The Three Questions

- What is the problem?
- What is new or different?
- What are the contributions and limitations?
OS Abstraction Barrier

- Fixed high-level abstractions
  - Hurt application performance
  - Hide information
  - Limit functionality
- Examples
  - Buffer cache management
  - Persistent storage
Goals

- **Extensibility**
  - Applications introduce specialized policies/services

- **Safety**
  - Kernel, applications, services are protected from each other

- **Performance**
  - Extensibility and safety have low cost
Why Is This Hard?

Key challenge: Can we get all three in a single system?
The Two Approaches

- SPIN: move application-specific functionality in kernel
- exokernels: make kernel barrier as low as possible
SPIN
SPIN Approach

- Put extension code into the kernel
  - Cheap communication
- Use language protection features
  - Static safety
- Dynamically impose on any service
  - Fine-grained extensibility
Modula-3

- Type-safe programming language
- Interfaces
- Garbage collection
- Other features
  - Objects, generic interfaces, threads, exceptions

- Most of kernel written in Modula-3
  - Drivers "borrowed" from DEC OSF/1
- Extensions must be written in Modula-3
- User-space applications written in any language
Safety

* Capabilities
  * Simply a pointer
    * Can we pass capabilities to user-land?
  * Protection domains
    * Language-level
    * Limit visibility of names
    * Enforced at dynamic link time
Extensibility

Extension model

- Events
  - Indicate the occurrence of some condition
- Event handlers
  - May execute synchronously, asynchronously, in bounded time
- Guards
  - Restrict invocation of event handlers based on arguments

Mechanism

- Event dispatcher
- Common case: an (indirect) procedure call
  - Module implementing the interface
Core Services

- Memory management
  - Physical addresses
  - Virtual addresses
  - Translations

- Thread management
  - Signals to scheduler
    - Block, unblock
  - Signals to thread manager
    - Checkpoint, resume
Performance

- It works
Exokernels
Exokernels Approach

* Make the application do it!
Exokernels Approach (again)

- Separate protection and management
- Expose allocation
- Expose (physical) names
- Expose revocation
- Expose information
The Big Picture

Unix Application
ExOS

Specialized Application
Specialized Library OS

User
Kernel

Disk
Control Transfer

Scheduling
Execution State

Packet Dispatch
Memory
Devices
At the Core

- Processor time slices
- Process environments
  - Hardware exceptions (Aegis, Xok)
  - Timer interrupts (Aegis, Xok)
  - Protected entries for building IPC (Aegis, Xok)
- Virtual memory addressing
  - Aegis: guaranteed mappings, apps notified of TLB misses
  - Xok: hardware page tables, apps specify mappings
- Hierarchical capabilities (Xok only)
- Book keeping
How to Protect Shared Abstractions?

- **Software regions**
  - Provide access to memory *only* through system calls
  - Are typically more fine-grained than pages

- **Hierarchically-named capabilities**
  - Easily restrict access

- **Wake-up predicates**
  - Ensure that processes get their time in the limelight

- **Robust critical sections**
  - Provides isolation with low overhead and without requiring cooperation
The Disk

* Problem
  * How to store meta-data?
    * Ownership of disk blocks
  * Failed approaches
    * Simple capabilities
      * Where to put them? In the block? A separate area?
    * Self-descriptive meta-data
      * How expressive is the description language?
      * How much space is used for descriptions?
    * Template-based descriptions
      * Again, how expressive is the description language?
The Disk (cont.)

- Untrusted deterministic functions
  - Programmatic templates that specify pointed-to blocks
- Shared data
  - System-wide buffer cache registry
    - Entries can be pinned
- Ordered disk writes
  - Ensure consistency after crash
    - Never reuse on-disk resource before nullifying pointers
    - Never create pointers before data has been initialized
    - Never reset old pointers before new one has been set
Performance

- It works
- It scales
Smackdown
SPIN Issues

- Trusted compiler
- Resource control
Exokernels Issues

- Extension model
- Downloaded code
  - Wake-up predicates (to identify interesting events)
  - Dynamic packet filters (to identify packets)
  - Application-specific handlers (to process packets)
  - Untrusted deterministic functions (to identify meta-data)
- Complexity of disk management
What Do You Think?