Meeting Critical Security Objectives with Security-Enhanced Linux

Peter A. Loscocco

Information Assurance Research Group

National Security Agency

Co-author: Stephen D. Smalley, NAI Labs

Presentation Outline

- Operating system security
- The Flask architecture
- Security-enhanced Linux
- Example security server
- Meeting critical security objectives
- Future Direction

The Need for Secure OS

- Increasing risk to valuable information
- Dependence on OS protection mechanisms
- Inadequacy of mainstream operating systems
- Key missing feature: Mandatory Access Control (MAC)
  – Administratively-set security policy
  – Control over all subjects and objects in system
  – Decisions based on all security-relevant information

Why is DAC inadequate?

- Decisions are only based on user identity and ownership
- No protection against malicious software
- Each user has complete discretion over his objects
- Only two major categories of users: superuser and other
- Many system services and privileged programs must run with coarse-grained privileges if not as superuser

What can MAC offer?

- Strong separation of security domains
- System and data integrity
- Ability to limit program privileges
- Protection against tamper and bypass
- Processing pipelines guarantees
- Authorization limits for legitimate users

MAC Implementation Issues

- Must overcome limitations of traditional implementations
  - More than just Multilevel Security
  - Address integrity, least privilege, separation of duty issues
  - Complete control using needed security relevant information
  - Control relationships between subjects and code
- Policy flexibility required
  - One size does not fit all!
  - Ability to change the model of security
  - Ability to express different policies within given model
  - Separation of policy from enforcement
- Maximize security transparency

Customize according to need

- Separation policies
  - Establishing Legal Restrictions on data
  - Restrictions to classified/compartmented data
- Confinement policies
  - Restricting web server access to authorized data
  - Minimizing damage from viruses and other malicious code
- Integrity policies
  - Protecting applications from modification
  - Preventing unauthorized modifications of databases
- Invocation policies
  - Guaranteeing that data is processed as required
  - Enforcing encryption policies

Security Solutions with Flexible MAC

- Confines malicious code
  - Can safely run code of uncertain pedigree
  - Constrains code inserted via buffer overflow attacks
  - Limits virus propagation
- Allows effective decomposition of root
  - Root no longer all powerful
  - Limits each root function to needed privilege
  - Eliminates most privilege elevation attacks
- Allows effective assignment of privilege
  - Servers need not run with complete access
  - Servers and needed resources can be isolated
  - Separate protections for system logs

