Extensible Kernel Security through the TrustedBSD MAC Framework

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Introduction

- Rationale for Security Extensions
- TrustedBSD MAC Framework
- FLASK/TE with SEBSD
- Porting TrustedBSD MAC Framework to Darwin

CBOSS: Community-Based Open Source Security

- DARPA CHATS program under Doug Maughan
  - Create a partnership between leading open source developers and industry security R&D laboratory
  - Additional research and development funding for maturity of MAC Framework, development of SEBSD, port of both to Darwin/Mac OS X
- By improving the security of open source systems, DARPA can impact a wide variety of COTS and research products
  - Rapid technology transfer path of open source

CBOSS Project Overview

- Many extremes in OS security work:
  - Write OS from the ground up
  - Don't change the OS at all
  - Maintain a local version with extensive modifications
- Avoid pitfalls of these approaches by:
  - Leveraging ability to modify open source FreeBSD operating system to provide security extensibility services
  - Working with open source developers to assure knowledge, process, technology transfer

Benefits to the CBOSS Approach

- Support for secure out-of-the-box COTS operating systems
  - Rapid time-to-market of open source already showing concrete benefits
  - Berkeley-licensed open source software rapidly transfers to closed source software products
  - Better support for future security research through extensibility and stronger support infrastructure
  - Long-term improvements in architecture, implementation, process outside of the research community

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

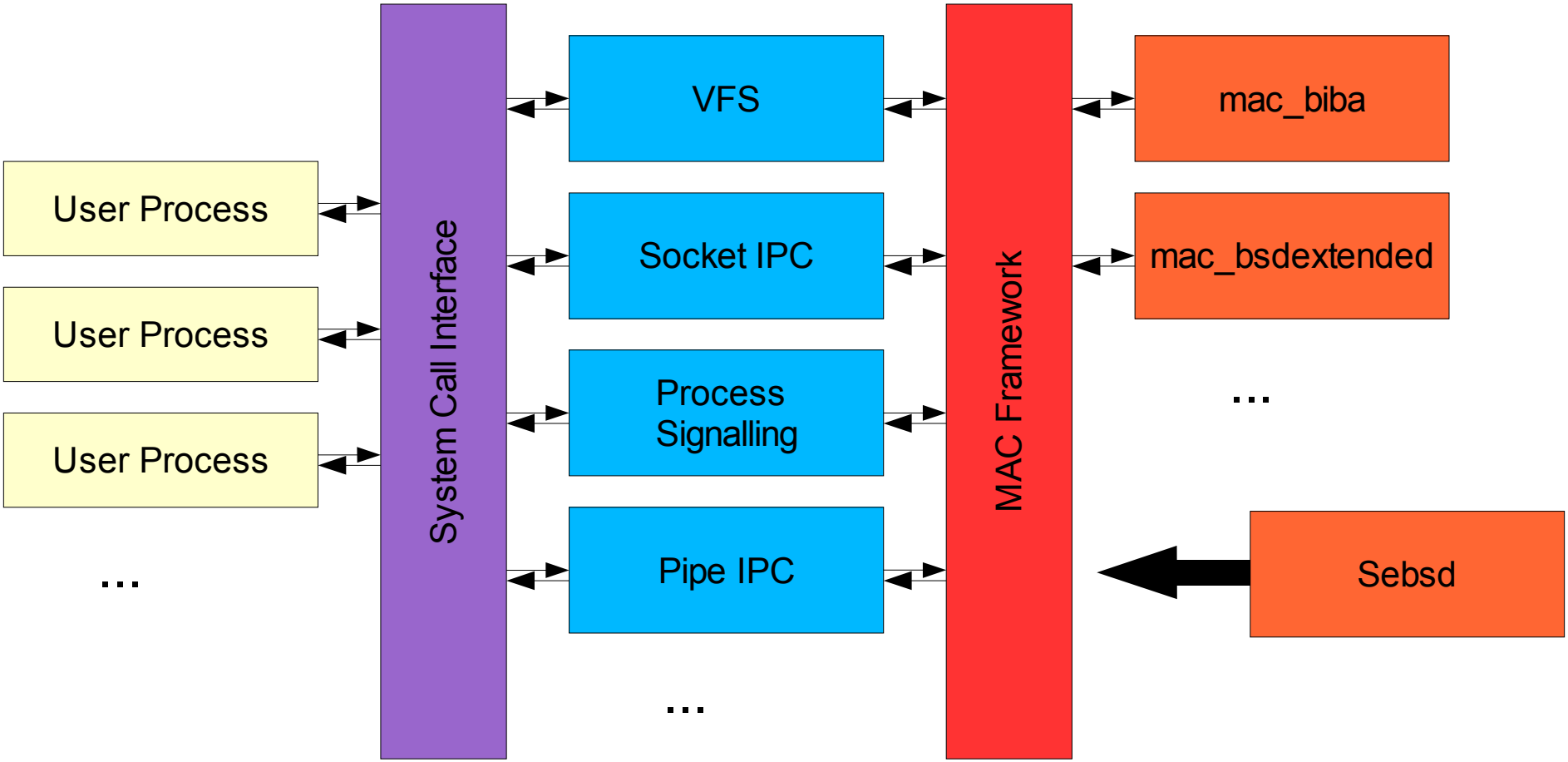
Why a MAC Framework?

