IPDPS 2013, 5/21/2013

Efficient and Scalable Retrieval Techniques for Global File Properties

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LLNL-PRES-636652

This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344. Lawrence Livermore National Security, LLC. It was supported in part by Department of Energy grants DE-SC0004061, 07ER25800, DE-SC0003922, DESC0002153, DE-SC0002154, and DE-SC0002155.

Efficient file accesses are becoming increasingly important and challenging

- Large-scale system sizes continue to grow
- This exponential growth in concurrency makes efficient file accesses increasingly important
- But optimizing file accesses require detailed run-time knowledge of file systems and location(s) of files on them
- HPC does not have a common, scalable way to retrieve such global file information

Program start-up manifested as a denial-of-service attack: A lesson learned

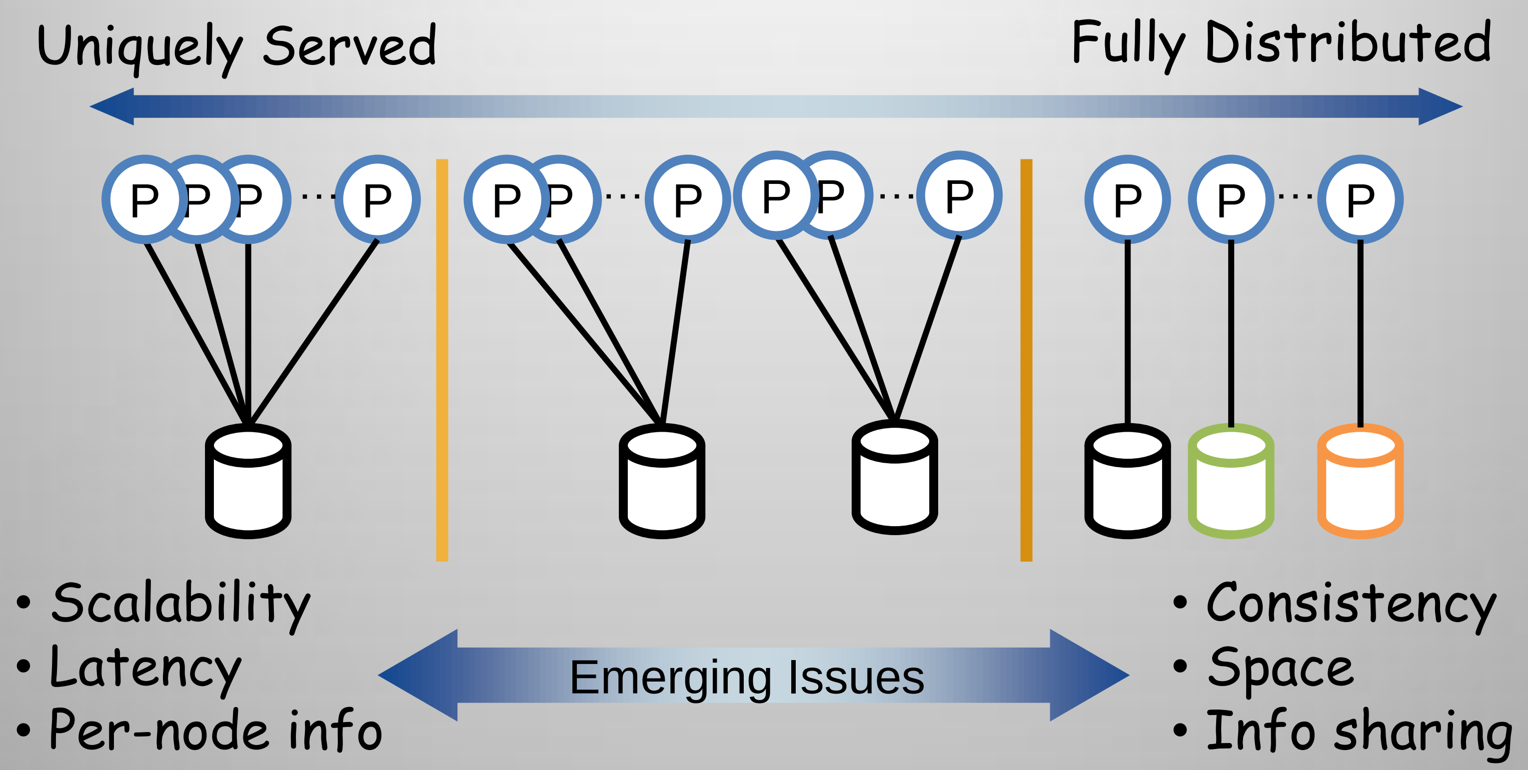
- KULL: a large, mission-critical multi-physics simulation code
- When this application was first run on DAWN, program start-up appeared to scale very poorly
- Start-up significantly disrupted the entire computing facility
- 16,384 instances of the dynamic loader (ld.so) were making combined 300 million open calls to an NFS server
  - 16K X 20 (lib search paths) X ~1000 (dependent shared libs) = 300M !

