05/15/2004

TrustedBSD: Trusted Operating System Features for BSD

Robert Watson, Research Scientist

Host Intrusion Prevention Research Group

McAfee Research

Introduction

- Introduction to TrustedBSD feature set
  - Background: Trusted Operating Systems
    - Feature sets of interest
    - Role of assurance
  - Evolution of the TrustedBSD Project
  - Infrastructure to support security features
    - Extended attributes, GEOM, ...
  - Security features provided via TrustedBSD/FreeBSD
    - ACLs, MAC, Audit, ...
  - Experimental work to port feature set to Darwin/Mac OS X

Background: Trusted Operating Systems

- Notions originated in security research and development in the 1960's and 1970's
  - Desire to support trustworthy and secure systems for military (and later general government, banking, etc)
- Two dimensions of importance:
  - Security feature set
  - Assurance of correct security functionality
- Specifications play an important role
  - 1980's-1990's: “Orange Book”
  - 1990's-2000's: NIAP and Common Criteria

Feature Set: Cx/CAPP

- "Common Access Protection Profile"
- Basic security functionality
  - High level of trust in administrator, hardware
  - Minimal coverage of network concepts
  - Basic notions of users, authentication
  - Separation of administrative role
  - Discretionary protections via Access Control Lists (ACLs)
  - Security event auditing
  - Software life cycle process documentation

Feature Set: Bx/LSPP

- "Labeled Security Protection Profile"
- Building on C2/CAPP
  - Add mandatory protection, notions of role
    - Typically Biba for integrity, MLS for confidentiality
  - Enhanced security event auditing
- Systems frequently also ship with trusted networking extensions
  - CIPSO, MAC integration for IPsec
- Compartmented Mode Workstation (CMW)

Assurance

- How can you provide assurance of security?
- Assurance arguments critical to trusted systems
  - Documentation of intent, assumptions of system
  - Documentation that system architecture addresses intent
  - Argument that system is correctly implemented
  - Documentation of software development and maintenance processes
- For lower levels, measured in inches of paper
- For higher levels, development and architectural processes critical to success

Evaluation Process: Common Criteria

- Select a target feature set (“protection profile”)
- Select a target assurance level (EALx)
- Contract to an evaluation lab
  - Probably also someone to help with evidence generation
- Notes
  - Narrow feature sets (cut down PP, context)
  - Evaluation process is expensive, but critical to provide software to some audiences (governments, etc).
  - Becoming more important as required by more consumers
  - Interactions with open source beginning to be understood

Security Infrastructure Features

- Additional infrastructure required
- Problem: cryptographic storage protection
  - Solution: extensible storage framework (GEOM)
- Problem: access control lists and MAC require storage
  - Solution: extended attributes (UFS extattr, UFS2)
- Problem: diverse access control approaches
  - Solution: centralized access control

Infrastructure: GEOM

- Mobile computing requires the ability to "revoke" data on mobile computing devices
  - Lowest cost solution is a cryptographic transform
  - Requires "insertion" of a transform in the storage stack
- Rather than implement a one-time transform, provide transformation infrastructure
  - GEOM allows "classes" to plug into the storage stack
    - Also used for other services (RAID, partitioning, et al.)
  - Cleanly separates storage producers and consumers
  - Facilities new security R&D for storage

Infrastructure: Extended Attributes

- New access control models frequently require new meta-data for file system objects
  - Access control lists require storage for list data
  - Mandatory access control requires storage for label data
  - Prevent work when adding more meta-data
- Extended attributes provide (name, value) pairs
  - Name is a character string; value is 0 or bytes of data
  - No semantics for content implied
  - Name spaces indicate protection (system, user)
  - Can be consumed by the kernel or userspace

Infrastructure: EAs on UFS1

- First generation implementation
  - Doesn't modify on-disk layout – facilitates prototyping
  - Allocates “backing files” by attribute name
  - Contains array of attribute data indexed by inode #
  - Requires explicit administrative configuration
  - Administrator-defined bound on max data size
  - Space reservation and efficiency are both issues
  - Works well for fixed-size attributes
  - Concurrency and locality issues for performance

