A few limitations in the available fs-related system calls...

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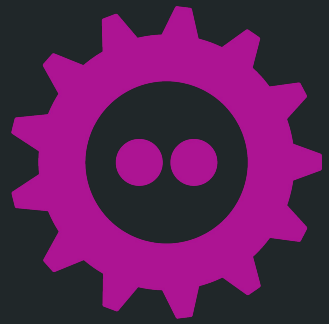

RISC-V for Cloud Services 2/

https://riser-project.eu

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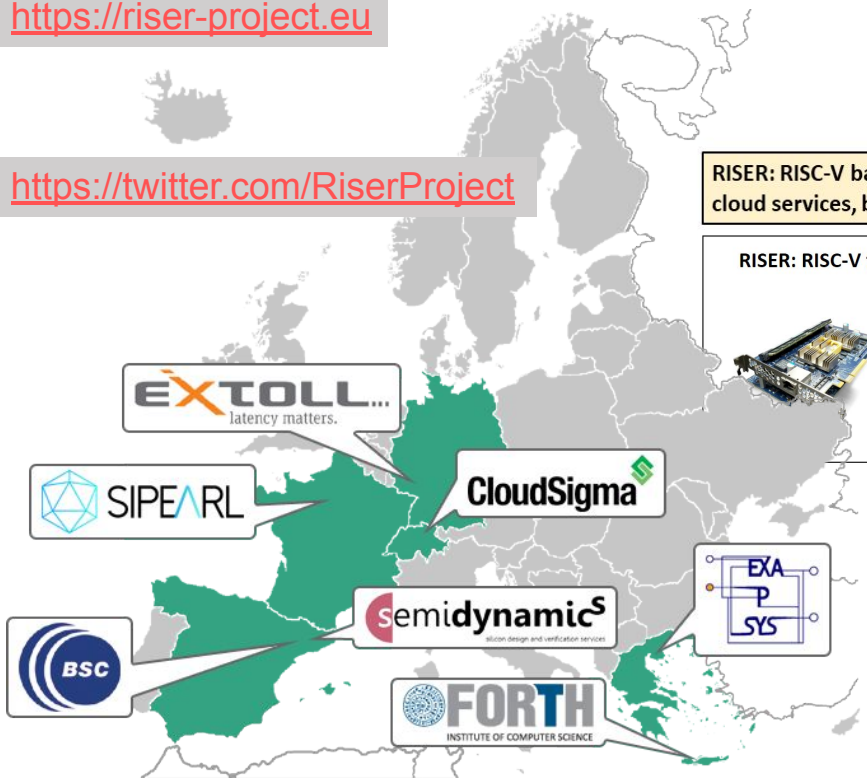

RISER: RISC-V based Linux server for cloud services, built on open interfaces

RISER: RISC-V for Cloud Services

RISC-V Processors
Source: EPI and EUPilot projects (chips)
* Currently operating on system boards designed for dev/test purposes

Server Boards (PCB + firmware)
Standard form factors (PCIe accelerator card, Microserver)
* Following industry standards to utilize server I/O peripherals

- DRAM Memory
- NVM-Express Storage
- 100 Gbps Ethernet

Boot Firmware
Initialization of execution platform, Including high-speed I/O peripherals (storage, networking)

OS, drivers, runtime
Configured/adapted for cloud services: workload acceleration, networked storage, containerized execution
*Integration in IaaS environment

Integrated all-European Hardware and Open-Source Software for Cloud Services and Applications

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Copying a file...

- Preserve file data
  - Time efficiency
  - Space efficiency
- Preserve file metadata
  - Permission bits
  - Ownership (user/group)
  - Timestamps
  - Old school attributes
  - Extended attributes

System calls for copying data...

- The naive approach: **open()**, **read()**, **write()**, **close()**
  - The most generic/portable way but very inefficient
  - Datapath goes through userspace, kernel copies to user on read, from user on write
- Using **sendfile()**
  - Linux, FreeBSD (thank you Netflix !)
  - Copying is done in-kernel, without going through userspace
  - Uses a temporary buffer: source -> buffer (pipe) -> dest
  - Probably the most common technique used today
- Using **copy_file_range()**
  - Linux-only
  - Takes advantage of fs features (e.g. COW, REFLINK, NFS server-side copy etc), and in the future will also take advantage of hw features (e.g. NVme simple copy)
  - This is meant to be the new/default API for this
- Preserve holes on sparse files: **lseek(SEEK_DATA/SEEK_END)**, **ftruncate()**

System calls for preserving metadata...

