What's New in the File System

Session 709

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Engineering Manager, File Systems

These are confidential sessions—please refrain from streaming, blogging, or taking pictures

File system and frameworks update

Storage industry trends

Recent changes

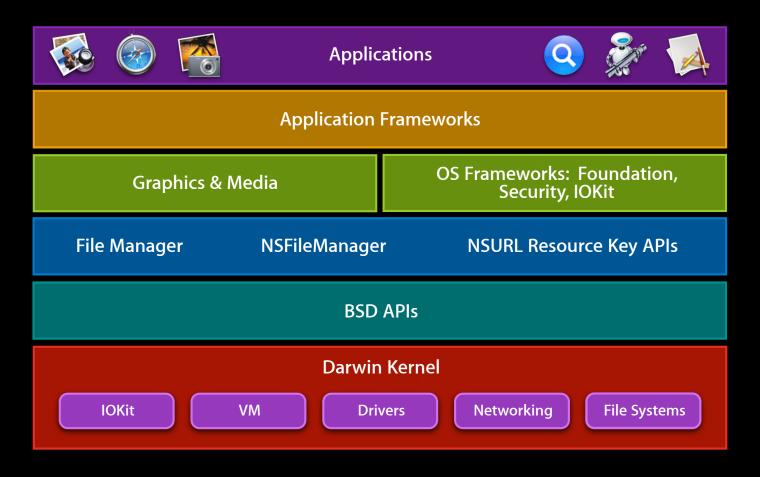
Best practices

File Vault 2

What it is

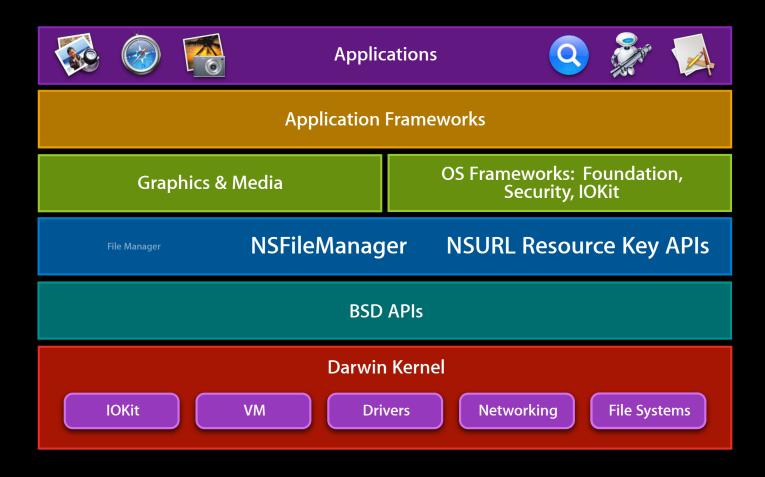
Architecture Overview

File system is ultimately responsible for your data



Architecture Overview

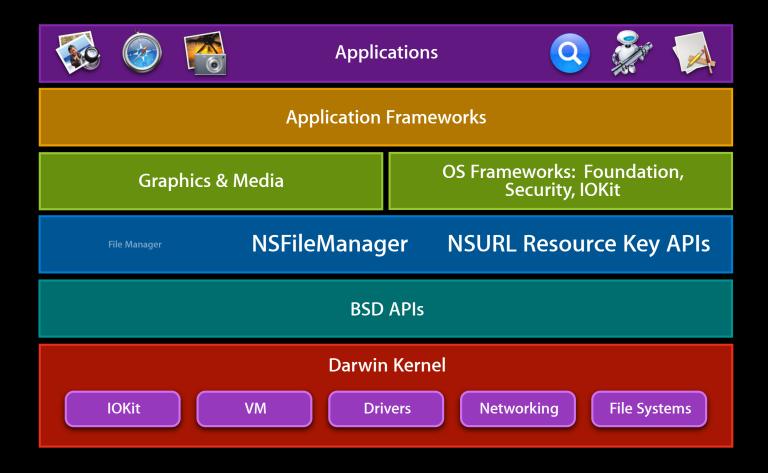
File system is ultimately responsible for your data



Architecture Overview

File Systems

File system is ultimately responsible for your data



/System/Library/Filesystems/

File Systems

Mac OS X 10.8

ExFAT	Read / Write (10.6)
FAT 16/32	Read / Write
HFS	Read Only (Deprecated)
HFS+	Journaled HFS+ everywhere
NTFS	Read Only
UDF	Read / Write

Same Code Base

iOS + OSX

- Journaled HFS+ is everywhere
- Improvements made for one platform improve the other
 - Bug fixes
 - Performance
 - TRIM
- Minor difference
 - iOS devices use case-sensitive HFS+ (HFSX)

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Trends in Storage SSDs

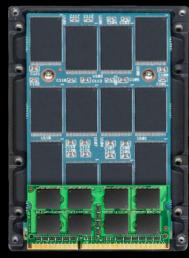
- Small, fast
 - SSD on PCle, controller integration
 - Better random I/O: 100X faster HDD
- Trending towards fewer write cycles
 - 3000 write cycles and dropping
- Security concerns
 - Spare blocks
 - Wear leveling
- Expensive



Trends in Storage SSDs

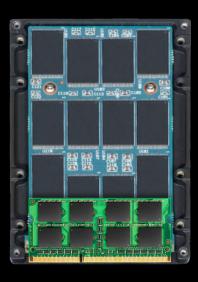
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Trends in Storage

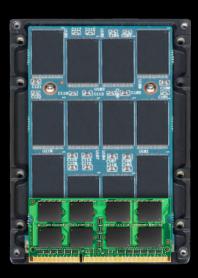
SSDs: Impact on file systems



Trends in Storage

SSDs: Impact on file systems

- Fast random I/O
 - Defragmenting less useful
 - More flexibility in future design decisions
- Trending towards fewer write cycles
 - TRIM support
 - Faster, longer lasting SSDs
 - Large sequential writes better



Trends in Storage

Distributed storage



- Devices store a subset of user's data
- Users getting new devices often (iPhone/iPad/iPod)
- Cloud
 - Secure backup
 - Efficient backup
 - Deduplication

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File Vault 2

What it is

Extended Attributes

- Introduced in OS X 10.4
 - Perfect for storing small application specific data in a file

```
getxattr(path, ptr, attrdatabuf, sizeof(attrdatabuf), 0, 0);
setxattr(path, EAname, EAvalue, strlen(EAvalue)+1, 0, 0);
listxattr(path, attrnamebuf, nsize, 0);
removexattr(path, EAname, 0);
```

- S @
 - com.apple.FinderInfo
 - com.intuit.TurboTax.2010.FilingStatus 28
- Maximum size: <4K
- 10.7
 - Maximum size: 128K

Extended Attributes

Pros, cons, and guidelines

- Ideal for storing file metadata
 - Author, window position, history, etc.
- Beware of storing critical data in EAs
 - Not all volume formats support extended attributes
 - "._Files"
- Small EAs are packed in Attributes B-Tree
 - Require less than one allocation block

Mounting Network Volumes

Deprecated APIs



FSMountServerVolumeSync(...OptionBits flags)

FSMountServerVolumeAsync(... CFRunLoopRef runloop)



NetFSMountURLSync(... CFMutableDictionaryRef open_options)

NetFSMountURLAsync(... dispatch_queue_t dispatchq)

Mount options replaced by dictionaries
Runloop and callback replaced by dispatch queue and block

Deprecated APIs

File Manager



FSGetCatalogInfo

FSGetCatalogInfoBulk



CFURLCopyResourcePropertiesForKeys

CFURLEnumerator

File Manager replaced by NSFileManager and CFURL Resource Key APIs

Also available in iOS 5

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What it is

Performance Tips

Getting the most out of the file system

- Throttled I/O
 - Schedule low-priority tasks
 - Spotlight, Time Machine, background encryption...
- Higher-level APIs
 - GCD I/O background queue is throttled