Infrastructure: EAs on UFS2

- Perform roll of on-disk layout version
  - Add additional explicit storage for attributes in new layout
  - Data referenced by inode, stored close to inode
  - Uses normal UFS fragment/block mechanism, but prepared for future use of UFS2 pseudo-extents
  - Tighter integration with soft updates
- While there, also...
  - Bump to 64-bit disk addressing
  - New ABIs for system calls, et al
  - Other misc. bits and pieces

Infrastructure: Centralized Access Control

- Review all kernel access control decisions
- Use explicit monitoring APIs rather than kmem
- Abstract “common” checks
  - vnode access control
  - Inter-process authorization (visibility, signals, debugging, ...)
- SMPng/KSE credential synchronization model
- Not a security feature “per se”
  - However, critical to adding security features

Security Features

- GBDE: Cryptographic Disk Protection
- POSIX.1e Access Control Lists (ACLs)
- OpenPAM
- NSS
- MAC Framework and policy modules
- SEBSD
- SEDarwin
- Audit

GBDE: GEOM-Based Disk Encryption

- Storage encryption using key or random key
  - Intended to be resilient to cryptographic attack
  - Appropriate for use on notebooks, for swap devices, etc.
- Performed at block level, not file system level
- Created using GEOM class; once instance per encrypted storage device
- Auto-configuring, subject to key availability
- Details covered in GBDE session yesterday.
- Implementation by Poul-Henning Kamp

POSIX.1e Access Control Lists (ACLs)

- Enhanced “discretionary” access control
  - Administrator/owners of objects control object protections
  - Extension of permission model permits new entries
    - Additional users, additional groups
    - Mode compatibility through “mask” entry
- Based on POSIX.1eD17 draft standard
  - Specification never finalized for a variety of reasons
- Model selected due to compatibility concerns
  - On the whole, API-compatible with IRIX, Linux
  - Semantics similar but syntax non-identical to Solaris

OpenPAM

- Pluggable Authentication Modules (PAM)
- FreeBSD used linux-pam derivative
- Desire for fresh implementation
  - More complete integration required
  - XSSO standards compliance, Solaris compatibility
  - Strong portability goals
  - Security audit and review
  - More complete set of modules
- OpenPAM integrated into FreeBSD 5.x

NSS – Name Service Switch

- NSS permits directory services to be plugged
  - Similar to PAM for password file, group file, etc
  - Allows new directory services to be plugged in as modules
    - LDAP particularly of interest
  - Requirement for extensibility so new database types and databases can be added easily
  - Current implementation uses shared libraries
    - On-going work to support IPC to NSS daemon for caching, reduced cost
- Integrated into FreeBSD 5.x

MAC Framework and Policy Modules

- Addresses two requirements
  - Mandatory Access Control (MAC) policies
  - Extensible/flexible kernel policy mechanism
- Allows extension of kernel access control model
  - Policies encapsulated in kernel or loadable modules
    - Compile-time, boot-time, and run-time extension
  - Modules can instrument critical access decisions in kernel
  - Provides common infrastructure, such as labeling, APIs
  - Automatic composition of multiple policies

Rationale for Security Extensions

- Common FreeBSD deployment scenarios
  - Banks, multi-user ISP environments
  - Web-hosting cluster, firewalls
  - “High-end embedded”
- Many of these scenarios have requirements poorly addressed by traditional UNIX security
  - OS hardening
  - Mandatory protection
  - Flexible, manageable, scalable protection

