Towards a Highly Adaptable Filesystem Framework for Linux

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Linux has a very flexible file system framework...

- Powerful VFS
  - Object oriented framework
    - Abstractions for superblock, inodes etc
    - Variety of file system types
  - Common helpers for data caching, libfs etc
- Rising no. of general purpose file systems
  - Different “sweet-spot” usage patterns
  - Advantage of parallel innovation
- Each filesystem is evolving independently
  - Advances in storage, protocols, appl reqmts
  - Change with compatibility
    - Adding options for new features (tune2fs, chattr)
    - Occasionally break off next gen as a new filesystem

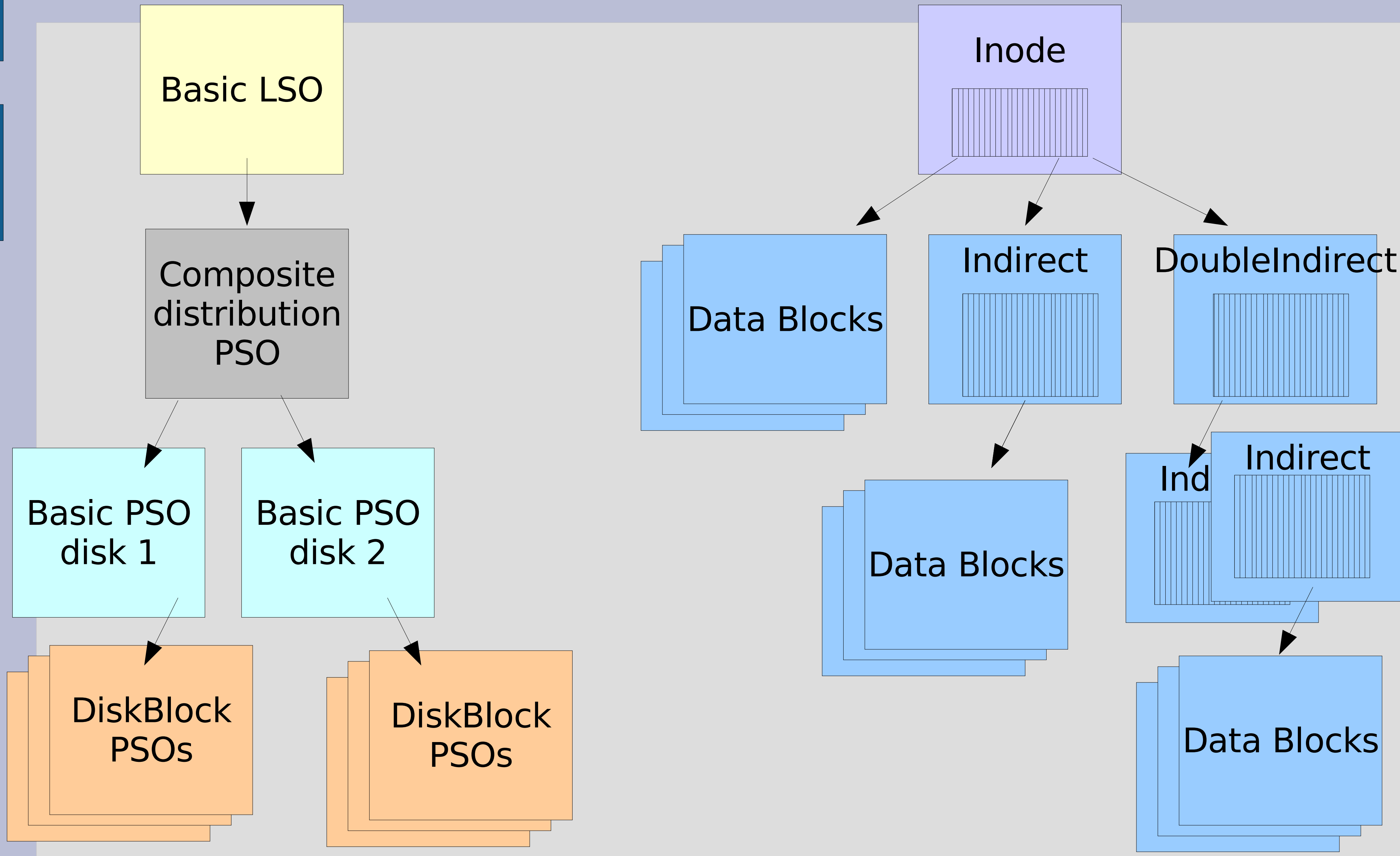
... but only a limited degree of adaptability

