Forensic Discovery

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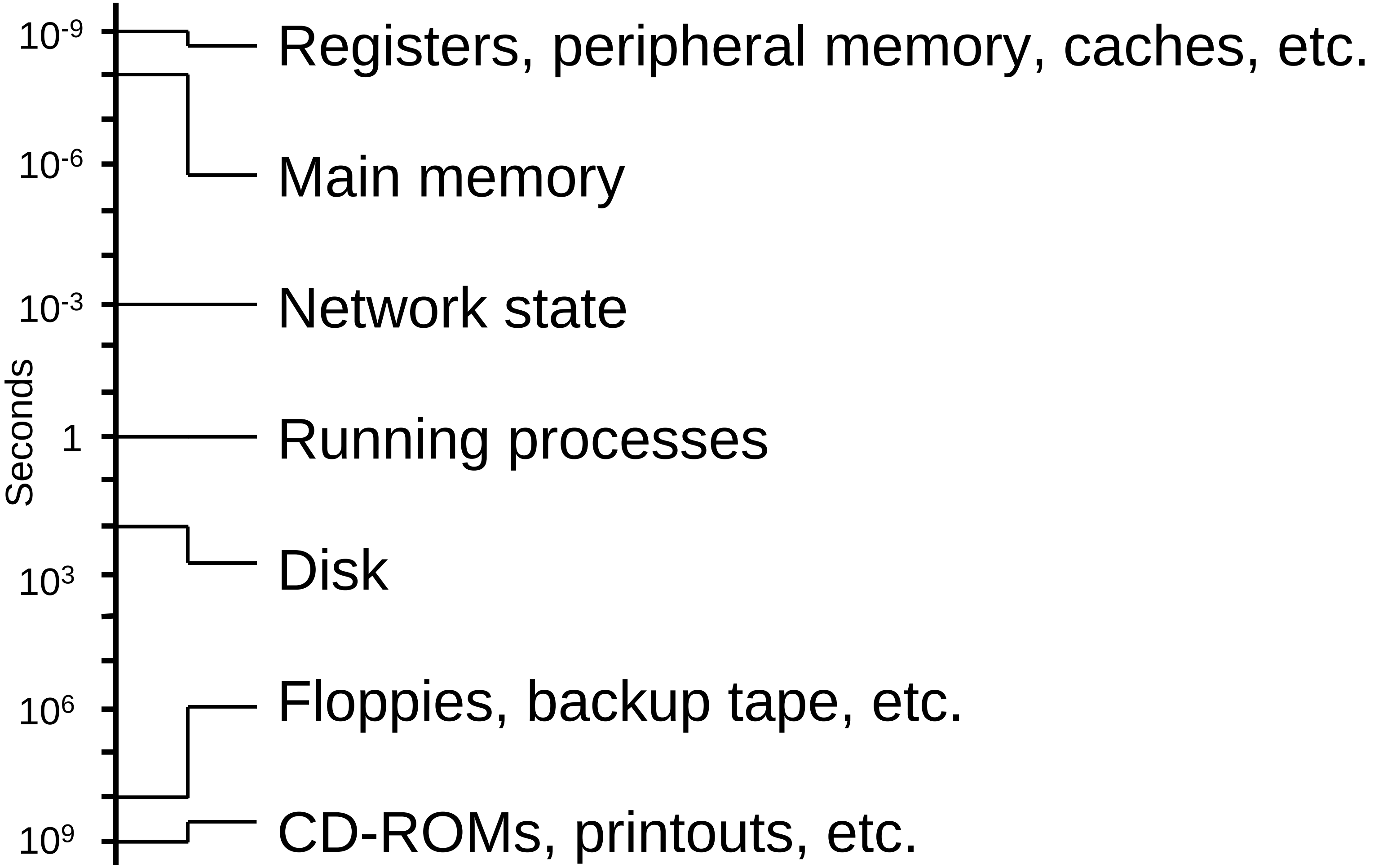
Overview

- Basic concepts.
- Time from file systems and less conventional sources.
- Post-mortem file system case study.
- Persistence of deleted data on disk and in main memory.
- Recovering WinXP/Linux encrypted files without key.
- Book text and software at author websites:
  - http://www.porcupine.org/
  - http://www.fish2.com/

Order of Volatility
(from nanoseconds to tens of years)



Registers, peripheral memory, caches, etc.

Main memory

Network state

Running processes

Disk

Floppies, backup tape, etc.

CD-ROMs, printouts, etc.

Most files are accessed rarely

	www.things.org	*www.fish2.com*	*news.earthlink.net*
less than 1 day	3 %	2 %	2 %
1 day – 1 month	4 %	3 %	7 %
1 - 6 months	9 %	1 %	72 %
6 months – 1 year	8 %	19 %	7 %
more than 1 year	77 %	75 %	11 %

Numbers are based on file read access times.

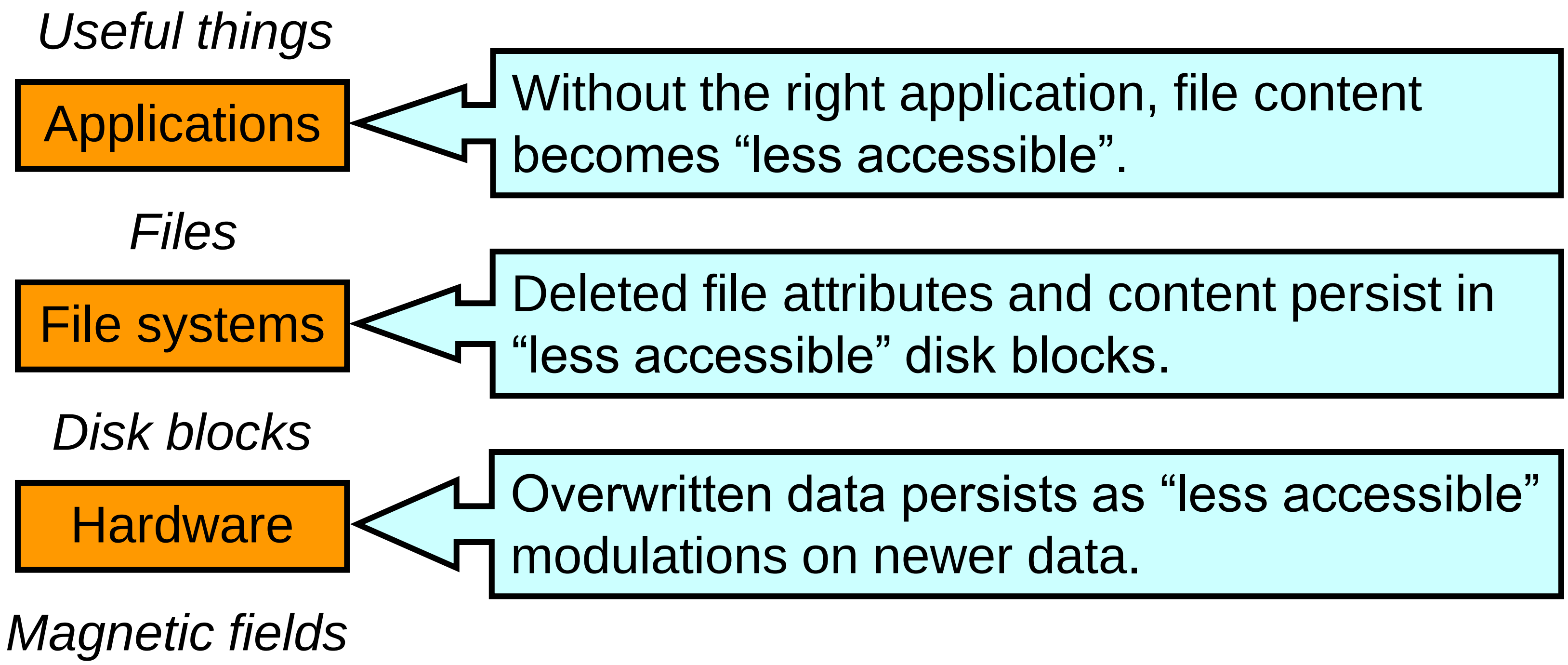
Erosion paradox

- Information disappears, even if you do nothing. Examples: logfiles and last file access times.

- Routine user or system activity touches the same files again and again - literally stepping on its own footprints.

- Footprints from unusual behavior stand out, and for a relatively long time.

Fossilization and abstraction layers
(not included: financial and political layers)



Useful things

Applications

Without the right application, file content becomes “less accessible”.

Files

File systems

Deleted file attributes and content persist in “less accessible” disk blocks.

Disk blocks

Hardware

Overwritten data persists as “less accessible” modulations on newer data.

Magnetic fields

- Information deleted at layer *N* persists at layers *N-1*, etc.
- It becomes <u>frozen in time</u>; older data sits in lower layers.

Cost of an investigation
(not entirely serious)

Effort	*Skill level*	*Time*
Do nothing	None	Almost none
Minimal	Install system s/w	< 1 Day
Recommended	Junior sysadmin	1-2 Days
Serious	Senior sysadmin	Days – weeks
Fanatical	Expert sysadmin	Months

MACtimes Introduction

What are MACtimes?

- **Mtime** Time of last modification
(Write/truncate, create/delete dir entry).
- **Atime** Time of last access
(Read/execute file, look up dir entry).
- **Ctime** Time of last attribute change
(Owner, permission, ref count, size, etc.).
- dtime Time of file deletion (LINUX).

Getting MACtimes

```
($dev,$inode,$mode,$nlink,$uid,$gid,$rdev,$size,
 $atime,$mtime,$ctime,$blksz,$blks) = lstat($file);
```

- Perl’s *lstat*() returns file attributes.
- Works in *UFS*, *Ext2fs*, *NTFS*, etc. (even *FAT*).
- TCT[1] Command: “*grave-robber -m*” or “*mactime -d*”.

[1] The Coroner’s toolkit, see references at end of file

Example – login session

(what the user sees)

```
$ telnet sunos.fish2.com
Trying 216.240.49.177...
Connected to sunos.fish2.com.
Escape character is '^]'.

SunOS UNIX (sunos)

login: zen
Password:
Last login: Thu Dec 25 09:30:21 from flying.fish2.com

Welcome to ancient history!
$
```

Question: Why does this example use a 15 year old system?

Example – login session

(MACtime view)

```
Time        Size   MAC   Permission   Owner  Group    File name
19:47:04   49152   .a.   -rwsr-xr-x   root   staff    /usr/bin/login
           32768   .a.   -rwxr-xr-x   root   staff    /usr/etc/in.telnetd

19:47:08     272   .a.   -rw-r--r--   root   staff    /etc/group
             108   .a.   -r--r--r--   root   staff    /etc/motd
            8234   .a.   -rw-r--r--   root   staff    /etc/ttytab
            3636   m.c   -rw-rw-rw-   root   staff    /etc/utmp
           28056   m.c   -rw-r--r--   root   staff    /var/adm/lastlog
         1250496   m.c   -rw-r--r--   root   staff    /var/adm/wtmp

19:47:09    1041   .a.   -rw-r--r--   root   staff    /etc/passwd
19:47:10  147456   .a.   -rwxr-xr-x   root   staff    /bin/csh
```

(m=modified, a=read/execute access, c=status change)

Uses for MACtimes

- Profiling user activity (activity footprint).
- Understanding systems (execution footprint).
- Improving system security (used/unused files).
- Dead or alive (deleted/existing file attributes).

MACtime Limitations

- Shows only the ***last time*** something happened.
- Easy to forge: UNIX **`utime`**(), Windows **`SetFileTime`**().
- Digital Alzheimer's. Data erodes over time.
- Only unusual behavior persists.

MACtimes in Journaling File Systems

Journal files are like trees,
growing one ring at a time

Example: MACtimes from cron job

(25-Hour Ext3fs journal)

```
Time          Size MAC Permissions Owner File name
19:30:00    541096 .a. -rwxr-xr-x  root  /bin/bash
19:30:00     26152 .a. -rwxr-xr-x  root  /bin/date
19:30:00         4 .a. lrwxrwxrwx  root  /bin/sh -> bash
19:30:00       550 .a. -rw-r--r--  root  /etc/group
19:30:00      1267 .a. -rw-r--r--  root  /etc/localtime
19:30:00       117 .a. -rw-r--r--  root  /etc/mtab
19:30:00       274 .a. -rwxr-xr-x  root  /usr/lib/sa/sa1
19:30:00     19880 .a. -rwxr-xr-x  root  /usr/lib/sa/sadc
19:30:00     29238 m.c -rw-------  root  /var/log/cron
19:30:00    114453 mac -rw-r--r--  root  /var/log/sa/sa19

19:40:00    541096 .a. -rwxr-xr-x  root  /bin/bash
19:40:00     26152 .a. -rwxr-xr-x  root  /bin/date
19:40:00         4 .a. lrwxrwxrwx  root  /bin/sh -> bash
19:40:00       550 .a. -rw-r--r--  root  /etc/group
19:40:00      1267 .a. -rw-r--r--  root  /etc/localtime
19:40:00       117 .a. -rw-r--r--  root  /etc/mtab
19:40:00       274 .a. -rwxr-xr-x  root  /usr/lib/sa/sa1
19:40:00     19880 .a. -rwxr-xr-x  root  /usr/lib/sa/sadc
19:40:00     29310 m.c -rw-------  root  /var/log/cron
19:40:00    115421 mac -rw-r--r--  root  /var/log/sa/sa19
```

What is a journaling file system?

- Principle: append some or all file system updates to a “journal file” *before* updating the file system itself.
- Sounds like extra work, but performance can be good (one reason is that disk updates can be sorted).
- Long-time feature with enterpri$e-class file systems.
- More recently popularized on Windows and *N*X: *Ext3fs*, *JFS*, *NTFS*, *Reiserfs*, *XFS*, Solaris *UFS* and others.
- Dramatically improves recovery time from system crash.

Why journaling file systems (1/2)

- Short answer: FSCK and SCANDISK are too slow :-(
- Long answer: need *multiple disk updates* for non-trivial file operations such as create, append, remove, etc.:
  - Update file *data* (when writing to file).
  - Update file *metadata*:
    - What disk blocks are “free”.
    - What disk blocks belong to a specific file.
    - What files belong to a specific directory.
    - And more. All this has to be kept consistent.

Why journaling file systems (2/2)

- Problem: can’t do multiple disk updates at the same time. Bummer.
- After system crash, file systems such as *UFS*[1], *Ext2fs* and *FAT* can be left in an inconsistent state. Examples:
  - Lost blocks (not “free” and not part of any file).
  - Dup blocks (both “free” and part of a file).
- With journaling, recovery is near instantaneous: discard incomplete operations, commit remainder to file system.

[1] With FreeBSD UFS + soft metadata updates, parts of fsck can run in the background. Eek!