All software elements on extreme-scale machines must efficiently use file systems

- Challenges go beyond large dataset access patterns: dynamic loader, run-time tools, input-deck readers, scripting languages etc
- Must optimize their file access schemes and consider a trade-off between communication and file accesses
- Optimization requires detailed run-time information of file systems and location(s) of files on them
- Non-trivial: today's machines mount many file systems with different performance characteristics

Need scalable, general-purpose mechanisms and abstractions to retrieve global file properties: Fast Global File Status (FGFS)

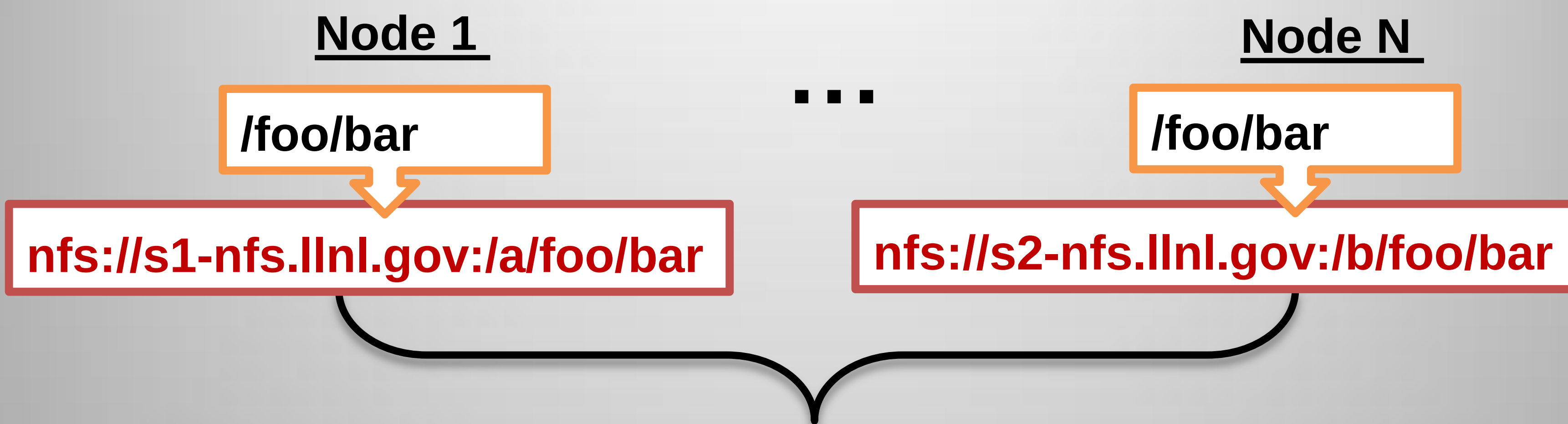
The trade-off space: HPC file distribution models introduce many different issues



FGFS is a query layer that assists HPC software in making I/O trade-off decisions

- Responsible for **scalably classifying files and file systems**
- Supports I/O trade-off decisions for a wide range of HPC software
- Directly with the software itself or through a global file I/O coordinator

Key idea for scalability: extracting global properties through name comparisons



- Is this file uniquely served?
- Is this file fully distributed?
- Will N simultaneous accesses thrash file systems or not?
- …

