Operating Systems

Christopher Kruegel
Department of Computer Science
UC Santa Barbara
http://www.cs.ucsb.edu/~chris/

Operating Systems Security

Operating Systems

- Why do we care about operating systems (OS) security
  - protect different applications that run at the same time
  - applications may belong to different users, have different privileges
  - keep buggy/malicious apps. from crashing each other
  - keep buggy/malicious apps. from tampering with each other
  - keep buggy/malicious apps. from crashing the OS

- OS provides security services
  - isolation (between processes)
  - access control (regulates who can access which resources)

Operating Systems

- Kernel
  - provides an hardware abstraction layer for user-space programs
  - complete access to all (physical) resources
  - trusted computing base

- Dual mode operation
  - hardware (processor) support
  - when in kernel-mode, can do anything (direct hardware access)
  - when in user-mode, restricted access
  - typically, mode of operation is indicated by processor status bit(s)
  - of course, this bit can only be directly manipulated in kernel-mode

Operating Systems

Transition between different modes

- this crosses the border between two security domains
- clearly, a security relevant action

- System calls
  - performs a transition from user mode to privileged (kernel) mode
  - usually implemented with hardware (processor) support
    - processor interrupt (int 0x80)
    - x86 call gates (far call)
    - fast system call features (sysenter)
  - ensure that only specific kernel code can be invoked
    - why not allow arbitrary calls into kernel code?

Operating Systems

- Memory protection
  - through virtual memory abstraction
  - every process gets its own virtual memory space
  - no direct access to physical memory
  - page tables and memory MMU perform translation
- Programs are isolated and cannot talk to each other directly
- Inter-process communication
  - in some cases, shared memory can be requested
  - pipes, messages (packets) -> input validation necessary
  - file system (which is shared state) -> race conditions

- Other type of memory protection
  - physical memory can also be accessed via DMA (devices attached to bus)
  - several attacks have been published based on this
    - attack of the iPods
  - idea of I/O MMU comes to rescue

Operating Systems

- Access control
  - determine the actions that a process (subject) may perform on resources (objects)
  - requires to establish “identity” of subjects
  - implemented *as access control lists (ACL)* on objects; or *capabilities* carried by subjects

- Establishing identity
  - process of authentication
  - via something that one has, that one knows, or that one is (does)
  - should be protected by a *trusted path*

Operating Systems

- Discretionary access control
  - common model for contemporary operating systems
  - subject (owner) can change permission of objects

- Mandatory access control
  - less common, but gains popularity
  - enforced by the OS when subject cannot change permissions of objects
  - often associated with multi-level security (MLS) systems and the Bell-LaPadula model

Unix (Posix) Security

Unix

- Kernel vulnerability
  - usually leads to complete system compromise
  - attacks performed via system calls
- Solaris / NetBSD call gate creation input validation problem
  - malicious input when creating a LDT (x86 local descriptor table)
  - used in 2001 by Last Stage of Delirium to win Argus Pitbull Competition
- Kernel Integer Overflows
  - FreeBSD `procfs` code (September 2003)
  - Linux `brk()` used to compromise debian.org (December 2003)
  - Linux `setsockopt()` (May 2004)
- Linux Memory Management
  - `mremap()` and `munmap()` (March 2004)

Unix

- More recent Linux vulnerabilities
  - Linux message interface (August 2005, CAN-2005-2490)
  - race condition - `proc` and `prctl` (July 2006, CVE-2006-3626)
  - local privilege escalation - (September 2007, CVE 2007-4573)

- Device driver code is particularly vulnerable
  - (most) drivers run in kernel mode, either kernel modules or compiled-in
  - often not well audited
  - very large code based compared to core services

- Examples
  - `aironet`, `asus_acpi`, `decnet`, `mpu401`, `msnd`, and `pss` (2004) found by sparse (tool developed by Linus Torvalds)
  - remote root (MadWifi - 2006, Broadcom - 2006)