Forensic information in journal files

Two types of journaling file system:

- ***Metadata only:*** *Ext3fs*, *JFS*, *NTFS*, *Reiserfs*, *XFS*.
- ***Data and metadata***: *Ext3fs*, but it’s not the default.

Focusing on MACtime information:

- File read/write activity generates file read/write access time entries in the file system journal.
- Journal is a time series of MACtimes.
- ! ! ! We can see before the “last” access ! ! !

Example: MACtimes from cron job

(25-Hour Ext3fs journal)

```
Time          Size MAC Permissions Owner File name
19:30:00   541096 .a. -rwxr-xr-x  root  /bin/bash
19:30:00    26152 .a. -rwxr-xr-x  root  /bin/date
19:30:00        4 .a. lrwxrwxrwx  root  /bin/sh -> bash
19:30:00      550 .a. -rw-r--r--  root  /etc/group
19:30:00     1267 .a. -rw-r--r--  root  /etc/localtime
19:30:00      117 .a. -rw-r--r--  root  /etc/mtab
19:30:00      274 .a. -rwxr-xr-x  root  /usr/lib/sa/sa1
19:30:00    19880 .a. -rwxr-xr-x  root  /usr/lib/sa/sadc
19:30:00    29238 m.c -rw-------  root  /var/log/cron
19:30:00   114453 mac -rw-r--r--  root  /var/log/sa/sa19

19:40:00   541096 .a. -rwxr-xr-x  root  /bin/bash
19:40:00    26152 .a. -rwxr-xr-x  root  /bin/date
19:40:00        4 .a. lrwxrwxrwx  root  /bin/sh -> bash
19:40:00      550 .a. -rw-r--r--  root  /etc/group
19:40:00     1267 .a. -rw-r--r--  root  /etc/localtime
19:40:00      117 .a. -rw-r--r--  root  /etc/mtab
19:40:00      274 .a. -rwxr-xr-x  root  /usr/lib/sa/sa1
19:40:00    19880 .a. -rwxr-xr-x  root  /usr/lib/sa/sadc
19:40:00    29310 m.c -rw-------  root  /var/log/cron
19:40:00   115421 mac -rw-r--r--  root  /var/log/sa/sa19
```

Journal MACtimes benefits

- Regular activity (*cron* job) shows up like a heart beat.
- Can actually see logfiles grow over time.
- With data journaling, can see file writes too.
- Journals are like watching a tree grow one ring at a time.

Journaling case study: Ext3fs

- Default file system with many Linux distributions.
- Same on-disk format as *Ext2fs* (easy migration).
- Journal is kept in a regular file:

```
linux# tune2fs -l /dev/hda2[1] | grep -i journal
Filesystem features:  has_journal [more stuff]
Journal inode:        8
Journal backup:       inode blocks
```

- Journal file has no name, but can be captured with, for example, *icat* from the Coroner's Toolkit:

```
linux# icat /dev/hda2[1] 8 >journalfile
```

[1] Actually, it was */dev/mapper/VolGroup00-LogVol00*, but that is too much text.

Looking inside the Ext3fs journal

- Linux *debugfs* command can examine the *Ext3fs* journal. You can search for only one file at a time :-(
- Example: query the journal for password file accesses:

```
linux# debugfs -R 'logdump -c -i /etc/passwd' /dev/hda2
| grep atime
 atime: 0x4614120d -- Wed Apr  4 17:01:01 2007
 atime: 0x4614201d -- Wed Apr  4 18:01:01 2007
 atime: 0x46142e2d -- Wed Apr  4 19:01:01 2007
```

- Specify "*logdump -f journalfile*" to use saved journal file.
- Modified *debugfs* source to dump all journal MACtime information is available at http://www.porcupine.org/.

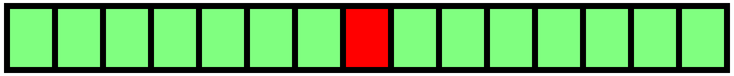
Example: booting up a Linux box

(records start after read/write remount)

```
Time       Size MAC Permissions File name
12:30:12      0 mac srwxr-xr-x  /dev/gpmctl
12:30:12   8538 .a. -rwxr-xr-x  /sbin/minilogd
12:30:13  10680 .a. -rwxr-xr-x  /bin/basename
12:30:13  81996 .a. -rwxr-xr-x  /bin/mount
12:30:13      0 ..c crw-------  /dev/audio
 . . . 89 other /dev records omitted . . .
12:30:13      0 ..c crw-------  /dev/sequencer
12:30:13   4096 m.c drwxr-xr-x  /etc
12:30:13   2453 .a. -rw-r--r--  /etc/security/console.perms
12:30:13     17 .a. lrwxrwxrwx  /lib/libcom_err.so.2 -> libcom_err.so.2.0
12:30:13  29205 .a. -rwxr-xr-x  /lib/libcom_err.so.2.0
12:30:13     16 .a. lrwxrwxrwx  /lib/libext2fs.so.2
12:30:13  56251 .a. -rwxr-xr-x  /lib/libext2fs.so.2.4 -> libext2fs.so.2.4
12:30:13   4096 .a. drwxr-xr-x  /lib/modules/2.4.18-14
12:30:13   4096 .a. drwxr-xr-x  /lib/modules/2.4.18-14/kernel
 . . . 185 other /lib/modules records omitted . . .
12:30:13     39 .a. lrwxrwxrwx  /lib/modules/2.4.18-14/pcmcia/yenta_socket.o
12:30:13  57624 .a. -rwxr-xr-x  /sbin/depmod
12:30:13  22424 .a. -rwxr-xr-x  /sbin/fsck
12:30:13  74528 .a. -r-xr-xr-x  /sbin/pam_console_apply
12:30:13  70550 .a. -rwxr-xr-x  /sbin/quotaon
 . . . 1326 records omitted . . .
```

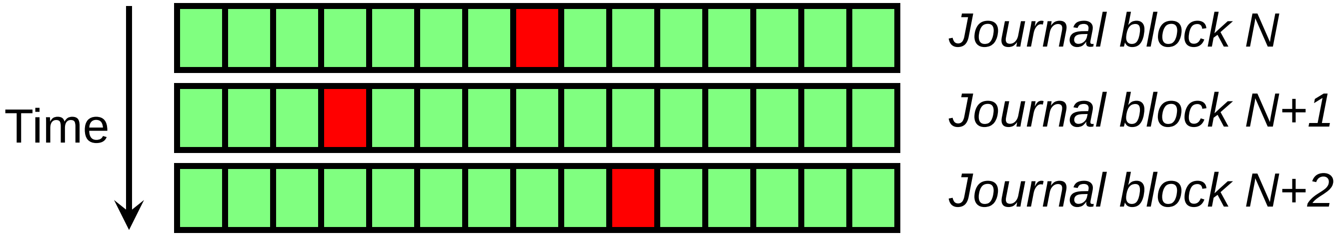
Ext3fs journaling gotchas: bystander attributes

- The journal contains updates for *entire* (meta)data disk blocks. An inode (file attribute block) is much smaller.



Disk block containing only one modified inode.

- When one file attribute is updated, many neighboring file attributes end up in the journal too, because they happen to live in the same disk block (bystanders).



Journal with modified inodes amidst bystander inodes.

Ext3fs journaling gotchas, cont’d

- The *debugfs* journal dumping feature sometimes does not recognize where the journal ends, and produces garbage from that point onwards.
- The *Ext3fs* journal file size is fixed (typically: 128MB with 2.6 kernels). The amount of history is limited.
- When saving the journal from a file system that uses data+metadata journaling, save the journal elsewhere, otherwise the journal will overwrite itself!

Journal MACtimes - conclusion

- *Ext3fs* journaling is forensics friendly. The journal is kept in a regular file, and is easy to capture and analyze.
- Other journaling file systems may not be as helpful.
- Non-journaling approaches to crash-proof file systems may or may not have forensic benefits:
  - *UFS* soft metadata are all about very carefully scheduled disk updates. No forensic benefits.
  - Solaris 10 *ZFS* ***copy-on-write*** file system. Obvious forensic benefits, because data is not overwritten (at least, not immediately).

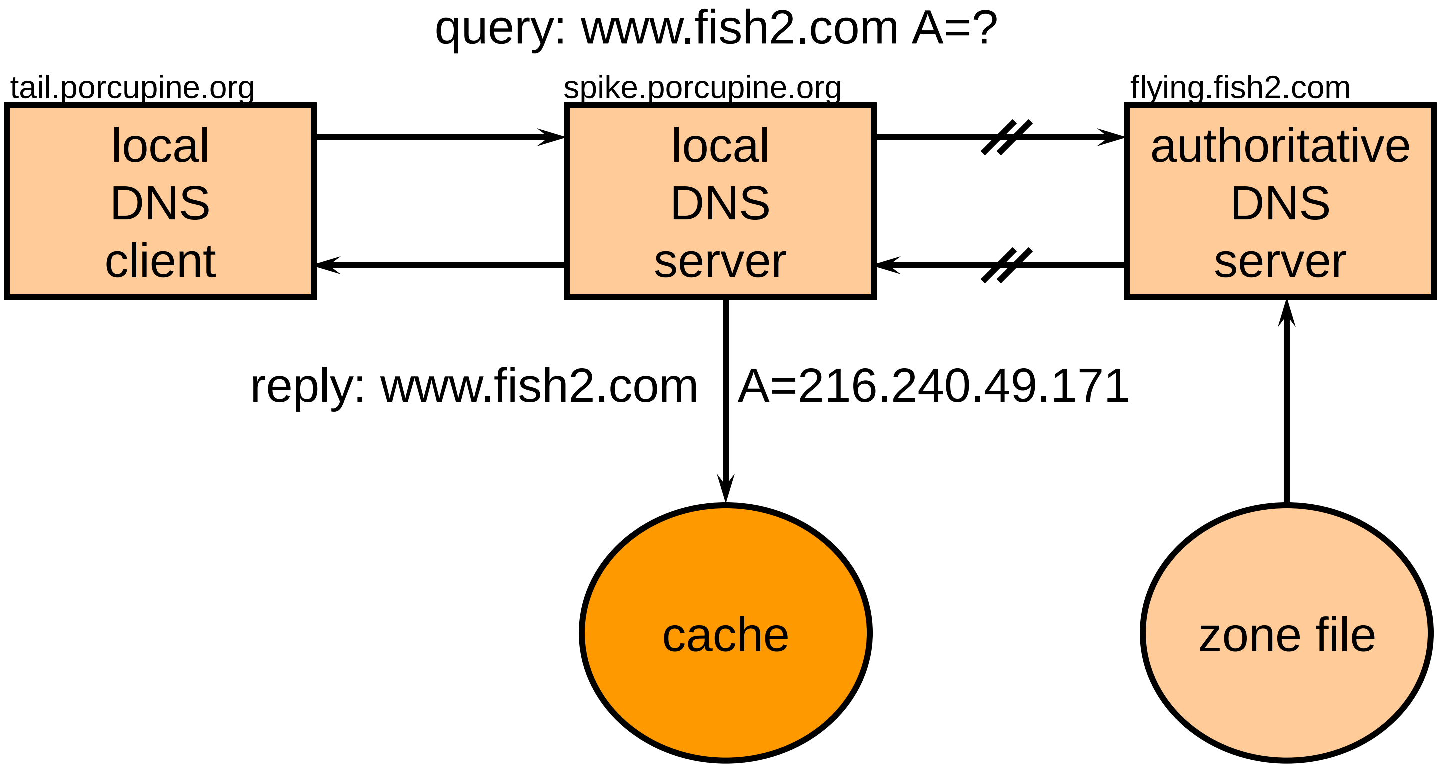
MACtimes in DNS

And sources of time in other unconventional places

DNS Terminology

- **A** – Address records, which map a domain name to an IP number.
- **PTR** - pointer records, which map an IP number to a domain name.
- **MX** – Mail Exchange records, which tell mail agents where email should be sent to.
- **TTL** - Time To Live, how long to remember a reply after it was received.

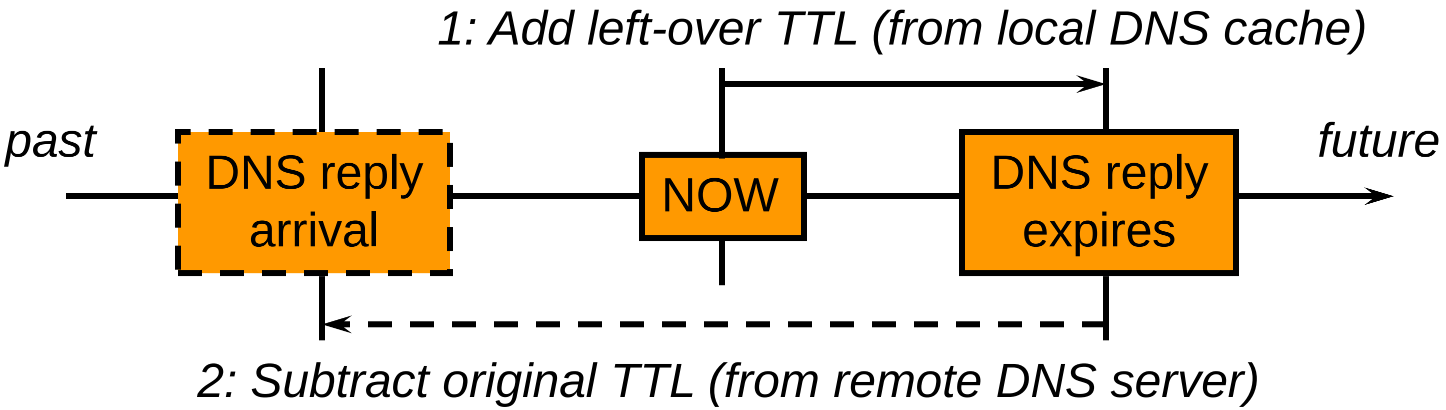
Simplified DNS architecture



- Not shown: root servers; other (non-)forwarding servers; other (non-)recursive queries; remote cache snooping.

MAC-DNS-time, theory

1 Get the ***left-over*** TTLs from the ***local*** DNS server cache.


1: Add left-over TTL (from local DNS cache)
past
DNS reply arrival
NOW
DNS reply expires
future
2: Subtract original TTL (from remote DNS server)

2 Look up the ***original*** TTL values from the ***remote*** DNS server for the corresponding PTR, A, MX, etc. records.

- The *computed* reply arrival time may be wrong, because the *original* TTL may have changed.