MountPointAttributes resolves a local file path into URI with no file-system access

```
string & resolvePath(const char *pth) {
  string uriStr;
  FileUriInfo uriInfo;

  MountPointInfo mpInfo(true);
  mpInfo.getFileUriInfo(pth, uriInfo);
  uriInfo.getUri(uriStr);

  return uriStr;
}
```

node1

```
void manageConfigs() {
  char *lid1="/etc/tool/conf";
  char *lid2="/usr/etc/tool/conf";
  char *lid3="/home/joe/.tool/conf";
  char *lid4="/lscracta/j_cwd/conf";

  string gid1 = resolvePath(lid1);
  string gid2 = resolvePath(lid2);
  string gid3 = resolvePath(lid3);
  string gid4 = resolvePath(lid4);
  ...
}
```

file://node1/etc/tool/conf

nfs://s1-nfs.llnl.gov:/e/usr/etc/tool/conf

nfs://dip-nfs.llnl.gov:/v/joe/.tool/conf

lustre://172.16.60.200:/tmp/j_cwd/conf

Global File Status queries capture our HPC file distribution models and pertaining issues

- The global namespace forms a reference space where parallel name comparisons extract global properties
  - the number of different sources
  - the process count and the representative process of each source
- ***FgfsParDesc*** is a primitive that returns this info
- ***GlobalFileStatusAPI*** exposes the HPC file distribution models
  - ***isUnique(), isFullyDistributed()***
  - ***isWellDistributed(), isPoorlyDistributed()***
  - ***isConsistent()***
- Support for both synchronous and asynchronous I/O patterns
  - ***SyncGlobalFileStatus***
  - ***AsyncGlobalFileStatus***

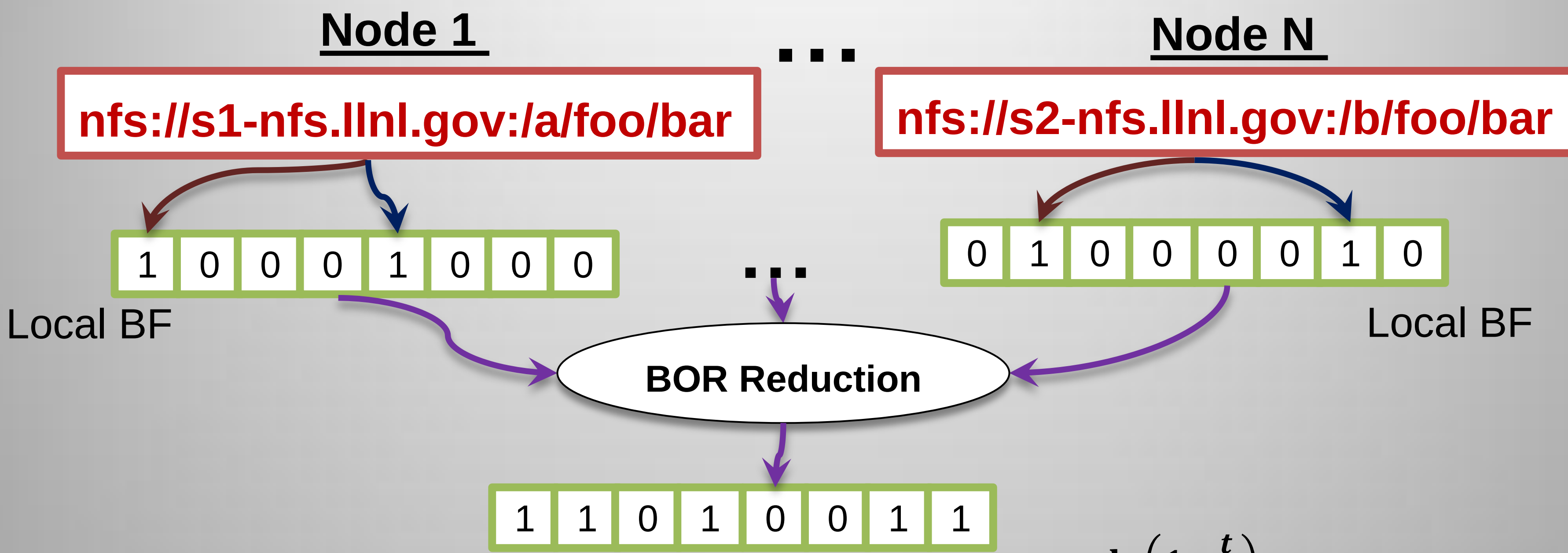
A highly scalable reduction algorithm extracts the degree of file distribution or replication

$$\text{file} \xrightarrow{\textbf{Raise}} \{URI(file)_0, URI(file)_1, \ldots, URI(file)_{n-1}\}$$

$$\xrightarrow{\textbf{Reduce}} \{UniqueURI(file)_0, \ldots, UniqueURI(file)_m\}$$