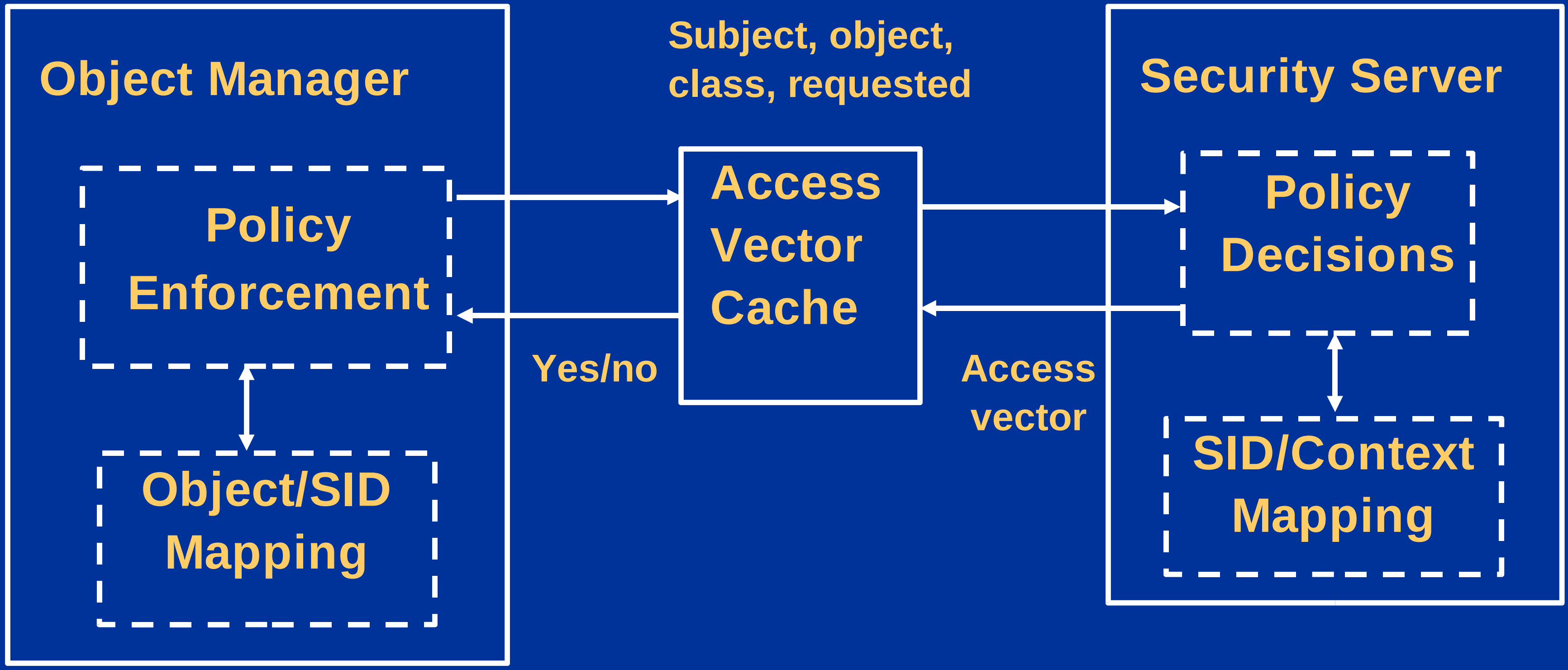
Toward a New Form of MAC

- Research by NSA with help from SCC
- Generalized from prior Type Enforcement work
- Provide flexible support for security policies
- Cleanly separate policy from enforcement
- Address limitations of traditional MAC
- DTMach, DTOS, Flask

The Flask Security Architecture

- Cleanly separates policy from enforcement.
- Well-defined policy interfaces.
- Support for policy changes.
- Allows users to express policies naturally.
- Fine-grained controls over kernel services.
- Caching to minimize performance overhead.
- Transparent to applications and users.

The Flask Security Architecture



Policy Decisions

- Labeling Decisions: Obtaining a label for a new subject or object.
- Access Decisions: Determining whether a service on an object should be granted to a subject.
- Polyinstantiation Decisions: Determining where to redirect a process when accessing a polyinstantiated object.

Policy Changes

- Interfaces to AVC for policy changes
- Callbacks to Object Managers for retained permissions
- Sequence numbers to address interleaving
- Revalidation of permissions on use

Controlled Services

- Permissions are defined on objects and grouped together into object classes
- Examples
  - Process: code execution, transitions, entrypoints, signals, wait, ptrace, capabilities, etc.
  - File: fd inheritance and transfer, accesses to files, directories, file systems
  - Socket: accesses to sockets, messages, network interfaces, hosts
  - System V IPC: accesses to semaphores, message queues, shared memory
  - Security: accesses to security server services

Security Server Interface

- Object Labeling
  - Request SID to label a new object
    - int security_transition_sid(ssid, tsid, tclass, *out_sid)
  - Example of usage for new file label
    - error = security_transition_sid(current->sid, dir->i_sid, FILE, &sid);

Security Server Interface (cont.)

- Access Decisions
  - Request Access Vector for a given object class/permission
    - int security_compute_av(ssid, tsid, tclass, requested, *allowed, *decided, *seqno);
  - Ignores access vectors for auditing and requests of notifications of completed operations

Security Server Interface (cont.)