MAC-DNS-time, practice

```
# kill -SIGINT <BIND-pid>      (BIND < 9)
# rndc dumpdb                  (BIND 9)
```

- Dumped log records + processing with small perl program[1], for an ftp connection event:

```
Oct 13 09:57:13 PTR=pox.remarque.org.
Oct 13 09:57:14 A=209.209.13.172
Oct 13 09:57:14 tsunami in.ftpd[5674]: connect
    from pox.remarque.org
```

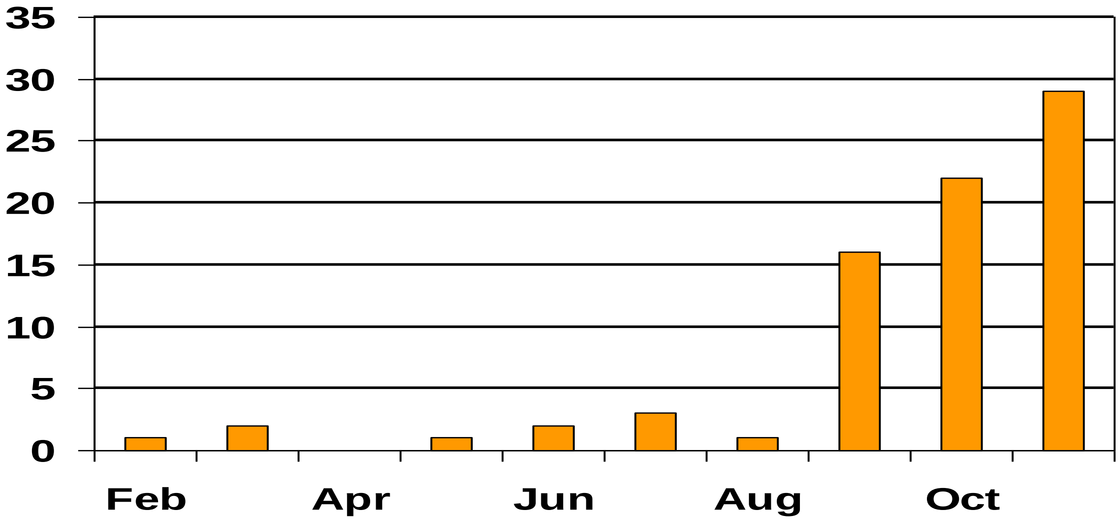
[1] Source code available at book website.

Other Time Sources

- Every cache can be exploited to some extent:
  - Proxy server caches.
  - DNS server caches.
  - ARP caches (e.g., IP to ethernet address mapping).

- Other unconventional sources of time information:
  - Long-lived process memory (syslogd!).
  - Main memory.
  - Swap files.
  - Deleted files.

Swap file persistence - YMMV
(translation: your mileage may vary)



- Nr. of time stamps per month for small www+ftp server:

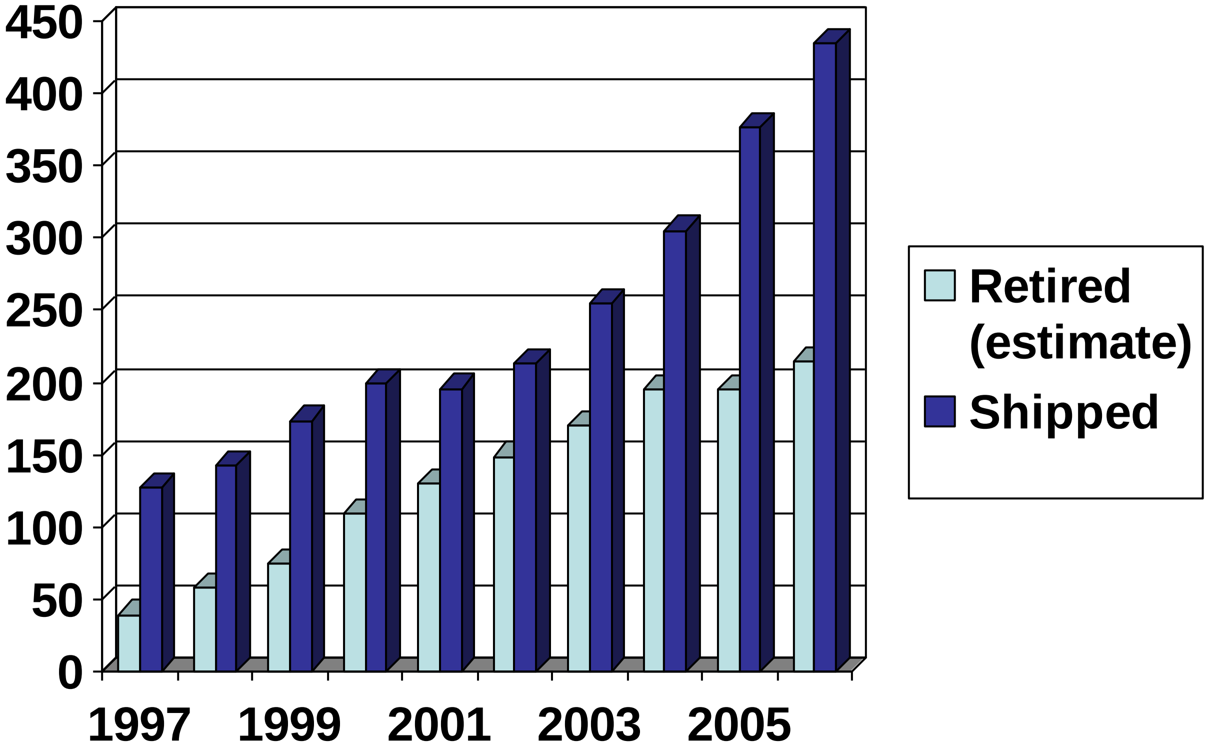
```
# strings /dev/rwd0b | grep ′^[A-Z][a-z][a-z] [ 0-3][0-
9] [0-9][0-9]:[0-9][0-9]:[0-9][0-9] ′ | awk ′{print $1}′
| sort -M | uniq -c
```

- No time stamps in swap file after hardware upgrade :-(

Intermezzo: information on retired disks

Global hard disk market

(Millions shipped, source: Dataquest, iSuppli)



Long-term collection of retired disks

- Experiment: buy used drives, mainly via Ebay.
- Time frame: 1998 - 2006.
- 1005 Drives purchased.
- 750 Drives included in “corpus” for research.
- 449 Drives contained active file system.
- 324 Drives had more than 5 files.
- 882 GB of file content was recovered.

Simson Garfinkel, DFRWS 2007

http://www.dfrws.org/2007/proceedings/p2-garfinkel.pdf

Results from early informal survey (Garfinkel & Shelat)

- Time frame: November 2000 - August 2002.
- 158 Drives purchased.
- 129 Drives still worked.
- 51 Drives “formatted”, leaving most data intact.
- 12 Drives overwritten with fill pattern.
- 75 GB of file content was found or recovered.

IEEE Privacy & Security January/February 2003, http://www.simson.net/clips/academic/2003.IEEE.DiskDriveForensics.pdf

What information can be found on a retired disk

- One drive with 2868 account numbers, access dates, balances, ATM software, but no DES key.
- One drive with 3722 credit card numbers.
- Corporate memoranda about personnel issues.
- Letter to doctor from cancer patient’s parent.
- Email (17 drives with more than 100 messages).
- 675 MS Word documents.
- 566 MS Powerpoint presentations.
- 274 MS Excel spreadsheets.

Deleted Files Introduction

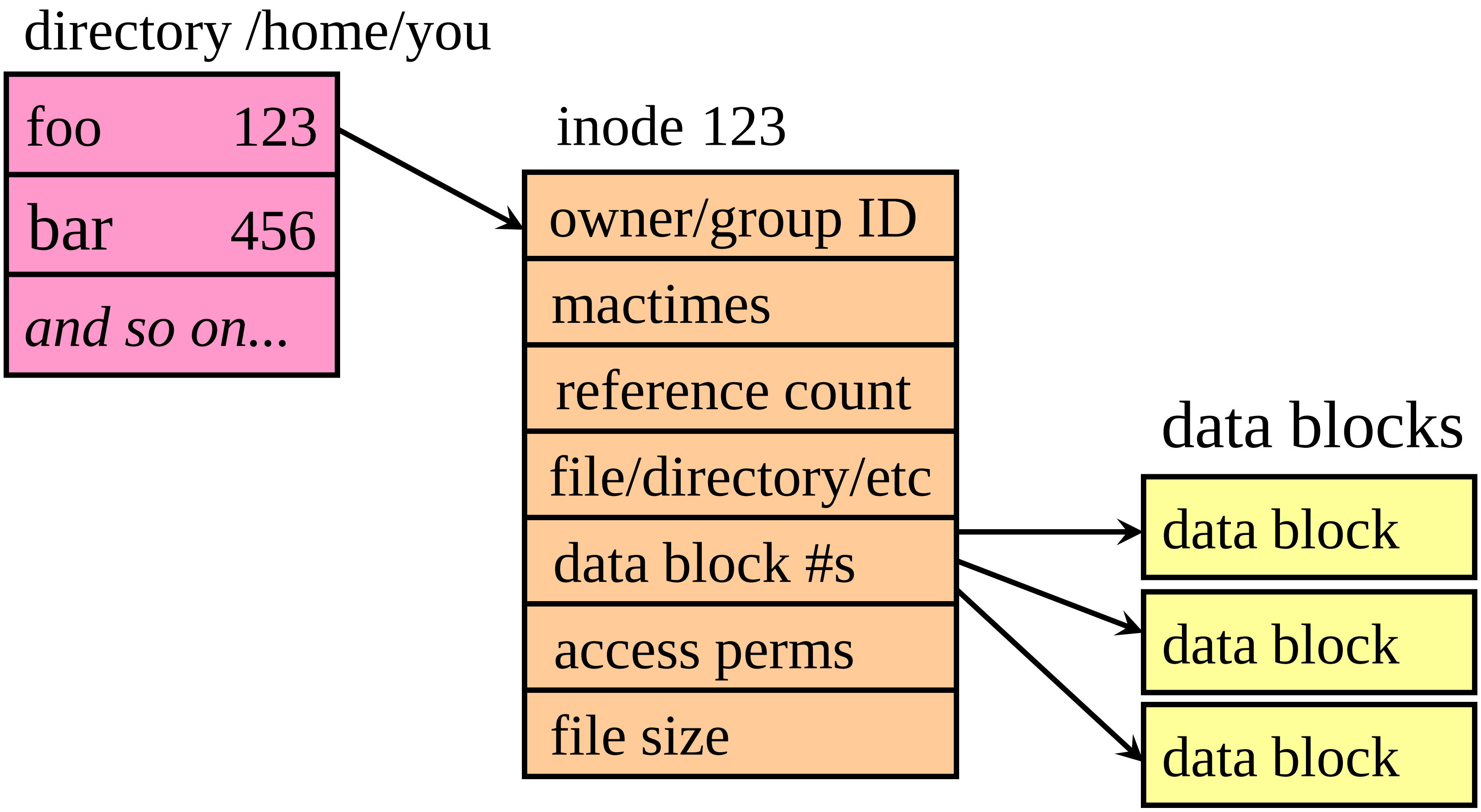
Deleted files - overview

- Organization of typical UNIX and Linux file systems: *UFS*[1], *Ext3fs*[2], and their direct family members.
- What information is destroyed and what is preserved when a file is deleted.
- Tools to access (deleted) file information.

[1] Berkeley fast file system, found on *BSD, Solaris, etc.

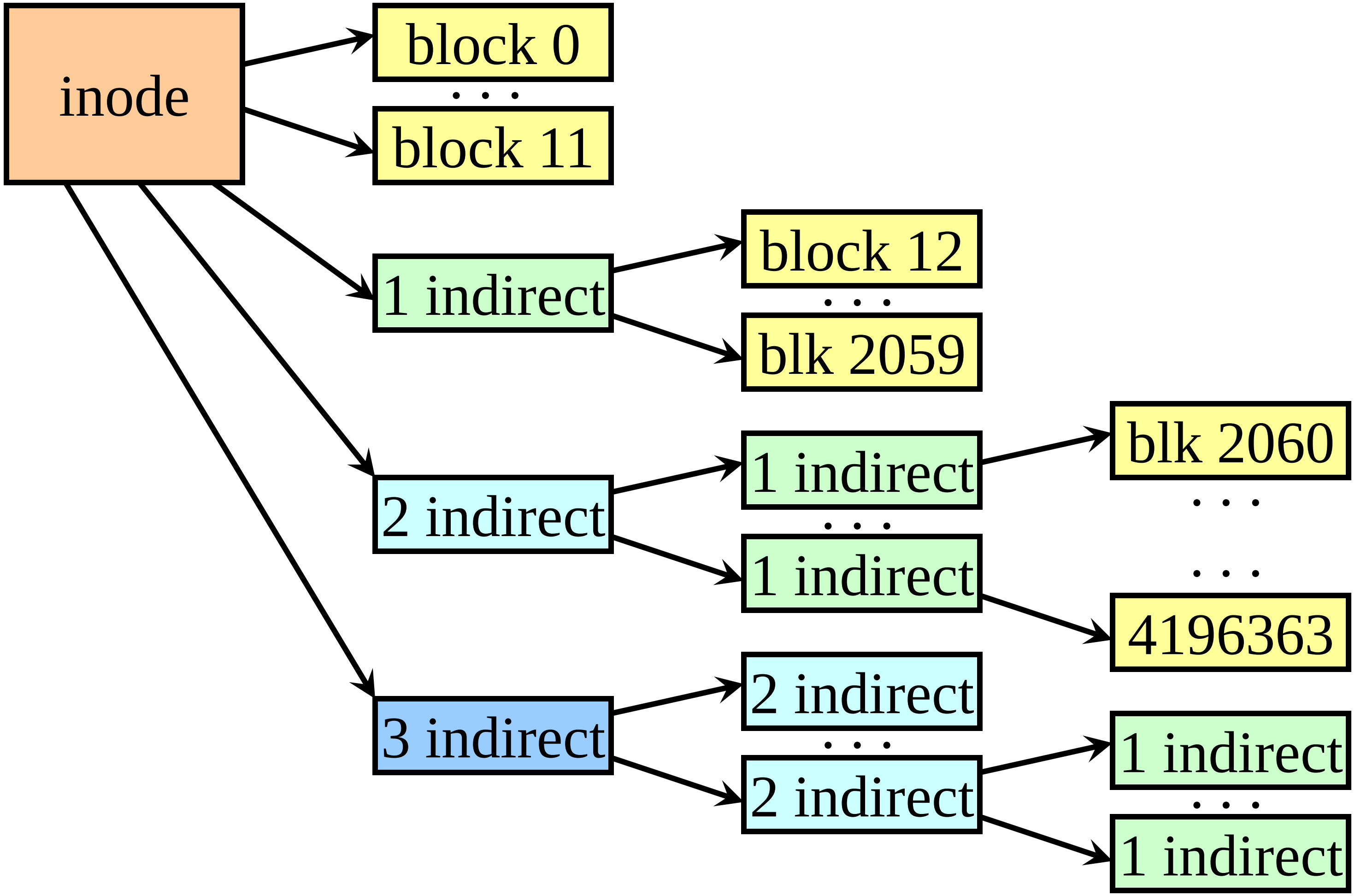
[2] Third extended file system, found on Linux.