Playing Nicely with Others

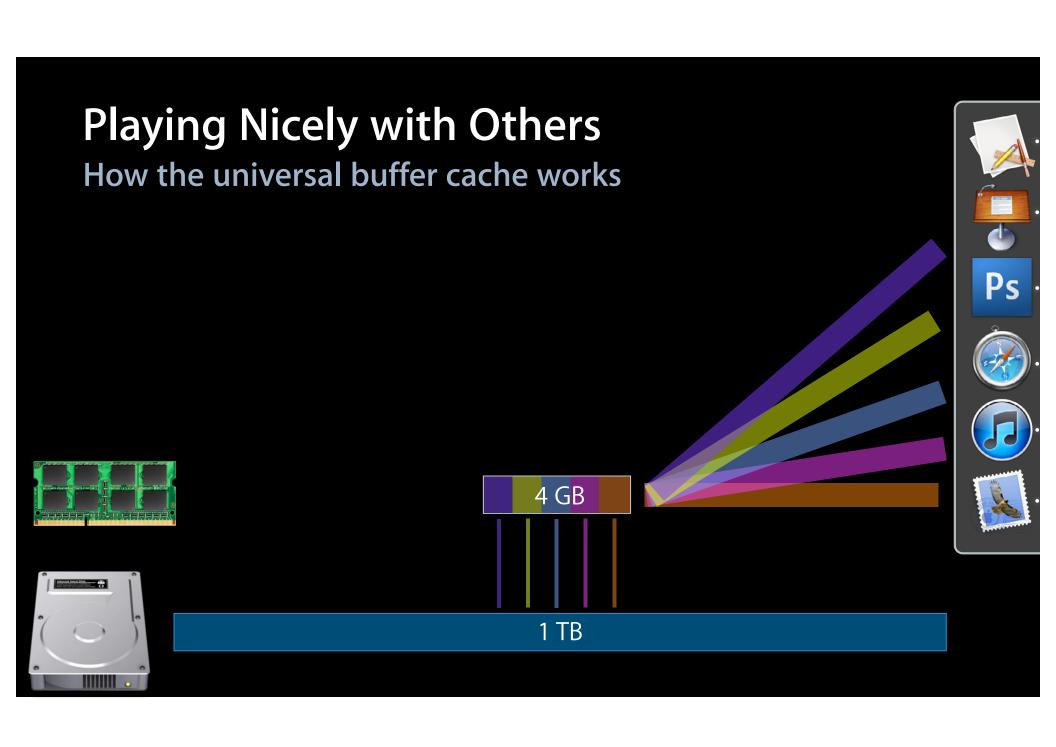
How the universal buffer cache works

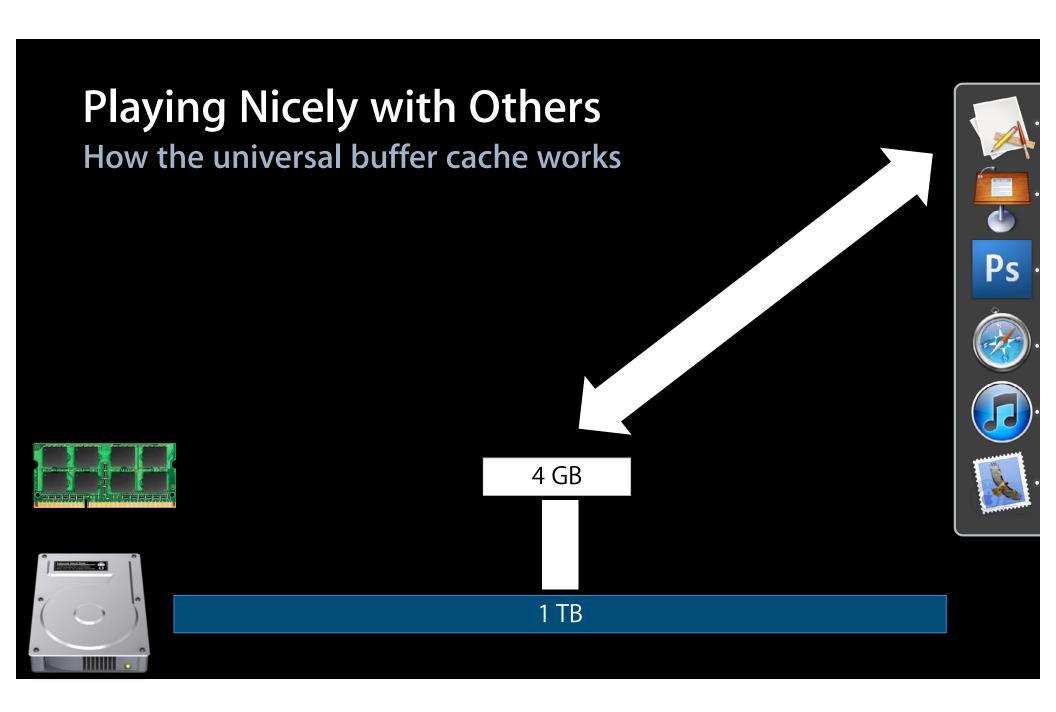


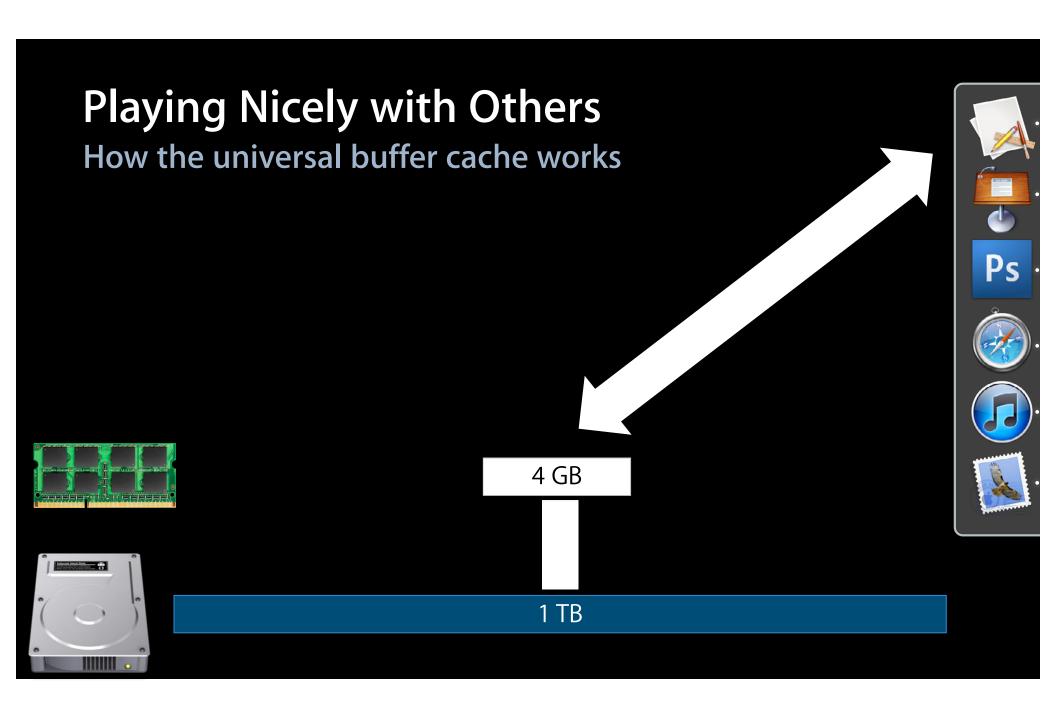


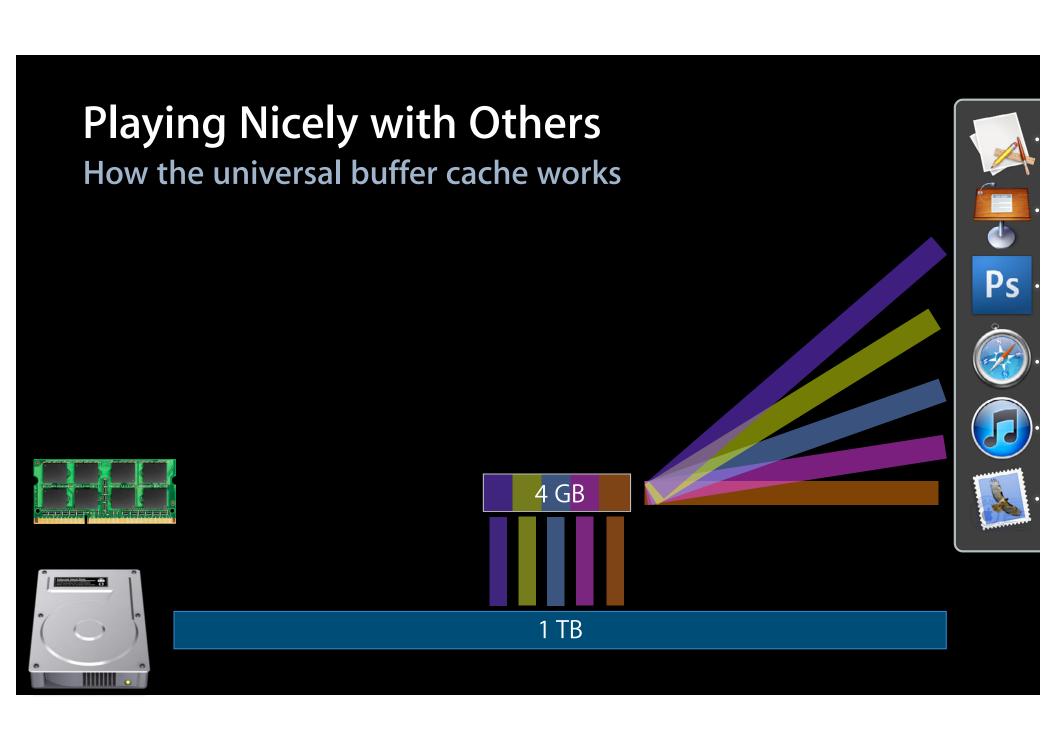
4 GB

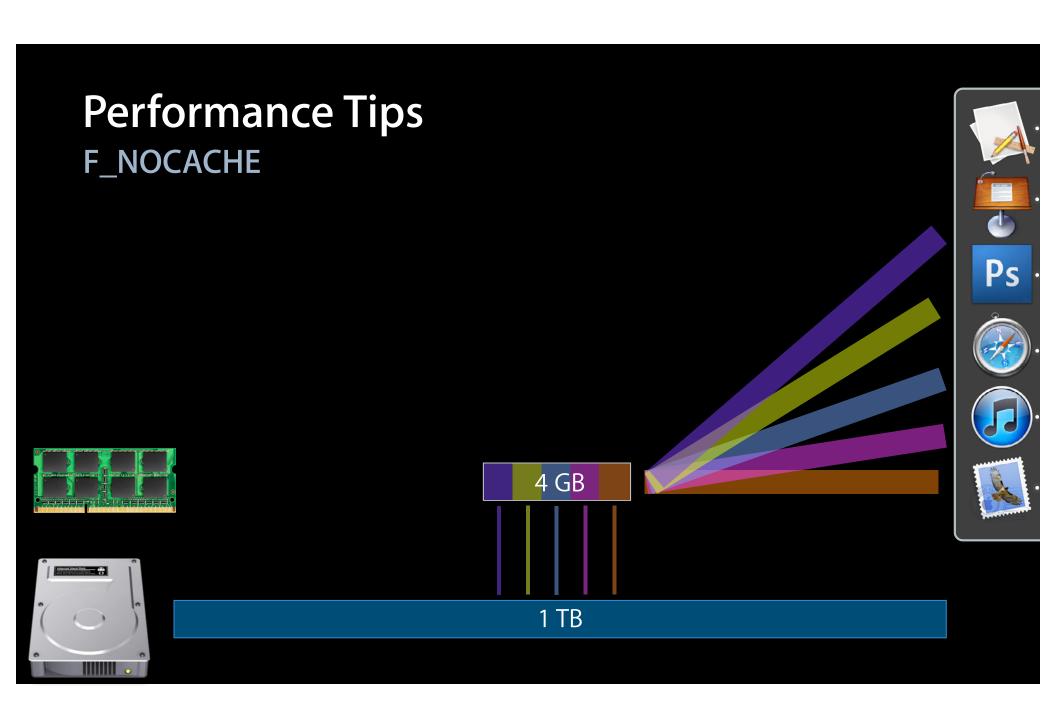






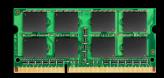








```
Turn caching OFF: fcntl(fd, F_NOCACHE, 1);
Turn caching ON: fcntl(fd, F_NOCACHE, 0);
```







