Administrivia

- **My office hours Wed 10:45am this week**
- **Antonio's office hours moved to Wednesday 3:30pm**
- **Lab 3A-C due next three classes**

Access control

- **Access control can be viewed as a matrix**
  - Model introduced in 70s by Bell & Lapadula
  - Subjects are rows, objects are columns
  - Each cell encodes access rights (read/write/etc.)
- **Have already seen Unix users and groups**
- **Systems also use often use access control lists (ACLs)**
  - For each object, store permissible subjects & rights
  - AFS does this, on class machines

Capabilities

- **Slicing matrix other way yields capabilities**
  - E.g., For each process, store a list of objects it can access
  - Process explicitly invokes particular capabilities
- **Three general approaches to capabilities:**
  - Hardware enforced (Tagged architectures like M-machine)
  - Kernel-enforced (Hydra, KeyKOS)
  - Self-authenticating capabilities (like Amoeba)

Hydra

- **Machine & programing env. built at CMU in ’70s**
- **OS enforced object modularity with capabilities**
  - Could only call object methods with a capability
- **Agumentation let methods manipulate objects**
  - A method executes with the capability list of the object, not the caller
- **Template methods take capabilities from caller**
  - So method can access objects specified by caller

KeyKOS

- **Capability system developed in the early 1980s**
- **Goal: Extreme security, reliability, and availability**
- **Structured as a "nanokernel"**
  - Kernel proper only 20,000 likes of C, 100KB footprint
  - Avoids many problems with traditional kernels
  - Traditional OS interfaces implemented outside the kernel (including binary compatibility with existing OSes)
- **Basic idea: No privileges other than capabilities**
  - Partition system into many processes akin to objects
  - Capabilities like pointers to objects in OO languages

Unique features of KeyKOS

- **Single-level store**
  - Everything is persistent: memory, processes, …
  - System periodically checkpoints its entire state
  - After power outage, everything comes back up as it was (may just lose the last few characters you typed)
- **“Stateless” kernel design only caches information**
  - All kernel state reconstructible from persistent data
- **Simplifies kernel and makes it more robust**
  - Kernel never runs out of space in memory allocation
  - No message queues, etc. in kernel
  - Run out of memory? Just checkpoint system

KeyKOS capabilities

- **Refered to as “keys” for short**
- **Types of keys:**
  - *devices* – Low-level hardware access
  - *pages* – Persistent page of memory (can be mapped)
  - *nodes* – Container for 16 capabilities
  - *segments* – Pages & segments glued together with nodes
  - *meters* – right to consume CPU time
  - *domains* – a thread context
- **Anyone possessing a key can grant it to others**
  - But creating a key is a privileged operation
  - E.g., requires “prime meter” to divide it into submeters