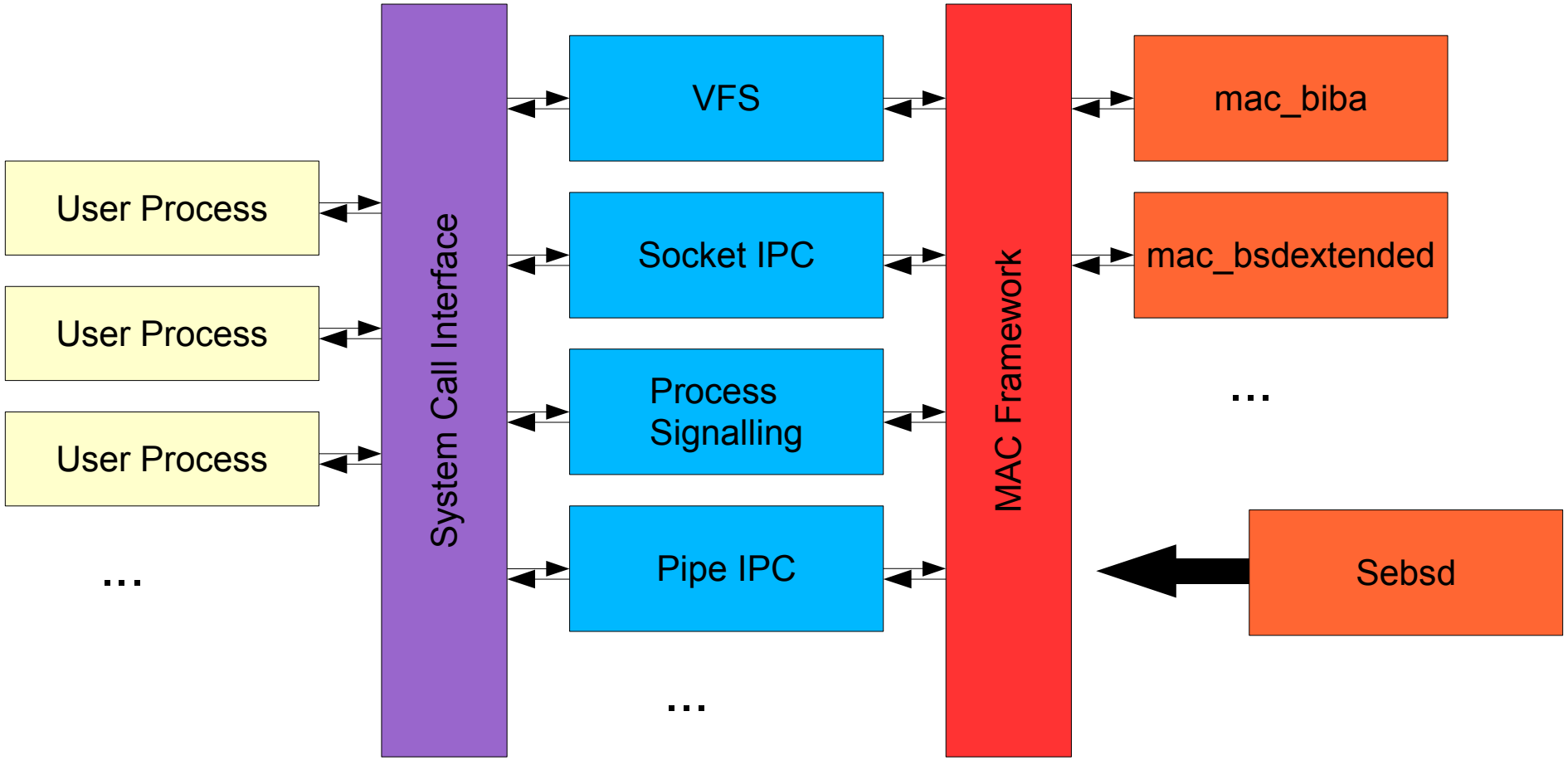
Why a MAC Framework?