- Access Vector Cache (AVC)
  - security_compute_av() called indirectly through AVC
    - int avc_has_perm_ref(ssid, tsid, tclass, requested, *aeref, *auditdata)
  - aeref is hint to cache entry. If invalid then security_compute_av() is called
- File permission check shortcuts
  - int dentry_mac_permission(struct dentry *d, access_vector_t av)

Permission Checking Examples

- unlink from fs/namei.c:vfs_unlink()

```
error = dentry_mac_permision(dentry, FILE_UNLINK);
if (error)
        return error;
```

  - Additional directory-based checks for search and remove_name permissions
- Process to socket check from net/ipv4/af_inet:inet_bind()

```
lock_sock(sk);
ret = avc_has_perm_ref(current->sid,sk->sid,sk->sclass,
        SOCKET_BIND &sk->avcr);
release_sock(sk);
if (ret) return ret;
```

Permission Checking Examples

- execve() from fs/exec.c:prepare_binprm()

```
if (!bprm->sid) {
    retval = security_transition_sid(current->sid, inode->i_sid,
                    SECCLASS_PROCESS, &bprm->sid);
    if (retval) return retval;}
if (current->sid != bprm->sid && !bprm->sh_bang){
    retval = AVC_HAS_PERM_AUDIT(current->sid, bprm->sid,
                    PROCESS, TRANSITION, &ad);
    if (retval) return retval;
    retval = process_file_mac_permission(bprm->sid, bprm->file,
                    PROCESS_ENTRYPOINT);
    if (retval) return retval;}
retval = process_file_mac_permission(bprm->sid, bprm->file,
                    PROCESS_EXECUTE);
if (retval) return retval;
```

- Also checks file:execute, fd:inherit, process:ptrace

API Enhancements

- Existing Linux API calls unchanged
- New API calls for security-aware applications: execve_secure, mkdir_secure, stat_secure, socket_secure, accept_secure, etc.
- New API calls for application policy enforcers: security_compute_av, security_transition_sid, etc.