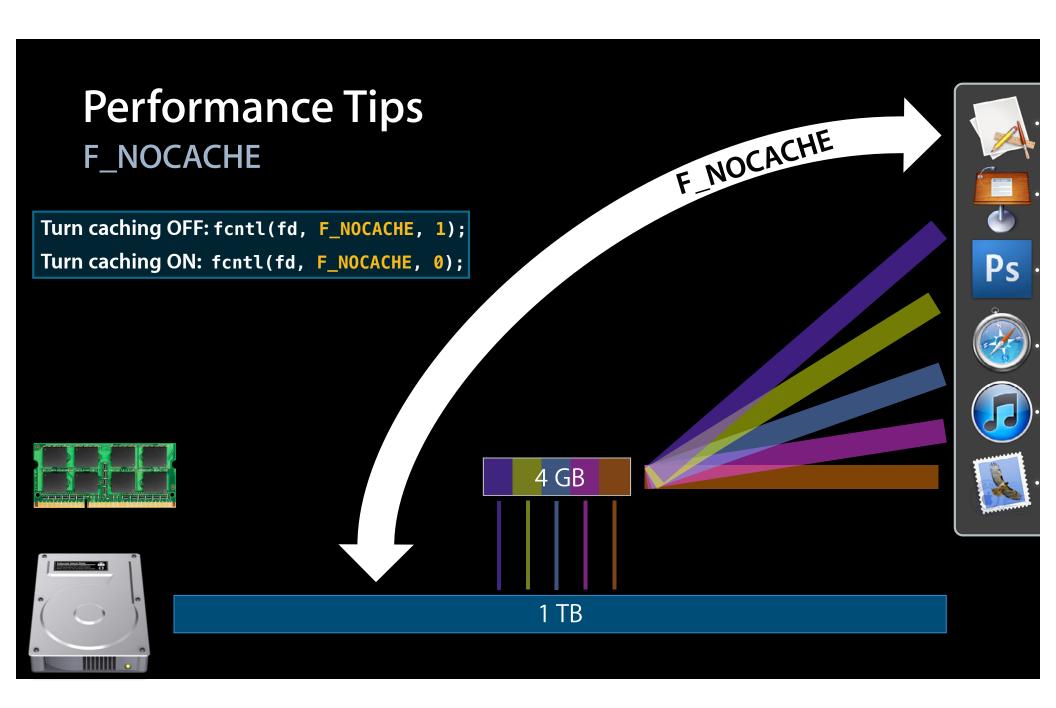












Performance Tips

Buy in bulk: Better performance = Better battery life

- Searching NSSearchField
 - NSMetadataQuery
 - Construct queries using NSPredicate
- Filesystem notification of changes to a directory hierarchy
 - FSEvents Push or pull events
- Filesystem metadata
 - CFURLCopyResourcePropertiesForKeys
 - CFURLEnumerator

Performance Tips Don't SPOD

- Keep I/O off the main UI thread
 - Applications SPOD if they don't service the event loop for two seconds
 - I/O latencies are unpredictable, especially over the network
- Ideally, UI thread should be used to handle events and update UI
- GCD and NSOperation are great ways to offload main thread



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NSFileCoordinator

Working with iCloud

- Coordinates multiple processes reading and writing to the same file
 - Used for managing documents in iCloud
- Notifies applications of changes to update their own data structures
- Recommended usage: UIDocument and NSDocument

```
// myDocument conforms to NSFilePresenter protocol
coordinator = [[NSFileCoordinator alloc] initWithFilePresenter:myDocument];
[NSFileCoordinator addFilePresenter:myDocument];
[NSFileCoordinator removeFilePresenter:myDocument];
```

Performance Tips

What's going on?

```
sudo fs_usage -w -f filesys
```

Performance Tips

What's going on?

sudo fs_usage -w -f filesys

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Performance Tips

What's going on?