- Problem of switching on-disk formats
  - Virtual lock-in to a choice
  - High lead time to adoption of format enhancements
  - Compounded on distribution across multiple disks
- Fragmentation from a user perspective
  - Choosing the right Linux filesystem charts
  - Low reuse of low-level building blocks
- One file layout does not fit all
  - Small vs large, streaming vs slow growing vs random, dense vs sparse, read-mostly vs r/w

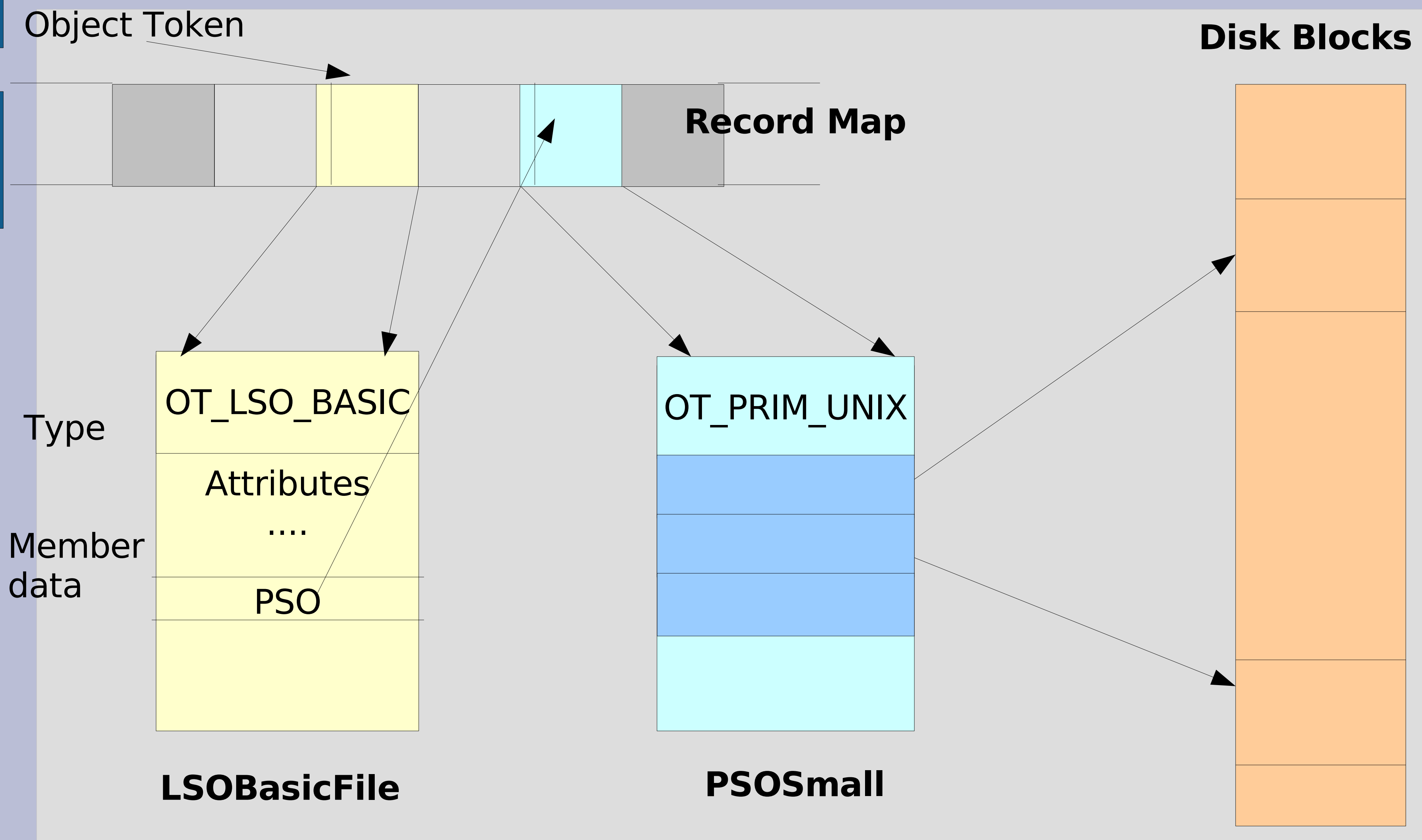
What if we push this flexibility further all the way ?

