EROS: A Fast Capability System

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EROS Goals

- Priorities
  1. Security & Integrity
  2. High availability
  3. Fault Tolerance
  4. Evolvability
  5. Performance
- This ordering has architectural and performance implications.

How is EROS Different?

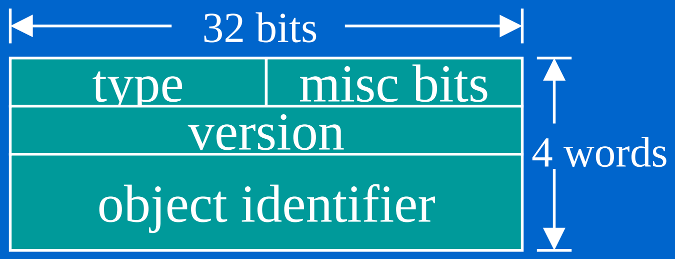
- Pure capability system
- Transparently persistent
- Recovers rapidly (< 30 seconds)
- Thoroughly paranoid implementation
  - Consistency checks to prevent snapshot of bad states
  - Implementation tries to be “fail fast”
  - Think: kernel *always* compiled for debugging
- Some emphasis on discretionary security

What is a Capability?

- A capability is an (object, permissions) pair
  - Unforgeable, so a basis for protection
  - Transferable, so a basis for authorization
- This can be generalized to
  (object, type)
- An object version number makes reallocation simple.
- The resulting representation is straightforward.

(myspace, {r, w})

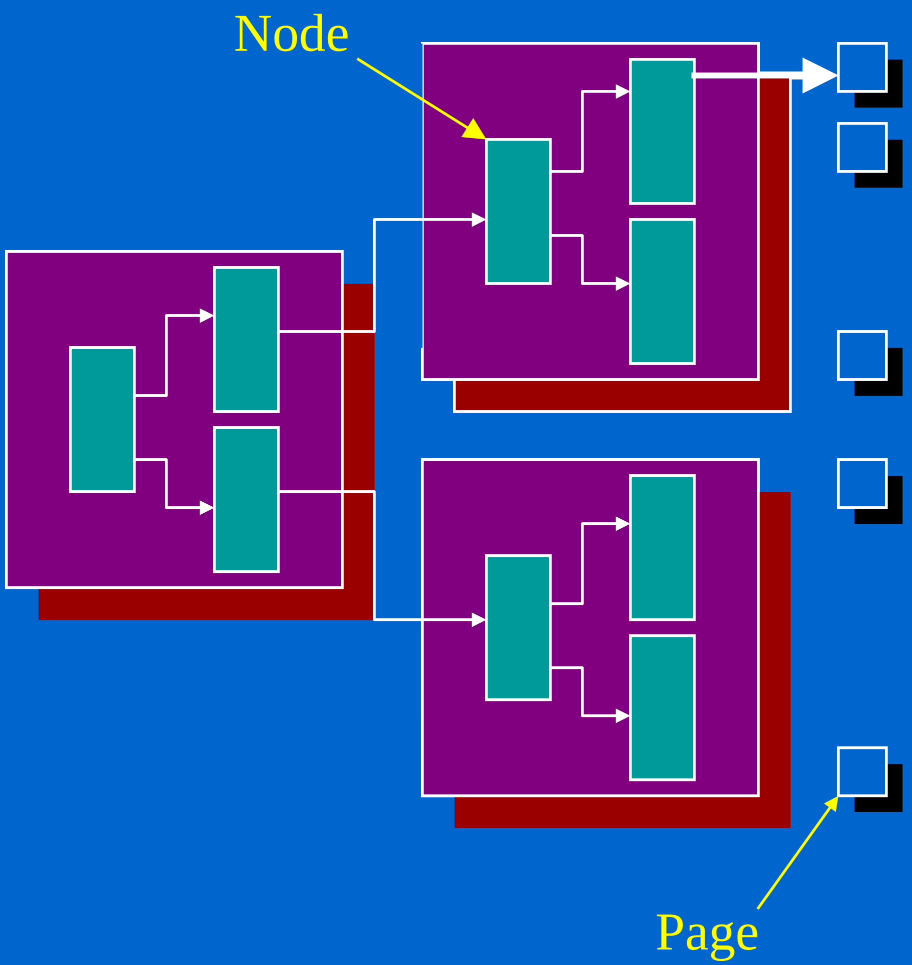
(spaceroot, rw-space)
(spaceroot, node)