- Cardinality/Group-info of the reduced list conveys a global structure
- A representative of each unique source helps minimize file accesses
- A tree-based parallel reduce for the general case
  - But scales like concatenation with too many unique names
- A multilevel triaging scheme imposes a scalability bound
  - First level: a fix-sized boolean reduce to determine *isFullyDistributed()*

Next refinement: Bloom-filter-based cardinality estimation



- Maximum likelihood cardinality estimation: $\frac{\ln\left(1-\frac{t}{m}\right)}{k * \ln\left(1-\frac{1}{m}\right)}$
  - m num of bits, t is the num of true bits, and k is the num of hash functions
- Set the Bloom-filter density to be 50% with respect to the worse case
  - The worst case for billion-core machine needs ~150KB

Global file systems status queries retrieve file systems that meet global properties requirements

- Inverse function of global file status queries
  - Given a set of required global properties of a file system, what are the best matching locations?
- ***GlobalFileSystemsStatus***
  - Is passed a ***FileSystemCriteria*** object
  - Mandatory ***space*** requirement, and optional ***speed***, ***distribution***, and ***scalability*** requirements
- A scoring function estimates performance and orders *qualified* file systems

$$\frac{\boldsymbol{Scalability(file\ system)}}{\mathbf{M}\boldsymbol{ax(Scalability(file\ system), Distribution(file\ system))}} * \boldsymbol{Speed(file\ system)}$$

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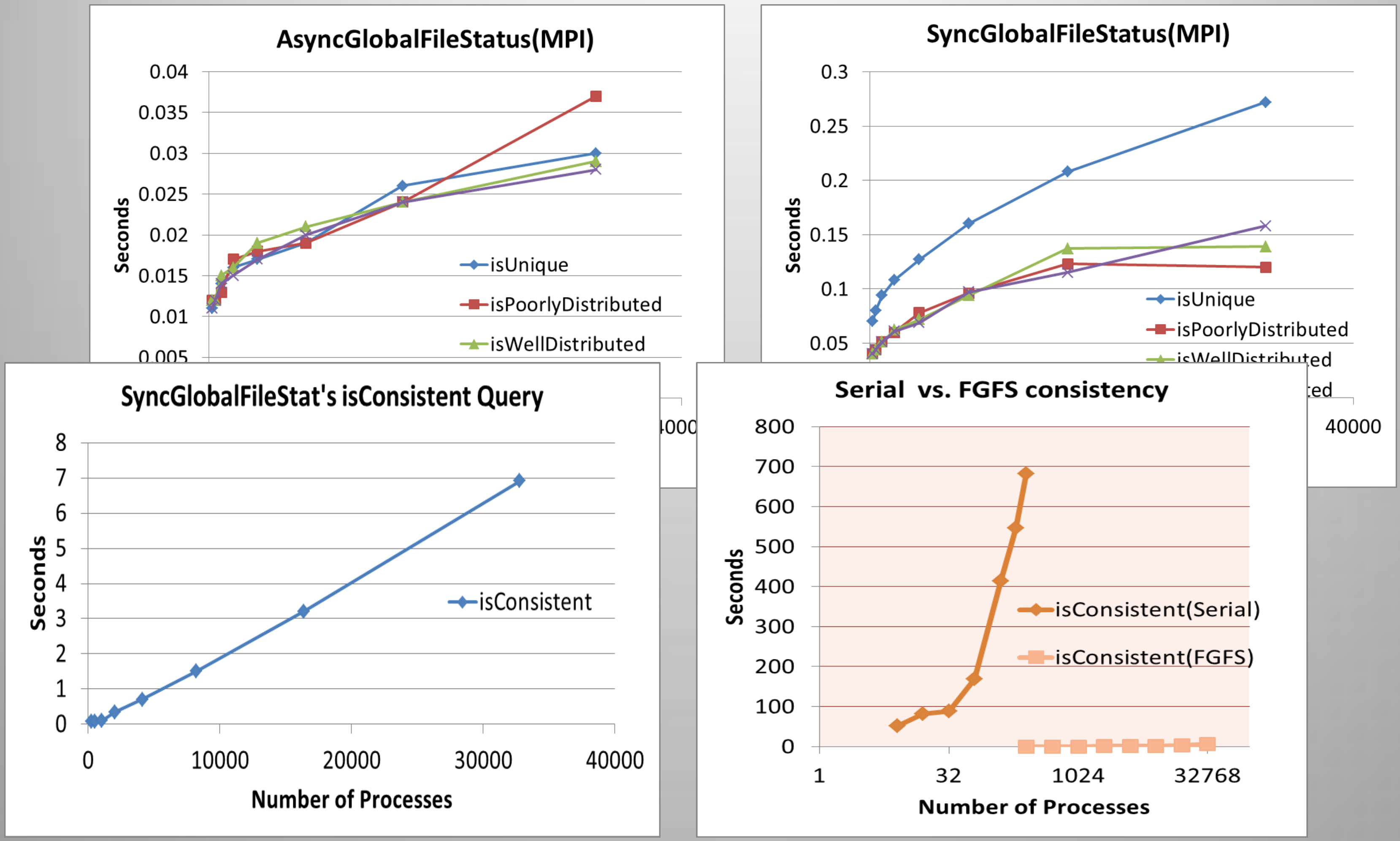
Our experiments are to evaluate FGFS' capability of assisting file access optimization