- All resources represented by storage objects (self describing)
  - e.g., No disk region for inodes
- Separation of concerns into re-usable objects
  - e.g., block mapping (physical) separated from inode (logical)
- Recursive use of OO design
  - Object stored within other object
  - Objects partition work to other objects
- Could enable
  - Per-file-element level adaptability
  - Addition of new formats while retaining old ones
  - Reuse of low-level layout structures

How is this different from what we do today ?



How meta-data may be stored recursively



Intuitively the overhead of flexibility in mapping ext2 is small

- Cached data handled mostly by VFS
- Cached meta data access has small extra overhead.
- IO for meta data should be about the same

While enabling new layout implementations to be added with ease

- Extent based
- Write near disk head
- File in inode
- Inode in directory
- Replication across disks
- Redundancy on per-file, per-directory basis

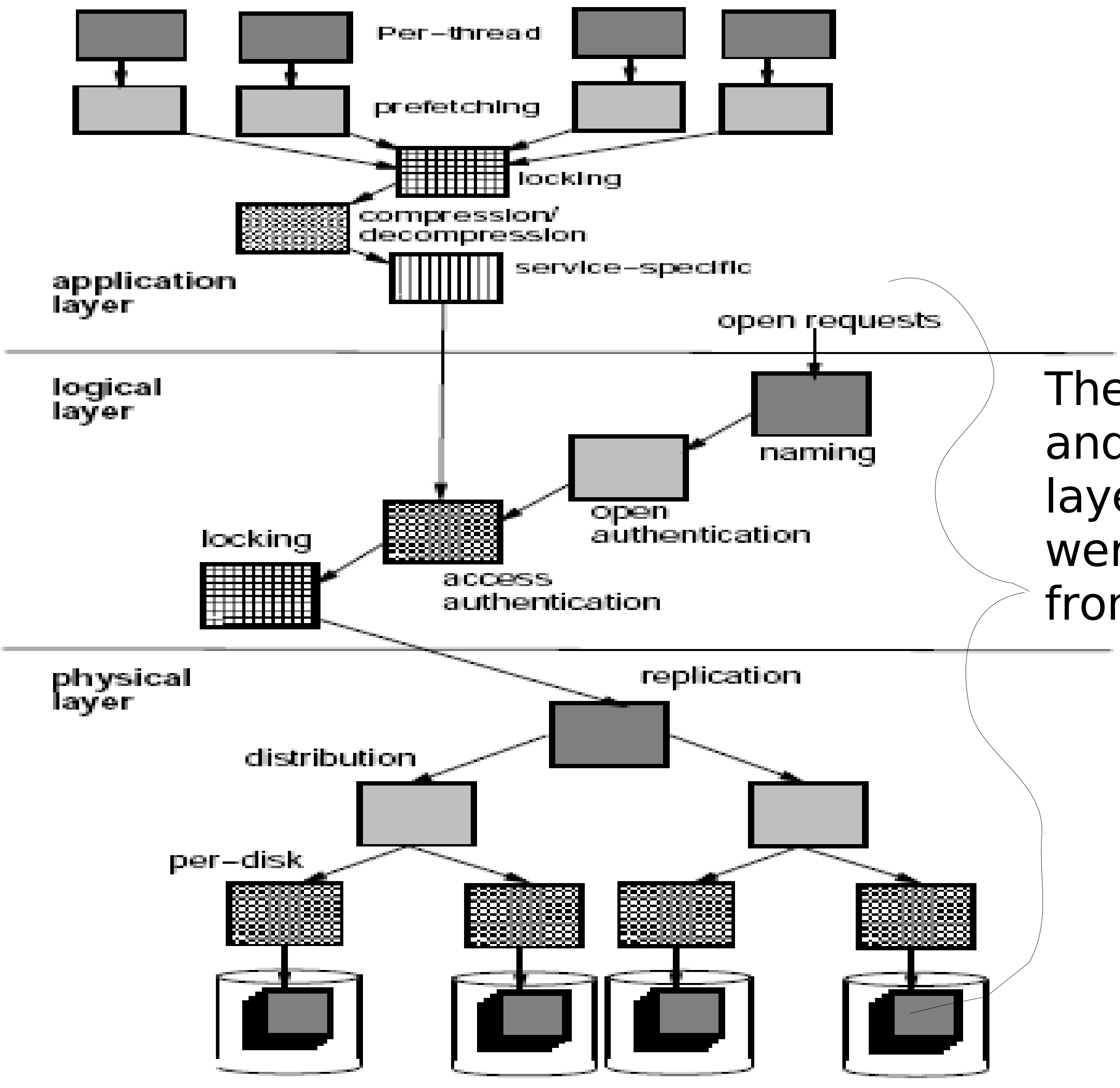
A few ways in which flexibility may be exploited

- Simple hints, different defaults
- HPC, Database, Application specific formats
- Old data can retain its old format
- Natural transition/decision points
  - File growth, aging/hot, multiple links ...
- Agents that determine workload characteristics, usage patterns, CPO