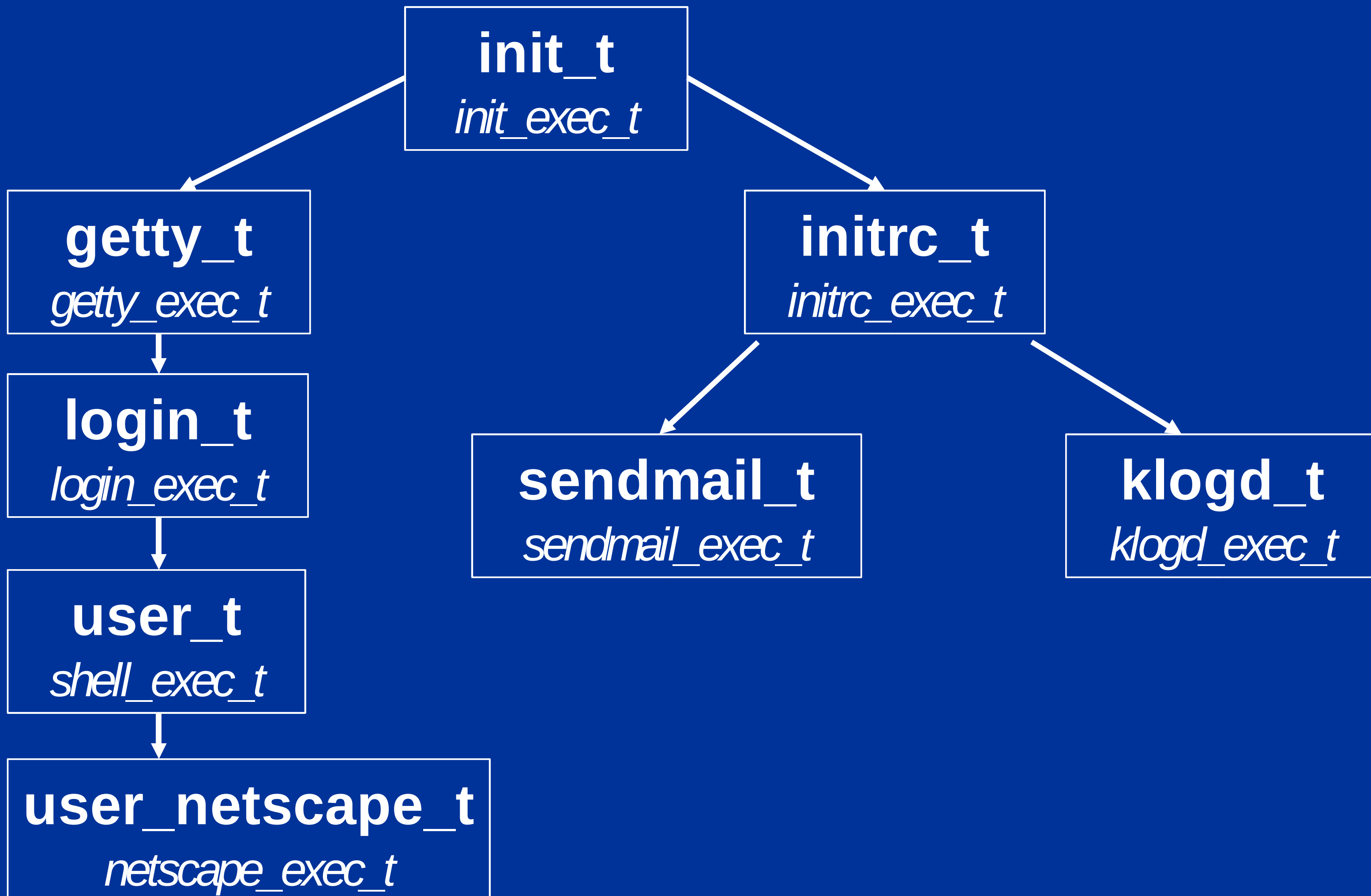
Example Security Server

- Implements combination of Role-Based Access Control, Type Enforcement, optional Multi-Level Security.
- Labeling, access, and polyinstantiation decisions defined through set of configuration files.
- Example policy configuration provided.

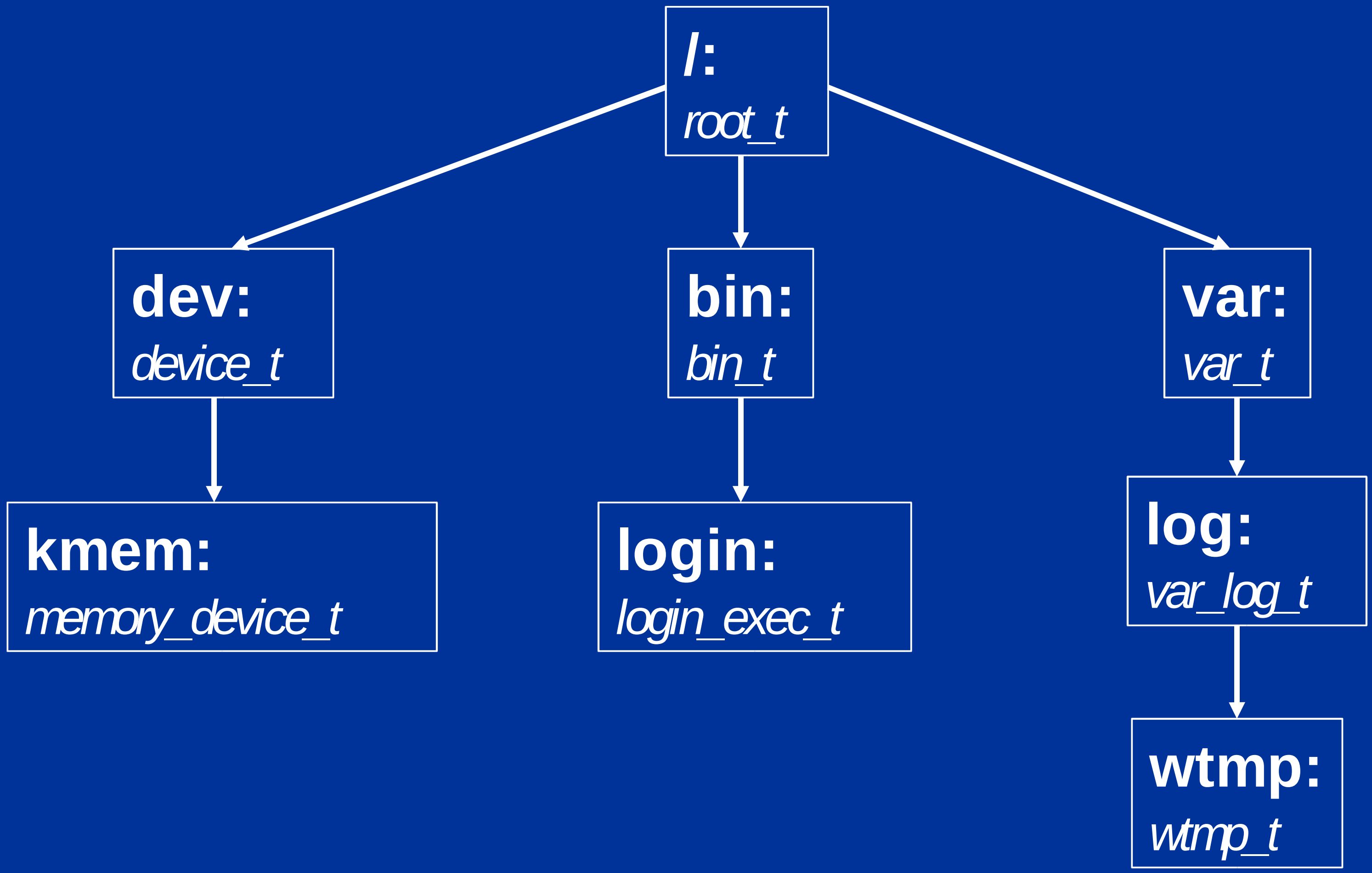
Example Policy Configuration: TE Concepts