- 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

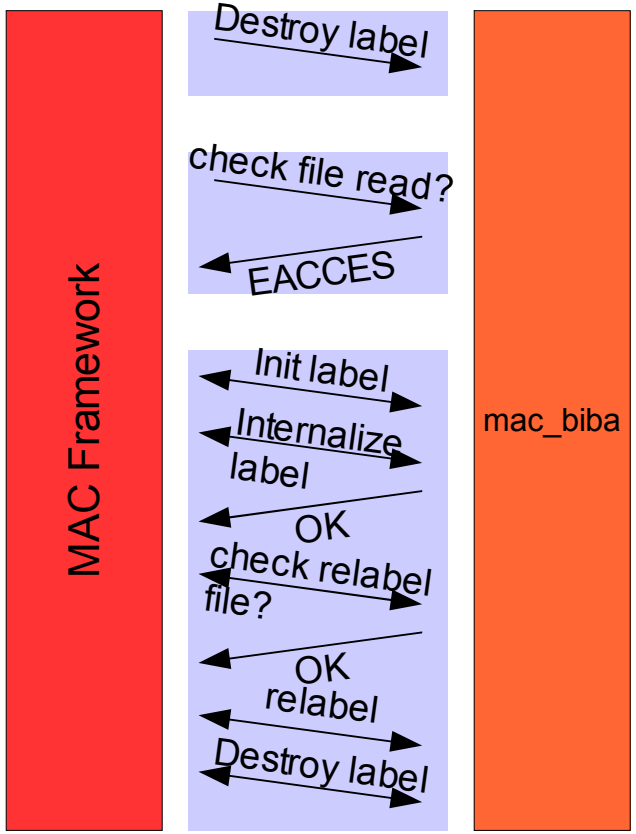
MAC Framework Background

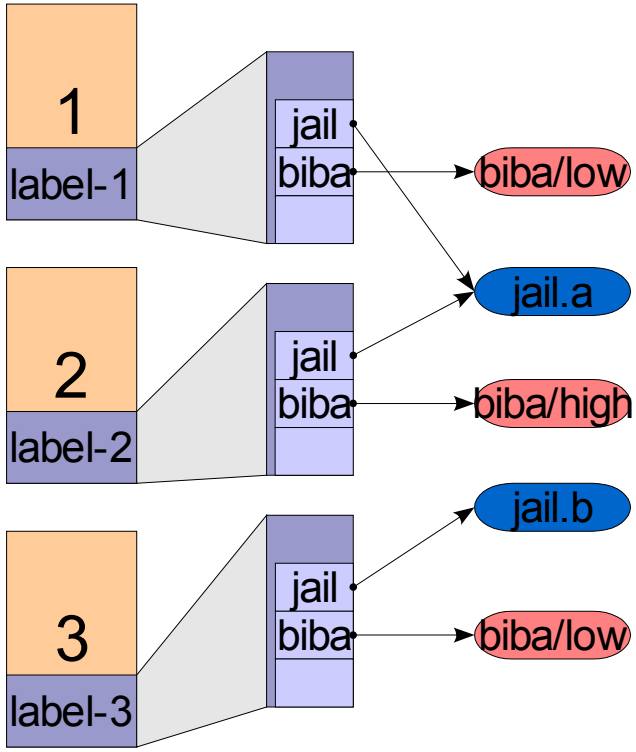
- Extensible security framework
  - Policies implemented as modules
  - Common policy infrastructure like labeling
  - Sample policy modules, such as Biba, MLS, TE, hardening policies, et al.