- Permission bits using **{f}chmod{at}()**
- Ownership using **{f,l}chown{at}()**
- atime/mtime using **utimens{at}()**
- Preserve old-style 32bit attributes mask using **ioctl(FS_IOC_{G,S}ETFLAGS)**

```
 *
 * We have recently hoisted FS_IOC_FSGETXATTR / FS_IOC_FSSETXATTR from
 * XFS to the generic FS level interface.  This uses a structure that
 * has padding and hence has more room to grow, so it may be more
 * appropriate for many new use cases.
 *
 * Please do not change these flags or interfaces before checking with
 * linux-fsdevel@vger.kernel.org and linux-api@vger.kernel.org.
 */
#define FS_SECRM_FL                     0x00000001 /* Secure deletion */
#define FS_UNRM_FL                      0x00000002 /* Undelete */
#define FS_COMPR_FL                     0x00000004 /* Compress file */
#define FS_SYNC_FL                      0x00000008 /* Synchronous updates */
#define FS_IMMUTABLE_FL                 0x00000010 /* Immutable file */
#define FS_APPEND_FL                    0x00000020 /* writes to file may only append */
#define FS_NODUMP_FL                    0x00000040 /* do not dump file */
#define FS_NOATIME_FL                   0x00000080 /* do not update atime */
/* Reserved for compression usage... */
#define FS_DIRTY_FL                     0x00000100
#define FS_COMPRBLK_FL                  0x00000200 /* One or more compressed clusters */
#define FS_NOCOMP_FL                    0x00000400 /* Don't compress */
/* End compression flags --- maybe not all used */
#define FS_ENCRYPT_FL                   0x00000800 /* Encrypted file */
#define FS_BTREE_FL                     0x00001000 /* btree format dir */
#define FS_INDEX_FL                     0x00001000 /* hash-indexed directory */
#define FS_IMAGIC_FL                    0x00002000 /* AFS directory */
#define FS_JOURNAL_DATA_FL              0x00004000 /* Reserved for ext3 */
#define FS_NOTAIL_FL                    0x00008000 /* file tail should not be merged */
#define FS_DIRSYNC_FL                   0x00010000 /* dirsync behaviour (directories only) */
#define FS_TOPDIR_FL                    0x00020000 /* Top of directory hierarchies*/
#define FS_HUGE_FILE_FL                 0x00040000 /* Reserved for ext4 */
#define FS_EXTENT_FL                    0x00080000 /* Extents */
#define FS_VERITY_FL                    0x00100000 /* Verity protected inode */
#define FS_EA_INODE_FL                  0x00200000 /* Inode used for large EA */
#define FS_EOFBLOCKS_FL                 0x00400000 /* Reserved for ext4 */
#define FS_NOCOW_FL                     0x00800000 /* Do not cow file */
#define FS_DAX_FL                       0x02000000 /* Inode is DAX */
#define FS_INLINE_DATA_FL               0x10000000 /* Reserved for ext4 */
#define FS_PROJINHERIT_FL               0x20000000 /* Create with parents projid */
#define FS_CASEFOLD_FL                  0x40000000 /* Folder is case insensitive */
#define FS_RESERVED_FL                  0x80000000 /* reserved for ext2 lib */

#define FS_FL_USER_VISIBLE              0x0003DFFF /* User visible flags */
#define FS_FL_USER_MODIFIABLE           0x000380FF /* User modifiable flags */
```

System calls for preserving metadata...

- Extended attributes (key:value pairs), using **{list,set,get}xattr()**
  - "POSIX" ACLs (acl(7)): system.posix_acl_access/default
  - NFSv4 ACLs (honored by the nfs client): system.nfs4acl/nfs4_acl
  - Inline-data (ext4(5)): system.data
  - Per-file capabilities (capabilities(7)): security.capability
  - SELinux file contexts: security.selinux/security.sehash
  - AppArmor labels (apparmor_xattrs(7)): e.g. security.apparmor
  - SMACK attributes: security.SMACK64*
  - Integrity measurement: security.evm/security.ima
  - Privileged userspace stuff: trusted.*
  - Unprivileged userspace stuff: user.*
  - and more...
  - Honor /etc/xattrs.conf, that includes xattr patterns to skip

Issues so far...