There is a framework to explore such an extreme approach to flexibility

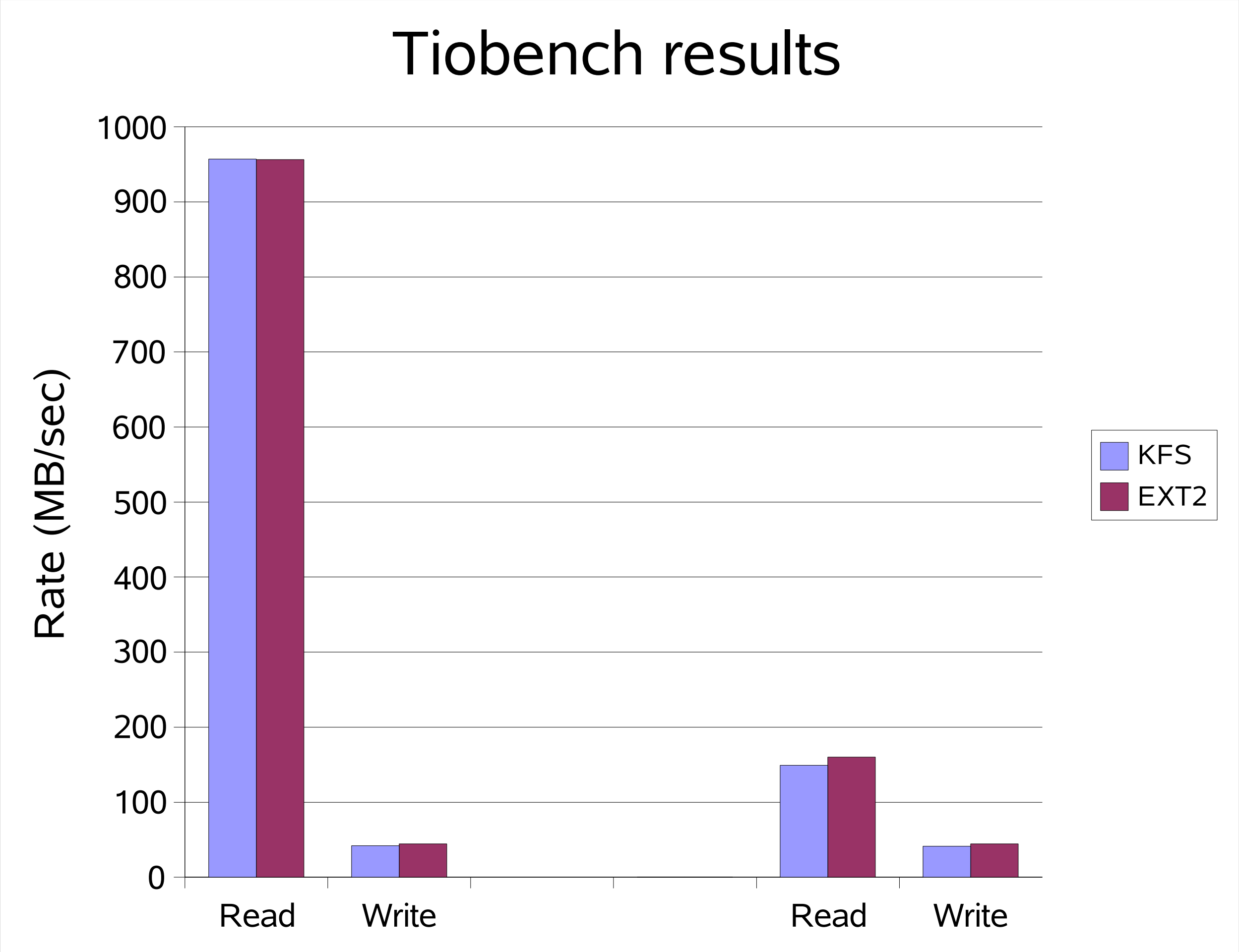
- HFS (Hurricane Filesystem) [Krieger, 1994]
  - A research filesystem designed to support:
    - fine grained flexibility
    - a wide variety of file structures and policies
    - dynamic changes in representation
  - Intended for large-scale SMP running diverse loads
    - Explored flexibility to maximize perf & scalability
    - Object-oriented building block approach
    - Achieved with low processing and I/O overhead
  - Led to the evolution of Tornado and K42 OS
- KFS (K42 filesystem)
  - Implemented the ideas of HFS in a Linux-compatible OS