Unix

- Code running in user mode is always linked to a certain identity
  - security checks and access control decisions are based on user identity
- Unix is user-centric
  - no roles
- User
  - identified by user name (UID), group name (GID)
  - authenticated by password (stored encrypted)
- User `root`
  - superuser, system administrator
  - special privileges (access resources, modify OS)
  - cannot decrypt user passwords

Process Management

- Process Attributes
  - process ID (PID)
    - uniquely identified process
  - user ID (UID)
    - ID of owner of process
  - effective user ID (EUID)
    - ID used for permission checks (e.g., to access resources)
  - saved user ID (SUID)
    - to temporarily drop and restore privileges
  - lots of management information
    - scheduling
    - memory management, resource management

User Authentication

- How does a process get a user ID?
- ➢ Authentication (`login`)

- Passwords
  - user passwords are used as keys for `crypt()` function
  - runs DES algorithm 25 times on a block of zeros
  - 12-bit "salt"
    - 4096 variations
    - chosen from date, not secret
    - prevent same passwords to map onto same string
    - make dictionary attacks more difficult

- Password cracking
  - dictionary attacks
  - `Crack`, `JohnTheRipper`

User Authentication

- Shadow passwords
  - password file is needed by many applications to map user ID to user names
  - encrypted passwords are not

- `/etc/shadow`
  - holds encrypted passwords
  - account information
    - last change date
    - expiration (warning, disabled)
    - minimum change frequency
  - readable only by superuser and privileged programs
  - MD5 hashed passwords (default) to slow down guessing

File System

- File tree
  - primary repository of information
  - hierarchical set of directories
  - directories contain file system objects (FSO)
  - root is denoted “/”

- File system object
  - files, directories, symbolic links, sockets, device files
  - referenced by *inode* (index node)

File System

- Access Control
  - permission bits
  - `chmod, chown, chgrp, umask`
  - file listing:

```
            -      rwx      rwx      rwx
(file type) (user)  (group) (other)
```

Type	r	w	x	s	t
File	read access	write access	execute	suid / sgid inherit id	sticky bit
Directory	list files	insert and remove files	stat / execute files, chdir	new files have dir-gid	files only delete-able by owner

SUID Programs

- Each process has *real* and *effective* user / group ID
  - usually identical
  - real IDs
    - determined by current user
    - `login`, `su`
  - effective IDs
    - determine the “rights” of a process
    - system calls (e.g., `setuid()`)
  - `suid` / `sgid` bits
    - to start process with effective ID different from real ID
    - attractive target for attacker
- Never use SUID shell scripts (multiplying problems)

Shell

- Shell
  - one of the core Unix application
  - both a command language and programming language
  - provides an interface to the Unix operating system
  - rich features such as control-flow primitives, parameter passing, variables, and string substitution
  - communication between shell and spawned programs via redirection and pipes
  - different flavors
    - bash and sh, tcsh and csh, ksh

Shell Attacks

- Environment Variables
  - $HOME and $PATH can modify behavior of programs that operate with relative path names
  - $IFS – internal field separator
    - used to parse tokens
    - usually set to [\t\n] but can be changed to "/"
    - "`/bin/ls`" is parsed as "`bin ls`" calling bin locally
    - IFS now only used to split expanded variables
  - `preserve` attack (`/usr/lib/preserve` is SUID)
    - called "`/bin/mail`" when `vi` crashes to preserve file
    - change IFS, create `bin` as link to `/bin/sh`, kill `vi`

Shell Attacks

- Control and escape characters
  - can be injected into command string
  - modify or extend shell behavior
  - user input used for shell commands has to be rigorously sanitized
  - easy to make mistakes
  - classic examples are `` `;' `` and `` `&' ``

- Applications that are invoked via shell can be targets as well
  - increased vulnerability surface