- Domains for processes, types for objects.
- Specifies allowable accesses by domains to types.
- Specifies allowable interactions among domains.
- Specifies allowable and automatic domain transitions.
- Specifies entrypoint and code execution restrictions for domains.

Type Enforcement: Domains



Type Enforcement: Types



Sample TE Rules

```
allow sendmail_t smtp_port_t:tcp_socket name_bind;

type_transition getty_t login_exec_t:process local_login_t;
```

Example Policy Configuration: RBAC concepts

- Roles for processes
- Specifies domains that can be entered by each role
- Specifies roles that are authorized for each user
- Initial domain associated with each user role
- Role transitions are typically explicit, e.g. login or newrole

Role-Based Access Control: Roles

system_r	user_r	sysadm_r
init_t	*user_t*	*sysadm_t*
getty_t	*user_netscape_t*	*insmod_t*
klogd_t	*passwd_t*	*fsadm_t*
sendmail_t		

Example Policy Configuration: Security Objectives

- Protect kernel integrity, including boot files, kernel modules, sysctl variables
- Protect integrity of system software, configuration files, and logs
- Protect administrator role and domain
- Confine system processes and privileged programs
- Protect against execution of malicious software

Limiting raw access to data

- Controlling *fsck* and related utilities

```
allow fsadm_t fsadm_exec_t:process
    { entrypoint execute };
allow fsadm_t fixed_disk_device_t:blk_file
    {  read write };
allow initrc_t fsadm_t:process transition;
allow sysadm_t fsadm_t:process transition;
```

Limiting raw access to data

- Granting access to *klogd*

```
allow klogd_t klogd_exec_t:process
    { entrypoint execute };
allow klogd_t memory_device_t:chr_file
    { read write };
allow initrc_t klogd_t:process transition;
```

Kernel integrity protection

- Protecting */boot* files

```
allow initrc_t boot_t:dir
    { read search add_name remove_name };
allow initrc_t boot_runtime_t:file
    { create write unlink };
type_transition initrc_t boot_t:file boot_runtime_t;
```