- Support required in operating system for new security services
  - Costs of locally maintaining security extensions are high
  - Framework offers extensibility so that policies may be enhanced without changing base operating system
- There does not appear to be one perfect security model or policy
  - Sites may have different security/performance trade-offs
  - Sites may have special local requirements
  - Third party and research products

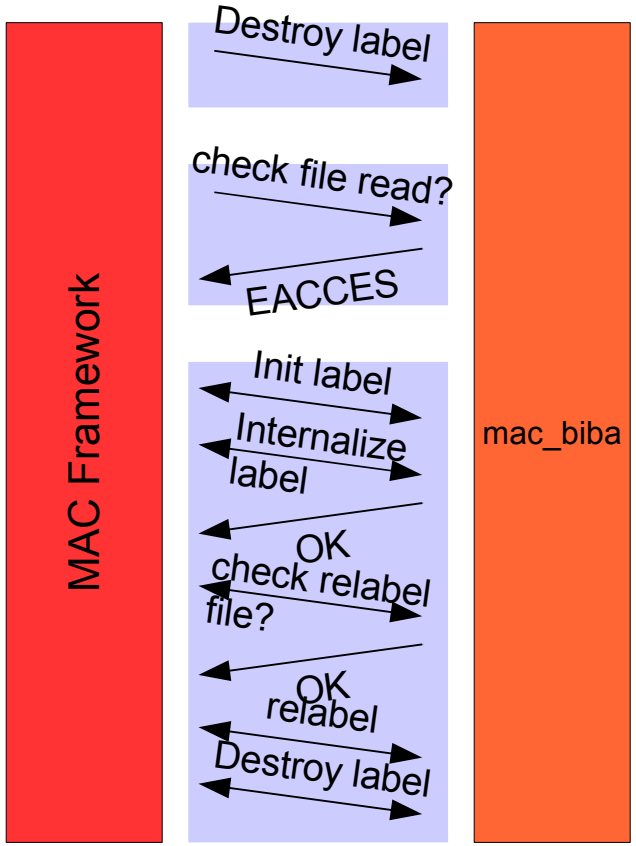
MAC Framework Background

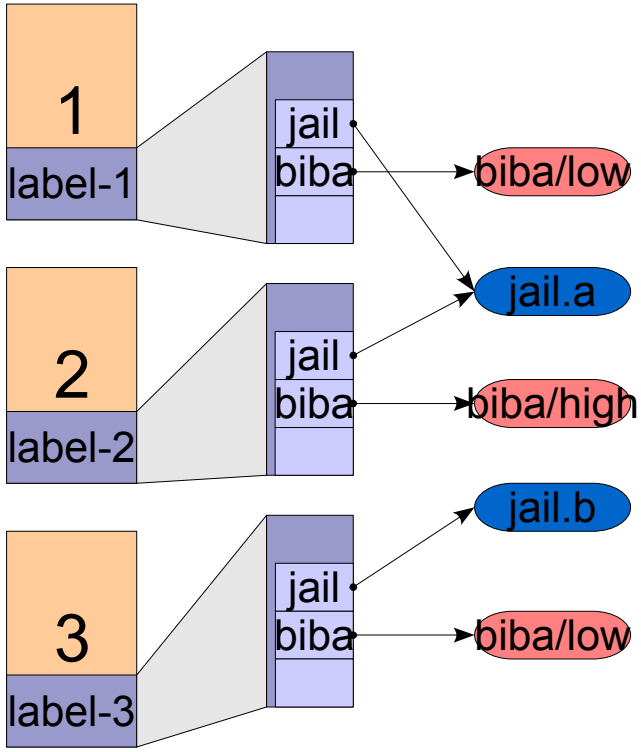
- Extensible security framework
  - Policies implemented as modules
  - Common policy infrastructure like labeling
  - Sample policy modules, such as Biba, MLS, TE, hardening policies, et al.
  - Composes multiple policies if present
  - Also provides APIs for label-aware and possibly policy-agnostic applications
- Shipped in FreeBSD 5.0 to 5.2, 5.2.1