  - Composes multiple policies if present
  - Also provides APIs for label-aware and possibly policy-agnostic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

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

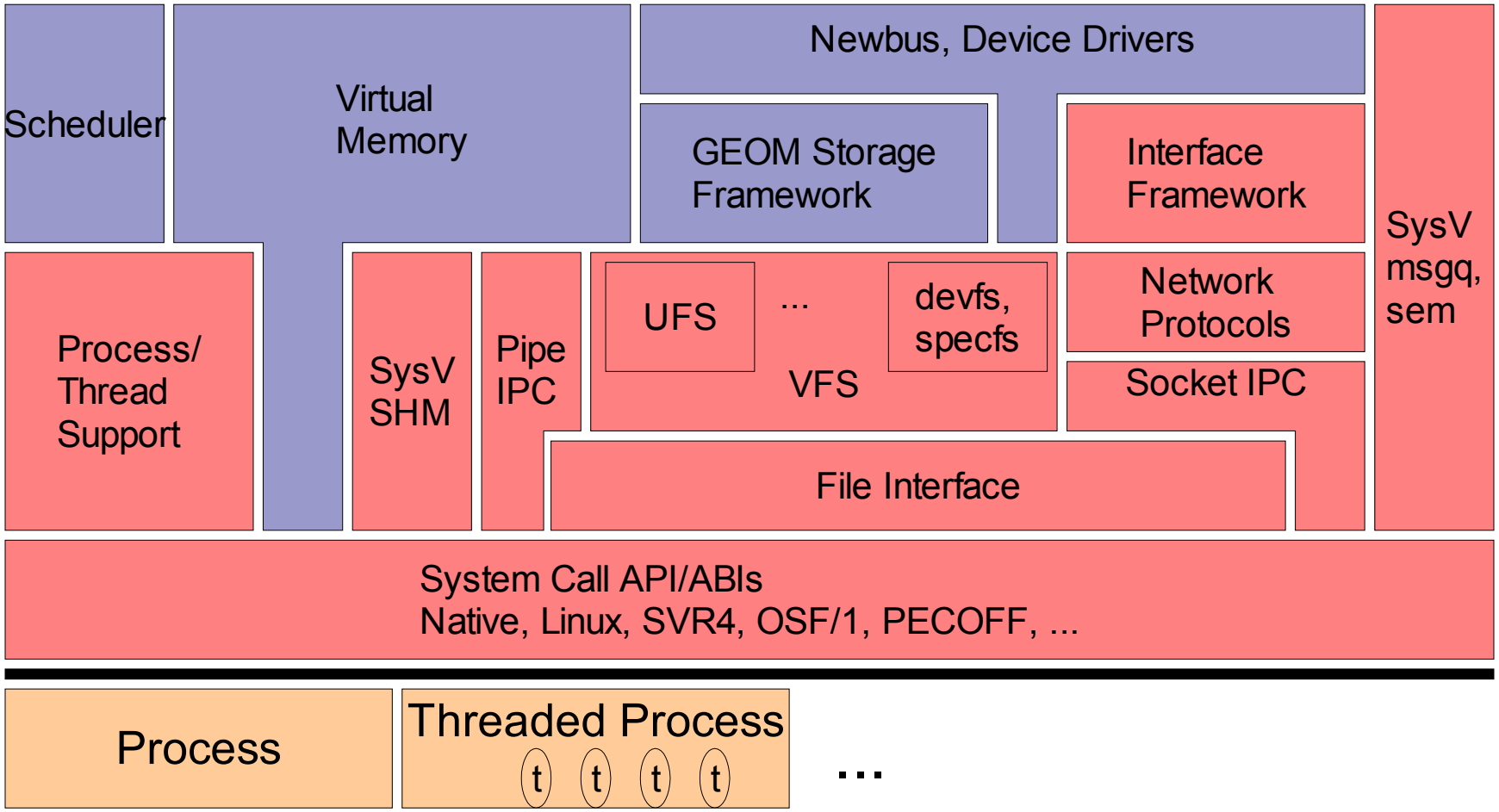
Modifications to FreeBSD to add the MAC Framework (cont)