sudo fs_usage -w -f filesys TextEdit > /tmp/out.txt

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14:06:38.811125	open	F=22 (_WC_T_	_) /Volumes/SSD/.TemporaryItems/folders.501/TemporaryItems/(A Document Being Saved By TextEdit)/HelloWorld.rtf	0.000115	TextEdit.51451
14:06:38.811144	write	F=22 B=0x12c		0.000018	TextEdit.51451
14:06:38.812328	WrData[AP]	D=0x003816d8 B=0x10	000 /dev/disk1s5	0.001172 W	TextEdit.51451
14:06:38.812436	fsync	F=22		0.001293	W TextEdit.51451
14:06:38.812455	close	F=22		0.000017	TextEdit.51451
14:06:38.812541	chmod	<rw-r></rw-r>	/Volumes/SSD/.TemporaryItems/folders.501/TemporaryItems/(A Document Being Saved By TextEdit)/HelloWorld.rtf	0.000047	TextEdit.51451
14:06:38.812554			/Volumes/SSD/.TemporaryItems/folders.501/TemporaryItems/(A Document Being Saved By TextEdit)/HelloWorld.rtf	0.000006	TextEdit.51451
14:06:38.812607	utimes		/Volumes/SSD/.TemporaryItems/folders.501/TemporaryItems/(A Document Being Saved By TextEdit)/HelloWorld.rtf	0.000035	TextEdit.51451
14:06:38.812636	lstat64	[2]	/Volumes/SSD/HelloWorld.rtf.sb-1efcc842-9Y3k7V	0.000009	TextEdit.51451
14:06:38.812646	lstat64		/Volumes/SSD/HelloWorld.rtf	0.000004	TextEdit.51451
14:06:38.812689			/Volumes/SSD/HelloWorld.rtf	0.000007	TextEdit.51451
14:06:38.812729			/Volumes/SSD/.TemporaryItems/folders.501/TemporaryItems/(A Document Being Saved By TextEdit)/HelloWorld.rtf	0.000009	TextEdit.51451
	access_extended		/Volumes/SSD/HelloWorld.rtf	0.000004	TextEdit.51451
14:06:38.812819	setattrlist		/Volumes/SSD/.TemporaryItems/folders.501/TemporaryItems/(A Document Being Saved By TextEdit)/HelloWorld.rtf	0.000047	TextEdit.51451
14:06:38.813400	rename		/Volumes/SSD/.TemporaryItems/folders.501/TemporaryItems/(A Document Being Saved By TextEdit)/HelloWorld.rtf	0.000568 W	TextEdit.51451



```
14:06:38.810798 mkdir
14:06:38.811125 Open
14:06:38.811144 Write
14:06:38.812328
                WrData[AP]
14:06:38.812436 fsync
14:06:38.812455 close
14:06:38.812541 chmod
14:06:38.812554
                getattrlist
14:06:38.812607
                utimes
                lstat64
14:06:38.812636
14:06:38.812646
                lstat64
14:06:38.812689
                getattrlist
14:06:38.812729
                getattrlist
14:06:38.812742
               access_extended
14:06:38.812819 setattrlist
14:06:38.813400 rename
```

```
/Volumes/SSD/.TemporaryItems/folders.501/TemporaryItems/(A Document Being Saved By TextEdit)
                                                                                                                                                0.000096
                                                                                                                                                            TextEdit.51451
  F=22
              (_WC_T_) /Volumes/SSD/.TemporaryItems/folders.501/TemporaryItems/(A Document Being Saved By TextEdit)/HelloWorld.rtf
                                                                                                                                                0.000115
                                                                                                                                                            TextEdit.51451
  F=22
          B=0x12c
                                                                                                                                                0.000018
                                                                                                                                                           TextEdit.51451
D=0x003816d8 B=0x1000
                               /dev/disk1s5
                                                                                                                                                0.001172 W TextEdit.51451
                                                                                                                                                0.001293 W TextEdit.51451
  F=22
F=22
                                                                                                                                                0.000017
                                                                                                                                                            TextEdit.51451
                      /Volumes/SSD/.TemporaryItems/folders.501/TemporaryItems/(A Document Being Saved By TextEdit)/HelloWorld.rtf/Volumes/SSD/.TemporaryItems/folders.501/TemporaryItems/(A Document Being Saved By TextEdit)/HelloWorld.rtf
<rw-r-->
                                                                                                                                                0.000047
                                                                                                                                                            TextEdit.51451
                                                                                                                                                0.000006
                                                                                                                                                            TextEdit.51451
                       /Volumes/SSD/.TemporaryItems/folders.501/TemporaryItems/(A Document Being Saved By TextEdit)/HelloWorld.rtf
                                                                                                                                                0.000035
                                                                                                                                                            TextEdit.51451
      [ 2]
                          /Volumes/SSD/HelloWorld.rtf.sb-1efcc842-9Y3k7V
                                                                                                                                                0.000009
                                                                                                                                                            TextEdit.51451
                      /Volumes/SSD/HelloWorld.rtf
                                                                                                                                                0.000004
                                                                                                                                                            TextEdit.51451
                      /Volumes/SSD/HelloWorld.rtf
                                                                                                                                                0.000007
                                                                                                                                                            TextEdit.51451
                      /Volumes/SSD/.TemporaryItems/folders.501/TemporaryItems/(A Document Being Saved By TextEdit)/HelloWorld.rtf
                                                                                                                                                0.000009
                                                                                                                                                            TextEdit.51451
                       /Volumes/SSD/HelloWorld.rtf
                                                                                                                                                0.000004
                                                                                                                                                            TextEdit.51451
                      /Volumes/SSD/.TemporaryItems/folders.501/TemporaryItems/(A Document Being Saved By TextEdit)/HelloWorld.rtf
                                                                                                                                                0.000047
                                                                                                                                                            TextEdit.51451
                      /Volumes/SSD/.TemporaryItems/folders.501/TemporaryItems/(A Document Being Saved By TextEdit)/HelloWorld.rtf
                                                                                                                                                0.000568 W TextEdit.51451
```



```
/Volumes/SSD/.TemporaryItems/folders.501/TemporaryItems/(A Document Being Saved By TextEdit)
14:06:38.810798 mkdir
                                                                                                                                                                                   0.000096
                                                                                                                                                                                              TextEdit.51451
                                       F=22
14:06:38.811125 Open
                                                   (_WC_T_) /Volumes/SSD/.TemporaryItems/folders.501/TemporaryItems/(A Document Being Saved By TextEdit)/HelloWorld.rtf
                                                                                                                                                                                  0.000115
                                                                                                                                                                                              TextEdit.51451
                                        F=22
                                               B=0x12c
                                                                                                                                                                                   0.000018
                                                                                                                                                                                              TextEdit.51451
                   WrData[AP]
                                     D=0x003816d8 B=0x1000
                                                                    /dev/disk1s5
                                                                                                                                                                                  0.001172 W TextEdit.51451
14:06:38.812436 fsync
                                        F=22
                                                                                                                                                                                   0.001293 W TextEdit.51451
14:06:38.812455
                                     F=22
                                                                                                                                                                                  0.000017
                                                                                                                                                                                              TextEdit.51451
                                                           /Volumes/SSD/.TemporaryItems/folders.501/TemporaryItems/(A Document Being Saved By TextEdit)/HelloWorld.rtf/Volumes/SSD/.TemporaryItems/folders.501/TemporaryItems/(A Document Being Saved By TextEdit)/HelloWorld.rtf
14:06:38.812541 chmod
                                                                                                                                                                                  0.000047
                                                                                                                                                                                              TextEdit.51451
                                     <rw-r-->
14:06:38.812554
                  getattrlist
                                                                                                                                                                                  0.000006
                                                                                                                                                                                               TextEdit.51451
14:06:38.812607
                  utimes
                                                            /Volumes/SSD/.TemporaryItems/folders.501/TemporaryItems/(A Document Being Saved By TextEdit)/HelloWorld.rtf
                                                                                                                                                                                  0.000035
                                                                                                                                                                                              TextEdit.51451
                                           [ 2]
                  lstat64
                                                               /Volumes/SSD/HelloWorld.rtf.sb-1efcc842-9Y3k7V
14:06:38.812636
                                                                                                                                                                                   0.000009
                                                                                                                                                                                              TextEdit.51451
14:06:38.812646
                  lstat64
                                                            /Volumes/SSD/HelloWorld.rtf
                                                                                                                                                                                              TextEdit.51451
                                                                                                                                                                                  0.000004
14:06:38.812689
                  getattrlist
                                                           /Volumes/SSD/HelloWorld.rtf
                                                                                                                                                                                  0.000007
                                                                                                                                                                                               TextEdit.51451
                  getattrlist
                                                           /Volumes/SSD/.TemporaryItems/folders.501/TemporaryItems/(A Document Being Saved By TextEdit)/HelloWorld.rtf
14:06:38.812729
                                                                                                                                                                                  0.000009
                                                                                                                                                                                               TextEdit.51451
14:06:38.812742
                  access_extended
                                                            /Volumes/SSD/HelloWorld.rtf
                                                                                                                                                                                  0.000004
                                                                                                                                                                                               TextEdit.51451
14:06:38.812819 setattrlist
                                                            /Volumes/SSD/.TemporaryItems/folders.501/TemporaryItems/(A Document Being Saved By TextEdit)/HelloWorld.rtf
                                                                                                                                                                                  0.000047
                                                                                                                                                                                              TextEdit.51451
14:06:38.813400 rename
                                                           /Volumes/SSD/.TemporaryItems/folders.501/TemporaryItems/(A Document Being Saved By TextEdit)/HelloWorld.rtf
                                                                                                                                                                                  0.000568 W TextEdit.51451
```

```
14:06:38.811125
                         .../HelloWorld.rtf
                                                          TextEdit.51451
                 open
                                              0.000096
14:06:38.811144
                 write
                                                          TextEdit.51451
                                              0.000018
14:06:38.812436
                                              0.001293 W TextEdit.51451
                 fsync
14:06:38.813400
                        .../HelloWorld.rtf
                                              0.000568 W TextEdit.51451
                 rename
```



```
/Volumes/SSD/.TemporaryItems/folders.501/TemporaryItems/(A Document Being Saved By TextEdit)
14:06:38.810798 mkdir
                                                                                                                                                                                  0.000096
                                                                                                                                                                                              TextEdit.51451
                                       F=22
14:06:38.811125 Open
                                                   (_WC_T_) /Volumes/SSD/.TemporaryItems/folders.501/TemporaryItems/(A Document Being Saved By TextEdit)/HelloWorld.rtf
                                                                                                                                                                                  0.000115
                                                                                                                                                                                              TextEdit.51451
                                        F=22
                                               B=0x12c
                                                                                                                                                                                   0.000018
                                                                                                                                                                                              TextEdit.51451
                   WrData[AP]
                                     D=0x003816d8 B=0x1000
                                                                    /dev/disk1s5
                                                                                                                                                                                  0.001172 W TextEdit.51451
14:06:38.812436 fsync
                                        F=22
                                                                                                                                                                                   0.001293 W TextEdit.51451
14:06:38.812455
                                     F=22
                                                                                                                                                                                  0.000017
                                                                                                                                                                                              TextEdit.51451
                                                           /Volumes/SSD/.TemporaryItems/folders.501/TemporaryItems/(A Document Being Saved By TextEdit)/HelloWorld.rtf/Volumes/SSD/.TemporaryItems/folders.501/TemporaryItems/(A Document Being Saved By TextEdit)/HelloWorld.rtf
14:06:38.812541 chmod
                                                                                                                                                                                  0.000047
                                                                                                                                                                                              TextEdit.51451
                                     <rw-r-->
14:06:38.812554
                 getattrlist
                                                                                                                                                                                  0.000006
                                                                                                                                                                                              TextEdit.51451
14:06:38.812607
                  utimes
                                                           /Volumes/SSD/.TemporaryItems/folders.501/TemporaryItems/(A Document Being Saved By TextEdit)/HelloWorld.rtf
                                                                                                                                                                                  0.000035
                                                                                                                                                                                              TextEdit.51451
                                           [ 2]
                  lstat64
                                                               /Volumes/SSD/HelloWorld.rtf.sb-1efcc842-9Y3k7V
14:06:38.812636
                                                                                                                                                                                  0.000009
                                                                                                                                                                                              TextEdit.51451
14:06:38.812646
                 lstat64
                                                           /Volumes/SSD/HelloWorld.rtf
                                                                                                                                                                                              TextEdit.51451
                                                                                                                                                                                  0.000004
14:06:38.812689
                  getattrlist
                                                           /Volumes/SSD/HelloWorld.rtf
                                                                                                                                                                                  0.000007
                                                                                                                                                                                              TextEdit.51451
                  getattrlist
                                                           /Volumes/SSD/.TemporaryItems/folders.501/TemporaryItems/(A Document Being Saved By TextEdit)/HelloWorld.rtf
14:06:38.812729
                                                                                                                                                                                  0.000009
                                                                                                                                                                                              TextEdit.51451
14:06:38.812742
                 access_extended
                                                           /Volumes/SSD/HelloWorld.rtf
                                                                                                                                                                                  0.000004
                                                                                                                                                                                              TextEdit.51451
14:06:38.812819 setattrlist
                                                           /Volumes/SSD/.TemporaryItems/folders.501/TemporaryItems/(A Document Being Saved By TextEdit)/HelloWorld.rtf
                                                                                                                                                                                  0.000047
                                                                                                                                                                                              TextEdit.51451
14:06:38.813400 rename
                                                           /Volumes/SSD/.TemporaryItems/folders.501/TemporaryItems/(A Document Being Saved By TextEdit)/HelloWorld.rtf
                                                                                                                                                                                  0.000568 W TextEdit.51451
```

```
.../HelloWorld.rtf
                                                          TextEdit.51451
14:06:38.811125
                 open
                                              0.000096
14:06:38.811144
                 write
                                                          TextEdit.51451
                                              0.000018
                                              0.001293 W TextEdit.51451
14:06:38.812436
                 fsync
14:06:38.813400
                        .../HelloWorld.rtf
                                              0.000568 W TextEdit.51451
                 rename
```



```
/Volumes/SSD/.TemporaryItems/folders.501/TemporaryItems/(A Document Being Saved By TextEdit)
14:06:38.810798 mkdir
                                                                                                                                                                                   0.000096
                                                                                                                                                                                              TextEdit.51451
                                       F=22
                                                   (_WC_T_) /Volumes/SSD/.TemporaryItems/folders.501/TemporaryItems/(A Document Being Saved By TextEdit)/HelloWorld.rtf
14:06:38.811125 Open
                                                                                                                                                                                  0.000115
                                                                                                                                                                                              TextEdit.51451
                                        F=22
                                               B=0x12c
                                                                                                                                                                                   0.000018
                                                                                                                                                                                              TextEdit.51451
                   WrData[AP]
                                     D=0x003816d8 B=0x1000
                                                                    /dev/disk1s5
                                                                                                                                                                                  0.001172 W TextEdit.51451
14:06:38.812436 fsync
                                        F=22
                                                                                                                                                                                   0.001293 W TextEdit.51451
14:06:38.812455
                                     F=22
                                                                                                                                                                                  0.000017
                                                                                                                                                                                              TextEdit.51451
                                                           /Volumes/SSD/.TemporaryItems/folders.501/TemporaryItems/(A Document Being Saved By TextEdit)/HelloWorld.rtf/Volumes/SSD/.TemporaryItems/folders.501/TemporaryItems/(A Document Being Saved By TextEdit)/HelloWorld.rtf
14:06:38.812541 chmod
                                     <rw-r-->
                                                                                                                                                                                  0.000047
                                                                                                                                                                                              TextEdit.51451
14:06:38.812554
                  getattrlist
                                                                                                                                                                                  0.000006
                                                                                                                                                                                               TextEdit.51451
                                                            /Volumes/SSD/.TemporaryItems/folders.501/TemporaryItems/(A Document Being Saved By TextEdit)/HelloWorld.rtf
14:06:38.812607
                  utimes
                                                                                                                                                                                  0.000035
                                                                                                                                                                                              TextEdit.51451
                                           [ 2]
                  lstat64
                                                               /Volumes/SSD/HelloWorld.rtf.sb-1efcc842-9Y3k7V
14:06:38.812636
                                                                                                                                                                                   0.000009
                                                                                                                                                                                              TextEdit.51451
14:06:38.812646
                  lstat64
                                                            /Volumes/SSD/HelloWorld.rtf
                                                                                                                                                                                              TextEdit.51451
                                                                                                                                                                                  0.000004
14:06:38.812689
                  getattrlist
                                                           /Volumes/SSD/HelloWorld.rtf
                                                                                                                                                                                  0.000007
                                                                                                                                                                                               TextEdit.51451
14:06:38.812729
                  getattrlist
                                                           /Volumes/SSD/.TemporaryItems/folders.501/TemporaryItems/(A Document Being Saved By TextEdit)/HelloWorld.rtf
                                                                                                                                                                                  0.000009
                                                                                                                                                                                               TextEdit.51451
14:06:38.812742
                                                                                                                                                                                               TextEdit.51451
                  access_extended
                                                            /Volumes/SSD/HelloWorld.rtf
                                                                                                                                                                                  0.000004
14:06:38.812819
                                                            /Volumes/SSD/.TemporaryItems/folders.501/TemporaryItems/(A Document Being Saved By TextEdit)/HelloWorld.rtf
                                                                                                                                                                                  0.000047
                                                                                                                                                                                              TextEdit.51451
                 setattrlist
14:06:38.813400 rename
                                                           /Volumes/SSD/.TemporaryItems/folders.501/TemporaryItems/(A Document Being Saved By TextEdit)/HelloWorld.rtf
                                                                                                                                                                                  0.000568 W TextEdit.51451
```

```
.../HelloWorld.rtf
14:06:38.811125
                                                          TextEdit.51451
                                               0.000096
                 open
14:06:38.811144
                                                          TextEdit.51451
                 write
                                               0.000018
14:06:38.812436
                                               0.001293 W TextEdit.51451
                 fsync
                        .../HelloWorld.rtf
14:06:38.813400
                                               0.000568 W TextEdit.51451
                 rename
```



```
/Volumes/SSD/.TemporaryItems/folders.501/TemporaryItems/(A Document Being Saved By TextEdit)
14:06:38.810798 mkdir
                                                                                                                                                                                   0.000096
                                                                                                                                                                                              TextEdit.51451
                                       F=22
14:06:38.811125 Open
                                                   (_WC_T_) /Volumes/SSD/.TemporaryItems/folders.501/TemporaryItems/(A Document Being Saved By TextEdit)/HelloWorld.rtf
                                                                                                                                                                                  0.000115
                                                                                                                                                                                              TextEdit.51451
                                        F=22
                                               B=0x12c
                                                                                                                                                                                   0.000018
                                                                                                                                                                                              TextEdit.51451
                   WrData[AP]
                                     D=0x003816d8 B=0x1000
                                                                    /dev/disk1s5
                                                                                                                                                                                  0.001172 W TextEdit.51451
14:06:38.812436 fsync
                                        F=22
                                                                                                                                                                                   0.001293 W TextEdit.51451
14:06:38.812455
                                     F=22
                                                                                                                                                                                  0.000017
                                                                                                                                                                                              TextEdit.51451
                                                           /Volumes/SSD/.TemporaryItems/folders.501/TemporaryItems/(A Document Being Saved By TextEdit)/HelloWorld.rtf/Volumes/SSD/.TemporaryItems/folders.501/TemporaryItems/(A Document Being Saved By TextEdit)/HelloWorld.rtf
14:06:38.812541 chmod
                                                                                                                                                                                  0.000047
                                                                                                                                                                                              TextEdit.51451
                                     <rw-r-->
14:06:38.812554
                  getattrlist
                                                                                                                                                                                  0.000006
                                                                                                                                                                                               TextEdit.51451
14:06:38.812607
                  utimes
                                                            /Volumes/SSD/.TemporaryItems/folders.501/TemporaryItems/(A Document Being Saved By TextEdit)/HelloWorld.rtf
                                                                                                                                                                                  0.000035
                                                                                                                                                                                              TextEdit.51451
                                           [ 2]
                  lstat64
                                                               /Volumes/SSD/HelloWorld.rtf.sb-1efcc842-9Y3k7V
14:06:38.812636
                                                                                                                                                                                   0.000009
                                                                                                                                                                                              TextEdit.51451
14:06:38.812646
                  lstat64
                                                            /Volumes/SSD/HelloWorld.rtf
                                                                                                                                                                                              TextEdit.51451
                                                                                                                                                                                  0.000004
14:06:38.812689
                  getattrlist
                                                           /Volumes/SSD/HelloWorld.rtf
                                                                                                                                                                                  0.000007
                                                                                                                                                                                               TextEdit.51451
                  getattrlist
                                                           /Volumes/SSD/.TemporaryItems/folders.501/TemporaryItems/(A Document Being Saved By TextEdit)/HelloWorld.rtf
14:06:38.812729
                                                                                                                                                                                  0.000009
                                                                                                                                                                                               TextEdit.51451
14:06:38.812742
                  access_extended
                                                            /Volumes/SSD/HelloWorld.rtf
                                                                                                                                                                                  0.000004
                                                                                                                                                                                               TextEdit.51451
14:06:38.812819
                                                            /Volumes/SSD/.TemporaryItems/folders.501/TemporaryItems/(A Document Being Saved By TextEdit)/HelloWorld.rtf
                                                                                                                                                                                  0.000047
                                                                                                                                                                                              TextEdit.51451
                 setattrlist
14:06:38.813400 rename
                                                           /Volumes/SSD/.TemporaryItems/folders.501/TemporaryItems/(A Document Being Saved By TextEdit)/HelloWorld.rtf
                                                                                                                                                                                  0.000568 W TextEdit.51451
```

```
14:06:38.811125
                         .../HelloWorld.rtf
                                                          TextEdit.51451
                 open
                                               0.000096
14:06:38.811144
                 write
                                                          TextEdit.51451
                                               0.000018
14:06:38.812436
                                               0.001293 W TextEdit.51451
                 fsync
14:06:38.813400
                         .../HelloWorld.rtf
                                               0.000568 W TextEdit.51451
                 rename
```



```
/Volumes/SSD/.TemporaryItems/folders.501/TemporaryItems/(A Document Being Saved By TextEdit)
14:06:38.810798 mkdir
                                                                                                                                                                                   0.000096
                                                                                                                                                                                              TextEdit.51451
                                       F=22
                                                   (_WC_T_) /Volumes/SSD/.TemporaryItems/folders.501/TemporaryItems/(A Document Being Saved By TextEdit)/HelloWorld.rtf
14:06:38.811125 Open
                                                                                                                                                                                  0.000115
                                                                                                                                                                                              TextEdit.51451
                                        F=22
                                               B=0x12c
                                                                                                                                                                                   0.000018
                                                                                                                                                                                              TextEdit.51451
                   WrData[AP]
                                     D=0x003816d8 B=0x1000
                                                                    /dev/disk1s5
                                                                                                                                                                                  0.001172 W TextEdit.51451
14:06:38.812436 fsync
                                        F=22
                                                                                                                                                                                   0.001293 W TextEdit.51451
14:06:38.812455
                                     F=22
                                                                                                                                                                                  0.000017
                                                                                                                                                                                              TextEdit.51451
                                                           /Volumes/SSD/.TemporaryItems/folders.501/TemporaryItems/(A Document Being Saved By TextEdit)/HelloWorld.rtf/Volumes/SSD/.TemporaryItems/folders.501/TemporaryItems/(A Document Being Saved By TextEdit)/HelloWorld.rtf
14:06:38.812541 chmod
                                                                                                                                                                                  0.000047
                                                                                                                                                                                              TextEdit.51451
                                     <rw-r-->
14:06:38.812554
                  getattrlist
                                                                                                                                                                                  0.000006
                                                                                                                                                                                               TextEdit.51451
14:06:38.812607
                  utimes
                                                            /Volumes/SSD/.TemporaryItems/folders.501/TemporaryItems/(A Document Being Saved By TextEdit)/HelloWorld.rtf
                                                                                                                                                                                  0.000035
                                                                                                                                                                                              TextEdit.51451
                                           [ 2]
                  lstat64
                                                               /Volumes/SSD/HelloWorld.rtf.sb-1efcc842-9Y3k7V
14:06:38.812636
                                                                                                                                                                                   0.000009
                                                                                                                                                                                              TextEdit.51451
14:06:38.812646
                  lstat64
                                                            /Volumes/SSD/HelloWorld.rtf
                                                                                                                                                                                              TextEdit.51451
                                                                                                                                                                                  0.000004
14:06:38.812689
                  getattrlist
                                                           /Volumes/SSD/HelloWorld.rtf
                                                                                                                                                                                  0.000007
                                                                                                                                                                                               TextEdit.51451
                  getattrlist
                                                           /Volumes/SSD/.TemporaryItems/folders.501/TemporaryItems/(A Document Being Saved By TextEdit)/HelloWorld.rtf
14:06:38.812729
                                                                                                                                                                                  0.000009
                                                                                                                                                                                               TextEdit.51451
14:06:38.812742
                  access_extended
                                                            /Volumes/SSD/HelloWorld.rtf
                                                                                                                                                                                  0.000004
                                                                                                                                                                                               TextEdit.51451
14:06:38.812819
                                                            /Volumes/SSD/.TemporaryItems/folders.501/TemporaryItems/(A Document Being Saved By TextEdit)/HelloWorld.rtf
                                                                                                                                                                                  0.000047
                                                                                                                                                                                              TextEdit.51451
                 setattrlist
14:06:38.813400 rename
                                                           /Volumes/SSD/.TemporaryItems/folders.501/TemporaryItems/(A Document Being Saved By TextEdit)/HelloWorld.rtf
                                                                                                                                                                                  0.000568 W TextEdit.51451
```

```
14:06:38.811125
                         .../HelloWorld.rtf
                 open
                                               0.000096
                                                          TextEdit.51451
14:06:38.811144
                 write
                                                          TextEdit.51451
                                               0.000018
14:06:38.812436
                 fsync
                                               0.001293 W TextEdit.51451
14:06:38.813400
                         .../HelloWorld.rtf
                                               0.000568 W TextEdit.51451
                 rename
```