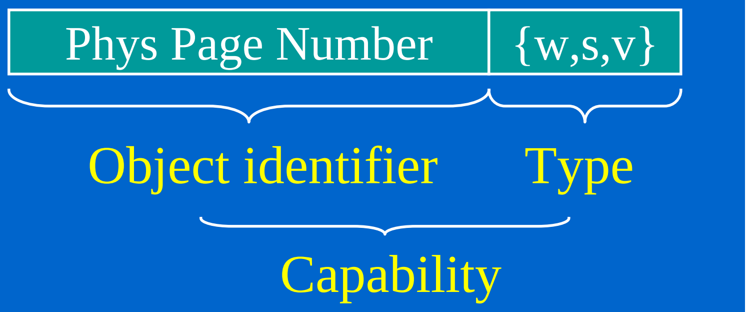
Comparison to Other Capability Systems

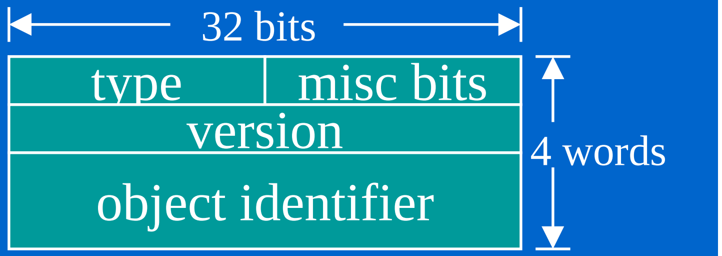
System	*HW/SW*	*Store*	*Persist*	*Cap Prot*	*Mem Model*	*IPC*
Cal TSS	SW	File	Explicit	Partition	Byte Segments	Buffered, Unbounded
CAP	HW	Object	Explicit	Partition	Byte Segments	Prot. Procedure Call
Hydra	Mixed	File	Explicit	Partition	Byte Segments	Prot. Procedure Call
S/38 (AS/400)	HW + Compiler	Object	Transparent	Tagging	Byte Segments	Prot. Procedure Call
i432	HW	Object	Explicit	Partition	Byte Segments	Prot. Procedure Call
Mach	SW	App. Defined	Explicit	Partition	Page Regions	Buffered, Unbounded
Amoeba	SW	Object	Explicit	Sparsity	Page Regions	Buffered, Bounded
KeyKOS/ EROS	**SW**	**Object**	**Transparent**	**Partition**	**Pages + Nodes**	**Unbuffered, Bounded**

Memory Mapping



Page Table Entry:

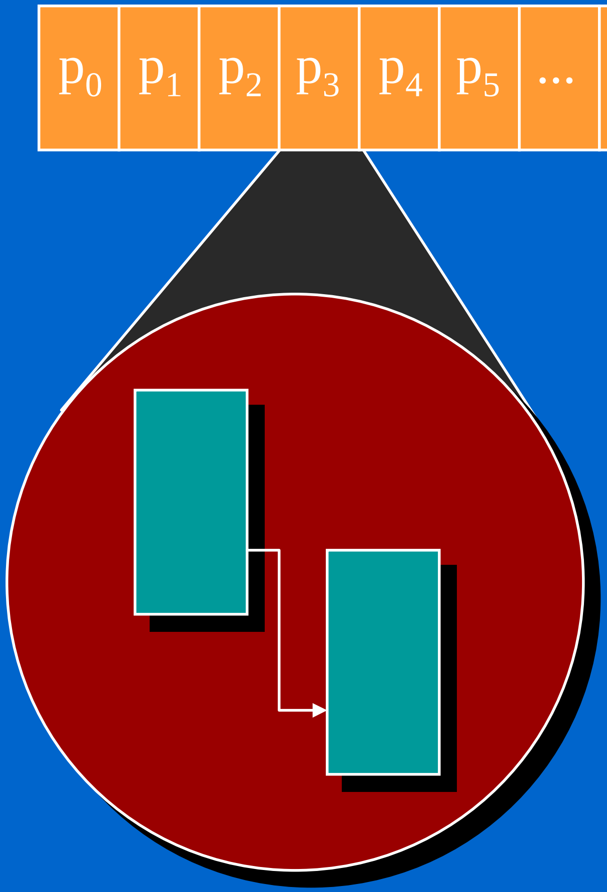




type	misc bits
version	
object identifier	

Processes

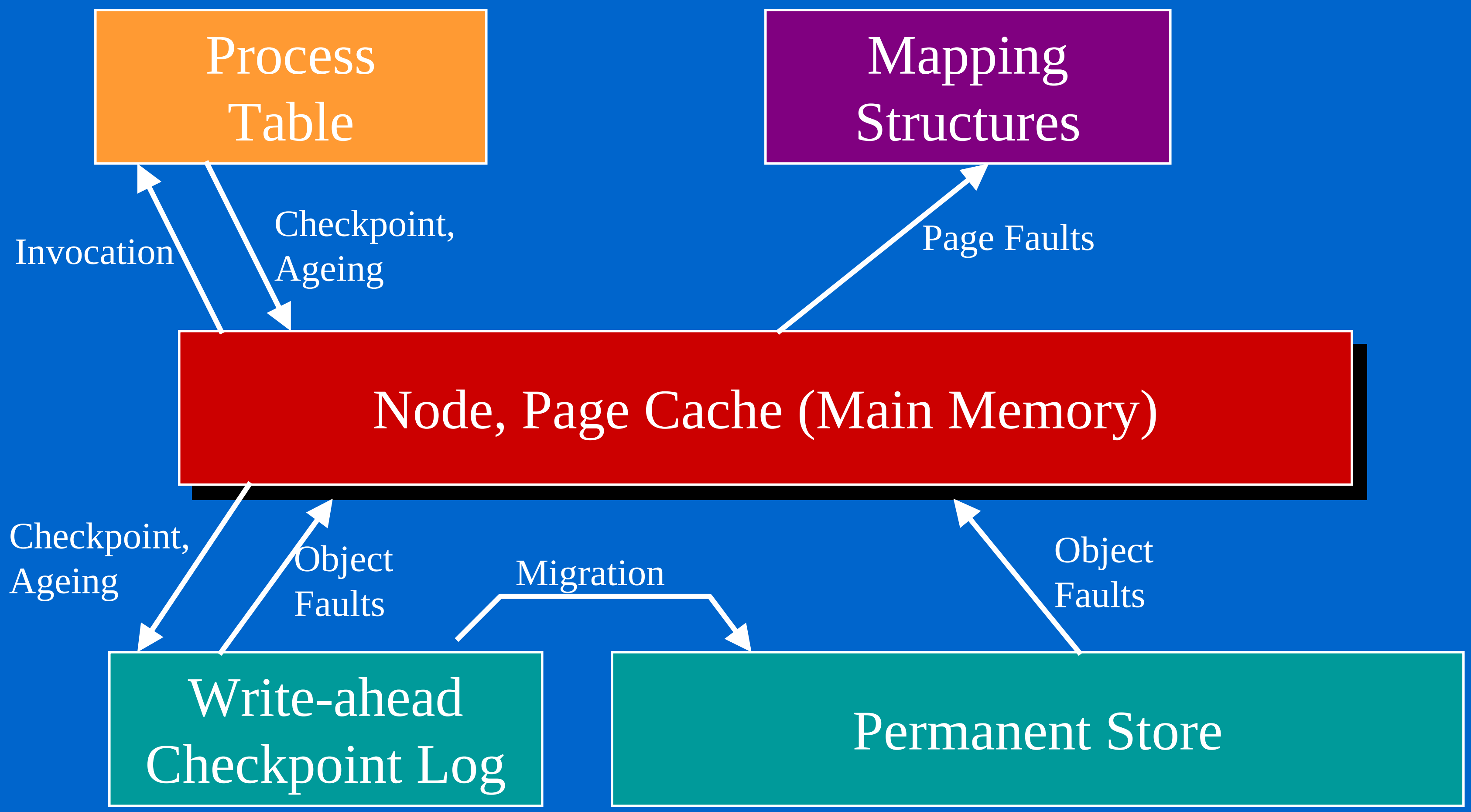
- Processes have user-mode machine state plus supervisor-implemented capability registers.
- Kernel implements a machine-specific process table
  - Used to *cache* active processes (c.f. Cache Kernel, Fluke).
  - Fast-path IPC uses this structure.
  - General capability invocation path uses both representations.
- Process state is recorded in nodes.