Kernel MAC Framework



Policy Entry Point Invocation
Policy-Agnostic Labeling Abstraction





Modifications to FreeBSD to Introduce MAC Framework

- A variety of architectural cleanups
  - Audit and minimize use of privilege
  - Centralize inter-process access control
  - Centralize discretionary access control for files
  - Clean up System V IPC permission functions
  - Prefer controlled and explicit export interfaces to kmem
  - Combine *cred structures into ucred; adopt td_ucred
  - Correct many semantic errors relating to credentials
  - Support moves to kernel threading, fine-grained locking, SMP

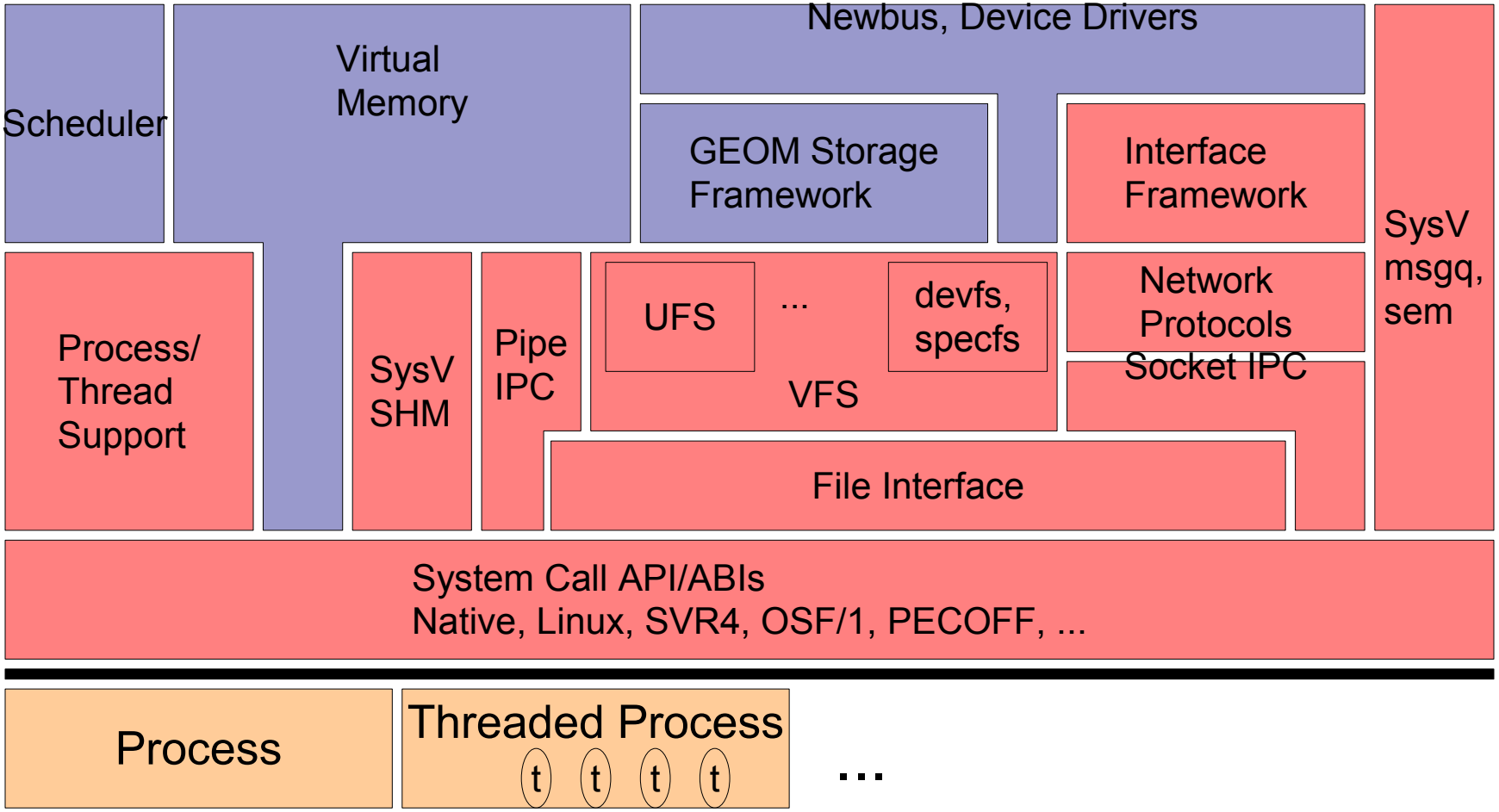
Modifications to FreeBSD to add the MAC Framework (cont)