NSDocument implements "Safe Save"



```
/Volumes/SSD/.TemporaryItems/folders.501/TemporaryItems/(A Document Being Saved By TextEdit)
14:06:38.810798 mkdir
                                                                                                                                                                                   0.000096
                                                                                                                                                                                              TextEdit.51451
                                       F=22
14:06:38.811125 Open
                                                   (_WC_T_) /Volumes/SSD/.TemporaryItems/folders.501/TemporaryItems/(A Document Being Saved By TextEdit)/HelloWorld.rtf
                                                                                                                                                                                  0.000115
                                                                                                                                                                                              TextEdit.51451
                                        F=22
                                               B=0x12c
                                                                                                                                                                                   0.000018
                                                                                                                                                                                              TextEdit.51451
                   WrData[AP]
                                     D=0x003816d8 B=0x1000
                                                                    /dev/disk1s5
                                                                                                                                                                                  0.001172 W TextEdit.51451
14:06:38.812436 fsync
                                        F=22
                                                                                                                                                                                   0.001293 W TextEdit.51451
14:06:38.812455
                                     F=22
                                                                                                                                                                                  0.000017
                                                                                                                                                                                              TextEdit.51451
                                                           /Volumes/SSD/.TemporaryItems/folders.501/TemporaryItems/(A Document Being Saved By TextEdit)/HelloWorld.rtf/Volumes/SSD/.TemporaryItems/folders.501/TemporaryItems/(A Document Being Saved By TextEdit)/HelloWorld.rtf
14:06:38.812541 chmod
                                     <rw-r-->
                                                                                                                                                                                  0.000047
                                                                                                                                                                                              TextEdit.51451
14:06:38.812554
                  getattrlist
                                                                                                                                                                                  0.000006
                                                                                                                                                                                               TextEdit.51451
14:06:38.812607
                  utimes
                                                            /Volumes/SSD/.TemporaryItems/folders.501/TemporaryItems/(A Document Being Saved By TextEdit)/HelloWorld.rtf
                                                                                                                                                                                  0.000035
                                                                                                                                                                                              TextEdit.51451
                                           [ 2]
                  lstat64
                                                               /Volumes/SSD/HelloWorld.rtf.sb-1efcc842-9Y3k7V
14:06:38.812636
                                                                                                                                                                                   0.000009
                                                                                                                                                                                              TextEdit.51451
14:06:38.812646
                  lstat64
                                                            /Volumes/SSD/HelloWorld.rtf
                                                                                                                                                                                              TextEdit.51451
                                                                                                                                                                                  0.000004
14:06:38.812689
                  getattrlist
                                                           /Volumes/SSD/HelloWorld.rtf
                                                                                                                                                                                  0.000007
                                                                                                                                                                                               TextEdit.51451
                  getattrlist
                                                           /Volumes/SSD/.TemporaryItems/folders.501/TemporaryItems/(A Document Being Saved By TextEdit)/HelloWorld.rtf
14:06:38.812729
                                                                                                                                                                                  0.000009
                                                                                                                                                                                               TextEdit.51451
14:06:38.812742 access_extended
                                                            /Volumes/SSD/HelloWorld.rtf
                                                                                                                                                                                  0.000004
                                                                                                                                                                                              TextEdit.51451
14:06:38.812819 setattrlist
                                                            /Volumes/SSD/.TemporaryItems/folders.501/TemporaryItems/(A Document Being Saved By TextEdit)/HelloWorld.rtf
                                                                                                                                                                                  0.000047
                                                                                                                                                                                              TextEdit.51451
14:06:38.813400 rename
                                                           /Volumes/SSD/.TemporaryItems/folders.501/TemporaryItems/(A Document Being Saved By TextEdit)/HelloWorld.rtf
                                                                                                                                                                                  0.000568 W TextEdit.51451
```

```
14:06:38.811125open.../HelloWorld.rtf0.000096TextEdit.5145114:06:38.811144write0.000018TextEdit.5145114:06:38.812436fsync0.001293W TextEdit.5145114:06:38.813400rename.../HelloWorld.rtf0.000568W TextEdit.51451
```