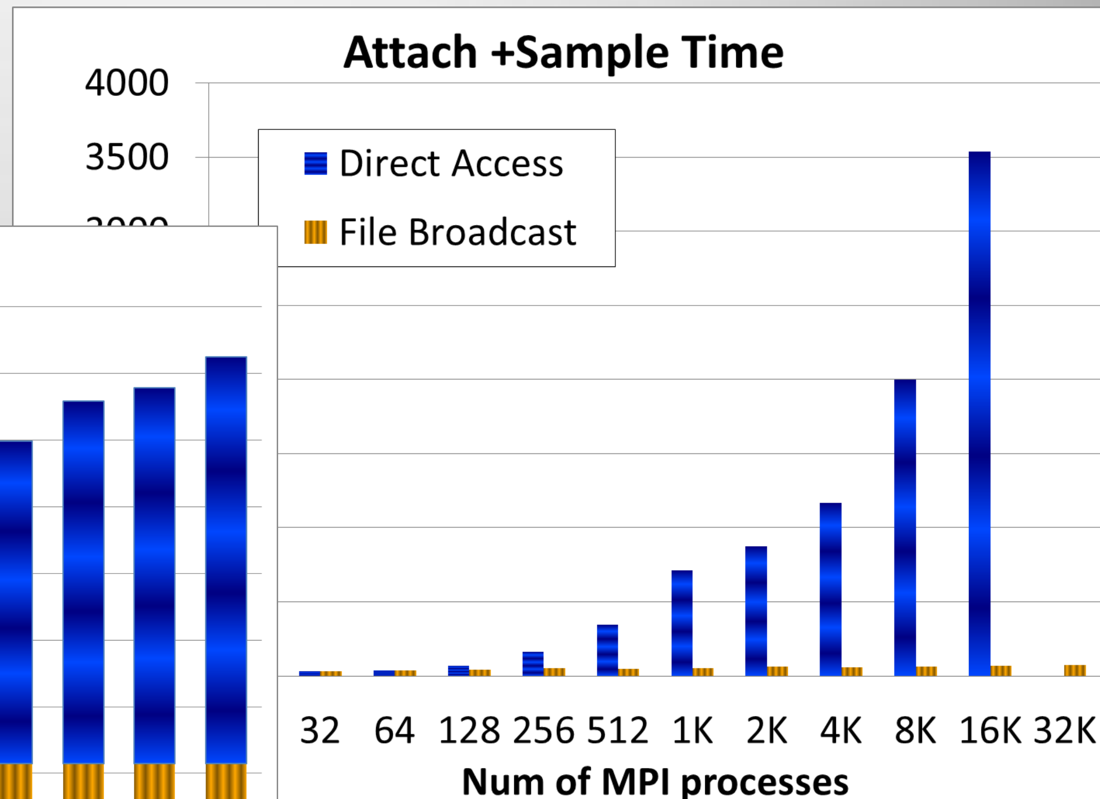
- Primary evaluation goals
  - The performance and scalability of various FGFS queries
  - The effectiveness and utility of FGFS on a variety of HPC software
- Controlled experiments and three case studies
  - Benchmark FGFS performance on three multi-physics applications
  - Integrate FGFS to HPC elements with vastly different characteristics
- Ran on Linux clusters installed at LLNL
  - 2-socket x 8-core Intel Sandy Bridge (2.6GHz) with 32 GB of RAM
  - The largest cluster (Zin) with up to 2,916 compute nodes = 46,656 cores
  - Qlogic Infiniband QDR interconnect