- Infrastructure components
  - Add support for extended attributes in UFS1; build UFS2
- Actual MAC Framework changes
  - Instrument kernel objects for labeling, access control
  - Instrument kernel objects for misc. life cycle events
  - Create MAC Framework components (policy registration, composition, label infrastructure, system calls, ...)
  - Create sample policy modules
  - Provide userspace tools to exercise new system calls
  - Modify login mechanisms, user databases, etc.

List of Labeled Objects

- Processes
  - Process credential, process
- File System
  - Mountpoint, vnode, devfs directory entries
- IPC
  - Pipe IPC, System V IPC (SHM, Sem, Msg) , Posix IPC
- Networking
  - Interface, mbuf, socket, Inet PCB, IP fragment queue, Ipsec, security association

Integration of MAC Framework into FreeBSD



Where Next for the TrustedBSD MAC Framework

- Continue to research and develop TrustedBSD MAC Framework on FreeBSD
  - Enhanced support for IPsec
  - Improve productionability of policy modules
  - Continued R&D for SEBSD
  - Integrate with Audit functionality

Sample Policy Modules

- mac_test regression test, stub, null modules
- Traditional labeled MAC policies
  - Biba fixed-label integrity, LOMAC floating-label integrity
  - Hierarchal and compartmented Multi-Level Security (MLS)
  - SELinux FLASK/TE “SEBSD”
- Hardening policies
  - File system “firewall”
  - Interface silencing
  - Port ACLs
  - User partitions

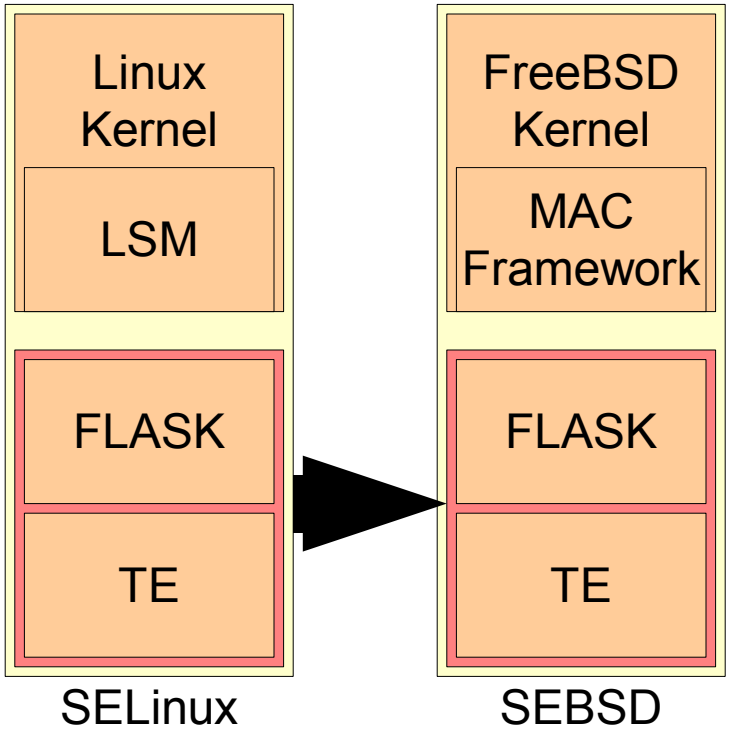
SEBSD: Security-Enhanced BSD Port of FLASK/TE from SELinux