Total Time: 0.003351 seconds 1/300 of a second

Agenda

File system and frameworks update

Storage industry trends

Recent changes

Best practices

File Vault 2

What it is

How it works

Agenda

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File Vault 2

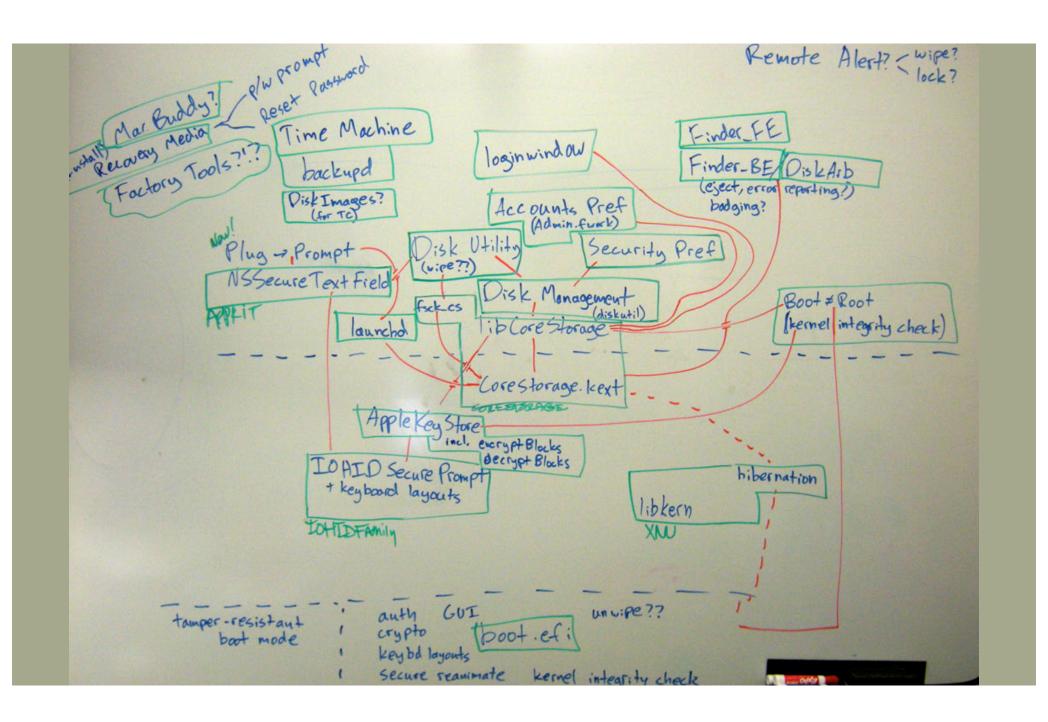
What it is

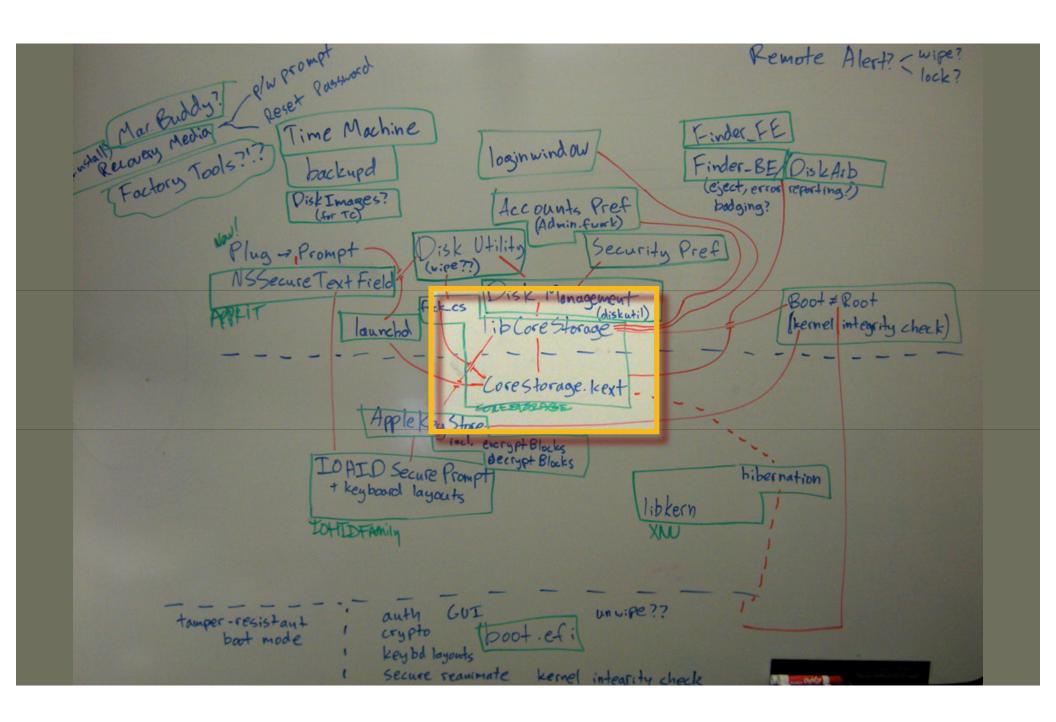
How it works

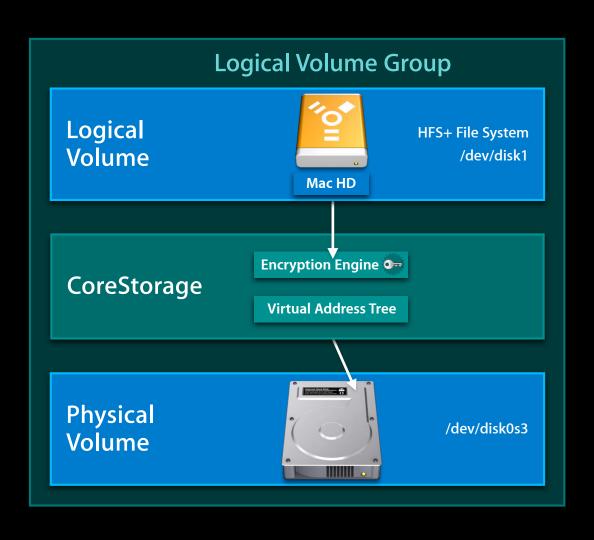
A thief recently stole a computer server belonging to a major U.S. insurance company, and company officials now fear that the personal data of nearly 1 million people could be at risk

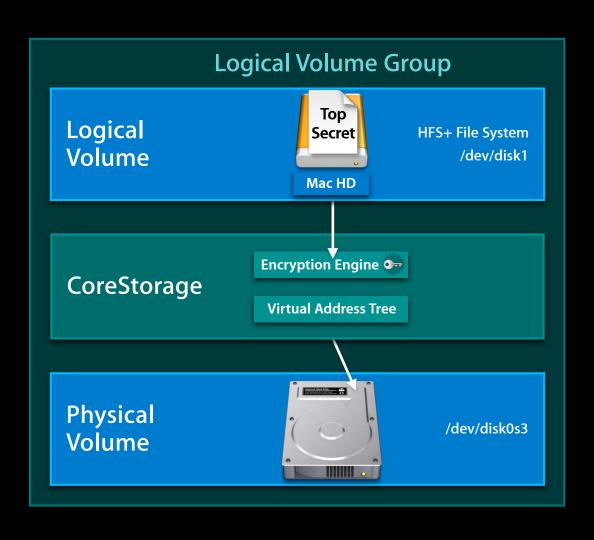
A thief recently stole a computer server belonging to a major U.S. insurance company, and company officials now fear that the personal data of nearly 1 million people could be at risk