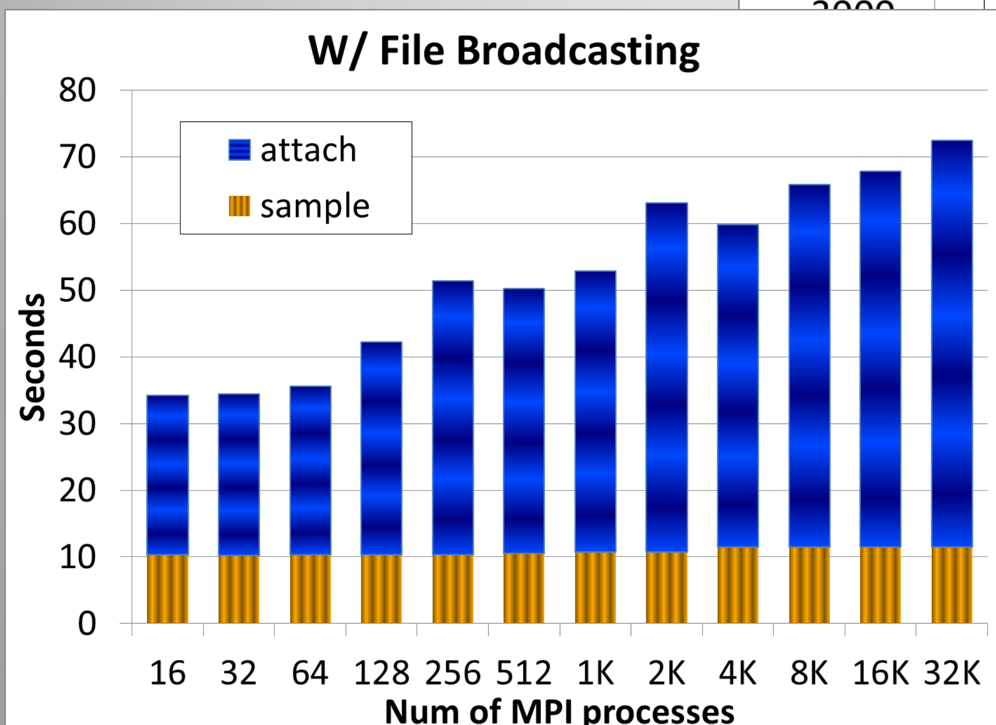
Most file status queries on KULL (w/ 848 shared libraries) complete in 272 msecs at 32K procs



FGFS addressed a scalability challenge in STAT's accessing of file systems

Log scaling with $R^2 = .958$





ULL (with big executable mode)

FGFS serves as a key component of a novel massive parallel loading service

- SPINDLE (Scalable Parallel Input Network for Dynamic Loading Environment)
- SPINDLE file-cache servers form a tree-based network and coordinate file-system accesses of the dynamic loader.
- SPINDLE servers use ***AsyncGlobalFileStatus*** to choose between a direct file-system access and file broadcasting.
- The Pynamic benchmark was shown to scale well up to 15,360 MPI processes with no disruption to shared file systems

We will present details of SPINDLE at ICS (6/10/13 – 6/14/13, Eugene, Oregon).

FGFS facilitates efficient, non-disruptive use of file systems for a wide range of HPC software

- Efficient files accesses are increasingly important and challenging
- Developed Fast Global File Status as a scalable, portable mechanism to retrieve global information on files or file systems
- FGFS queries are highly scalable and provide orders-of-magnitude improvements over traditional approaches
- Various case studies suggest that FGFS can be effective for a wide range of HPC software elements
- FGFS will deeply be integrated into various HPC software systems, extending its benefits to many essential elements of HPC

- MountPointAttributes has been released: http://dongahn.github.io/MountPointAttributes
- Other components coming soon.

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