- Restricted shell
  - invoked with `-r`
  - more controlled environment

Shell Attacks

- `system(char *cmd)`
  - function called by programs to execute other commands
  - invokes shell
  - executes string argument by calling `/bin/sh -c string`
  - makes binary program vulnerable to shell attacks
  - especially when user input is utilized

- `popen(char *cmd, char *type)`
  - forks a process, opens a pipe and invokes shell for `cmd`

File Descriptor Attacks

- SUID program opens file
- forks external process
  - sometimes under user control
- on-execute flag
  - if `close-on-exec` flag is not set, then new process inherits file descriptor
  - malicious attacker might exploit such weakness
- Linux Perl 5.6.0
  - getpwuid() leaves /etc/shadow opened (June 2002)
  - problem for Apache with mod_perl

Resource Limits

- File system limits
  - *quotas*
  - restrict number of storage blocks and number of inodes
  - hard limit
    - can never be exceeded (operation fails)
  - soft limit
    - can be exceeded temporarily
  - can be defined per mount-point
  - defend against resource exhaustion (denial of service)

- Process resource limits
  - number of child processes, open file descriptors

Signals

- Signal
  - simple form of interrupt
  - asynchronous notification
  - can happen anywhere for process in user space
  - used to deliver segmentation faults, reload commands, …
  - `kill` command

- Signal handling
  - process can install signal handlers
  - when no handler is present, default behavior is used
    - ignore or kill process
  - possible to catch all signals except SIGKILL (-9)

Signals

- Security issues
  - code has to be be re-entrant
    - atomic modifications
    - no global data structures
  - race conditions
  - unsafe library calls, system calls
  - examples
    - wu-ftpd 2001, sendmail 2001 + 2006, stunnel 2003, ssh 2006
- Secure signals
  - write handler as simple as possible
  - block signals in handler

Windows Security

Windows

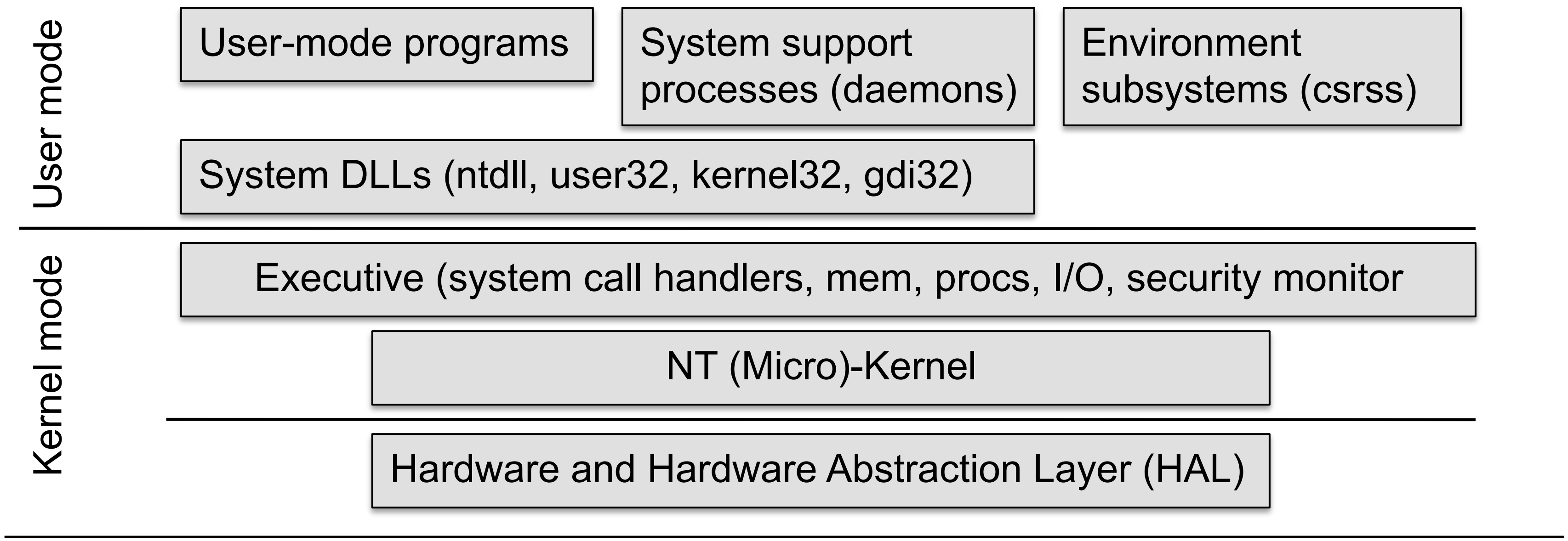
- > 90 % of all computers run Windows
  - when dealing with security issues, it is important to have (some) knowledge of Windows
  - good example of non-open source system and security issues