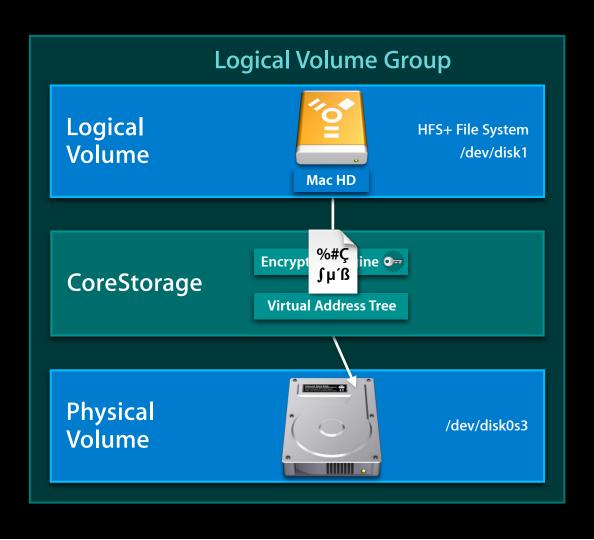
California's law SB 1386, and 41 other states, requires companies to notify consumers whose personal information has been compromised

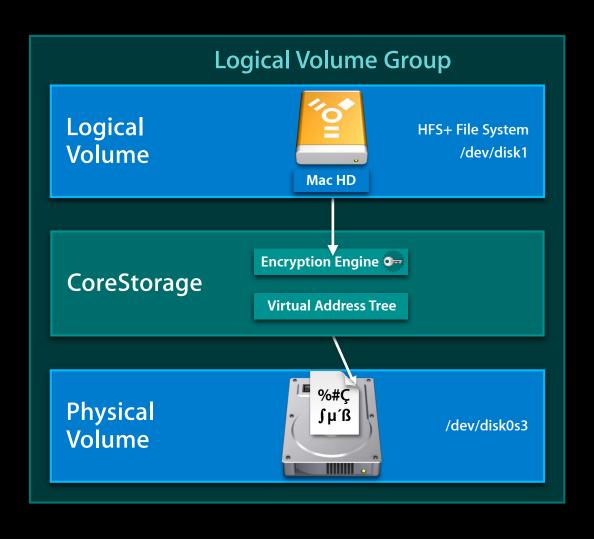












Full disk encryption

- Password protects your volume
- Encrypts every block on your volume
- Includes file data and metadata
 - Names, dates, attributes, etc.
- Encrypt external drives (thumb drives)
- Keychain integration!
- Encrypted Time Machine backups



AES-XTS



- AES-128 + cipher stealing
 - For each 512 byte block
 - Encrypt 16 bytes at a time with AES
 - Mix result across entire block
- FIPS compliant
- NIST standard
 - 1/27/10 NIST recommended AES-XTS mode

AES-XTS



- AES-128 + cipher stealing
 - For each 512 byte block
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How big is 2¹²⁸?

AES-XTS



- AES-128 + cipher stealing
 - For each 512 byte block
 - Encrypt 16 bytes at a time with AES
 - Mix result across entire block
- FIPS compliant
- NIST standard
 - Imagine a computer the size of a grain of sand that could test a key in the amount of time it takes light to cross it.

If the whole planet were covered in 1 meter of these computers, it would take on average 1,000 years to crack a 128-bit key.

"Treat 1st Reboot Special"

- Solves two problems
 - Keyboard no longer functions from EFI
 - User forgot their password
- Reboot into Recovery OS
 - Pair Bluetooth keyboard
 - Unencrypt volume



Personal recovery

- Computer generated password to unlock FDE volume
 - EPD8-8NRF-24T3-ZDUR-J5XM-UATW
- Boots to "Password Reset" in Login Window UI
- Option of saving recovery password with Apple
 - Recovery password is encrypted with three "Bankers Questions"
 - Apple can NOT unlock your disk
 - There is NO back door

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How it works

FileVault 2 How it works

Soren SpiesStorage Technologies

- CoreStorage and in-place encryption
- FileVault 2 Keys
- FileVault 2 Tools
- Investigations/Requests

CoreStorage -> HFS+

root> disk /dev/disk0				
#:		NAME	SIZE	IDENTIFIER
0:	GUID_partition_scheme		*121.8 GB	disk0
1:	EFI		209.7 MB	disk0s1
2:	Apple_CoreStorage		60.7 GB	disk0s2
3:	Apple_Boot	Boot OSX	650.0 MB	disk0s3
3: 4:	Apple_Boot Apple_HFS		650.0 MB 60.2 GB	disk0s3 disk0s4
		Untitled		
4:	Apple_HFS Apple_Boot	Untitled	60.2 GB	disk0s4
4: 5:	Apple_HFS Apple_Boot	Untitled	60.2 GB	disk0s4



CoreStorage

CoreStorage -> HFS+

```
root> diskutil list
/dev/disk0
   #:
                                                                      IDENTIFIER
                             TYPE NAME
                                                           SIZE
   0:
           GUID_partition_scheme
                                                          *121.8 GB
                                                                      disk0
                                                                      disk0s1
                                                           209.7 MB
  2:
               Apple_CoreStorage
                                                           60.7 GB
                                                                      disk0s2
  3:
                      Apple_Boot Boot OSX
                                                           650.0 MB
                                                                      disk0s3
                       Apple_HFS Untitled
                                                           60.2 GB
                                                                      disk0s4
   5:
                      Apple_Boot Boot OSX
                                                           134.2 MB
                                                                      disk0s5
/dev/disk1
                             TYPE NAME
  #:
                                                           SIZE
                                                                      IDENTIFIER
  0:
                        Apple_HFS 11A395
                                                          *60.3 GB
                                                                      disk1
```



CoreStorage

CoreStorage -> HFS+

root> disku /dev/disk0	itil list			
#:	TYPE 1	NAME	SIZE	IDENTIFIER /
0:	GUID_partition_scheme		*121.8 GB	disk0
1:	EFI		209.7 MB	disk0s1
2:	Apple_CoreStorage		60.7 GB	disk0s2
3:	Apple_Boot I	Boot OSX	650.0 MB	disk0s3
4:	Apple_HFS U	Untitled	60.2 GB	disk0s4
5:	Apple_Boot I	Boot OSX	134.2 MB	disk0s5
/dev/disk1				
#:	TYPE I	NAME	SIZE	IDENTI IER
0:	Apple_HFS :	11A395	*60.3 GB	disk1

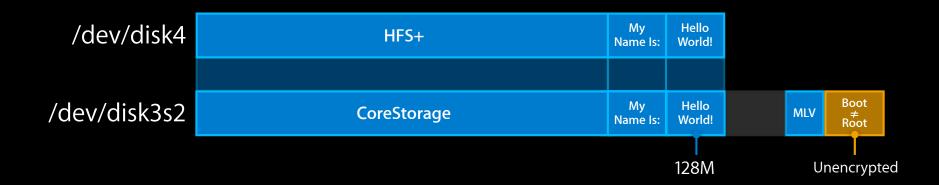


CoreStorage

In-place encryption

- 128 MB mapping window
- Read, modify, write
- Crash -> redo last 128 MB

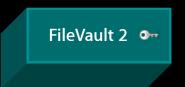




Understanding FileVault 2

In-place encryption

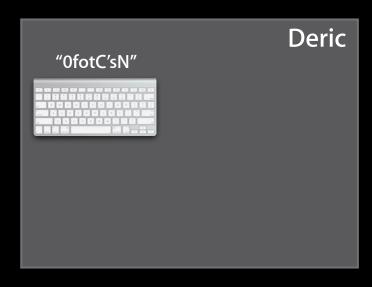
- 128 MB mapping window
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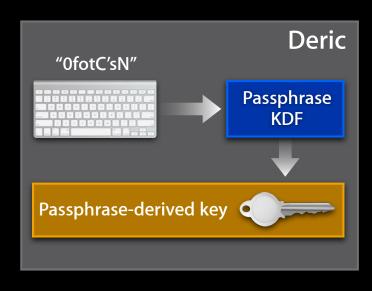


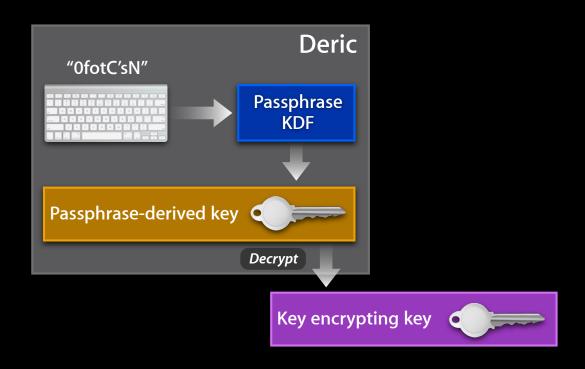


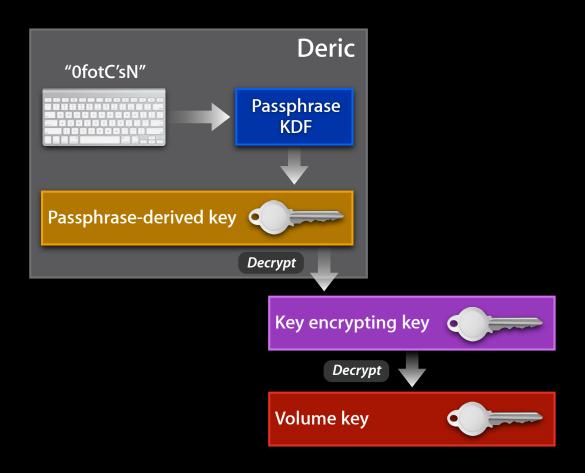
FileVault 2 Keys Storage hierarchy

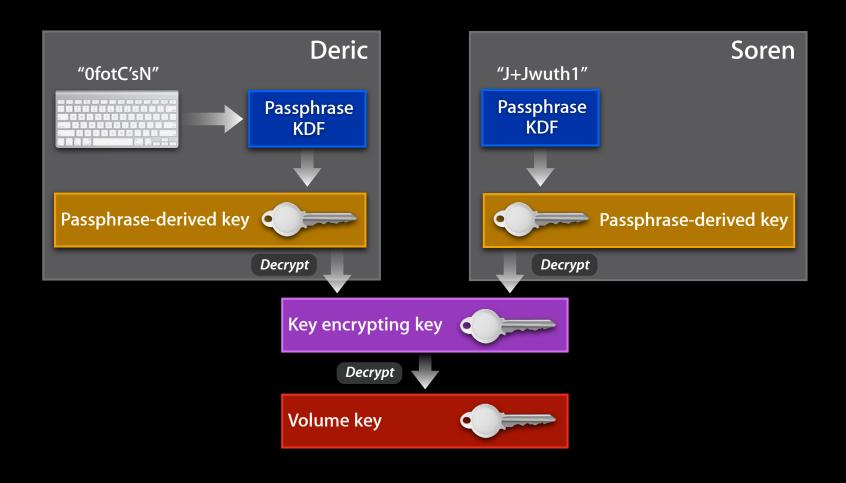
- Random volume key
- Random "key encrypting key"
- Copy of "KEK" for each user











