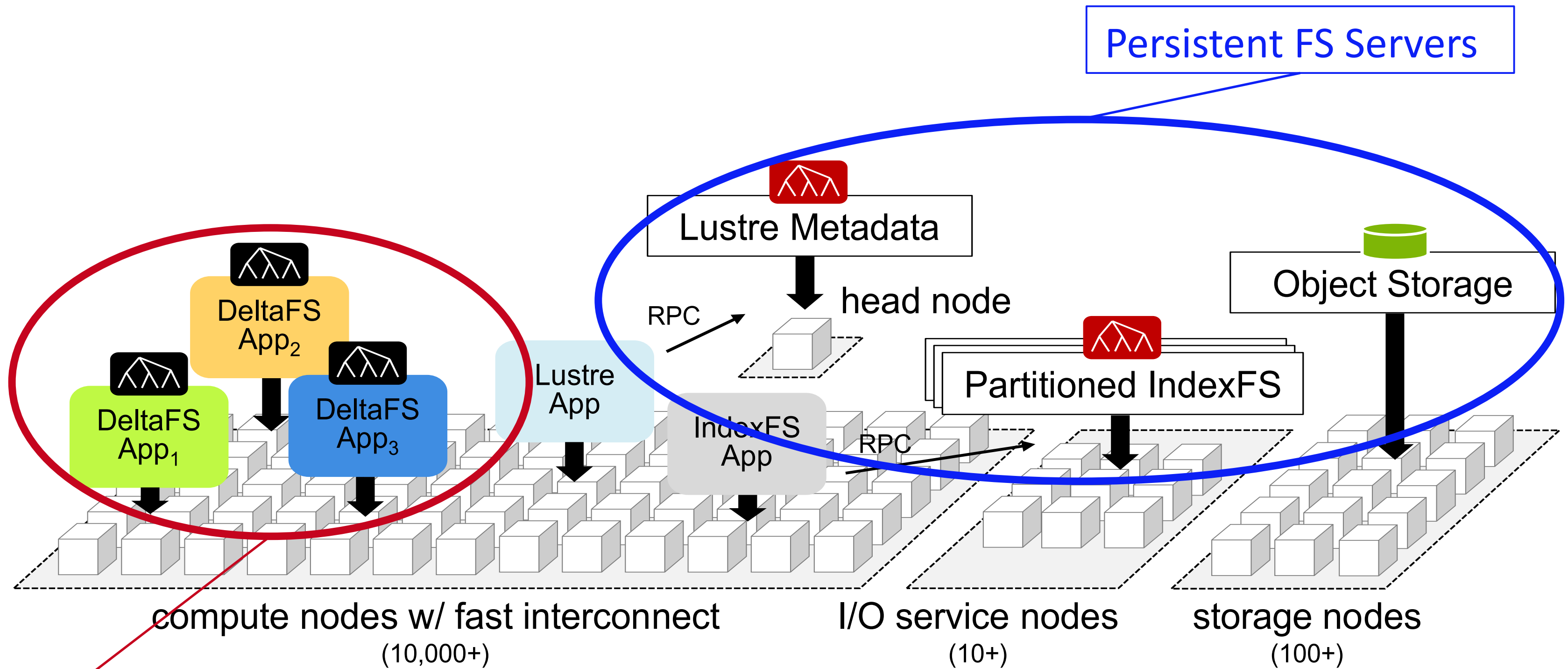
Fast Userspace Metadata Query

Brief VPIC Overview

- **Particle-in-cell MPI code (scales to ~100K processes)**
  - Fixed mesh range assigned to each process
  - 32 – 64 Byte particles
  - Particles move frequently between 10's of thousands of processes
  - Million particles per node (Trillion particle in target simulation)
  - Interesting particles identified at ***simulation end***