- Started in 1985
  - graphical add-on to MS DOS

- Two main families
  - building on DOS legacy
    Windows 1.0, Windows 3.11, Windows 95, Windows ME
  - NT line (true 32 bit, multi-user OS)
    started with NT 3.1, NT 4.0, Windows 2K, XP, Vista

Windows NT

- Competitor to Unix
  - true multi-user
  - emphasis on portability and object-oriented design
  - isolation for applications and resource access control
  - similar to Unix, kernel and user mode



Windows NT

Important system processes

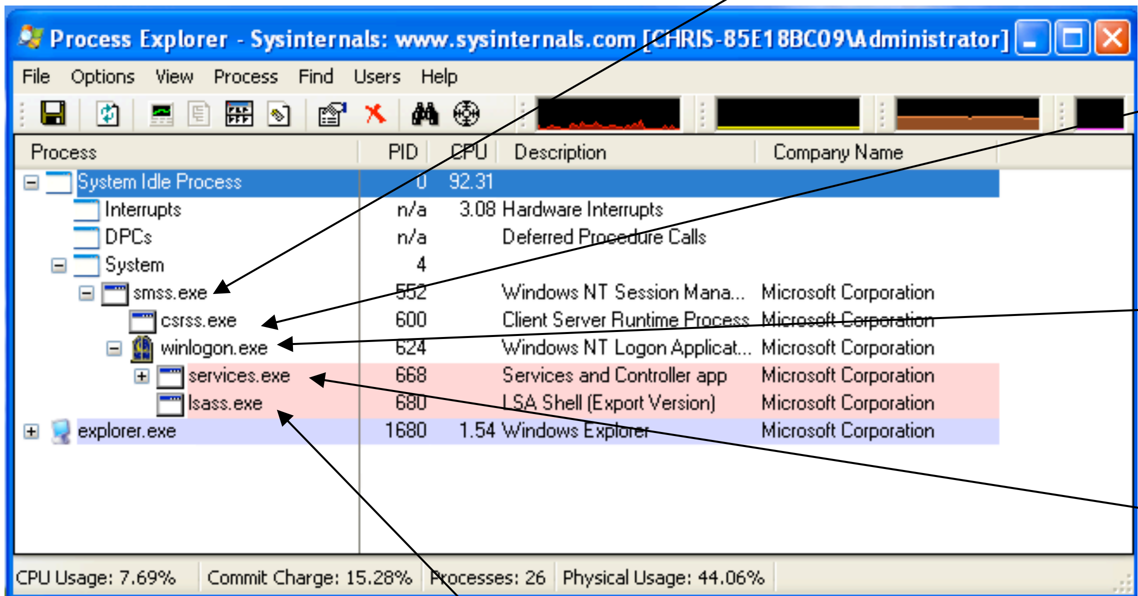
Session Manager (similar to `init`)

Client Server Runtime Process (Win32)

Windows Logon Process (`login`)

Service Control Manager (SCM)