UNIX/Linux file system basics



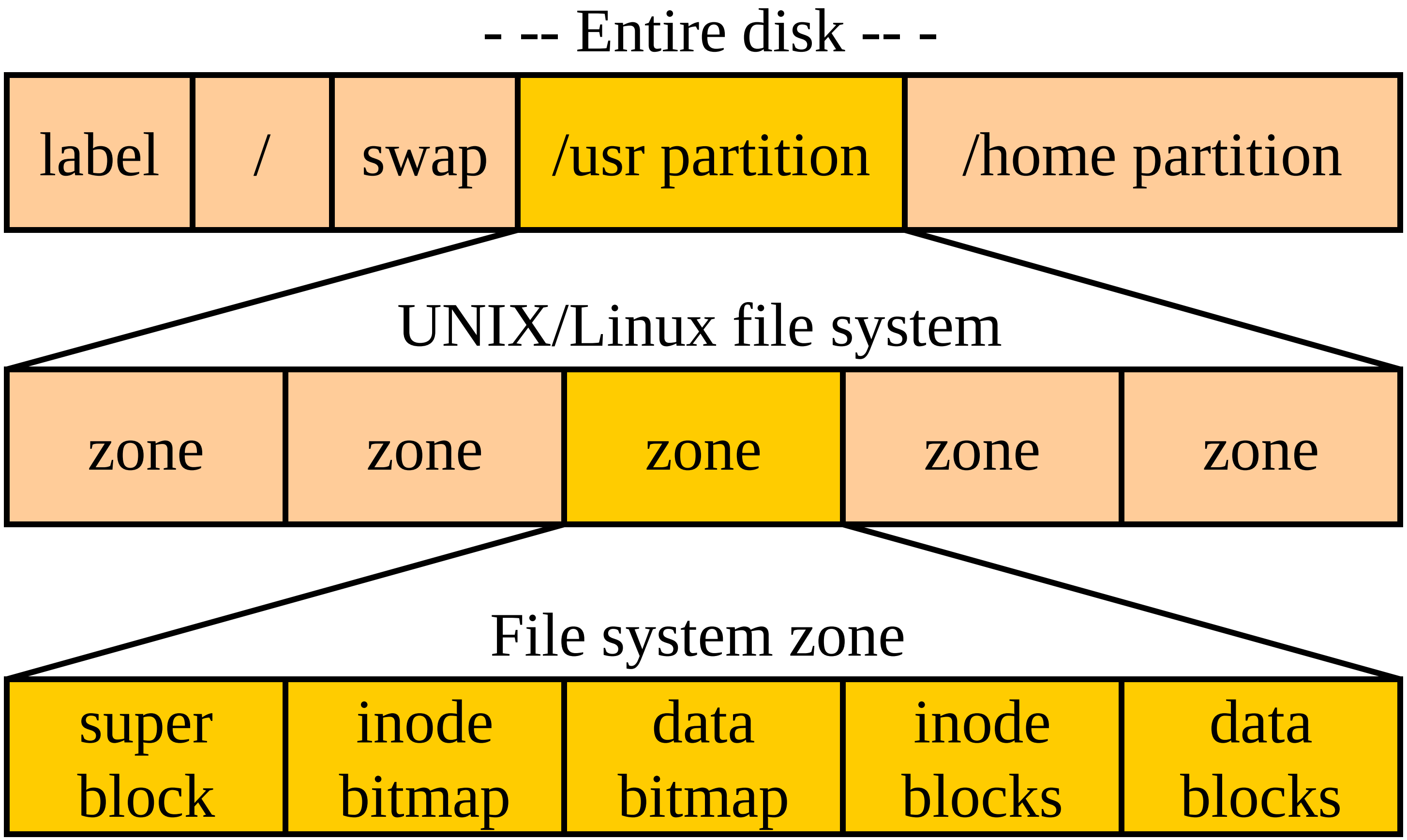
Direct and indirect data blocks

(the truth, the whole truth, and nothing but the truth)



Specific block numbers are typical for Berkeley UFS-like file systems

Typical UNIX/Linux disk layout



- -- Entire disk -- -

label | / | swap | /usr partition | /home partition

UNIX/Linux file system

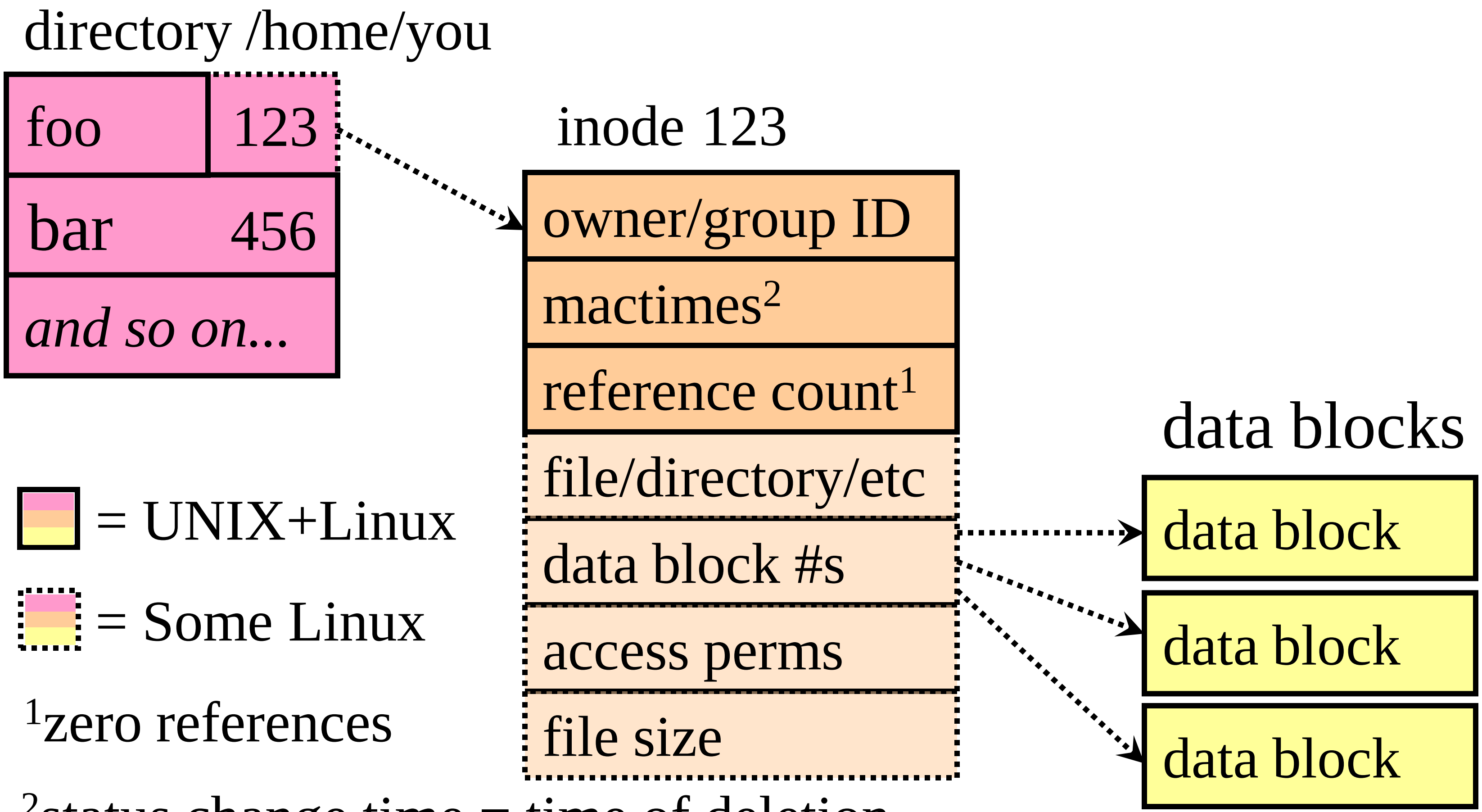
zone | zone | zone | zone | zone

File system zone

super block | inode bitmap | data bitmap | inode blocks | data blocks

If possible, all data about a file is within the same zone.

What is preserved when a file is deleted: UNIX/Linux systems



directory /home/you

foo 123

bar 456

and so on...

inode 123

owner/group ID

mactimes[2]

reference count[1]

file/directory/etc

data block #s

access perms

file size

data blocks

data block

data block

data block

▨ = UNIX+Linux

⬚ = Some Linux

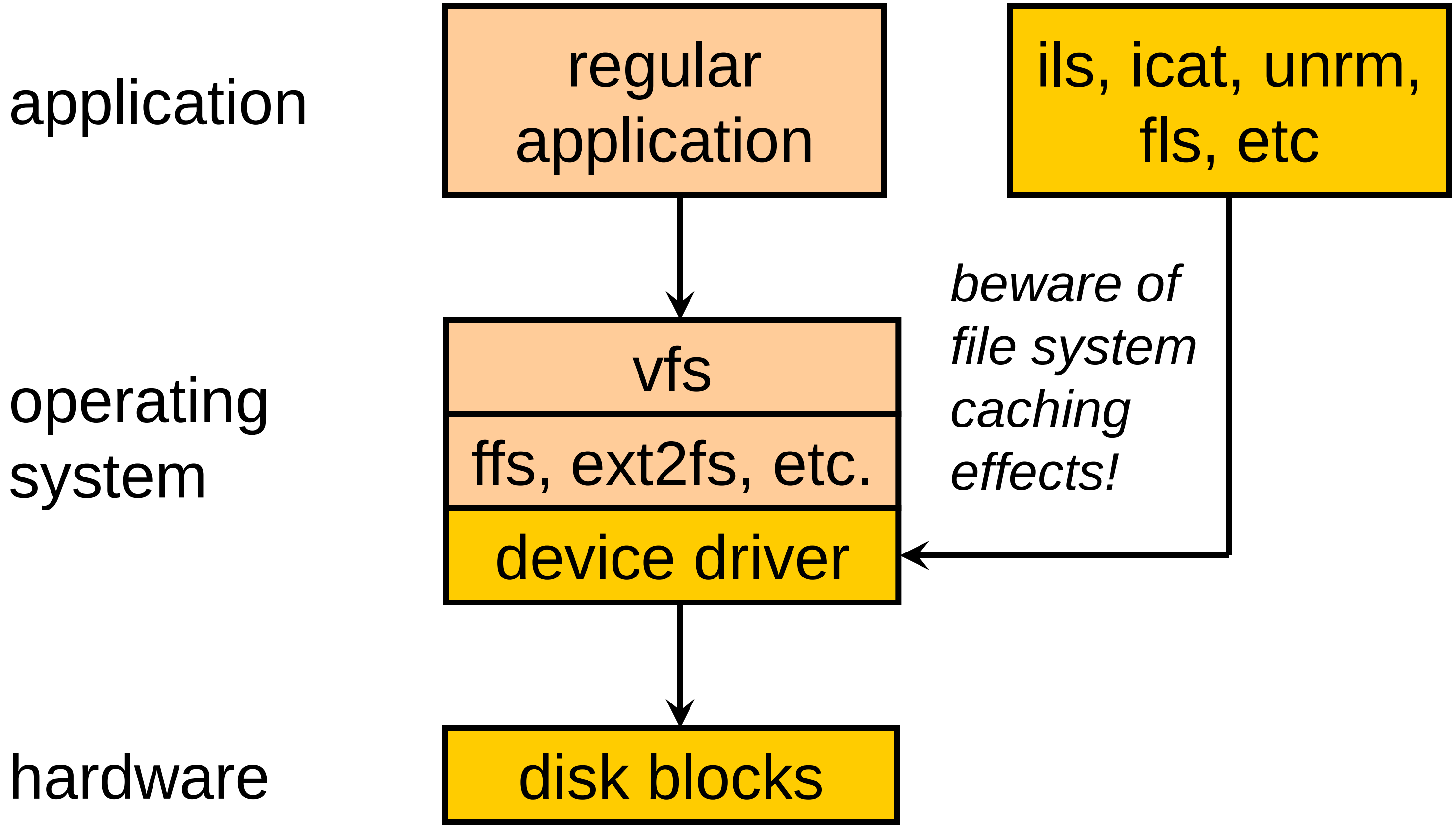
[1] zero references

[2] status change time = time of deletion

Summary: what happens when a file is deleted?

File property	Stored in	Status
Directory entry	Directory	Marked as unallocated
File name		Preserved
Inode number		*System dependent*
File attributes	Inode block	Marked as unallocated
Owner/group		Preserved
Last read time		Preserved
Last write time		*System dependent*
Last status change		Time of deletion
Reference count		Zero
Type/Permissions		*System dependent*
Size/Data block #s		*System dependent*
File content	Data blocks	Preserved, unallocated.

Techniques to access (deleted) file information



Tools to access (deleted) file information

- Coroner's Toolkit utilities[1]:
  - access file attributes by inode nr: *ils /dev/hda8 30199*
  - access file content by inode nr: *icat /dev/hda8 30199*
  - access deleted data blocks: *unrm /dev/hda8*
- Sleuthkit (Brian Carrier)[2]:
  - list directory entries: *fls /dev/hda8*
  - several others.
- Tools can also be used *before* data is deleted.

[1,2] See pointers at end of document

Overview

- Basic concepts.
- Time from file systems and less conventional sources.
- Post-mortem file system case study.
- Persistence of deleted data on disk and in main memory.
- Recovering WinXP/Linux encrypted files without key.
- Book text and software at author websites:
  - http://www.porcupine.org/
  - http://www.fish2.com/

Post-mortem analysis example

Tracing an intruder’s file back to its origin

Post-mortem analysis - overview

- What was logged.
- Chronological analysis of:
  - What files were accessed.
  - What files were modified or created.
  - What deleted file information is available.
- Not (see book or website for these):
  - How the duplicate disk image was created.
  - How the duplicate disk image was mounted on an analysis workstation.