Brief DeltaFS Overview

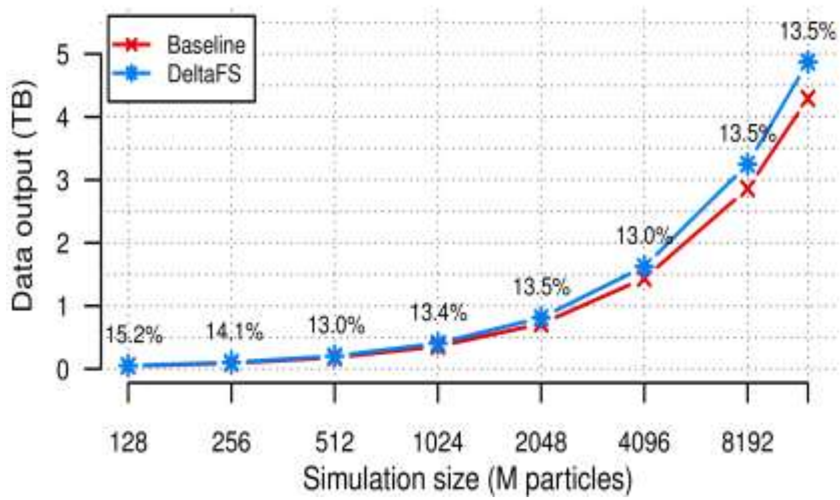


Every process:

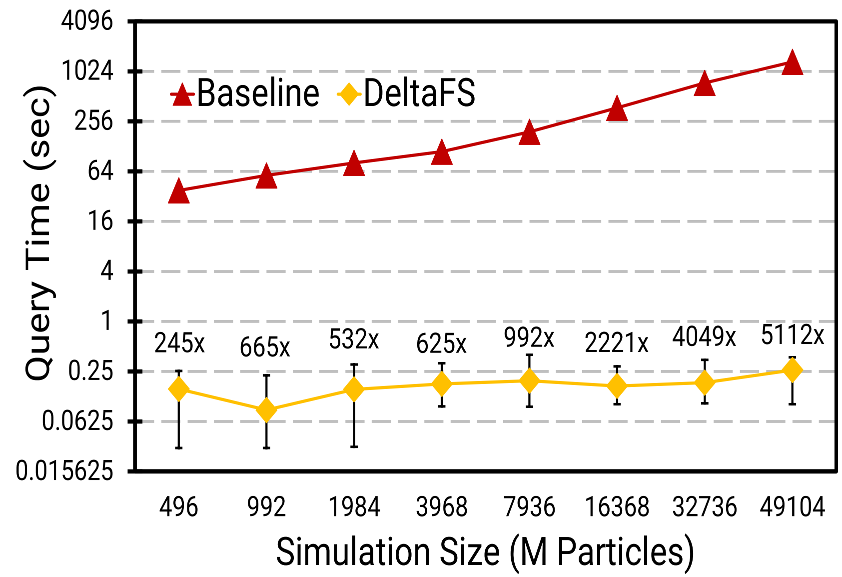
- Runs a linkable KVS in the app that looks like a file system (IndexFS) (LevelDB)
- “Checks Out” its namespace for the particles files it will hold – loads a LevelDB SSTable with hundreds of thousands of ”particle files” time stamp records.
- When Storing article records are sent to the appropriate “file”
- This is writing data to a 10’s of thousands distributed KVS

Tracking the Highest Energy Particles
Recall the intent is 1 Trillion particles
These thousand particles are interesting, where have they been?

VPIC Particle Dump Size



VPIC Particle Trajectory Query



Collaboration of CMU, LANL, ANL, HDF Group

(papers at PDSW 15, PDSW 17, SC18)

Application thought it was writing/reading from 1 file per trillion particles but really was writing records to massive parallel distributed KVS!
Today we are getting like 8 Billion Particle File Ops/Sec. (yes Billion)

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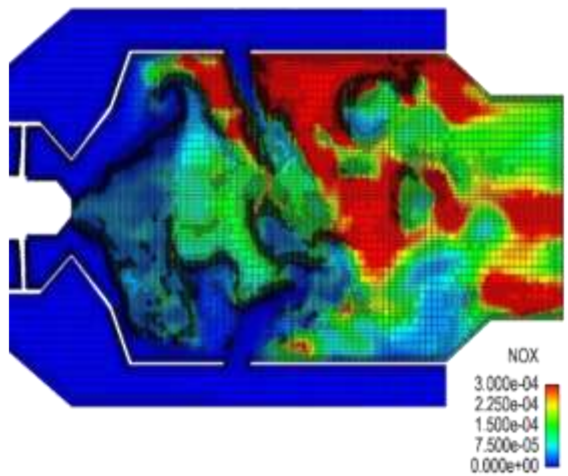
Isn't 8 Billion Metadata ops/sec good enough? Well maybe, but that was low dimensional Metadata. What about higher dimensional Metadata?