- 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

- NSA sponsored port of SELinux functionality to the FreeBSD platform
  - Port SELinux policy language and access control model
  - Implement FLASK/TE in a MAC Framework policy module
  - Provide result as open source

SELinux Background

- FLASK security framework
  - FLASK provides an access control framework abstraction
  - Initially integrated directly into Linux kernel
  - Now plugged in using “LSM” framework
- Implements Type Enforcement (TE) Policy
  - Extensive and comprehensive rule language and policy configuration
  - Mature policy documents privileges for many userspace system components and common applications
  - Also limited MLS, RBAC

SELinux FLASK Abstraction

- FLASK plays a similar role to the TrustedBSD MAC Framework
  - Treats existing system components as “object managers”
  - Abstracts notions of subjects, objects, and methods
  - Label storage using SIDs (Security Identifiers)
  - Differences from MAC Framework are substantial
- Access Vector Cache holds cached computation results for SID and method tuples
- “Security Server” security policy implementation

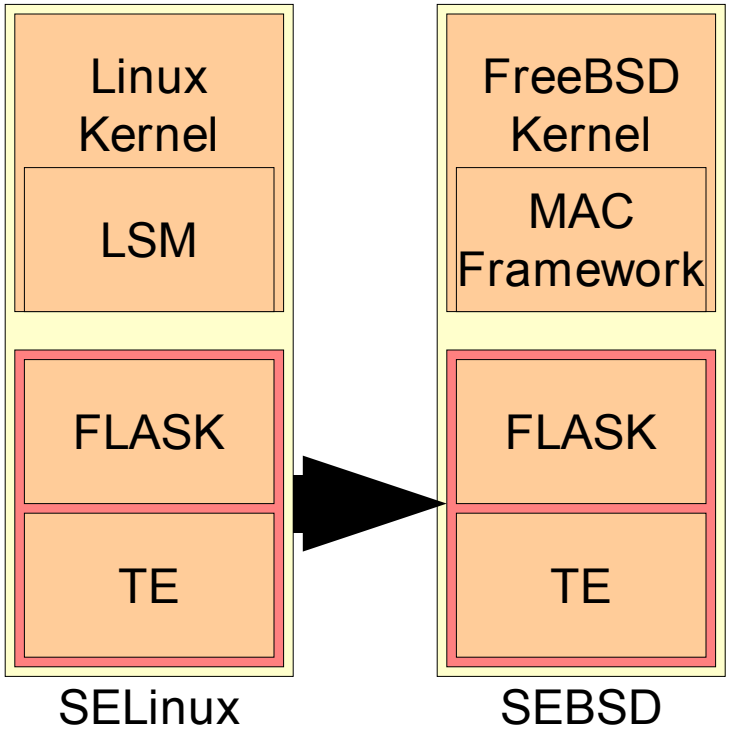
SELinux Type Enforcement

- Type Enforcement represents the set of permitted actions as rules in terms of:
  - Subjects (processes, generally) assigned domains
  - Objects (files, sockets, ...) assigned types
  - Object methods that may be performed on objects
  - Rules specifying permitted combinations of subject domains, object types, and object methods
- Labeling specification assigns initial labels
- New objects have labels computed from rules