What was logged

A scream of agony in the middle of the night:

```
Sep 25 00:44:49 dionysis rpc.statd[335]: gethostbyname error for
  [a very long non-conformant hostname...]
Sep 25 00:45:16 dionysis inetd[473]: extra conf for service
  telnet/tcp (skipped)
Sep 25 00:45:28 dionysis in.telnetd[11554]: connect from 10.83.81.7
Sep 25 01:02:02 dionysis inetd[473]: pid 11554: exit status 1
Sep 25 17:31:47 dionysis in.telnetd[12031]: connect from 10.83.81.7
Sep 25 17:32:08 dionysis in.telnetd[12035]: connect from 10.83.81.7
```

(IP address information changed to protect the guilty)

What was accessed, part 1/2
(initial intrusion)

```
Sep 25 2000 00:45:15
   Size MAC Permission Ownership   File name
 207600 .a. -rwxr-xr-x root   root  /image/usr/bin/as
  63376 .a. -rwxr-xr-x root   root  /image/usr/bin/egcs
  63376 .a. -rwxr-xr-x root   root  /image/usr/bin/gcc
  63376 .a. -rwxr-xr-x root   root  /image/usr/bin/i386-redhat-linux-gcc
   2315 .a. -rw-r--r-- root   root  /image/usr/include/_G_config.h
   1297 .a. -rw-r--r-- root   root  /image/usr/include/bits/stdio_lim.h
   4680 .a. -rw-r--r-- root   root  /image/usr/include/bits/types.h
   9512 .a. -rw-r--r-- root   root  /image/usr/include/features.h
   1021 .a. -rw-r--r-- root   root  /image/usr/include/gnu/stubs.h
  11673 .a. -rw-r--r-- root   root  /image/usr/include/libio.h
  20926 .a. -rw-r--r-- root   root  /image/usr/include/stdio.h
   4951 .a. -rw-r--r-- root   root  /image/usr/include/sys/cdefs.h
1440240 .a. -rwxr-xr-x root   root  /image/usr/lib/gcc-lib/[...]/cc1
  45488 .a. -rwxr-xr-x root   root  /image/usr/lib/gcc-lib/[...]/collect2
  87312 .a. -rwxr-xr-x root   root  /image/usr/lib/gcc-lib/[...]/cpp
   5794 .a. -rw-r--r-- root   root  /image/usr/lib/gcc-lib/[...]/include/stdarg.h
   9834 .a. -rw-r--r-- root   root  /image/usr/lib/gcc-lib/[...]/include/stddef.h
            (m=modified, a=read/execute access, c=status change)
```

What was accessed, part 2/2
(initial intrusion)

```
       Size MAC Permission Ownership   File name
       1926 .a. -rw-r--r-- root  root  /image/usr/lib/gcc-lib/[...]/specs
Sep 25 2000 00:45:16
     205136 .a. -rwxr-xr-x root  root  /image/usr/bin/ld
     176464 .a. -rwxr-xr-x root  root  /image/usr/bin/strip
       8512 .a. -rw-r--r-- root  root  /image/usr/lib/crt1.o
       1124 .a. -rw-r--r-- root  root  /image/usr/lib/crti.o
        874 .a. -rw-r--r-- root  root  /image/usr/lib/crtn.o
       1892 .a. -rw-r--r-- root  root  /image/usr/lib/gcc-lib/[...]/crtbegin.o
       1424 .a. -rw-r--r-- root  root  /image/usr/lib/gcc-lib/[...]/crtend.o
     769892 .a. -rw-r--r-- root  root  /image/usr/lib/gcc-lib/[...]/libgcc.a
     314936 .a. -rwxr-xr-x root  root  /image/usr/lib/libbfd-2.9.5.0.22.so
        178 .a. -rw-r--r-- root  root  /image/usr/lib/libc.so
      69994 .a. -rw-r--r-- root  root  /image/usr/lib/libc_nonshared.a
```

(m=modified, a=read/execute access, c=status change)

- Conclusion: intruder compiled a simple C program.

Modifications to existing files

```
Sep 25 2000 00:45:16
   Size MAC Permission Ownership   File name
      0 m.c -rw-r--r-- root  root  /image/etc/hosts.allow
      0 m.c -rw-r--r-- root  root  /image/etc/hosts.deny
   3094 mac -rw-r--r-- root  root  /image/etc/inetd.conf
```

(m=modified, a=read/execute access, c=status change)

- TCP Wrapper allow/deny access control disabled.
- Extra telnet service entry in inetd.conf:

```
$ grep telnet /image/etc/inetd.conf
telnet  stream  tcp   nowait  root  /usr/sbin/tcpd  in.telnetd
telnet  stream  tcp   nowait  root  /usr/sbin/tcpd  in.telnetd
```

- Suspicion: an intruder installed a backdoor.

Two new files in system directories: prick, xstat

- Not part of the RedHat 6.2 Linux distribution:

```
Date and time              Size MAC Permission Ownership   File name
Sep 25 2000 00:45:15      20452 m.c -rwxr-xr-x root   root  /image/bin/prick
Sep 25 2000 00:45:16       3448 m.. -rwxr-xr-x root   root  /image/usr/bin/xstat
```

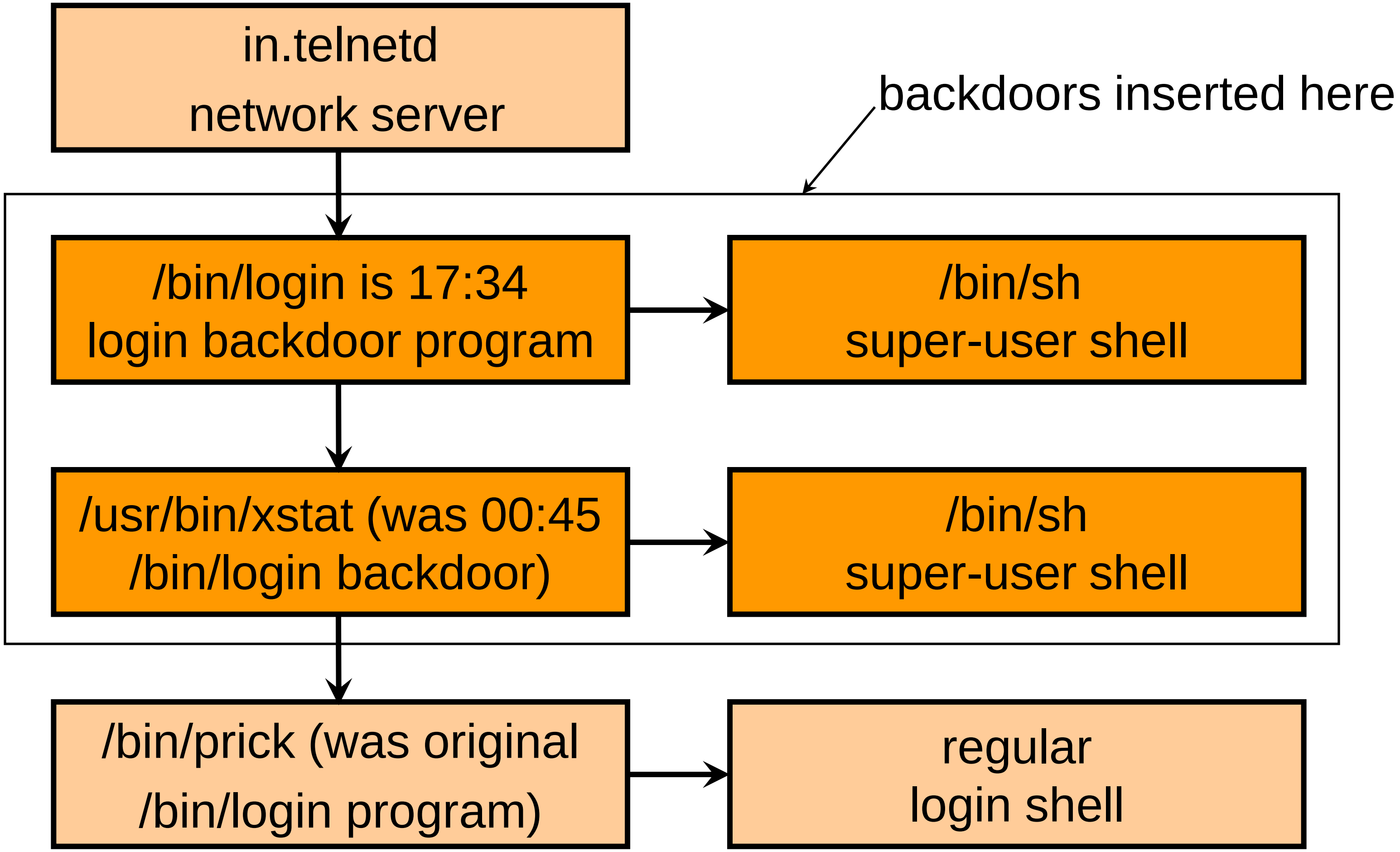
- */bin/prick* is a copy of RedHat 6.2 Linux */bin/login*[1].
- What about the present */bin/login* program?

```
Date and time              Size MAC Permission Ownership   File name
Sep 25 2000 17:34:17       3448 ..c -rwxr-xr-x root   root  /image/usr/bin/xstat
Sep 25 2000 17:34:20      12207 ..c -rwxr-xr-x root   root  /image/bin/login
```

- “**strings /bin/login**” reports “***/usr/bin/xstat***”.
- “**strings /usr/bin/xstat**” reports “**/bin/prick**”.

[1] Found by comparing the MD5 hash with a “clean” RedHat install.

Login backdoor upon backdoor



in.telnetd
network server

backdoors inserted here

/bin/login is 17:34
login backdoor program

/bin/sh
super-user shell

/usr/bin/xstat (was 00:45
/bin/login backdoor)

/bin/sh
super-user shell

/bin/prick (was original
/bin/login program)

regular
login shell

Theory: Inode sequence number analysis

- When the operating system is installed, files installed together are assigned successive inode numbers.

- Example: FreeBSD directory listing in **unsorted** order:

```
$ ls -fli /bin
Inode Permission Ref Ownership     Size Last update   Name
70657 -r-xr-xr-x  1 root   wheel    8052 Nov  4   2004 cat
70658 -r-xr-xr-x  1 root   wheel    4960 Nov  4   2004 chflags
70659 -r-xr-xr-x  1 root   wheel   14096 Nov  4   2004 chio
70660 -r-xr-xr-x  1 root   wheel    5864 Nov  4   2004 chmod
70661 -r-xr-xr-x  1 root   wheel   15344 Nov  4   2004 cp
```

- Jumps in inode numbers are normal, but an out-of-order entry indicates that a file was added or replaced later.

Deleted file analysis

- Deleted file with inode 30199 is original */bin/login* file[1]:

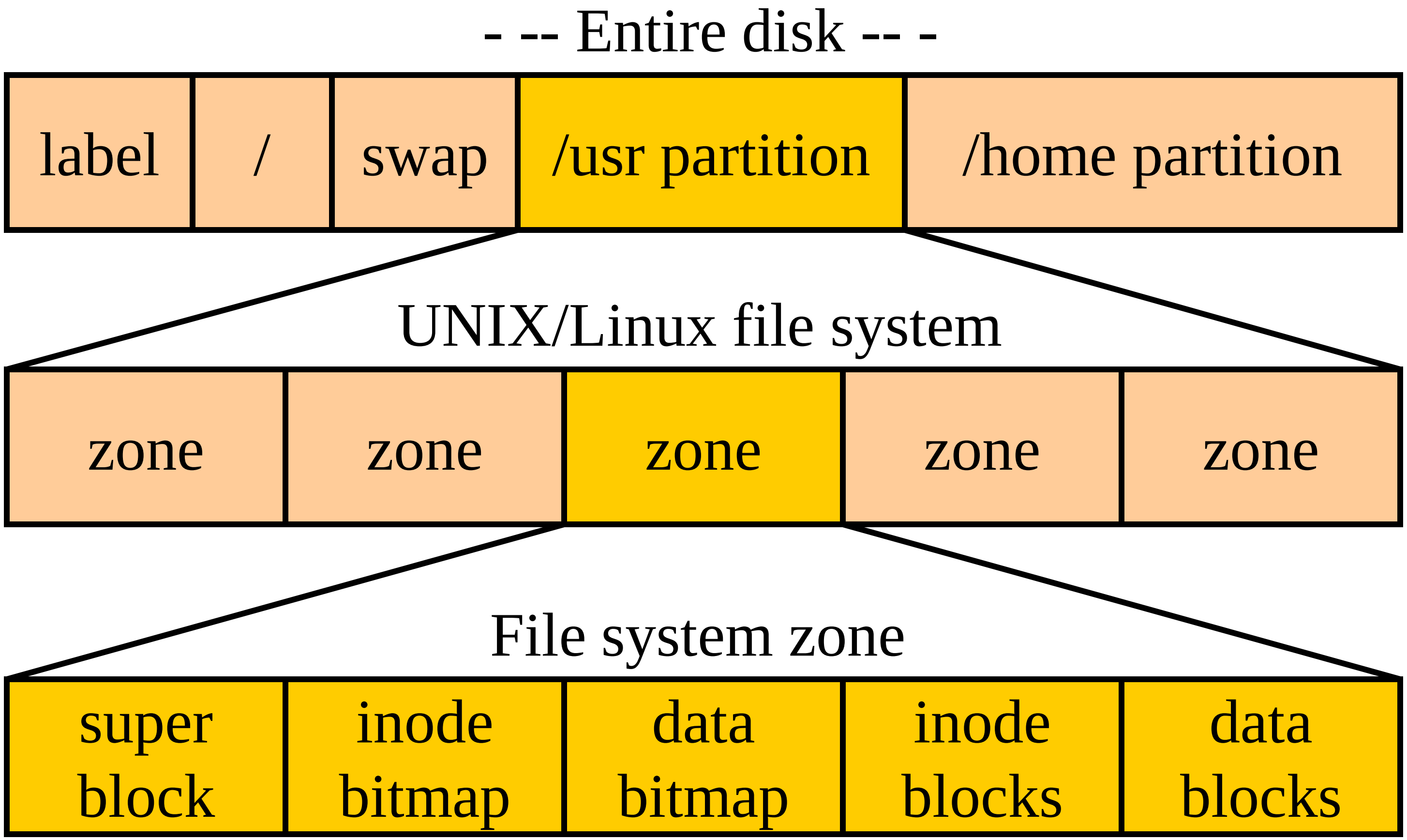
```
Date and time            Size MAC Permission Ownership          Disk Inode
Mar 07 2000 04:29:44    20452 m.. -rwxr-xr-x root   root   <image.hda8-30199>
Sep 25 2000 00:45:15    20452 .a. -rwxr-xr-x root   root   <image.hda8-30199>
Sep 25 2000 00:45:16    20452 ..c -rwxr-xr-x root   root   <image.hda8-30199>
```

- Inode 30199 matches a sequence perfectly:

```
$ ls -fli /image/bin    # list directory entries in unsorted order
...skipped...
Inode Permission   Ref Ownership      Size Last update  Name
30197 -rwxr-xr-x    1 root  root      4016 Mar  7  2000 dmesg
30198 -rwxr-xr-x    1 root  root      7952 Mar  7  2000 kill
60257 -rwxr-xr-x    1 root  root     12207 Aug 18  2000 login     replaced!
30200 -rwxr-xr-x    1 root  root     23600 Mar  7  2000 more
30201 -rwxr-xr-x    1 root  root       362 Mar  7  2000 vimtutor
```

[1] Attributes + content recovered with *ils* + *icat* from Coroner's toolkit.