FileVault 2 Keys User types

- OS user
 - Automatically created and synchronized
- Disk passphrase
 - Disk Utility, Time Machine, Finder
 - Optionally store in keychain
- Personal recovery
- Institutional recovery

Bonus: Fast wipe

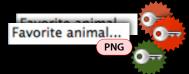
- Encrypted keys in CoreStorage metadata
 - Metadata encrypted with "wipe key"
 - Keys, users, pictures, hints, etc.
- Wipe key in the clear
- Wipe key destruction leaves data "cryptographically inaccessible"

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- Encrypted keys in CoreStorage metadata
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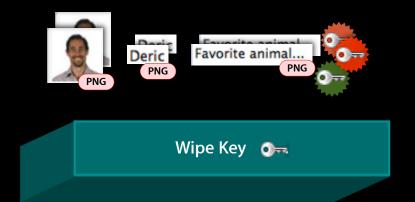






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- Attacks
 - Password
 - Algorithm
- Increase attack cost

Password attacks

- 128-bit keys >> user passwords
 - Precomputed hashes
 - Brute force
- Attack surface
 - Password-encrypted keys
 - Encrypted volume data
- Money, time, computing resources

Mitigating password attacks

- PBKDF2(<password>, <16byteSalt>, ~100k)
 - Calibrated to 1/10 second
- Password verification
 - Store SHA256(32B_RandPrefix | KeyEncryptingKey | 32B_RandSuffix)
 - Unlock KEK, hash, compare

Puppies, 88a8 644a 9d1f 4be3 5a20 b6aa 2bc8 719d



Mitigating password attacks

- PBKDF2(<password>, <16byteSalt>, ~100k)
 - Calibrated to 1/10 second
- Password verification
 - Store SHA256(32B_RandPrefix | KeyEncryptingKey | 32B_RandSuffix)
 - Unlock KEK, hash, compare

4ffc 5343 3ce1 df7d 157a 592a 23df 4d90

~100,000 iterations ~1/10th second

Algorithm attacks

- Attacks
 - Side-channel (timing, power, etc.)
 - Reduced round variant
 - Related key
 - Known-plaintext
 - Chosen-plaintext

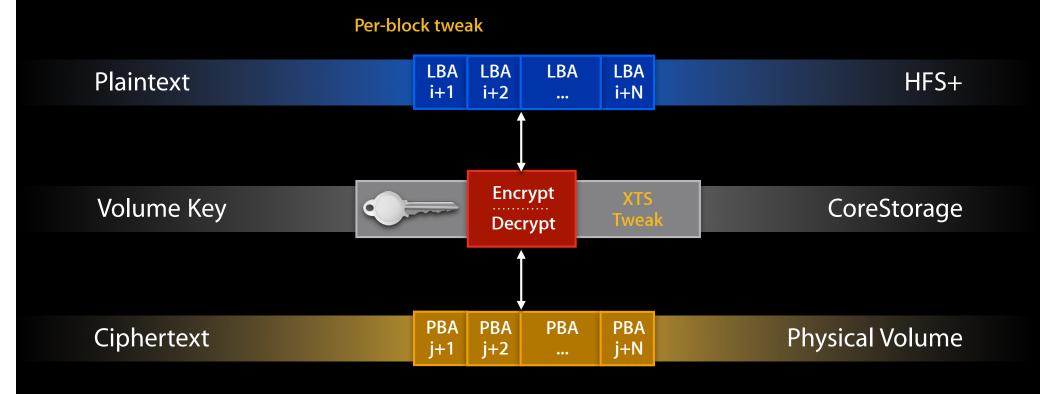
Mitigating algorithm attacks

- Duplicate plaintext
 - Unique ciphertexts within one volume
 - Unique ciphertexts on different volumes

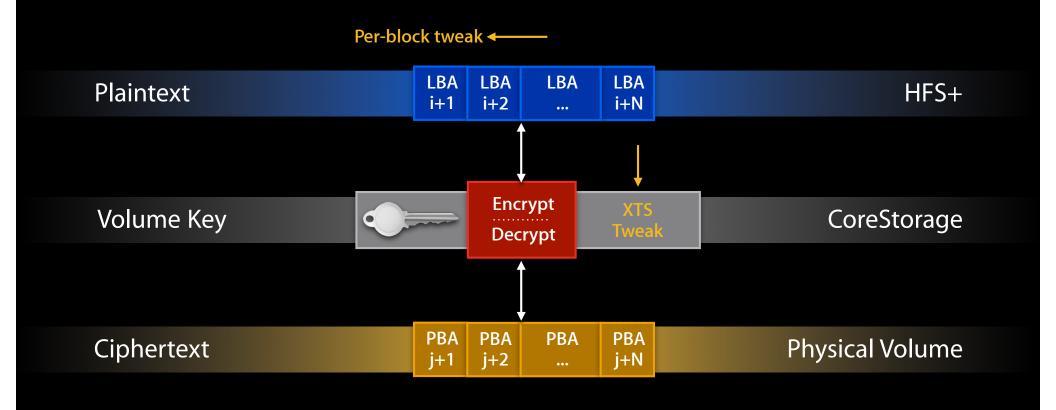
Mitigating algorithm attacks: Tweaking

- Within one volume
 - Every 512 bytes tweaked with logical block address
- On different volumes
 - Random volume key
 - XTS tweaked with SHA256(<volKey>|<volUUID>)

Mitigating algorithm attacks: Tweaking



Mitigating algorithm attacks: Tweaking



diskutil(8)



New: Modify existing CoreStorage volumes

```
diskutil cs encryptVolume
diskutil cs decryptVolume
diskutil cs deleteVolume
```

• Lion

```
diskutil cs create
diskutil cs createVolume
diskutil cs convert [-passphrase]
```

fdesetup(8)



Full FileVault 2 on the command line!

```
$ sudo fdesetup --enable
Enter the primary user name: soren
Enter the password for the user 'soren':
Recovery key = 'PCJ4-99VT-YGHV-G79M-RH3Z-OT55'
Please reboot to complete the process.

$ sudo reboot
...
$ sudo fdesetup --status
Encryption in progress: Percent completed = 35.30
```

fdesetup(8)



Full FileVault 2 on the command line!

```
$ sudo fdesetup --enable
Enter the primary user name: soren
Enter the password for the user 'soren':
Recovery key = 'PCJ4-99VT-YGHV-G79M-RH3Z-OT55'
Please reboot to complete the process.

$ sudo reboot
...
$ sudo fdesetup --status
Encryption in progress: Percent completed = 35.30
```

fdesetup(8)

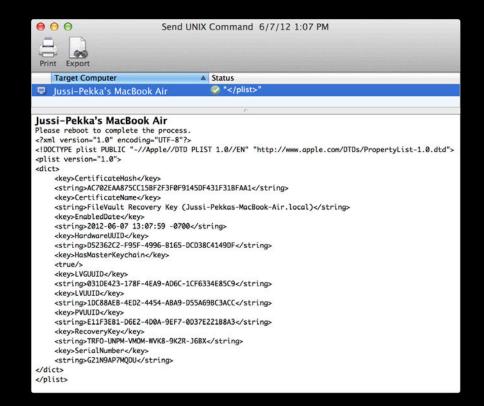


- Add, remove users
 - \$ sudo fdesetup --adduser --usertoadd deric --usertoadd brad
 - \$ sudo dscl delete /Users/brad
 - \$ sudo fdesetup --syncusers
- Disable
 - \$ sudo fdesetup --disable

fdesetup(8) via Remote Desktop

```
# PromptForSecrets |
    fdesetup --enable --inputplist
    --outputplist | EscrowSettings
```

• fdesetup(8) under construction



Securing sleep

- "Data at rest"
 - Sleep ≠ maximally secure
- Stand By
 - Restores keys to RAM
 - A/C power, USB devices

Securing sleep

- "Data at rest"
 - Sleep ≠ maximally secure
- Stand By
 - Restores keys to RAM
 - A/C power, USB devices

\$ sudo pmset —a destroyfvkeyonstandby 1 hibernatemode 25

Requests and Investigations

Requests and Investigations

No promises!

- Authenticated reboot
- Recovery keys
 - Change
 - Detect use
 - Validate installation
- Low-level rekeying
- OS X Server integration
- Mandatory FileVault 2

More Information

Paul Danbold

Core OS Evangelist danbold@apple.com

Documentation

File System Programming Guide http://developer.apple.com

Apple Developer Forums

http://devforums.apple.com

Related Sessions

iOS App Performance: Responsiveness	Presidio Thursday 11:30AM
Asynchronous Design Patterns with Blocks, GCD, and XPC	Pacific Heights Friday 9:00AM
	Nob Hill Friday 9:00AM

Labs

File System Lab	Core OS Lab B Thursday 3:15PM
iCloud Storage Lab	Essentials Lab B Thursday 4:30PM
OS X Performance Lab	Developer Tools Lab A Friday 9:00AM
Power Management Lab	Core OS Lab B Friday 10:15AM

Summary

Remember...

- Performance ~ energy consumption
- Use recommended APIs and frameworks
 - Apple always optimizing
- Beware unexpected latency
 - No I/O on main UI thread

ÉWWDC2012