- SELinux based on:
  - NSA's FLASK architecture
    - Developed on FLUX, a Mach/BSD microkernel
    - Access control abstraction based on subjects, objects, sids
  - Type Enforcement policy language
    - Similar to Domain and Type Enforcement (DTE)
    - Subjects assigned domains, objects types
    - Rule language permits subject methods on objects
    - Domain transitions occur on selected binaries
  - Policy file determines nature and granularity of policy

MAC Framework Modifications Required for SEBSD

- Framework parallel to LSM in construction
  - Similarity between LSM and MAC Framework simplify implementation; differences simplify it further
- Provides stronger label manipulation and management calls
  - Don't need a number of the system call additions required to run FLASK on Linux
- Removed notion of SID exposed to userspace since mature APIs for labels already existed
  - This approach later adopted in SELinux, also.

Creating SEBSD Module from Largely OS-Independent FLASK/TE



- At start
  - SELinux tightly integrated FLASK/TE into Linux kernel
  - Over course of SEBSD work, similar transformation was made with LSM
- MAC Framework plays similar role to LSM for SEBSD

Current Status of SEBSD

- Kernel module “sebsd.ko” functional
  - Most non-network objects labeled and enforced for most interesting methods
  - File descriptor, privilege adaptations of MAC Framework complete
- Userspace experimental but usable
  - Libsebsd port complete, ports of SELinux userland programs completed as needed (checkpolicy, newrole, ...)
  - Adapted policy allows many applications to run
    - Few changes needed for third party applications, mostly change required for base system components

SEBSD: Implementation

- Fairly straight forward to port FLASK/TE
  - FLASK/TE originally developed on BSD
  - Encapsulated FLASK/TE into MAC Framework module
- Some enhancement to MAC Framework
  - Requires labeling, access control for file descriptors
  - Requires greater policy control over superuser privilege
  - Required tighter integration into user space components
- In many ways easier on FreeBSD than Linux
  - MAC Framework infrastructure critical (labels, APIs, tools)
  - FreeBSD locking much better defined

SEDarwin: Security-Enhanced Darwin Port of MAC Framework, SEBSD

- Currently experimental work
  - Ported extended attributes, MAC Framework to XNU
  - Ported SEBSD module and simple sample TE policy
  - Modified some user space applications
  - Explored applying mandatory protections to Mach
  - Now porting other policies, improving maturity
- Many lessons learned concerning Darwin
  - Build environment, architectural similarities and differences, HFS+ issues, closed source pieces, working with Apple, windowing systems, Mach, ...

Security Event Auditing

- Fine-grained security event auditing
  - Create a detailed audit log of security events
    - Postmortem
    - Intrusion detection
  - Required by various security standards
    - Including Orange Book, Common Criteria
- Detailed audit of result of many event classes
  - Access to controlled objects (files, network, etc)
  - Authentication events
  - System configuration events

Implementation Requirements

- Process properties (audit ID, session, ...)
- System calls to set properties on login
- System calls to configure audit support
- Instrument kernel events to generate audit trail
- System calls to submit user audit records
- Modifications to user applications (login, et al)
- Kernel record queue, queue limits, disk drain
- User databases and library
- Applications for printing, parsing, managing

Audit Implementation

- McAfee Research implemented Audit on Mac OS X/Darwin platform under contract
  - Uses Solaris BSM API, user interfaces, trail format
- Currently porting implementation to FreeBSD
  - Subject to code drops, licensing from Apple
- Hard problems to solve, however, include
  - How to generate file paths to use in audit records for UFS
  - Problems solved in HFS+ due to different name properties
- Work in progress; 6.x/5.4 time frame

Conclusion

- TrustedBSD Project active
  - Steady stream of features applied to FreeBSD 4.x, 5.x, and upcoming 6.x branches
  - Some features quite mature (GEOM, UFS2, extended attributes, OpenPAM, NSS, ACLs)
  - Other features in the process of maturing (MAC Framework, MAC policies)
  - Others in early development (Audit)
- Information at http://www.TrustedBSD.org/
- Feel free to join lists, post messages, pitch in!