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

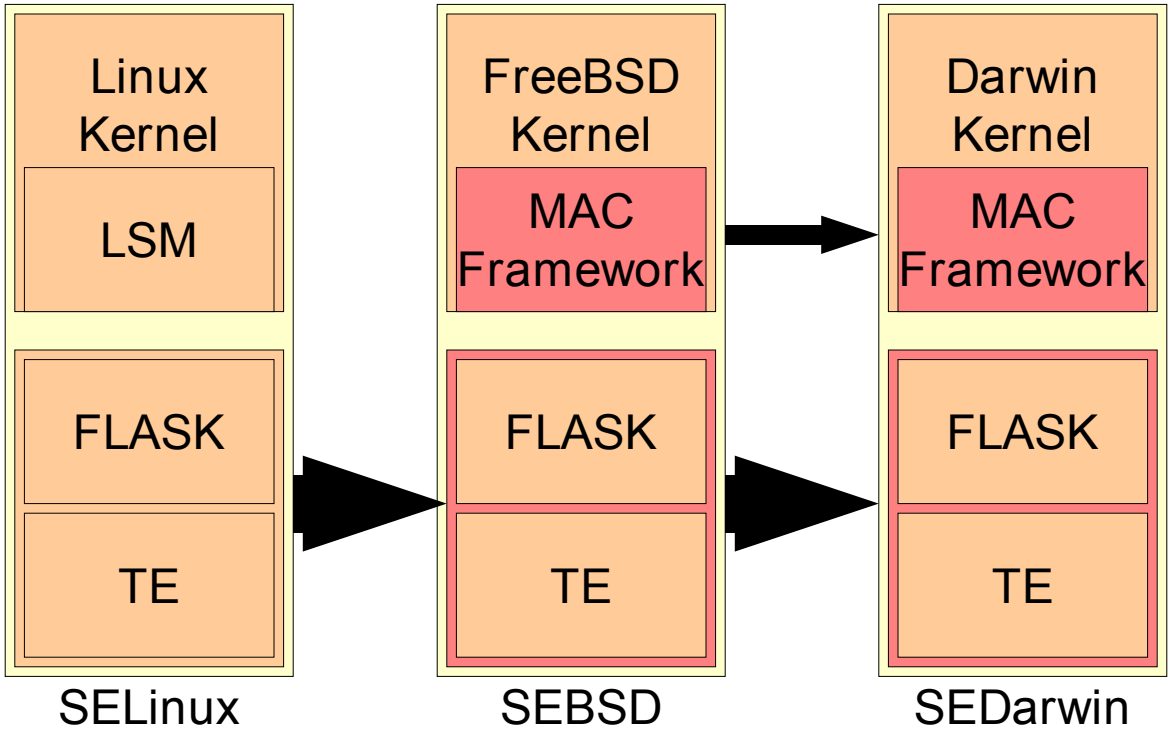
Current Status of SEBSD

- 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

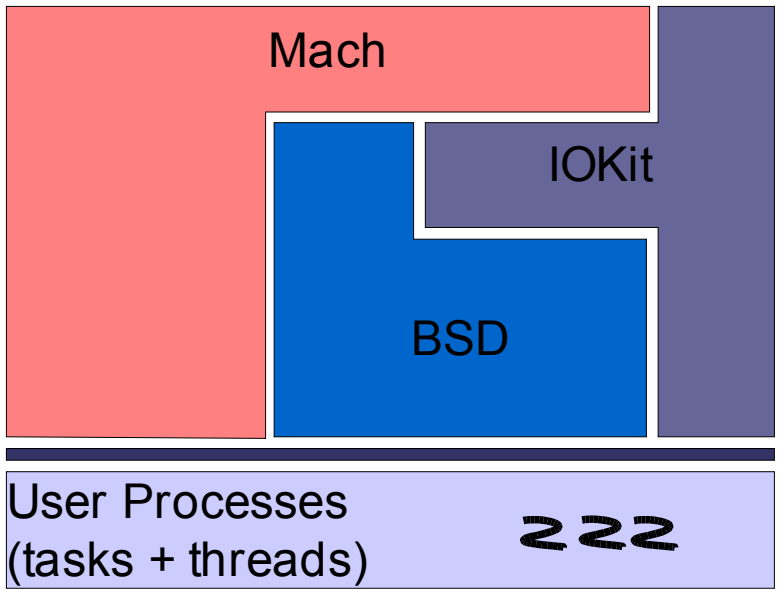
Strategy: Migrate MAC Framework to Darwin, Port SEBSD as SEDarwin

- Exploit common source code and design roots of FreeBSD and Darwin
  - Migrate MAC Framework to Darwin
    - And dependencies, such as extended attributes, etc.
  - Migrate SEBSD, MLS, and other policies to Darwin
  - Expand MAC Framework and policies to address Darwin-specific features, such as Mach IPC
    - Requires MAC Framework to sit between various layers
  - Modify Darwin userspace applications
  - Produce adapted SEBSD TE policy

Strategy: Migrate MAC Framework to Darwin, Port SEBSD as SEDarwin



Architecture of Darwin (Gross Over-Simplification)



- Mach provides low-level IPC, memory, synchronization primitives
- IOKit provides OO driver infrastructure
- BSD provides high level IPC, networking, storage services