Now that I know "where the interesting particles were" what was going on around those interesting particles? MDHIM->XDHIM (Thank you to DoD and DoE ECP funding)

Multidimensional Hashed Indexed Middleware



DeltaFS

A File System Service for Simulation Science

GUFI XHIM

Fast Userspace Metadata Query / Indexing for Scientific Data

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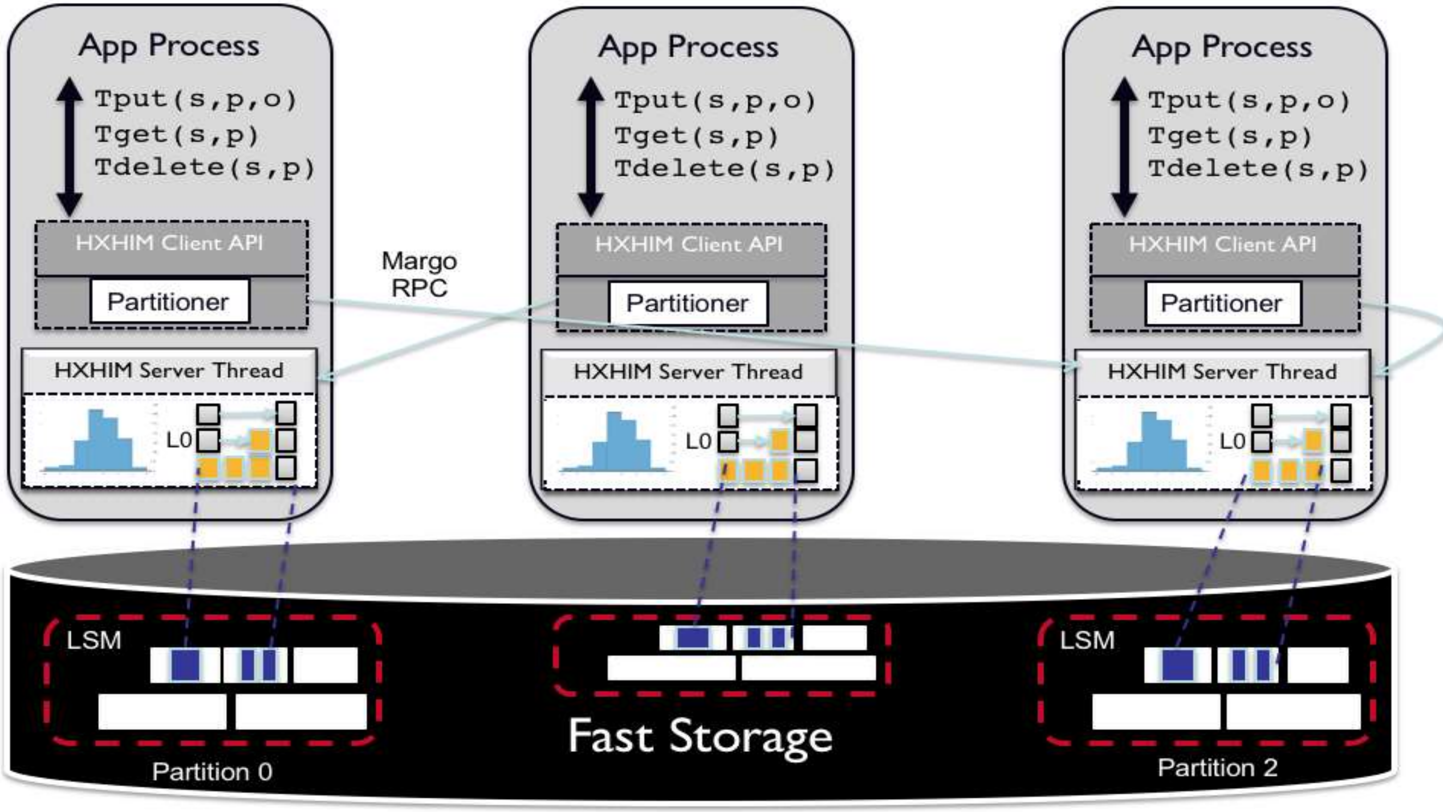
MDHIM/XDHIM (why make100 thousand KVS's look like one)