Local security authentication (LSA) process



Windows NT

Security Components

- Security Reference Monitor (SRM)
  - kernel process
  - *performs access control decisions*
  - generates security context
- Local Security Authentication (LSA)
  - user process
  - manages security policies (permission settings)
  - user authentication
- Windows Logon
  - user process
  - gather login information

Access Control Decisions

- Object
  - Windows is object-oriented, everything is an object
  - each object has security settings (*security descriptor*)
- Subject
  - threads / processes
  - have a *security context*
- Operation
  - determines desired access (read, write, delete, …)
- Access Control Decision
  - determines whether object permits certain operations for security context
  - implemented by SRM functionality (SeAccessCheck)
  - if access is permitted, typically an object handle is returned

Security Context

- Security Context
  - stored in (access) token
  - associated with every thread / process

- Access token
  - kernel data structure that determines rights of a subject
  - important fields
    - *User SID (Security IDentifiers)*
    - *Group SIDs*
    - *Privileges*
    - Default permissions (used for files that are created)
    - Management information

Security Identifiers (SID)

- Secure Identifiers
  - used to uniquely identify entities (users, groups, …)
  - similar concept to UID/GID in Unix, but unified
  - variable length, numeric values

- Structure
  - SID structure revision number – 48-bit authority value – variable number of 32-bit sub-authority
  - Administrator has S-1-5-21-XXX-XXX-XXX-500

- Administrator
  - account similar to the `root` user in Unix

Impersonation

- Impersonation
  - used to create access tokens with different permissions
  - the Windows equivalent of setuid* calls
  - can be used to elevate or drop access rights

Security Descriptors

- Security descriptor
  - security information associated with objects
  - important fields
    - owner SID
    - primary group SID (only used by POSIX)
    - discretionary access control list (DACL) – relevant for access control
    - system access control list (SACL) – relevant for logging

- Access control list
  - header + list of access control entries (ACE)

Security Descriptors

- Access control entry (ACE)
  - contains a SID (e.g., for user chris)
  - corresponding operations (e.g., write, read)
  - type (that specifies either allow *or deny*)

- ACL assignment
  - complex set of rules:
    either directly set
    or determined via “inheritance” – e.g., from the current directory
    or default taken from access token

Security Descriptors

- Access decision
  - traverse the DACL until
    either all requested permissions are granted, or
    a requested permission is denied
  - this implies that the order of the ACE might matter!
  - typically, deny entries appear first

- Owner of resource always gets right to modify the DACL

- In principle, concepts are more powerful that Unix
  - permissions for many groups can be defined
  - fine-grain control via allow and deny rules possible