Properties of this Design

- Everything (all resources) is named by a uniform naming mechanism: capabilities.
- The protection state of the system can be directly realized by the hardware.
- All user-visible state is stored in pages and nodes
  - This plus “run list” is all you need to define a recoverable system state.
- Object reference is a protected operation
  - Conventional operating system services can therefore be implemented outside the kernel.

Transparent, Global Persistence



Process Table

Mapping Structures

Invocation

Checkpoint, Ageing

Page Faults

Node, Page Cache (Main Memory)

Checkpoint, Ageing

Object Faults

Migration

Object Faults

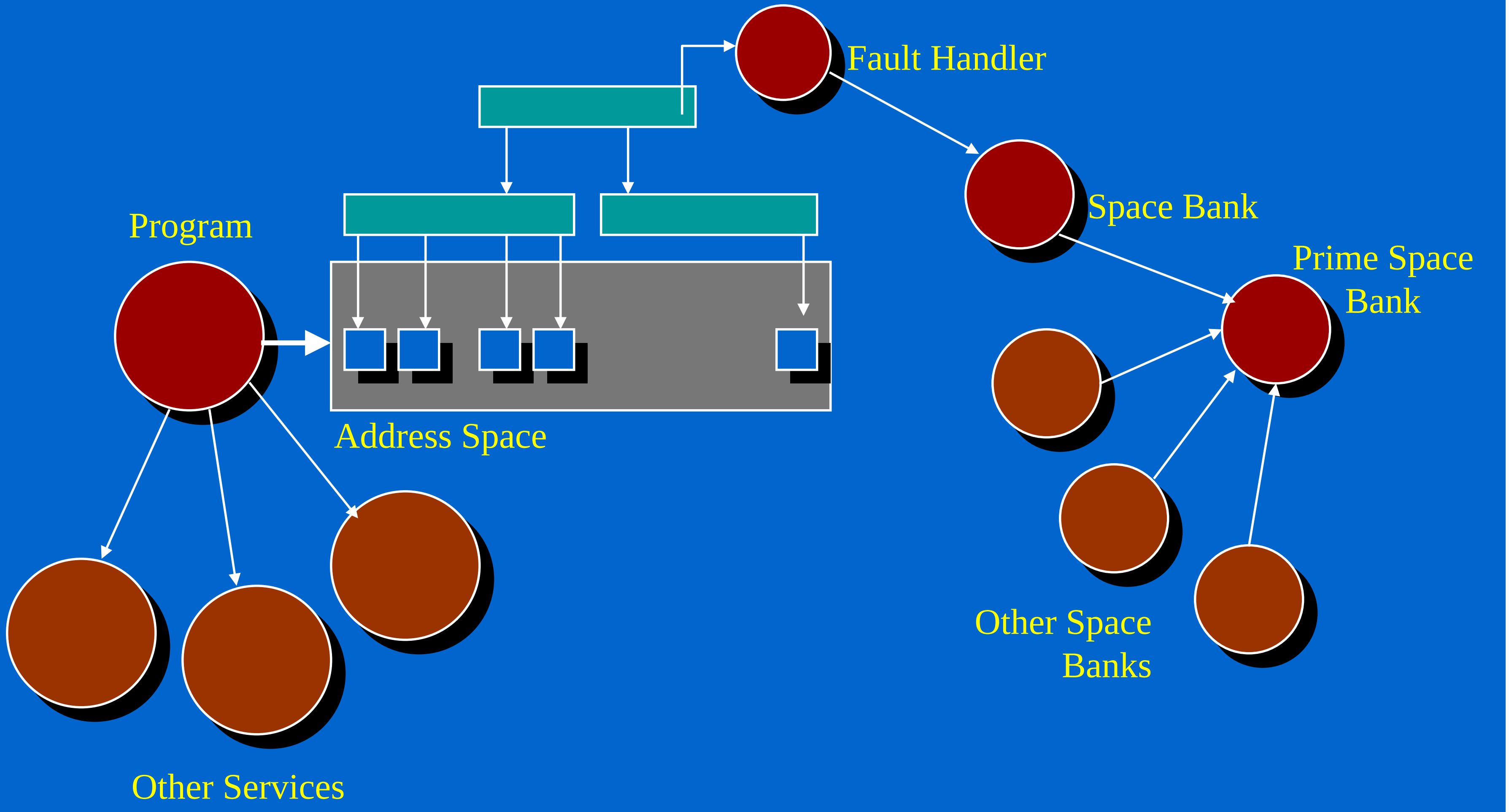
Write-ahead Checkpoint Log

Permanent Store

Key Questions

- How might a system be structured on top of this kind of platform?
- How does it perform?
- Given that it is unconventional, why should you care?
- Where do we go from here?