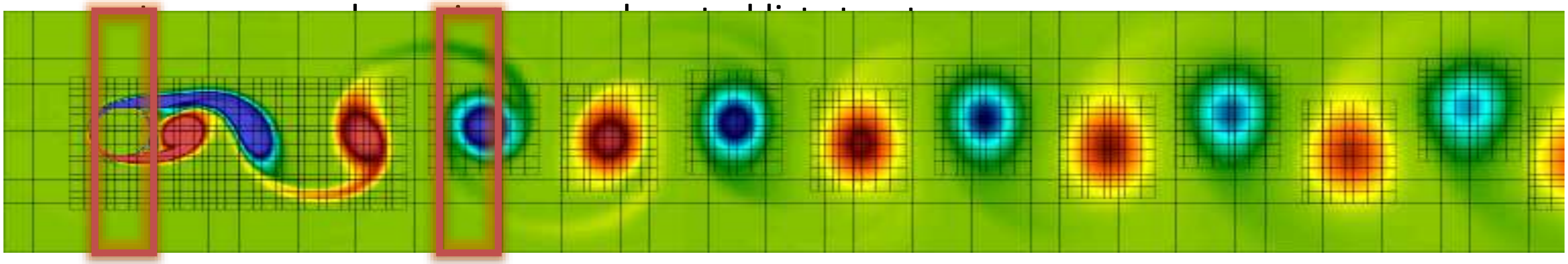
An application linkable parallel KVS Framework

KVS is linked in the application, bulk put/get ops, uses key range sharding and server side stored procedures, X Dimensional Sharded Index (Hexastore 6 dimensional linkable KVS is currently in use)



HXHIM – Indexing for Unstructured Meshes

- **How do you store/represent an AMR mesh?**
- **(What is AMR and Why Do We Care?)**



How many rows are in each of these columns?

(For that matter, how many columns are in each of these columns?!)

How do you store this kind of time series data in a usable form?

- **Key-value exposes the data structures underlying most FS**
- **Key-value allows fine-grained data annotation**
- **Need to add some HPC research to make efficient for HPC platforms**
  - Mercury RPC and Margo (lightweight IO threads) for platform services
  - Multidimensional Hashing Indexing Middleware

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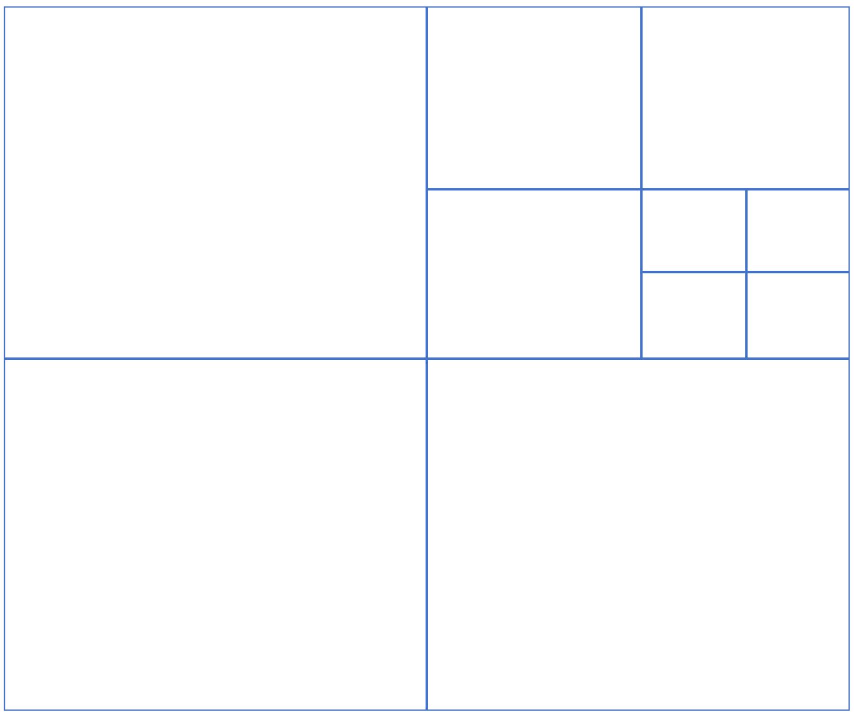
HXHIM Mesh Storage Example