A Full Example of an HFS file : 3 layer architecture



The logical and physical layers of KFS were derived from HFS

Initial results on Linux 2.6 with tiobench on unoptimized KFS



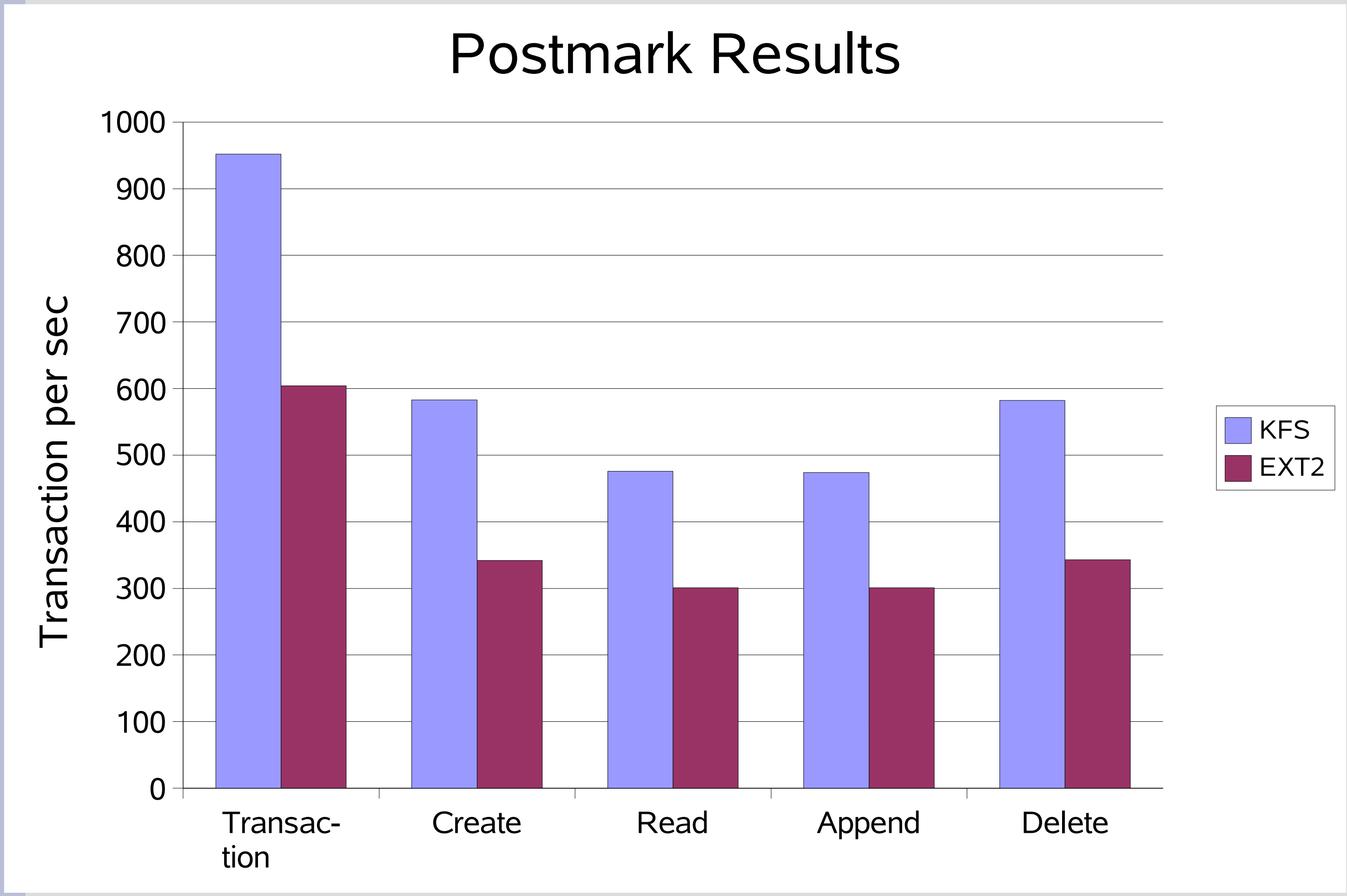
1 thread 4 threads

Avg of 3 runs. (Each run followed by reboot and format).

File size : 100MB per thread

Sequential Write

Initial results on Linux 2.6 with Postmark on unoptimized KFS



Base No of files : 20000

Transactions : 100000

Sub-directories : 400

(Avg of 3 runs and each run is followed by a reboot and remount)

The way forward: Pursue multiple aspects to adaptable Linux filesystems

- Full embedding of an existing filesystem format to evaluate if KFS is an appropriate starting point
- Demonstrate 2 or more embedded filesystems with negligible performance overhead
  - Explore building block sharing across filesystems
- Switch formats to suit access patterns
  - Add new formats, work with multiple formats
    - Discard experimental layout changes
  - Continuation inodes (ArjanV, Val Henson)
- Evaluate alternate layouts and policies
  - Collocation of file data and meta-data
  - Other ideas from file system workshop
- Study reliability aspects
  - Adaptability in the file system checker

In Summary

- The very flexibility that has been the strength of the Linux VFS, appears to have exposed its own set of problems over time
- We hypothetize that pushing the flexibility all the way through to on-disk layouts could help us address these problems in the long run
- While we are exploring KFS as one possible starting point towards such a framework, we have yet to understand whether it is an appropriate approach
- There are many open questions to explore, and we welcome community involvement in this exciting endeavour

Our Thanks to ...