Typical Program Structure

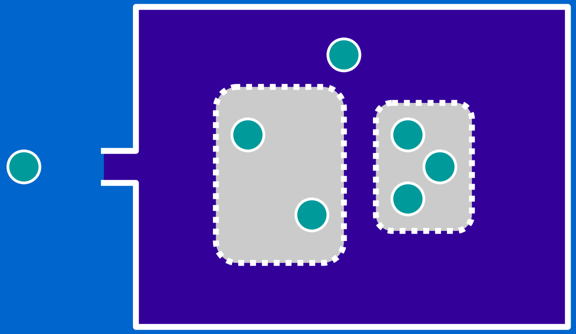


User-Mode Services

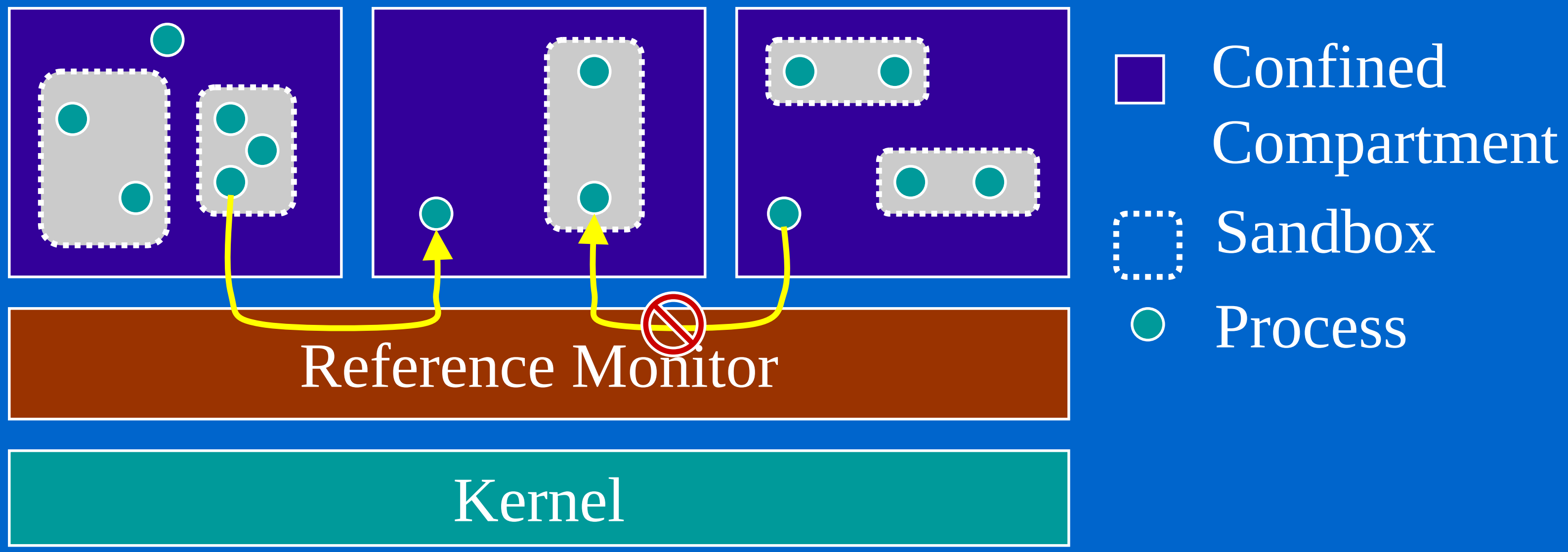
- Memory fault handlers
- Storage allocator (space bank)
- Files and Directories
- Pipes
- Constructor (confinement implementation)
- Reference monitor

Confinement (Lampson '73)

- Initial Conditions:
  - Client has exclusive access to service.
  - Confined entity has no unauthorized channels.
- Confined entity can be a complex subsystem.
- Client therefore completely controls communication.