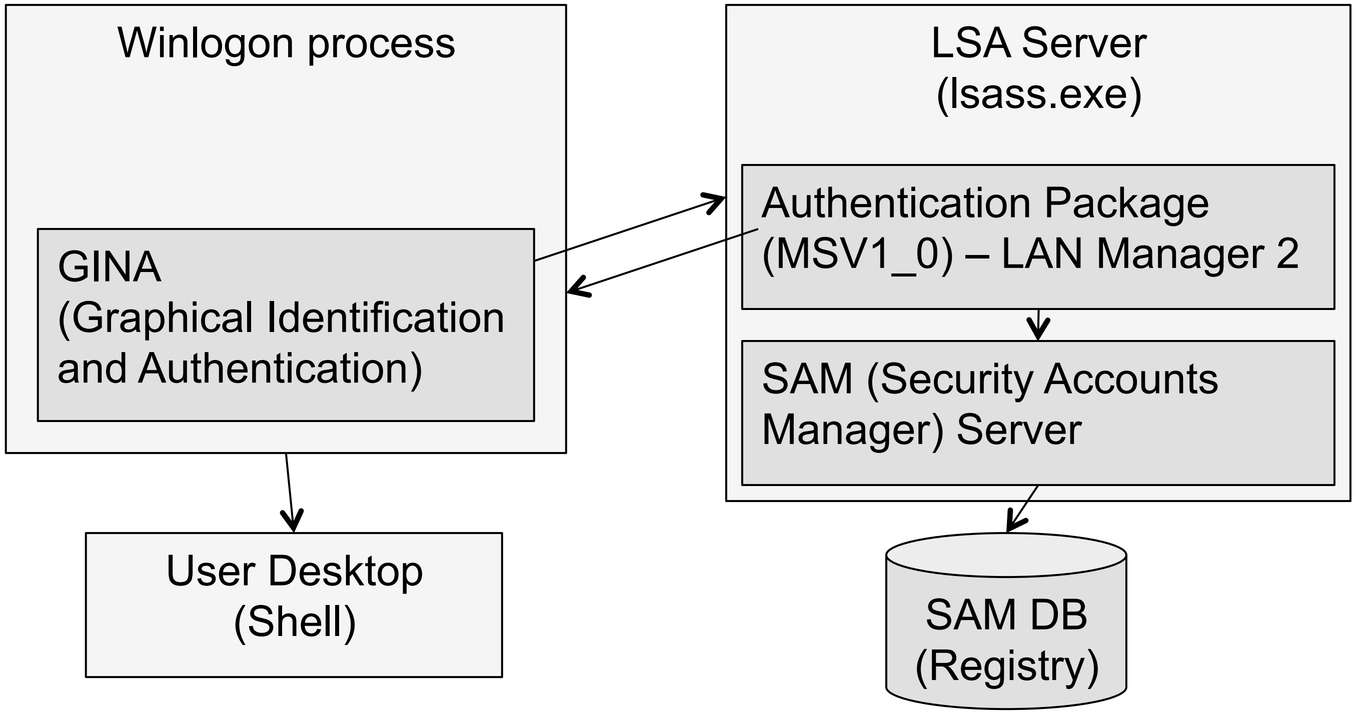
Privileges

- Recall that access token also stores privileges

- Privileges
  - not all (security-relevant) operations are associated with objects
    examples: shut down computer, set system time, …
  - other privileges might disable or bypass access control checks
    examples: backup files, debug processes, …

- Super privileges
  - some privileges are so powerful that they basically grant full access
    “Act as part of the OS,” “Debug Program,” “Restore files” …

Authentication



SAM DB

- Stores hashed passwords
  - similar to /etc/passwd (and /etc/shadow)