Theory: UNIX/Linux disk layout



- -- Entire disk -- -

label | / | swap | /usr partition | /home partition

UNIX/Linux file system

zone | zone | zone | zone | zone

File system zone

super block | inode bitmap | data bitmap | inode blocks | data blocks

If possible, all data about a file is within the same zone.

Tracing an intruder file to its origins

- The backdoor *login* program with inode number 60257 was created in a different zone of the same file system.

```
$ find /image -xdev -print0 | xargs -0 ls -id | sort -n
...skipped...
60256 /image/etc/.tmp/.tmp
60257 /image/bin/login    backdoor!
60261 /image/etc/.tmp/install
60262 /image/dev/.l
60263 /image/etc/.tmp/.tmp/.m.list
...skipped...
```

- *fls* finds deleted directory entry with inode nr. 60257:

```
Size  MAC Permission Owner File name                inode   comments
12207 ..c -rwxr-wr-x root  /image/etc/.tmp/.tmp/l <60257> (deleted)
```

- Suggests that from here it was moved to */bin/login*.

Clues found so far

00:44:49 Break-in with *rpc.statd* exploit.

00:45:15 Relatively small program compiled.

00:45:16 First login backdoor installed. Original */bin/login* program saved as */bin/prick*.

00:45:16 Truncated *hosts.allow/deny* files.

00:45:16 Duplicate *telnet* service configured.

00:45:28 Telnet connection (no login).

17.31.47 Telnet connection (end 17:32:06).

17.32:08 Telnet connection (end 17:34:27).

17:34:20 Second login backdoor installed. First backdoor renamed to */usr/bin/xstat*.

Lessons from a honeypot, part 1/2

- Confession time: this was a honeypot machine.
- Honeynet project: http://project.honeynet.org/
- Lots of deleted Solaris files, including log files and firewall configuration files (in swap space).
- False evidence in the form of deleted copies of white papers that discussed similar break-ins.
- False evidence as the result of using the same machine for target practice.

Lessons from a honeypot, part 2/2

- Wipe the file system(s) before installing the OS.

  dd if=/dev/zero of=/dev/hda1, etc.

- Wipe the swap space too.

- Limit your downstream liability by limiting what connections the honeypot is allowed to make (the honeynet people already did this).

- Don’t use the honeypot for target practice.

- Don’t let any sensitive data near the honeypot. Computers are like tar pits.

Persistence of deleted information

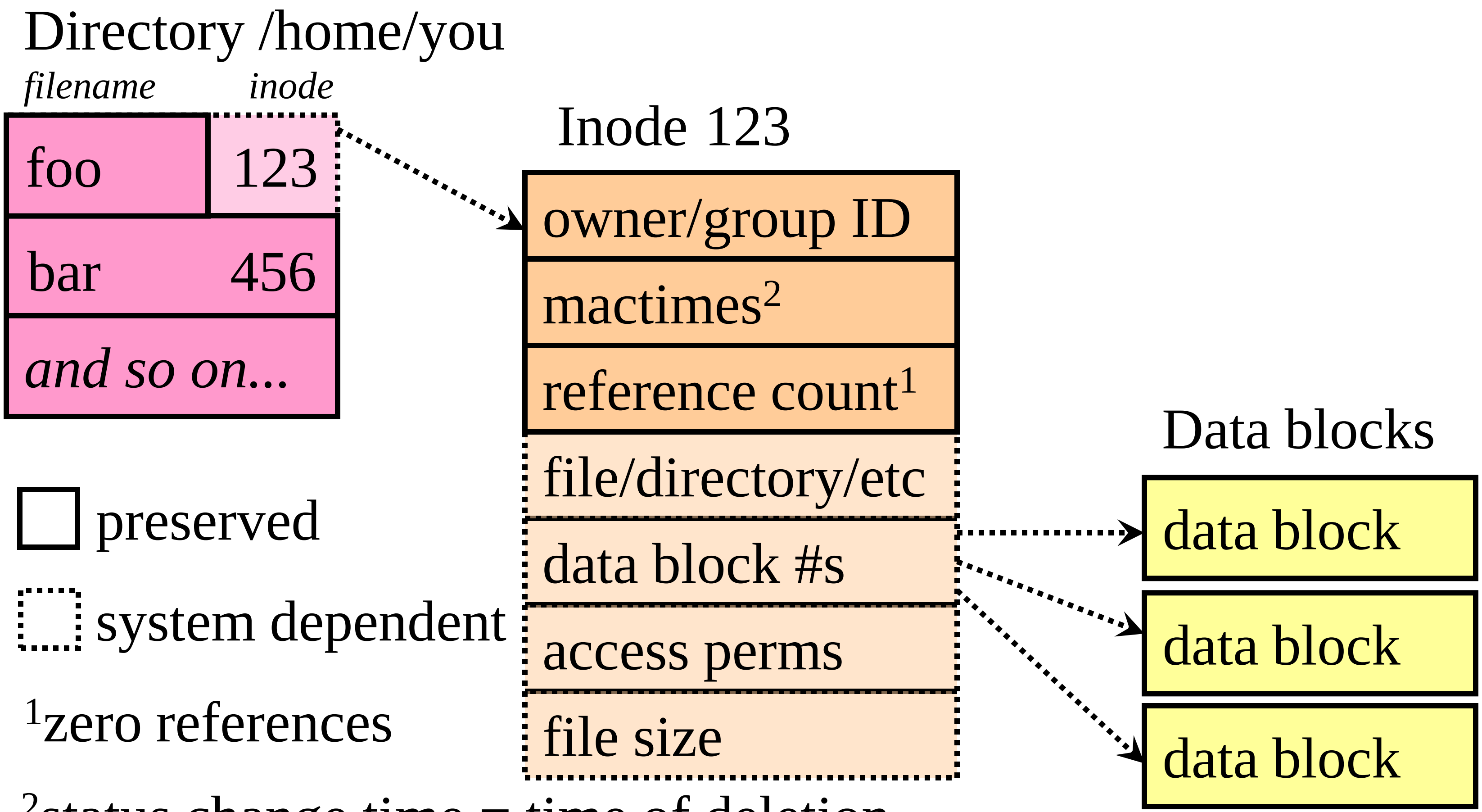
Overview

- Persistence of deleted file information.
- Persistence of information in main memory.
- Recovering encrypted Linux/WinXP files without key.

Persistence of deleted file information

Why deleted file data can be more persistent than existing file data

Deleting a file destroys structure but not content



Directory /home/you

filename	*inode*
foo	123
bar	456
and so on...	

Inode 123

- owner/group ID
- mactimes[2]
- reference count[1]
- file/directory/etc
- data block #s
- access perms
- file size

Data blocks

- data block
- data block
- data block

□ preserved

⬚ system dependent

[1] zero references

[2] status change time = time of deletion

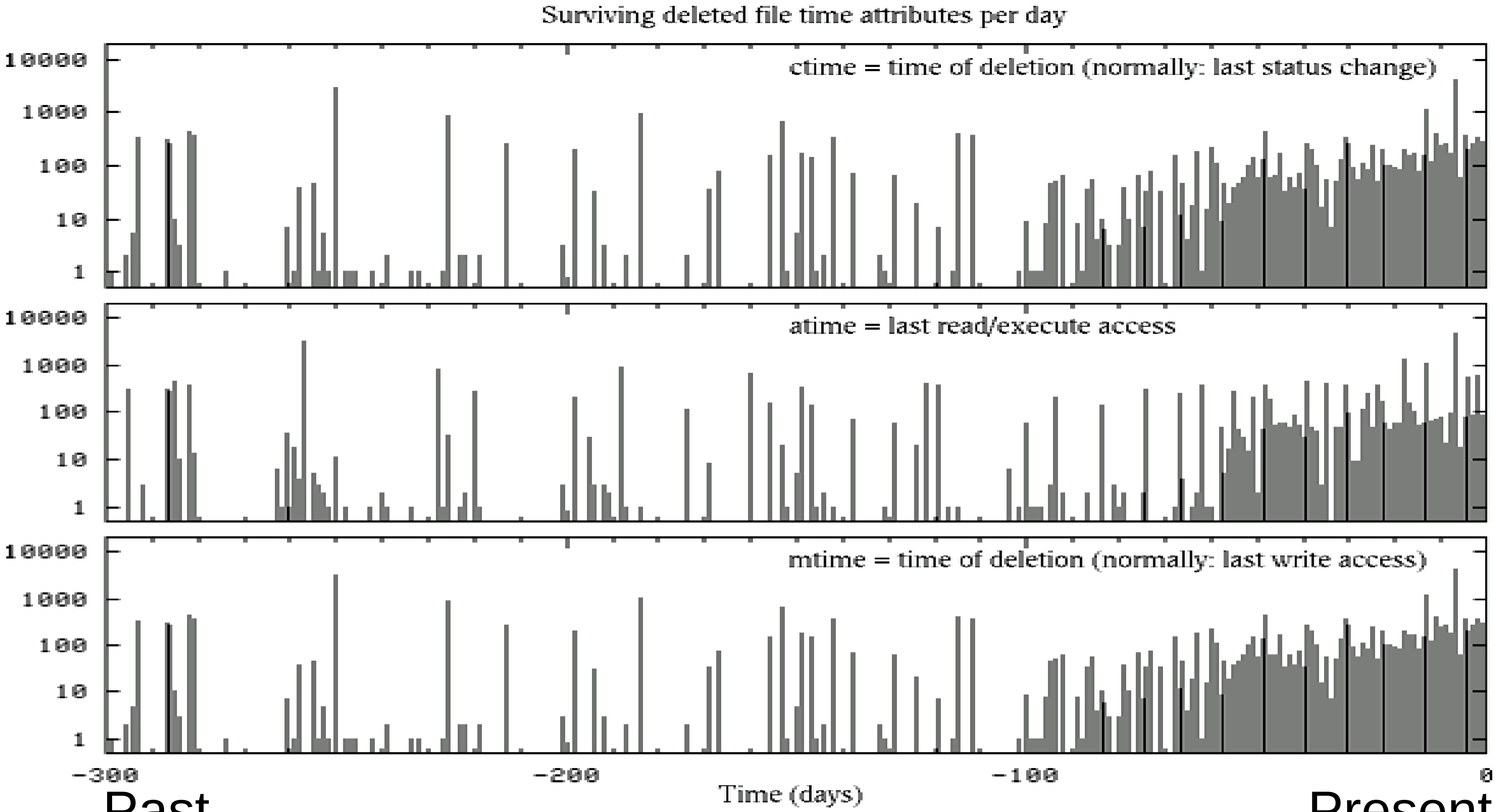
Measurements with deleted file attributes (easy)

- Deleted file attributes are collected with *grave-robber* or with *ils* from the Coroner’s Toolkit. This takes only a few minutes, depending on the file system size.

- Slightly altered MACtime semantics for deleted files:
  - **Mtime**: Linux: the last modification before deletion. Other: the time of deletion.
  - **Atime**: the last read/execute access before deletion.
  - **Ctime**: the time of deletion.
  - (dtime: Linux-specific time of deletion).

Persistence of deleted file *attributes*

(dedicated UNIX server, 9GB half full disk)



Past

Present

Measurements with deleted file content (not so easy)

- Problem: deleted file content rarely gives hints about the time of deletion (exception: short-lived logfiles).

- We actually have to measure when a file is deleted, and how long it takes before its content is overwritten.

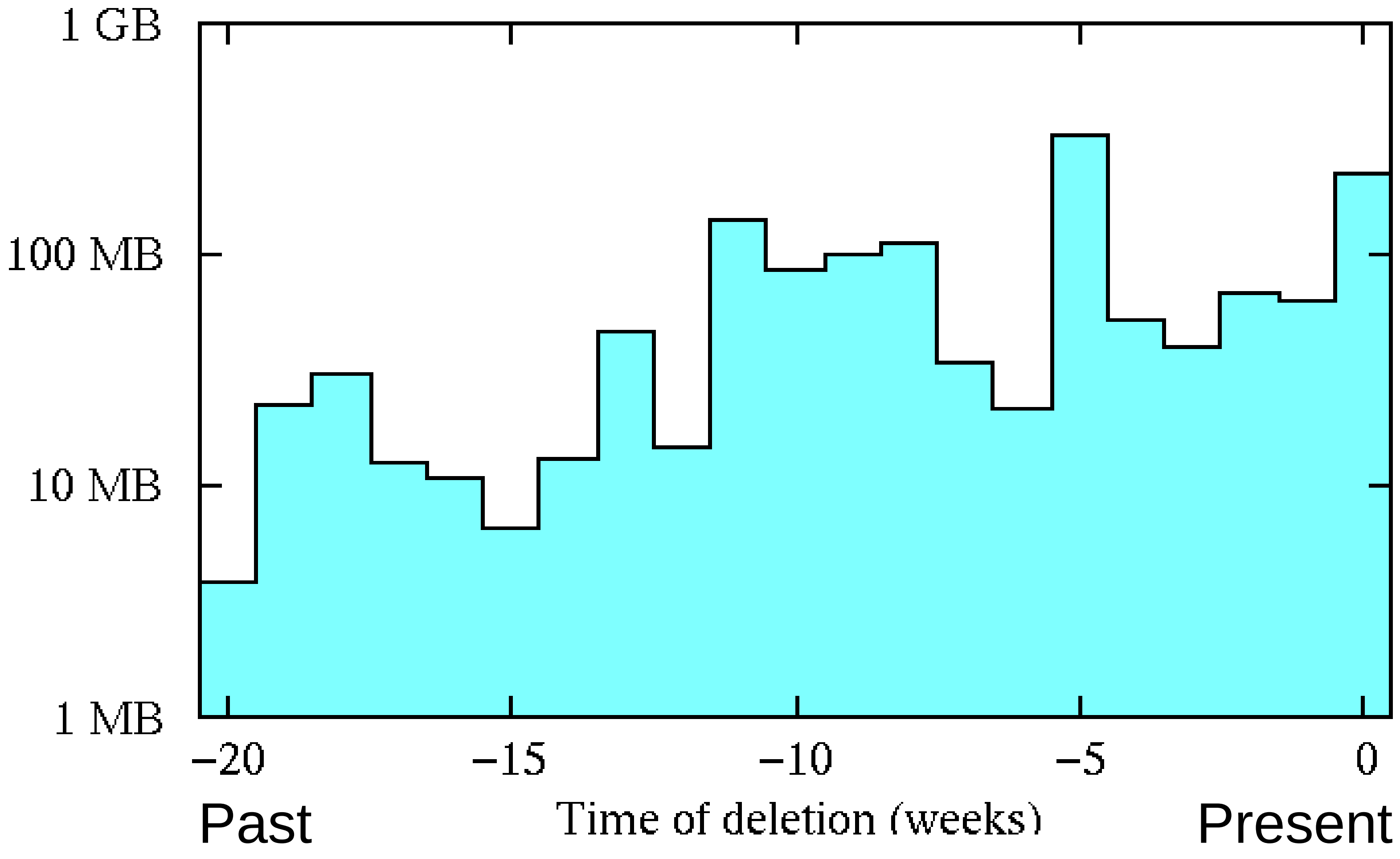
- Experiment with half-dozen file systems: every night, hash every disk block[1] and record its status (*allocated*, *free*, *metadata*)[2]. Keep doing this for several months. Result: 100 MBytes of data.