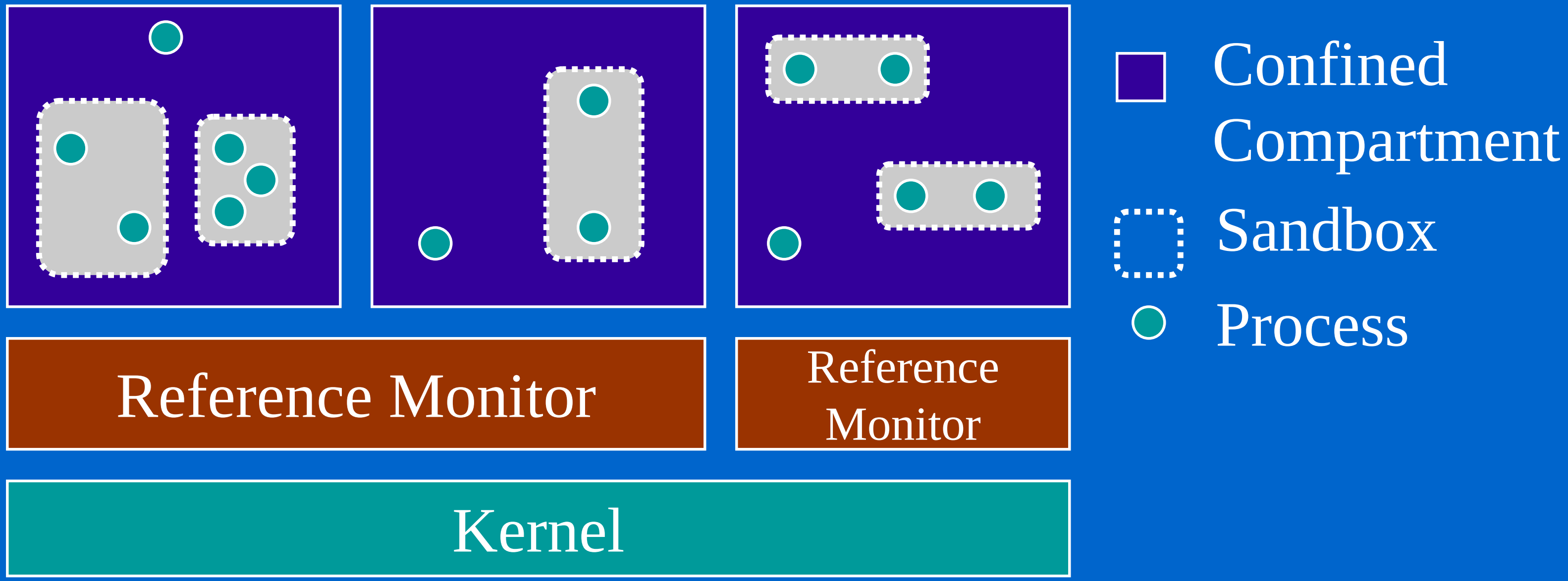


Reference Monitor w/Confinement



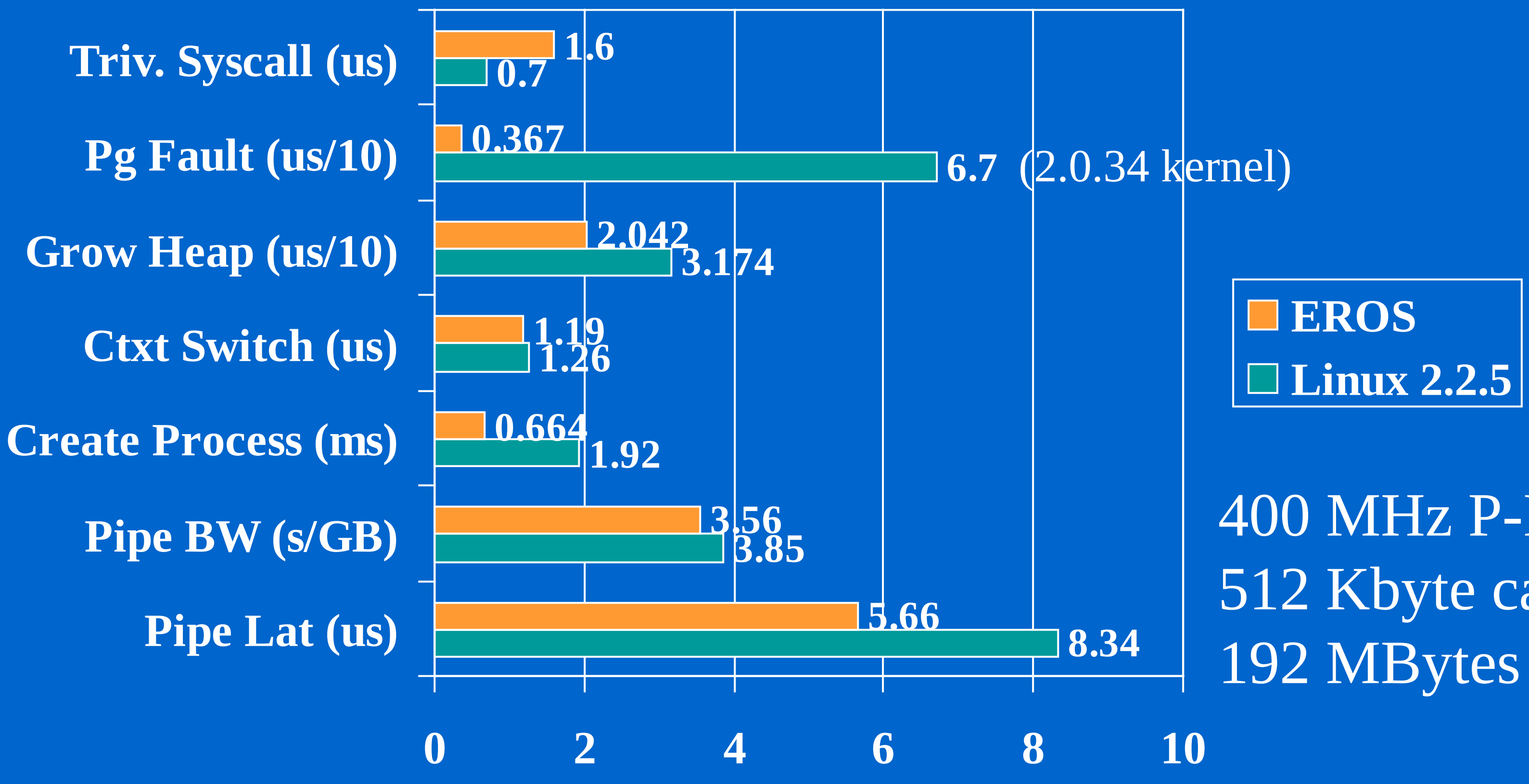
- Reference monitor knows object semantics.
- Interposes transparent forwarding objects where appropriate.
- Can be evolved as new object types are introduced.

Disjoint Reference Monitors



- Multiple reference monitors can securely manage disjoint logical systems on the same hardware.
- Remote Hot Standby

Microbenchmark Performance



400 MHz P-II
512 Kbyte cache
192 MBytes

Note: 2.2.x kernel introduced a temporary performance bug in page fault handling.

IPC Semantics: EROS and L4

Property	***L4***	***EROS***	***Issue***
Registers saved	Most	All	Covert Channel
Payload	31 x 4M	1 x 64k	Resource Exhaustion,
Target name	Thread ID	Capability	Encapsulation
Authority Xfer	Permissions for Pages	Capabilities	Access Control, Channel audits
Atomicity	No: Preemption, Page Faults	Yes	Bounding resources and time
Missing page strategy	Timeout, then discard	Discard	Covert Channel

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Latency	**454 cycles**	**640 cycles**	Large spaces

Conclusions

- It *appears* possible to build a high-performance capability system.
- Persistence greatly simplifies some components, and therefore assurance.
- Capabilities provide a sufficient primitive protection mechanism to implement other security policies at user level.
- Using performance as the only evaluation criterion can obscure important issues, including security.

Research Questions

- How can a capability system be distributed securely and efficiently?
- How is multiparty administration and just-in-time software provisioning to be managed?
- How can assurance be achieved using an open development model?
- Compatibility and (r)evolution
- System structure – design and architecture
- Language integration: how to do it successfully

The Future: *Cougar*

- IBM Research has started the *Cougar* project to investigate secure, high-performance underpinnings for pervasive devices and their supporting servers.
- Cougar will be capability based, and will borrow from both the L4 and the EROS architectures.