- KFS Contributors
  - Livio Soares (KFS on K42 & Linux 2.4)
  - Ajit Burad & Tarun Mittal (KFS on Linux 2.6)
- And to
  - Suzuki K.P., V Srivatsa, Mingming Cao, Dave Kleikamp, Stephen Tweedie, Theodore Tso, Andreas Dilger, Val Henson, Paul McKenney, H. Peter Anvin, Chris Mason, Arjan Van De Ven, Christoph Hellwig, Mel Gorman

Availability: http://www.research.ibm.com/k42

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The benchmarks discussed in this presentation were conducted for research purposes only, under laboratory conditions. Results will not be realised in all computing environments

BACKUP

KFS is based on composition & specialization of building blocks

- Physical Server Object (PSO)
  - PSODiskBlock
  - PSOSmall, PSOSmallMeta
  - PSOExtent
  - PSOReplicated, PSOStriped
- Logical Server Object (LSO)
  - LSOBasicFile,
  - LSOBasicDir,
  - LSOEmbDir
  - LSOBasicSymLink

A variety of file system element types may be defined

```
OT_PRIM_UNIX = 2,   /* primitive unix like file <- replace this */
OT_PRIM_UNIX_META = 3,   /* primitive unix like file for meta-data */
OT_STRIPED = 4,     /* striped  file <- replace this */
OT_BASIC_RW = 5,       // A basic per/disk read/write object
OT_BASIC_SPARSE = 6,   // A basic per/disk sparse object
OT_BASIC_DENSE = 7,    // A basic per/disk dense object
OT_NM_SMALL = 8,       // A non-mapped small object
OT_RECORD_MAP = 9,     // A non-mapped record store object
OT_COMP_STR = 10,      // A composite striped object
OT_COMP_REP = 11,      // A composite replicated object
OT_COMP_DIS = 12,
OT_COMP_CHCK = 13,
OT_COMP_PAR = 14,
OT_LSO_BASIC = 16,
OT_LSO_BASIC_DIR = 17,
OT_LSO_BASIC_LNK = 18,
OT_DISK_BLOCK = 20,    // Low-level disk-based object
OT_BASIC_EXTENT = 21,
OT_SYMLINK_EXT = 22,
OT_LSO_DIR_EMB = 23
```

Example Scenario for adaptation to access patterns

- Start with a PSORecEmb which stores data in the PSO record itself
- As file grows, switch to a PSOSmall which employs direct-block mapping
- As file grows further, depending on contiguity of blocks, add a PSO sub-obj that is either PSOExtent (extent maps) or PSOBasicRW (indirect blocks) or PSOSparse (sparse maps) or PSOPreallocSeq/PSOPreallocRan (preallocated)
- As file grows to require 64 bit relative block number, add a PSO64 sub-obj of the corresponding type (or use a distribution PSO).

Example Collocated Meta-data

- 64 bit Object ID = recmap id + rec id
- Local record maps vs global record map
- LSODirEmb embeds records within the directory

KFS for Linux 2.6 is currently under stabilization

- KFS on Linux 2.4 [Silva, Soares, Krieger]
  - Proof of concept
- KFS on Linux 2.6
  - Under stabilization and optimization by Ajit Burad and Tarun Mittal
  - Results will be made available at http://k42.ozlabs.org/Wiki/KfsExperiments