- **If "position" in the mesh is the key, and you keep subdividing the key, how do you have a reasonable key structure**
- **Old trick using hierarchy of keys (borrow from Farsite FS - Microsoft)**



Subject	Predicate	Object
mesh	name	"My Mesh"
sim	timestep	3.0
c0	position	[0.0,0.0]
c1	position	[0.1,0.0]
c2	position	[0.0,0.1]
c3.0	position	[0.1,0.1]
c3.1.0	position	[0.15,0.1]
c3.1.1	position	[0.175,0.1]
c3.1.2	position	[0.125,0.15]
c3.1.3	position	[0.125,0.125]
c3.2	position	[0.1,0.15]

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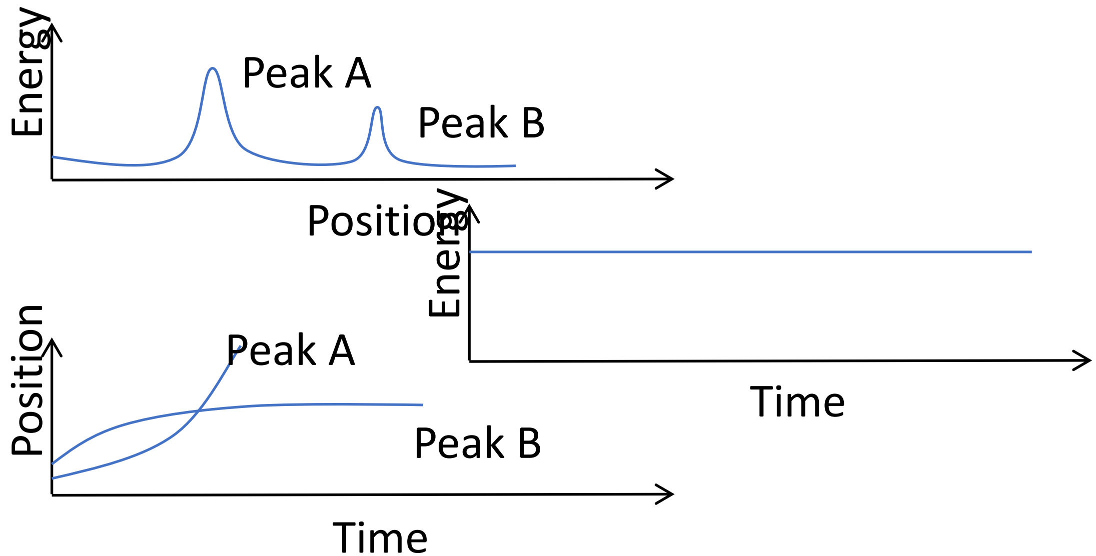
Sample Query: Tracking a Wave thru Time



- A fast multi-dimensional index
  - Time is discretized separately (indexing not required)
  - Energy and position must both be indexed (and not trivially)
    - Energy extrema search is worse than VPIC example!
  - Efficient filtering for contiguity!
    - We could probably work around most of these problems, but level arrays will always convert spatially contiguous workloads into disjoint query sets
    - Neighbor lists won't limit the pointer chasing
- Why do I think a Key-Value organization can do better?

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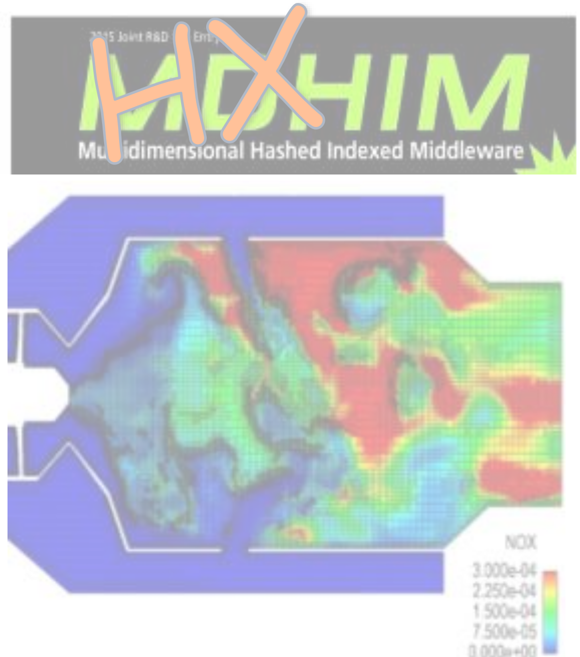
Range-based Iteration with Stored Procedures