Kernel integrity protection

- Controlling use of *insmod* program

```
allow sysadm_t insmod_exec_t:file x_file_perms;
allow sysadm_t insmod_t:process transition;
allow insmod_t insmod_exec_t:process
    { entrypoint execute };
allow insmod_t sysadm_t:fd inherit_fd_perms;
allow insmod_t self:capability sys_module;
allow insmod_t sysadm_t:process sigchld;
```

System file integrity protection

- Separate types for system programs
  - *e.g.* bin_t, sbin_t
- Separate types for system configuration files
  - *e.g.* etc_t
- Separate type for shared libraries
  - *e.g.* shlib_t
- Separate types for system logs
  - *e.g.* wtmp_t
- Separate type for dynamic linker
  - *e.g.* ld_so_t

System file integrity protection

- Granting sendmail accesses

```
allow sendmail_t etc_aliases_t:file { read write };
allow sendmail_t etc_mail:dir
    { read search add_name remove_name };
allow sendmail_t etc_mail_t:file
    { create read write unlink };
```

- Granting logfile accesses

```
allow local_login_t wtmp_t:file { read write };
allow remote_login_t wtmp_t:file { read write };
allow utempter_t wtmp_t:file { read write };
```

Confining privileged processes

- excerpt for sendmail

```
allow sendmail_t smpt_port_t:tcp_socket name_bind;
allow sendmail_t mail_spool_t:dir
    { read search add_name remove_name };
allow sendmail_t mail_spool_t:file
    { create read write unlink };
allow sendmail_t mqueue_spool_t:dir
    { read search add_name remove_name };
allow sendmail_t mqueue_spool_t:file
    { create read write unlink };
```

Confining privileged processes

- excerpt for ftpd

```
allow ftpd_t wtmp_t:file append;
allow ftpd_t var_log_t:file append;
allow ftpd_t ls_exec_t:process execute;
```

Separating Processes

- Access across domains restricted to privilege processes
  - signals, ptrace, /proc
- Access to temporary files controlled

```
allow user_t tmp_t:dir
    { read search add_name remove_name } ;
allow user_t user_tmp_t:file
    { creat read write unlink  };
type_transition user_t tmp_t:file user_tmp_t;
```

- Similar controls for home directories and terminal devices

Administrator domain protection

- Controlling access to sysadm_t

```
type_transition getty_t login_exec_t:process local_login_t;
allow local_login_t sysadm_t:process transition;
allow newrole_t sysadm_t:process transition;
```

- Execution limited to approved types
- Separation from other domains

Malicious software protection

- Example putting netscape in its own domain

```
type_transition user_t netscape_exec_t:process user_netscape_t;
allow user_t netscape_exec_t:process
    { entrypoint execute } ;
allow user_netscape_t user_netscape_rw_t:file
    { read write create unlink };
```

Performance

- Initial performance measurements reported at 2001 Usenix Conference
- Benchmark Summary
  - Macrobenchmarks showed no measurable overhead
  - Microbenchmarks showed small fixed overhead proportional to complexity of permission checks
  - Should be treated as upper bound - no optimization done
- Ongoing performance work (IBM Watson)
  - Scalability and locking issues

Ongoing and future work

- Define generalized hooks for kernel (LSM Project)
- Integrate with IPSEC/IKE and extend to support packet labeling and policy-based protection.
- Implement labeling and controls for NFS.
- Implement complete polyinstantiation support.
- Develop policy specification and analysis tools

Linux Security Module Project

- Goal is to develop common set of kernel hooks to allow security LKMs to be defined
- Hosted by WireX
  - http://lsm.immunix.com/
  - linux-security-module@wirex.com
- Status
  - Patch to 2.4.6 kernel w/most hooks defined
  - Currently working on networking hooks
- SELinux LKM using LSM patch ready
  - Available at http://www.nsa.gov/selinux/ soon

Questions?

Available at: http://www.nsa.gov/selinux/

Mailing list: Send ‘subscribe selinux’ to majordomo@tycho.nsa.gov

email: loscocco@tycho.nsa.gov
ssmalley@nai.com