[1] We kept only 16 bits of each hash, to save space.

[2] Data collection tools are at the book website.

Persistence of deleted file *content*

(same dedicated UNIX server, 9GB half full)



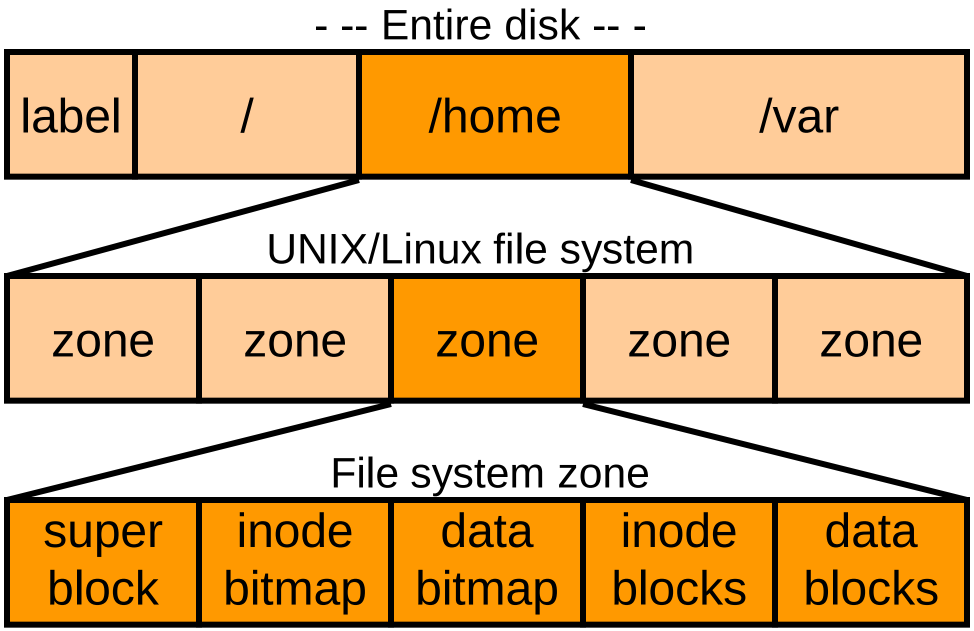
Summary: persistence of deleted file content

Machine	File system	Half-life
spike.porcupine.org[1]	entire disk	35 days
flying.fish.com[2]	/	17 days
flying.fish.com[2]	/usr	19 days
www.porcupine.org[1]	entire disk	12 days

[1] FreeBSD [2] Linux

Why deleted file data can be more persistent than existing file data

- Existing files are easy to access, and easy to modify. Deleted files are less accessible, and become fossils.



- File system locality protects deleted data. Example: a deleted file in zone X survives write activity in zone Y.

Main Memory Persistence

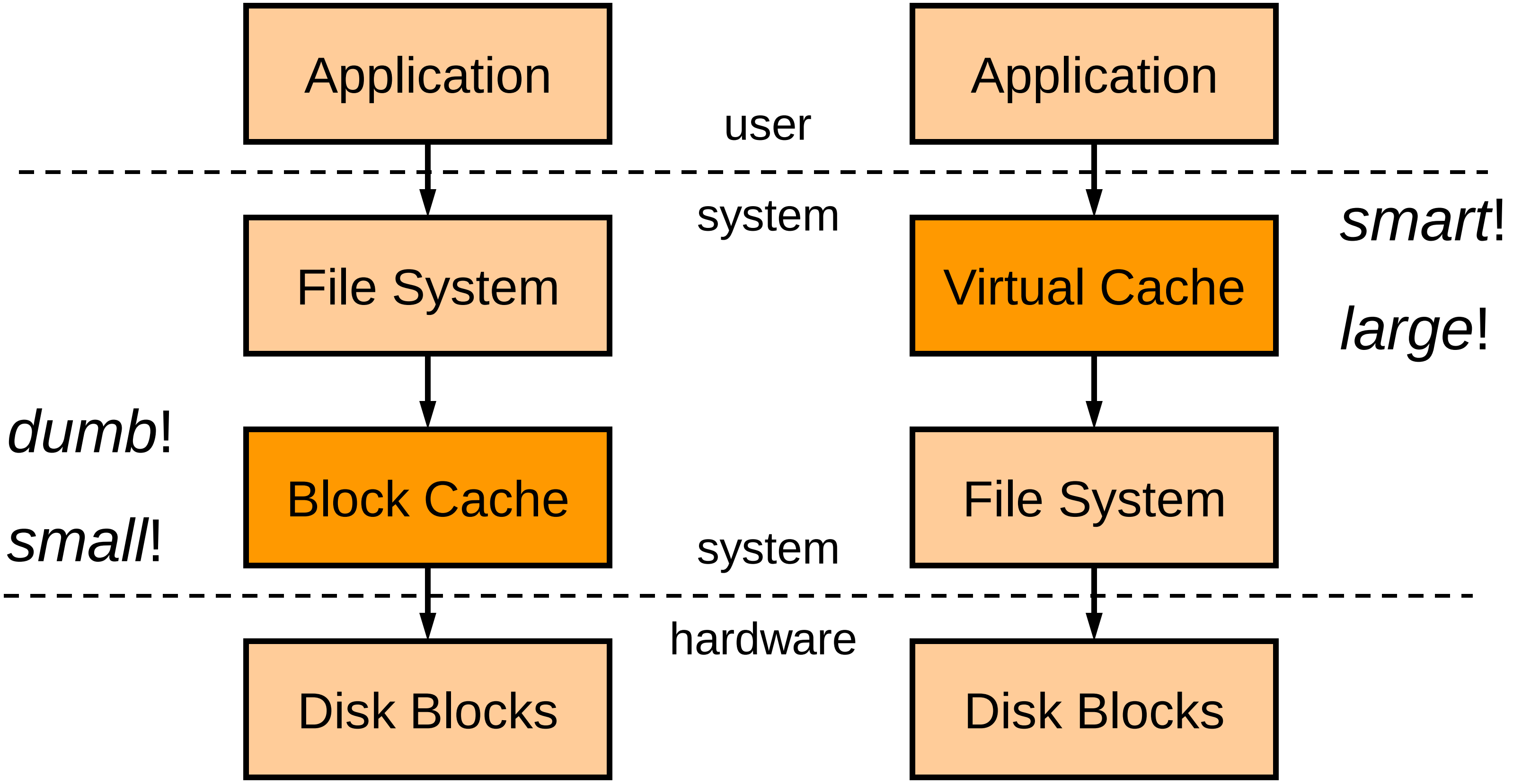
Recovering Linux/WinXP
encrypted files without the key

Information in main memory

- Running processes[1].
- Terminated processes[1].
- Kernel memory.
- Recently active files/directories (file cache).
- Deleted files (from processes[1] or from file cache).
- Different persistence properties.

[1] Some information may be found in swap files.

File block cache <=> virtual cache
(owned by system, not by applications)



DOS, Win95/98/ME, old BSD

BSD, Linux, Solaris,WinNT/2K/XP

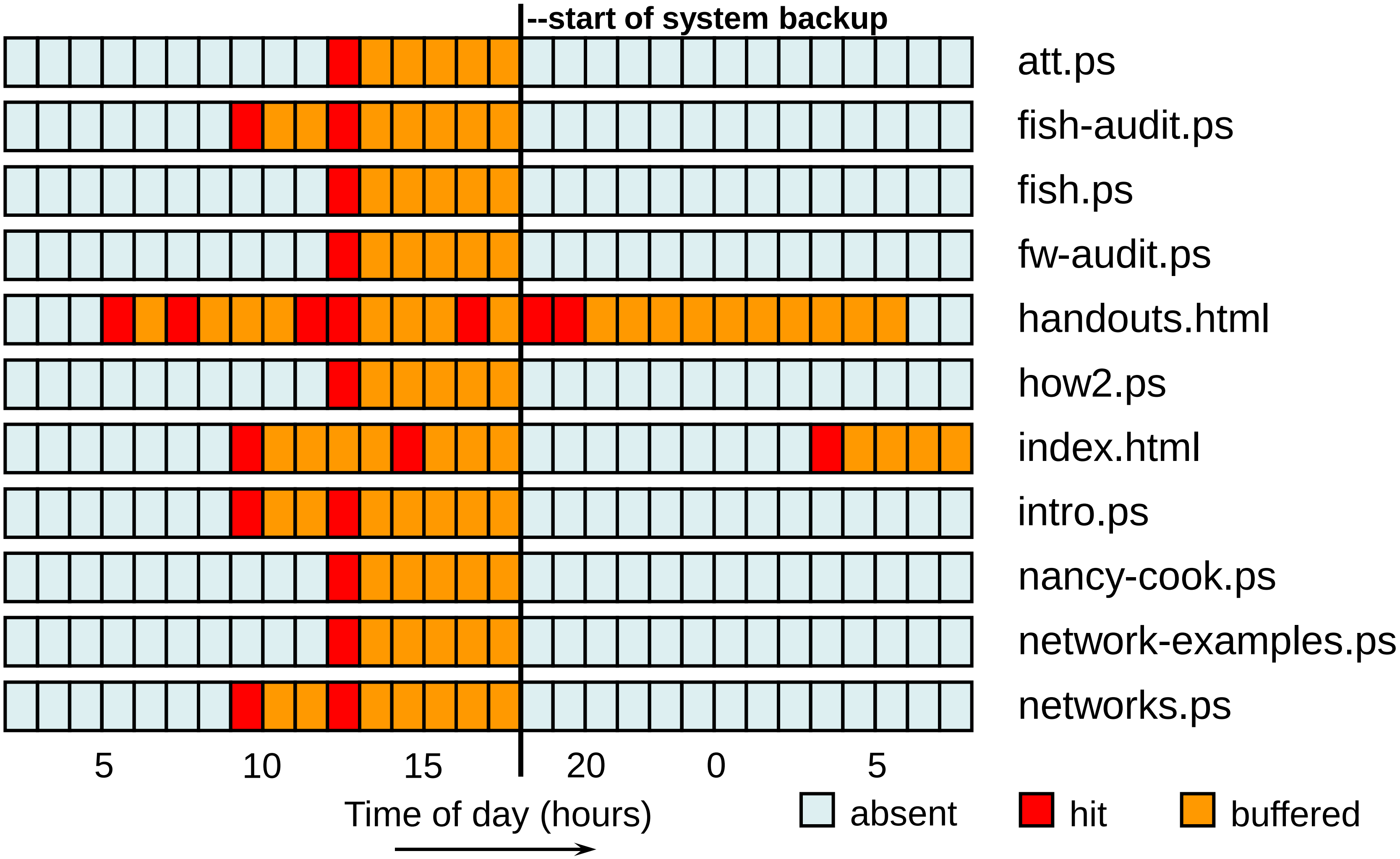
File caching in main memory measurements

- Disk blocks are cached in memory in page size chunks.
- Every hour, compute a hash of every 1kbyte memory block[1].
- Once: compute hashes of 1kbyte file blocks, zero-padding short blocks.
- Off-line analysis: compare memory hashes with file hashes to get an idea of what is cached in memory.
- Minor impact from collisions, such as all-zero blocks.

[1] Tools are at the book website.

File caching in main memory

(low-traffic web pages, FreeBSD)



Recovering WinXP/Linux encrypted files without key

Two experiments with remarkably similar outcomes

Experiment 1: Windows/2K/XP EFS

- *EFS*[1] provides encryption by *file* or by *directory*. Encryption is enabled via an Explorer property dialog box or via the equivalent system calls.
- With encryption by directory, files are encrypted *before* they are written to disk.
- Is unencrypted content of *EFS* files cached in main memory?
- If yes, for how long?

[1] EFS=Encrypting File System

Experiment 1: create encrypted file

- Create “encrypted” directory *c:\temp\encrypted*.
- Download 350kB text file via FTP, with content:

```
00001 this is the plain text
00002 this is the plain text
...
11935 this is the plain text
11936 this is the plain text
```

- Scanning the disk from outside (VMware rocks!) confirms that no plaintext is written to disk.

Experiment 1: search memory dump

- Log off from the Windows/XP console and press Ctrl/ScrollLock twice for memory dump[1] (160 MB).
- Analyze dumped memory with standard UNIX tools.
- 99.6% of the plain text was found undamaged.

[1] Microsoft KB 254649: Windows 2000 memory dump options.

Experiment 2: Linux eCryptfs

- *eCryptfs*[1] provides encryption by *file system*.
- Standard with kernel version 2.6.19 and later.
- Files are encrypted *before* they are written to disk.
- Is unencrypted content of *eCryptfs* files cached in main memory?
- If yes, for how long?

[1] http://ecryptfs.sourceforge.net/

Experiment 2: create encrypted file

(tested with kernel 2.6.15)

- Mount *eCryptfs* file system on */mnt*.
- Run script that generates 29 MB easy to recognize text:

```
$ awk ′BEGIN { for (i = 0; i < 100000; i++)
   printf(“%5d This is the plain text\n”, i) }′
   >/mnt/test
```

- This produces the following content:

```
00000 This is the plain text
00001 This is the plain text
...
99998 This is the plain text
99999 This is the plain text
```

Experiment 2: search memory dump

- Unmount the file system and dump the VMware guest[1] memory (256 MB) with the *pcat* command from TCT.
- Analyze dumped memory with standard UNIX tools.
- 99% Of the plaintext was found undamaged. One hour later, 96% of the plaintext still persisted.

[1] Kernel 2.6 /dev/mem and /proc/kcore appear to be crippled. SBO?

Conclusion - recovering encrypted files without key

- Good: file system encryption provides privacy by encrypting file content before it is written to disk.