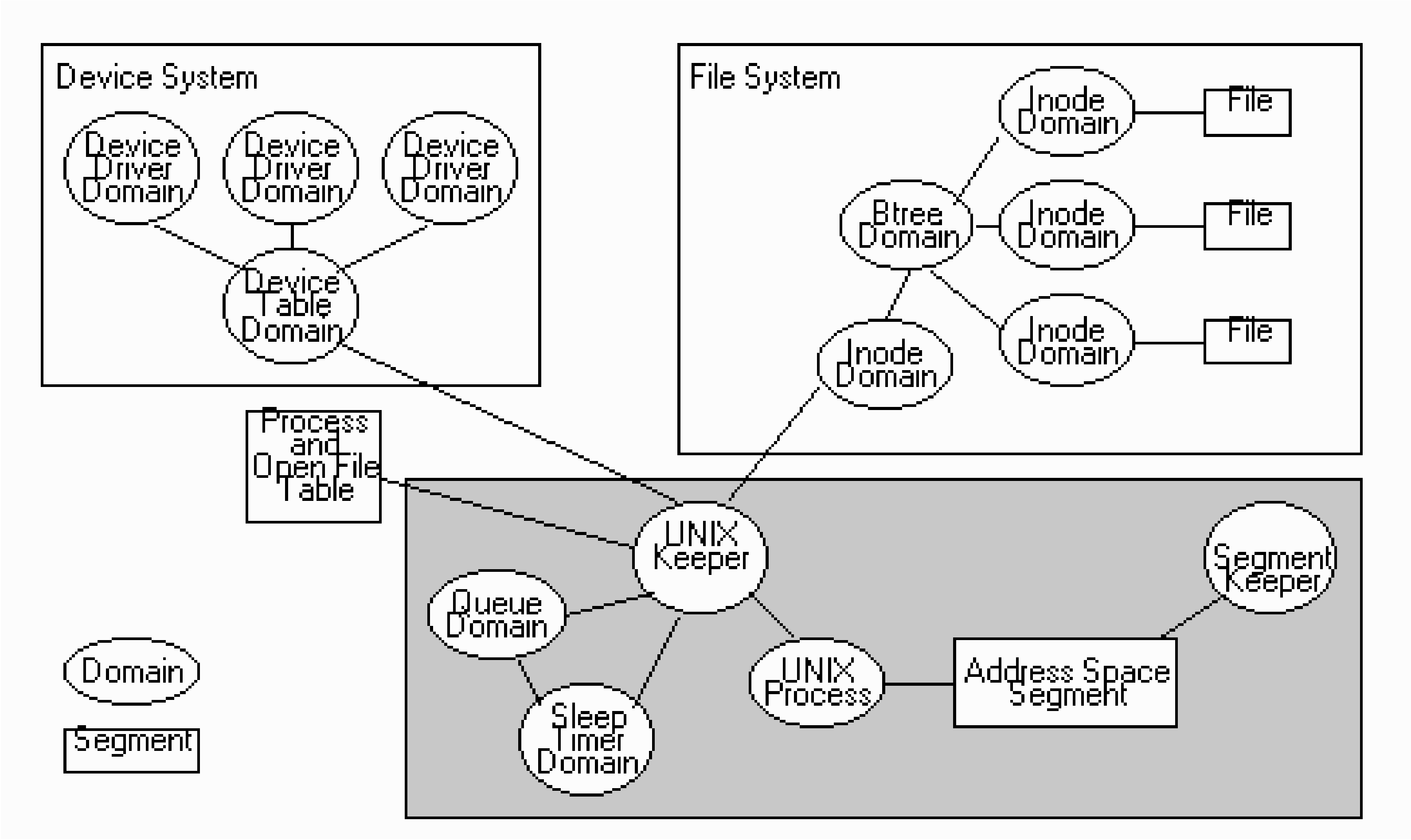
Capability details

- **Each domain has a number of key “slots”:**
  - 16 general-purpose key slots
  - *address slot* – contains segment with process VM
  - *meter slot* – contains key for CPU time
  - *keeper slot* – contains key for exceptions
- **Segments also have an associated keeper**
  - Process that gets invoked on invalid reference
- **Meter keeper (allows creative scheduling policies)**
- **Calls generate return key for calling domain**
  - (Not required–other forms of message don’t do this)

KeyNIX: UNIX on KeyKOS

- **“One kernel per process” architecture**
  - Hard to crash kernel
  - Even harder to crash system
- **Proc’s kernel is it’s keeper**
  - Unmodified Unix binary makes Unix syscall
  - Invalid KeyKOS syscall, transfers control to Unix keeper
- **Of course, kernels need to share state**
  - Use shared segment for process and file tables

KeyNIX overview



Keynix I/O

- **Every file is a different process**
  - Elegant, and fault isolated
  - Small files can live in a node, not a segment
  - Makes the `namei()` function very expensive
- **Pipes require queues**
  - This turned out to be complicated and inefficient
  - Interaction with signals complicated
- **Other OS features perform very well, though**
  - E.g., fork is six times faster than Mach 2.5

Self-authenticating capabilities

- **Every access must be accompanied by a capability**
  - For each object, OS stores random *check* value
  - Capability is: $\{\text{Object}, \text{Rights}, \textsc{mac}(\textit{check}, \text{Rights})\}$
- **OS gives processes capabilities**
  - Process creating resource gets full access rights
  - Can ask OS to generate capability with restricted rights
- **Makes sharing very easy in distributed systems**
- **To revoke rights, must change *check* value**
  - Need some way for everyone else to reacquire capabilities
- **Hard to control propagation**

Limitations of capabilities

- **IPC performance, as we've discussed**
- **Capability programming model never took off**
    - Requires changes throughout application software
    - Call capabilities "file descriptors" or "Java pointers" and people will use them
    - But discipline of pure capability system challenging so far