- **copy_file_range()** may expand holes on sparse files
- No io_uring op for **sendfile()** / **copy_file_range()**
- The {at} system call variants (using O_PATH descriptors) are very useful !
  - **But there are no {list,set,get}xattrat() syscalls !**
  - **fchmodat()** doesn't support the AT_EMPTY_PATH flag -> Fixed on 6.6 with **fchmodat2()**
  - **utimensat()** does support AT_EMPTY_PATH but the man page doesn't mention it
- IMHO There should be a single API for file attributes, having to use ioctl() doesn't look nice.
- No registry of xattrs used by the kernel, more documentation is needed ! Multiple xattrs cannot be set through xattr API.

Capabilities required for backup...

- For read access to files we don't own: CAP_DAC_READ_SEARCH
- For preserving special files (devices/sockets etc): CAP_MKNOD
- For preserving ownership: CAP_CHOWN
- For chmod/utimens, attrs, most xattrs, using O_NOATIME etc: CAP_FOWNER
  - If we have CAP_CHOWN we can skip this, we can preserve all we can and then change owner
- For the APPEND/IMMUTABLE attr: CAP_LINUX_IMMUTABLE
- For security.capabilities: CAP_SETFCAP
- For security/trusted xattrs: CAP_SYS_ADMIN -> That's overkill !
- This is confusing and inconsistent !

When to backup a file...

- We can track data changes through mtime/size and compare between src/dst
  - But this is insecure/unreliable.
  - Rsync does crc32 which is still insecure, we could do e.g. SHA on both src/dst but that also has a serious overhead.
  - We could use IMA (security.ima) but that's not available over NFS.
  - We could compare ctime to make sure that mtime wasn't modified since our last backup but we can't preserve ctime on dst to do the comparison !
- We can't track metadata changes without reading them all (including all xattrs) !
  - Also because ctime cannot be preserved on dst, so we can't compare it with src.

On preserving ctime for comparison...

- Why are we able to preserve atime/mtime and not ctime ?
  - There is a chicken-and-egg issue, since changing ctime should also update ctime
  - It's the most reliable way to determine if a file's data/metadata changed, better let the kernel handle it
- But there are ways around this for privileged users
  - One can set the system time and force a ctime update by performing a modification on data/metadata
  - It's possible to modify the data on-disk, like I did for example with ext4backup (https://github.com/mickflemm/ext4backup)
  - It could even be done without unmounting the partition, using fsfreeze.
- And in some cases it's not maintained in a consistent way e.g. for networked file systems (look for S_NOCTIME).
- So why not have a privileged API (e.g. a flag on utimens{at} or something new, with a proper capability e.g. CAP_CTIME) ?

What about btime/crtime ?

- It’s probably more useful as it is, no need to preserve it.
  - There are cases where a file will be re-created on edit (e.g. vi does that) so btime/crtime says nothing about when the file’s contents were created.
  - We could however have a standard xattr for file content creation (in case it’s not supported by the file format).
- BTW NFS server exports btime/crtime but NFS client doesn’t use it.

Backing up encrypted files...

- With eCryptfs -> just copy the encrypted files (and ~/.ecryptfs etc)
- With fscrypt -> Not possible !
  - We can use statx to see if a file/dir/symlink is encrypted (STATX_ATTR_ENCRYPTED)
  - We can determine if the required key is present (so that we can copy them unencrypted)
    - For regular files we can try to open() them and fail with ENOKEY
    - For dirs we can do an ioctl()
    - For symlinks -> Not possible !
  - No way to copy data in encrypted form !

Summary...

- Add {list,set,get}xattrat() syscalls.
- Wrap old attrs as xattrs so that we don't use ioctl(FS_IOC_{G,S}ETFLAGS) and have a common API for all attributes.
- Add a flag to copy_file_range() to preserve holes on sparse files, and also make it a io_uring op.
- Document all special xattrs / those used/set by the kernel, and the required capabilities to get/set them. Maybe also a new capability to set security/trusted xattrs without requiring CAP_SYS_ADMIN.
- Come up with a way to get a file's measurement (or even just a hash of its data/metadata, as long as it's only the kernel that can set it) without having to read the whole thing in userspace, that works over NFS.
- Come up with a privileged API to preserve ctime.
- Come up with an API for backing up fscrypt files in encrypted form.

Questions ?

Thank you !