- **Advantages of Key-Value Organization**
  - Decouples file size, I/O size from data set size (efficient I/O)
  - Keyspace *dimension* can change dynamically
    - Leverage naming technique described by Farsite FS
  - Supports iteration across multiple dimensions simultaneously
  - In-situ rather than post-hoc
- **Advantages of client-server architectures**
  - Even with the above we can't accomplish what we need
  - Stored procedures to identify extrema in-situ

How do we ever find anything in our trillions of files? GUFI Grand Unified File Index

DeltaFS

A File System Service for Simulation Science



HXHIM

Indexing for Scientific Data

GUFI

Fast Userspace Metadata Query

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Motivation

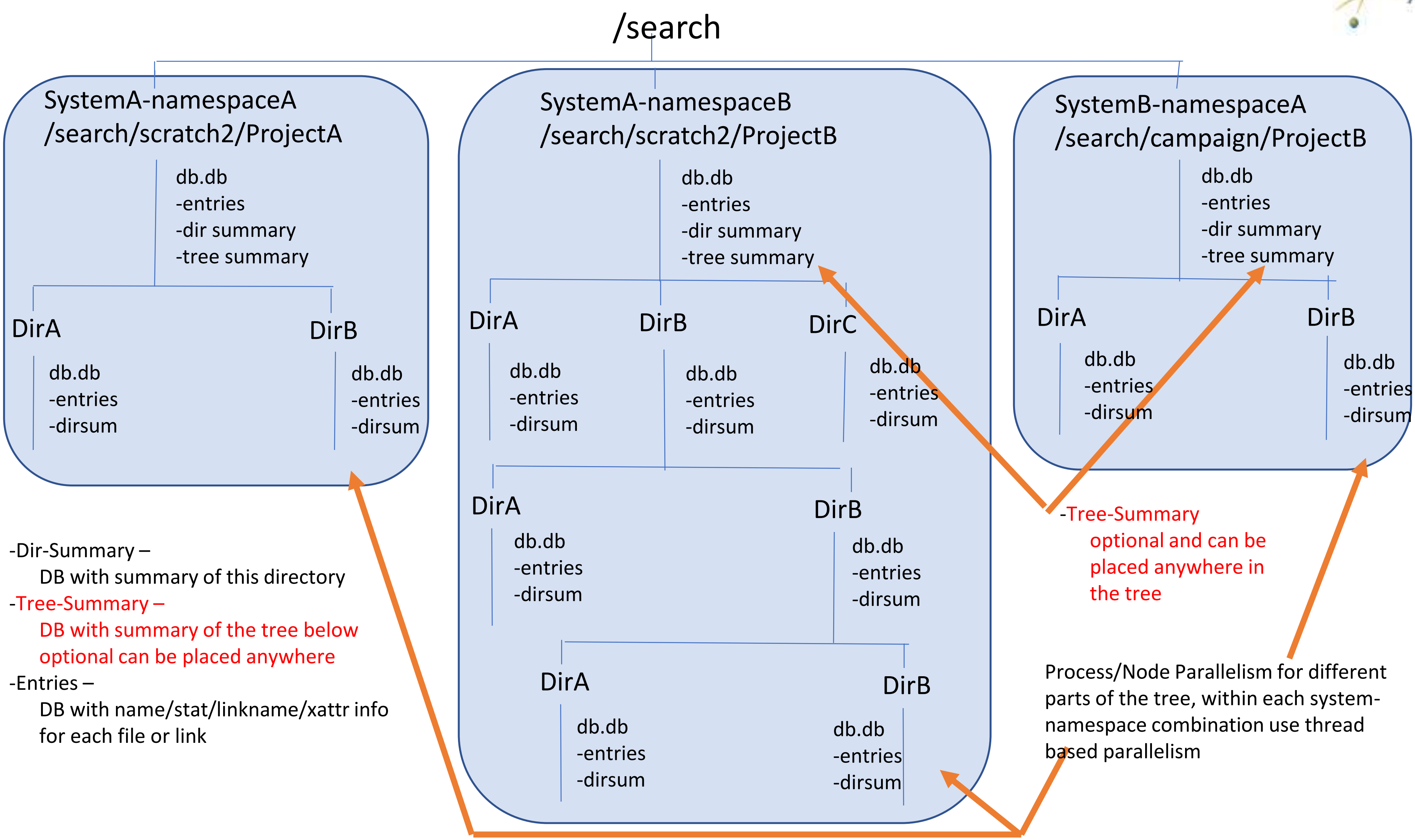
- **Many layers of storage at LANL**
  - By design – users would have us only buying storage if we used HSMs
- **Data management by users is driven by need, sporadically**
  - Users go find unneeded data and delete, if prodded
  - Users have no easy way to find particular datasets unless they have a good hierarchy or they remember where they put it
  - Users have bad memories and bad hierarchies…(you can see where this leads)
  - ...lower (longer) tiers of storage systems accumulate cruft over time