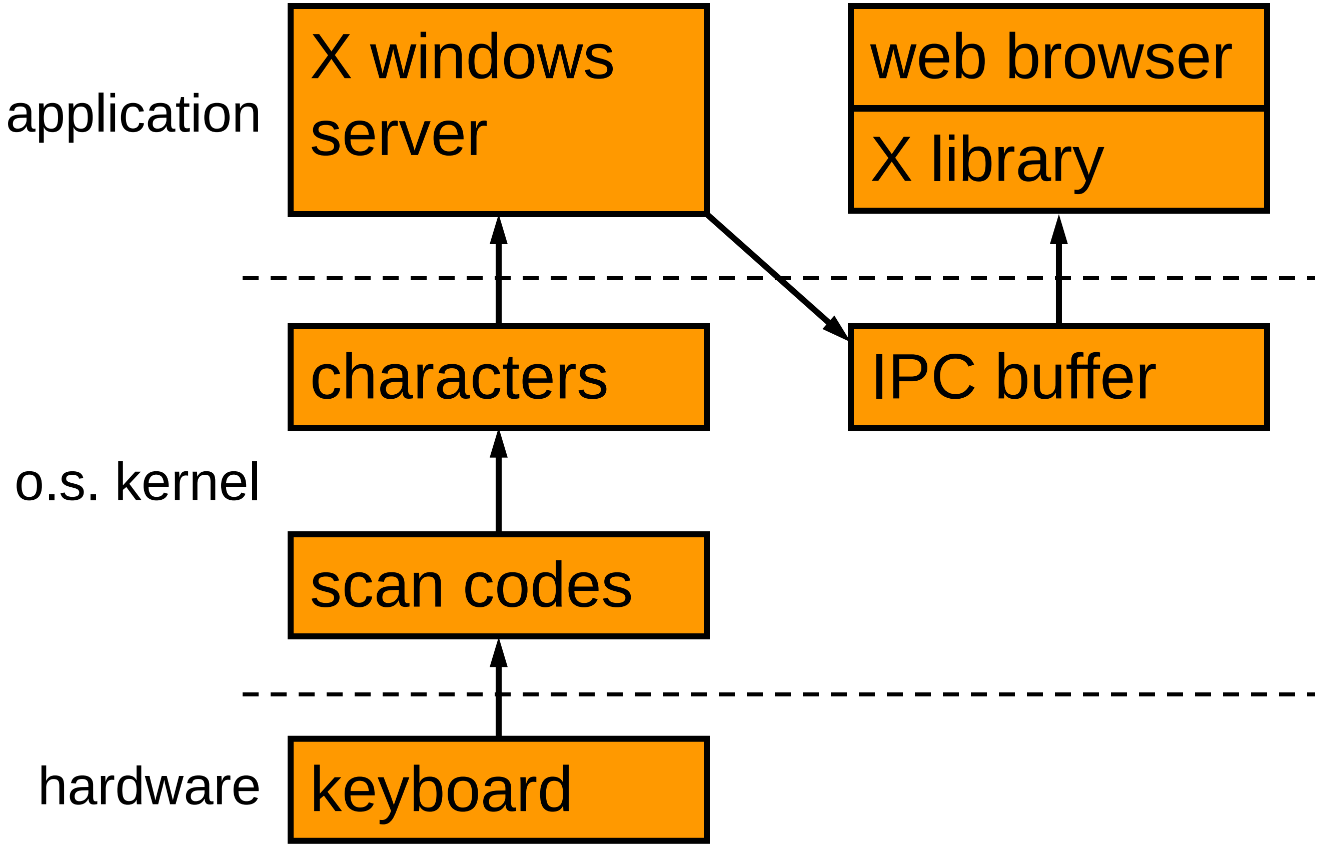
- Bad: unencrypted content stays cached in main memory even after the user has logged off (WinXP) or after the file system is unmounted (Linux).

- Similar experiments are needed for other encrypting file systems, but we expect to find similar plaintext caching behavior.

Long-term memory persistence

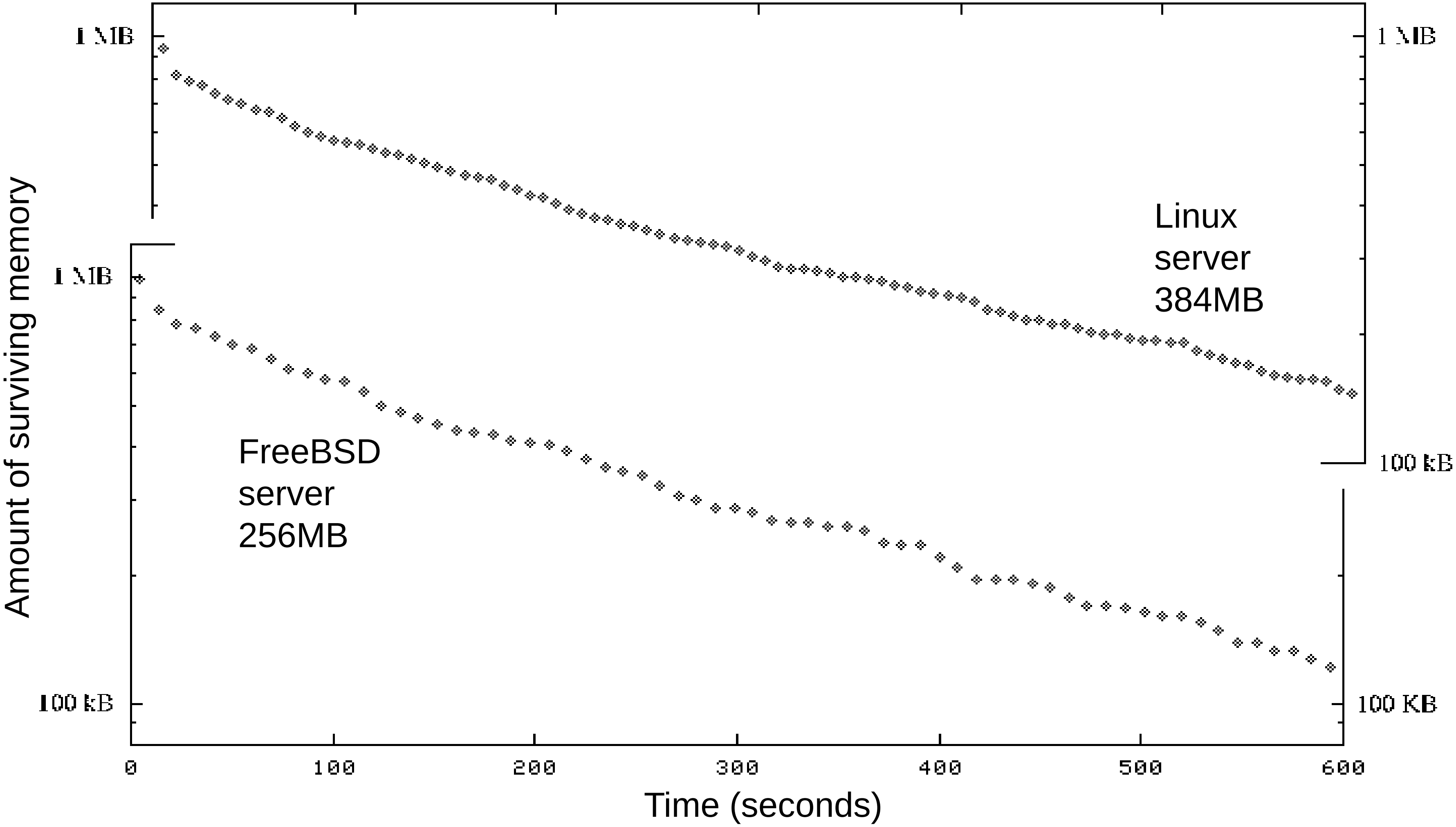
Trail of secrets across memory

(Chow *et al*., USENIX Security 2004)



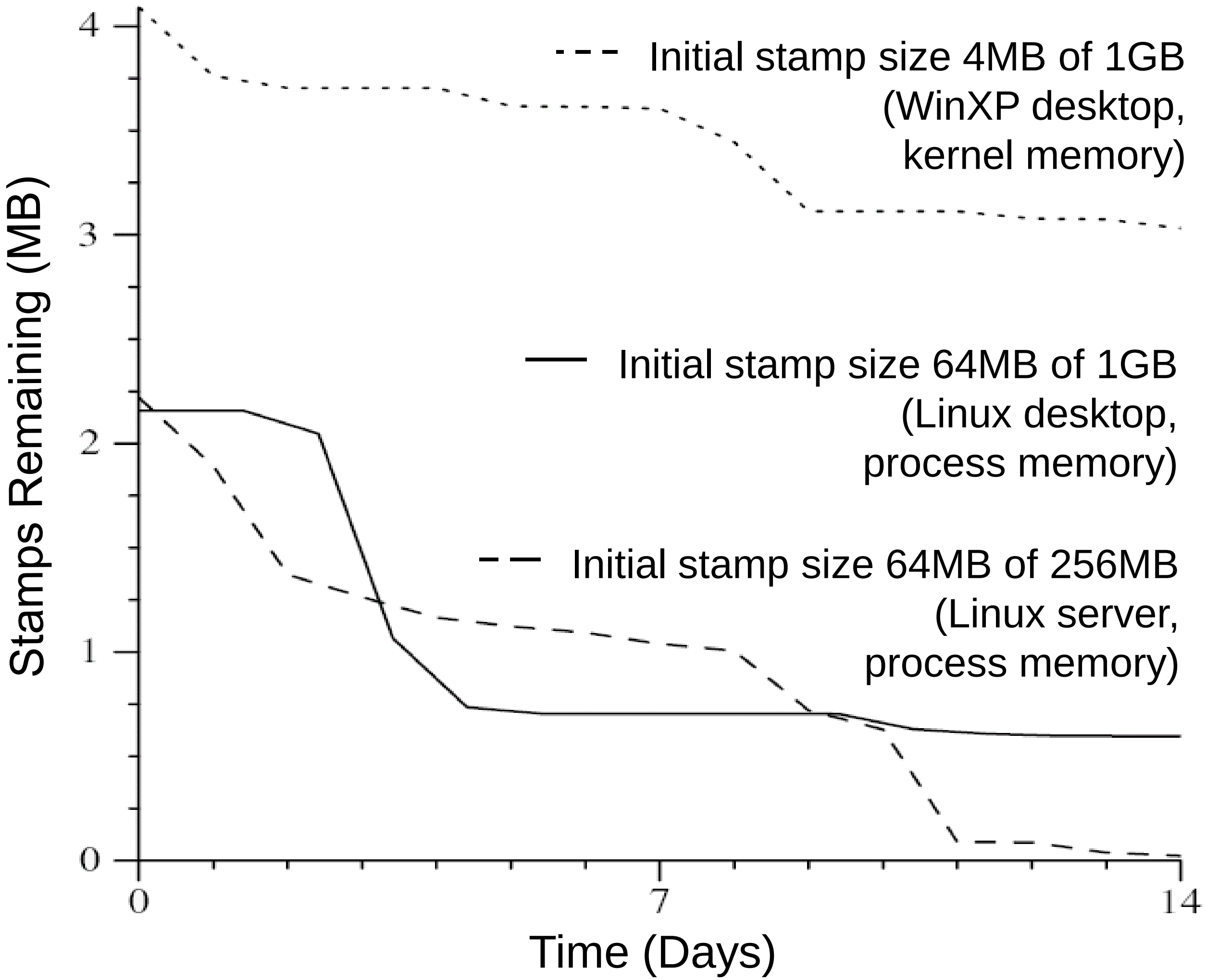
Short-term memory persistence

after process termination (1MB stamp)



Long-term memory persistence

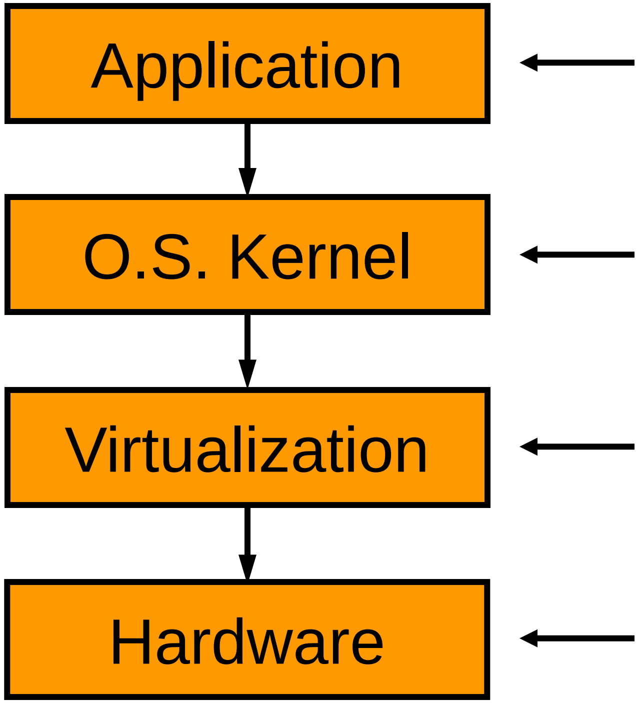
(Chow *et al*., USENIX Security 2005)



Progress in subversion

Hardware is getting softer

Progression in subversion
(also known as rootkits)



Application ← 1994 SunOS mass exploitation

O.S. Kernel ← 1997 Bugtraq demo
1999 Knark mass exploitation

Virtualization ← 2005 Subvirt (VMware+VirtualPC)
2006 Bluepill (AMD VT extensions)

Hardware ← 2006 ACPI+PCI Firmware demo

Also: malicious USB or Firewire devices, CD-Roms, etc.

Firmware: reflashing for fun and profit

- It’s all about business models:
  - Time to market: ship it now, fix it later.
  - CPU updates (Intel: non-peristent, “signed”).
  - Hard drive, BIOS, etc. updates.
- Already popular with consumer electronics:
  - Watch TV without paying.
  - Re-enable wireless telephone features.
  - Disable DVD player “region lock”.
  - Upgrade digital camera to more expensive model.

Conclusion

- Deleted file information can survive for a year or more, even with actively used file systems.
- Main memory becomes a *primary* source of forensic information, especially with infection of *running* processes or *running* operating system kernels.
- Hardware is becoming softer[1] all the time, as complexity increases. Do not blindly trust that a device will give you all the information that is stored on it.

[1] Field upgradable firmware.

Pointers

- Dan Farmer, Wietse Venema: "*Forensic Discovery*", Addison-Wesley, Dec. 2004; "*The Coroner's Toolkit*".

  http://www.porcupine.org/forensics/

  http://www.fish2.com/forensics/
- Jim Chow *et al.*: "*Shredding Your Garbage*", USENIX Security 2005; "*Understanding Data Lifetime via Whole System Simulation*", USENIX Security 2004.
- Brian Carrier, Sleuthkit and other software.

  http://www.sleuthkit.org/
- DFRWS (digital forensics research) website.

  http://www.dfrws.org/