Graduate Operating Systems
(History & Architecture)

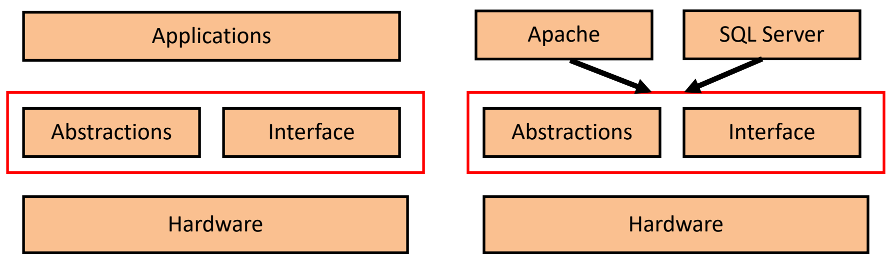
Fall 2020

Today's Paper

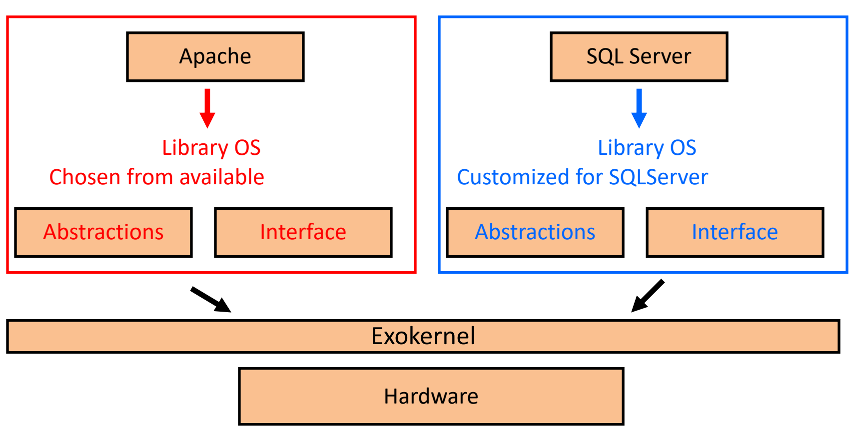
- **[3]** Dawson R. Engler, M. Frans Kaashoek, and James O'Toole Jr., "Exokernel: An Operating System Architecture for Application-Level Resource Management", Proc. of the 15th Symposium on Operating Systems Principles, December 1996.

Traditional Operating Systems

- Traditional operating systems fix the interface and implementation of OS abstractions



Example: Exokernel



Problems with Traditional OS

- Performance
  - Denies applications the advantages of **domain-specific optimizations**
- Flexibility
  - Restricts the flexibility of application builders
  - Concept: **“with more information exposed, resources can be utilized ’better’”**!
- Functionality
  - Discourages changes to the implementations of existing abstractions

Solution: Exokernel

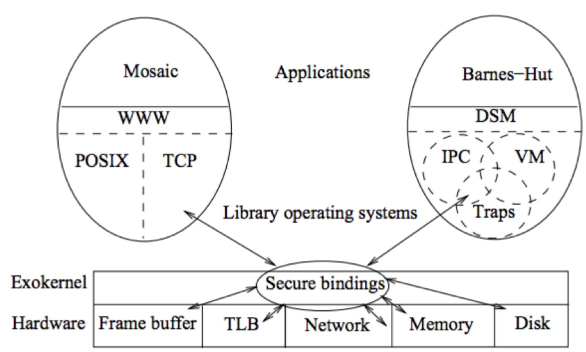
- **Separate protection from management!**
  - Allow user level to manage resources
    - Application libraries implement OS abstractions
  - Exokernel exports resources
    - Low level interface
    - Protects, does not manage
    - Expose hardware
- End-to-end argument; “applications know better”

Exokernel + Library OS

- **Exokernel**'s resource management:
  - Allocate, revoke, share, track ownership
- **Library OS**:
  - Uses low-level Exokernel interface, provides higher-level abstractions; provides special purpose implementations

An application can choose the library which best suits its needs, or even build its own.

Exokernel

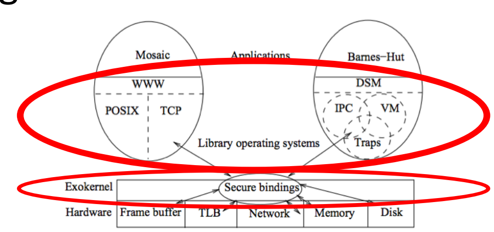


Exokernel

- Hypotheses:
  - Exokernels can be very **efficient**
  - Low-level, secure multiplexing of hardware resources can be implemented **efficiently**
  - Traditional operating system abstractions can be implemented **efficiently** at application level
  - Applications can create **special-purpose implementations** of these abstractions

Library Operating Systems

- Simpler
- Specialized
- Multiple can exist
- Few kernel crossings



Design Challenge

- How can an Exokernel allow libOSes to freely manage physical resources while protecting them from each other?
  - Track ownership of resources
    - Secure bindings – libOS can securely bind to machine resources
  - Guard all resource usage
    - Invisible/visible resource revocation
  - Revoke access to resources
    - Abort protocol

Design Principles

- Securely expose hardware
  - Kernel should provide secure low-level primitives that allow all hardware resources to be accessed as directly as possible.
- Expose allocation
  - Allow to request specific physical resources
- Expose names
  - Export physical names.
  - Remove a level of indirection: Translation
- Expose revocation
  - Utilize a visible resource revocation protocol

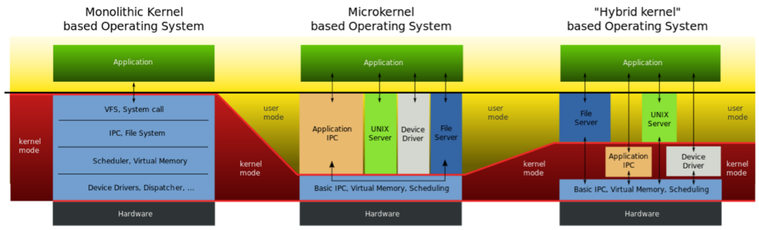
Secure Bindings

- Exokernel allows LibOSes to bind resources using secure bindings
- Decouples authorization from the actual use of a resource
- Multiplex resources securely
- Performs authorization only at bind time
  - Allows the kernel to protect resources without having to understand them

Some Terminology

- Packet filters
- TLB
- Downloadable code (ASH)
- RPC
- DMA

Kernel Comparisons



Microkernels

- A good idea in the 1970s and 80s
- Not up to demands of modern processors
    - Virtual memory
    - Heavy caching
- Not up to demand of modern operating systems
- Resurrection:
    - Mobile phones, PDAs, handheld devices
        - Fixed or limited functionality
        - No general purpose files
        - No dynamic virtual memory

$\Rightarrow$

- Simple context switches
- All code already in memory
- Easy IPC