GUFI Goals

- **Unified** index over home, project, scratch, campaign, and archive
- **Metadata only** with extended attribute support
- Shared index for **users** and admins
- **Parallel search** capabilities that are very fast (minutes for billions of files/dirs)
- Search results can appear as a **mounted File System**
- Full/Incremental update from sources with reasonable update time/annoyance
- Leverage **existing tech** as much as possible both hdwr and software: flash, threads, clusters, sql as part of the interface, commercial db tech, commercial indexing systems, commercial file system tech, threading/parallel process/node run times, src file system full/incremental capture capabilities, posix tree attributes (permissions, hierarchy representation, etc.), open source/agnostic to leveraged parts where possible.
- **Simple** so that an admin can easily understand/enhance/troubleshoot

- **Why not a flat namespace?**
  - Performance is great, but…Rename high in the tree is terribly costly
  - Security becomes a nightmare if users/admins can access the namespace

GUFI Prototype



-Dir-Summary –
DB with summary of this directory

-Tree-Summary –
DB with summary of the tree below
optional can be placed anywhere

-Entries –
DB with name/stat/linkname/xattr info
for each file or link

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Programs Included / In Progress

- DFW – depth first walker, prints pinode, inode, path, attrs, xattrs
- BFW – breadth first walker, prints pinode, inode, path, attrs, xattrs
- BFWI – breadth first walker to create GUFI index tree from source tree
- BFMI – walk Robinhood MySQL and list tree and/or create GUFI index tree
- BFTI – breadth first walker that summarizes a GUFI tree from a source path down, can create treesummary index of that info
- BFQ – breadth first walker query that queries GUFI index tree
  - Specify SQL for treesummary, directorysummary, and entries DBs
- BFFUSE – FUSE interface to run POSIX md tools on a GUFI search result
- Querydb – dumps treesummary, directorysummary, and optional entry databases given a directory in GUFI as input
- Programs to update, incremental update (in progress):
  - Lustre, GPFS, HPSS

Early performance indicators

- **All tests performed on a 2014 Macbook (quad core + SSD)**
- **No tree indexes used**
- **~136k directories, mostly small directories, 10 1M entry dirs, 20 100K size dirs, and 10 20M size dirs**
- **~250M files total represented**
- **Search of all files: 2m10s (~1.75M files/sec)**
- **Search of all files and dirs: 2m19s (~1.63 M entries/sec)**
- **Search of all files and dirs, but exclude some very large dirs: 1m18s**
- **Search of all files and dirs, but exclude all < 1000 file directories: 1m59s**
- **…on a laptop!**

Open Source
BSD License
Partners Welcome

https://github.com/mar-file-system/marfs
https://github.com/pftool/pftool
https://github.com/mar-file-system/GUFI
https://github.com/mar-file-system/erasureUtils

Thanks to all that participated in this work

Thanks For Your Attention

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