- Two formats
  - LM (LAN Manager) hash
  - NTLM

- LM hash
  - uses DES to encrypt static string
  - however, a few flaws

    no salt

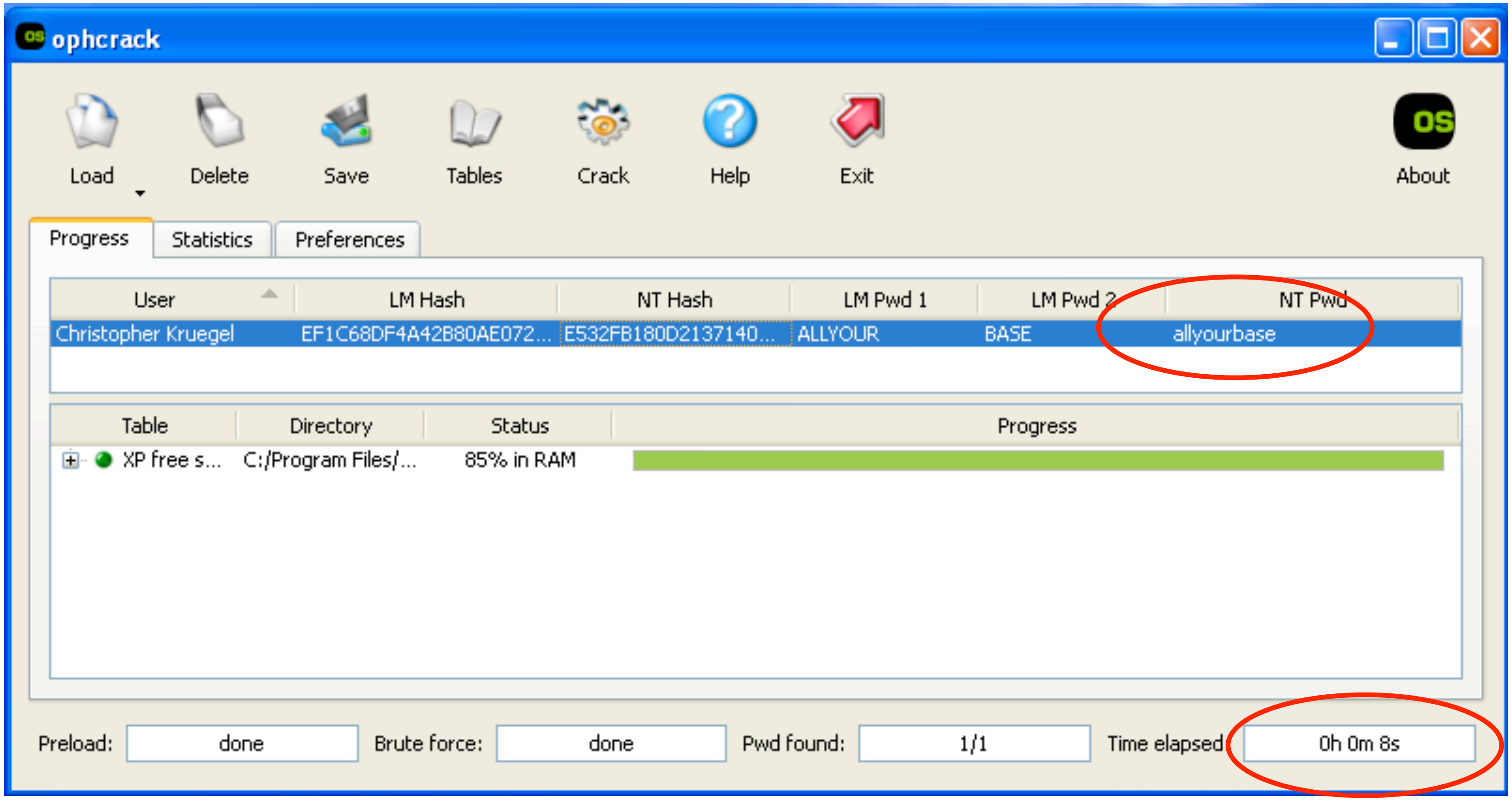
    splits 14 characters into 2 blocks of 7 characters (hashed separately)

    all characters converted to uppercase (further reduces key space)

SAM DB

- LM hash
  - can be cracked trivially (ophcrack)
  - disabled by default in Vista (or when password > 14 characters)
- NTLM
  - better security (MD5)
  - still no salt, thus effective rainbow table attacks possible

SAM DB


ophcrack
Load
Delete
Save
Tables
Crack
Help
Exit
About
Progress
Statistics
Preferences
User
LM Hash
NT Hash
LM Pwd 1
LM Pwd 2
NT Pwd
Christopher Kruegel
EF1C68DF4A42B80AE072...
E532FB180D2137140...
ALLYOUR
BASE
allyourbase
Table
Directory
Status
Progress
XP free s...
C:/Program Files/...
85% in RAM
Preload:
done
Brute force:
done
Pwd found:
1/1
Time elapsed
0h 0m 8s

File System

- NT File System (NTFS)
  - successor of FAT (file allocation table) file system
  - better performance, journaling support, quotas
  - supports Windows security features (in particular, access control features)

- Interesting features
  - links (since Vista, even symbolic links :-))
  - alternate data streams (ADS)

- ADS
  - adds additional streams to a file
  - original file size is not modified, and ADS are difficult to identify
  - accessed in the form of filename:streamname (e.g., text.txt:secret)
  - planned to hold meta-data
  - used by malware to hide presence