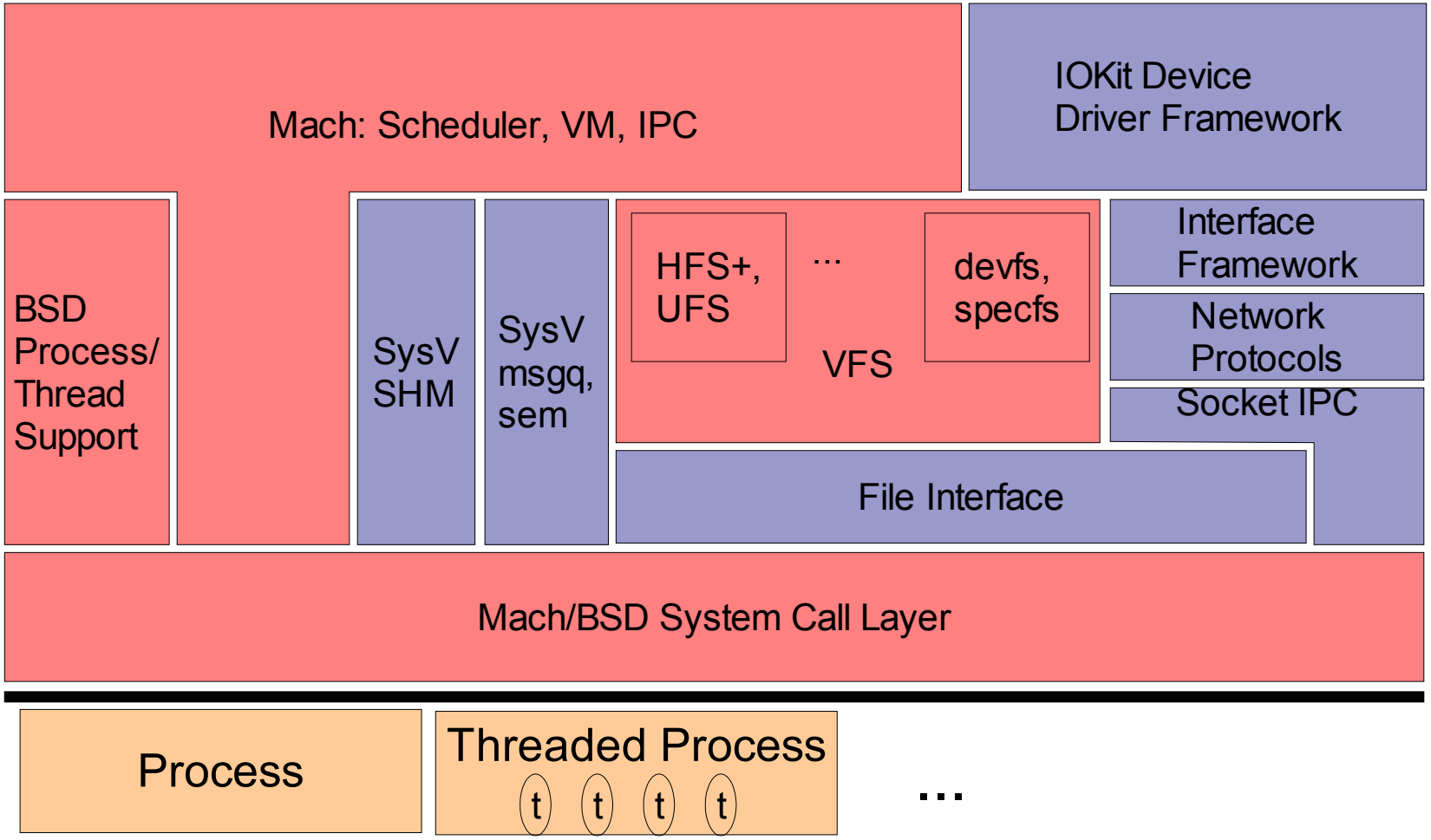
Porting Activities So Far

- Port MAC Framework
  - Focus on getting base functionality up and running
  - Adapt to Mach memory allocation, synchronization
  - Port labeling, access control for devfs
  - Port UFS1 extended attributes to HFS+
  - Port support libraries (libextattr, libmac)
  - Port tools (mac_tools)
  - Adapt base Darwin tools (system_cmds, file_cmds)
  - Port mac_test module
  - Extend MAC Framework to incorporate Mach tasks, IPC

Porting Activities So Far (cont)

- Port SEBSD module
  - Port FLASK, AVC (largely synchronization, allocation issues)
  - Port “Security Server” for Type Enforcement (TE)
  - Port libsebsd
  - Port sebsd_cmds
  - Create minimal policy to get system up and running
  - Create GUI role selection, relabel tools
  - Hook up process, file system labeling and access control
  - Experiment with controls and policy for Mach primitives

Integration of MAC Framework into Darwin Prototype



Issues and Concerns

- Lack of unified build infrastructure for Darwin
  - Challenging to build and maintain extensive modifications
- Serious binary compatibility issues
  - Drivers when expanding data structures for labels
  - Had to back off initial port of network stack components
- Mach wait_queue primitive much weaker
- Mach IPC
  - Mach IPC primitives very weak, semantically
  - Requires applications to be much more involved in access control than in traditional UNIX system

Additional Issues and Concerns

- HFS+ lacks generation numbers
  - May break NFS, also prevents us from checking consistency of attributes with file system objects
  - Prefer that HFS+ had a native extended meta-data service
- Source code for loginwindow not available
  - Jaguar substantially less mature than Panther
  - While there have been improvements to the login process and credential management, still much to be done
- Jaguar applications behave poorly on failure

Additional HFS+ concerns

- TrustedBSD MAC Framework splits ownership of label management with file system
  - Performs access control checks at cross-file system layer
  - Some file systems provide per-label storage
  - Other file systems rely on VFS layer labeling
- Darwin offers a number of stronger file system system calls
  - Permits more direct reading, manipulating of disk catalog
  - Requires MAC Framework to become more involved in HFS+, not to mention layring issues

Conclusion

- TrustedBSD MAC Framework provides flexibl, extensible OS access control
- SEBSD is experimental port of SELinux FLASK/TE to FreeBSD using MAC Framework
- Experimental port of MAC Framework to Darwin reveals opportunities, weaknesses in Darwin