A System for Migrating Computing Environments

Zap

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Benefits of Migration

- Dynamic Load Balancing
- Mobility
- Data Access Locality
- Improved Administration
- Fault Resilience

Clustered System Approach

- Single system image across a cluster
- Good for load-balancing

Examples include, MOSIX, Sprite

- May leave dependency on previous host
- May be new operating system or significant kernel changes

Middleware/Language Approach

- Object-based approach using special programming language or middleware

Examples include, Abacus, Emerald, Globus, Legion, Rover

- Requires applications to be rewritten

User-level Approach

- No operating system changes
- Good for long-running applications

Examples include, Condor, CoCheck, Libckpt, MPVM

- Does not support many common operating system services

Virtual Machine Monitor Approach

- Support any operating system
- No application changes

Example, using VMware for migration

- Must migrate the whole operating system
- Potentially higher overhead

Introducing Zap

- Transparent migration
- Unmodified legacy applications
- Networked applications
- Commodity operating system
- Minimal operating system changes
- Leaves nothing behind
- Low overhead

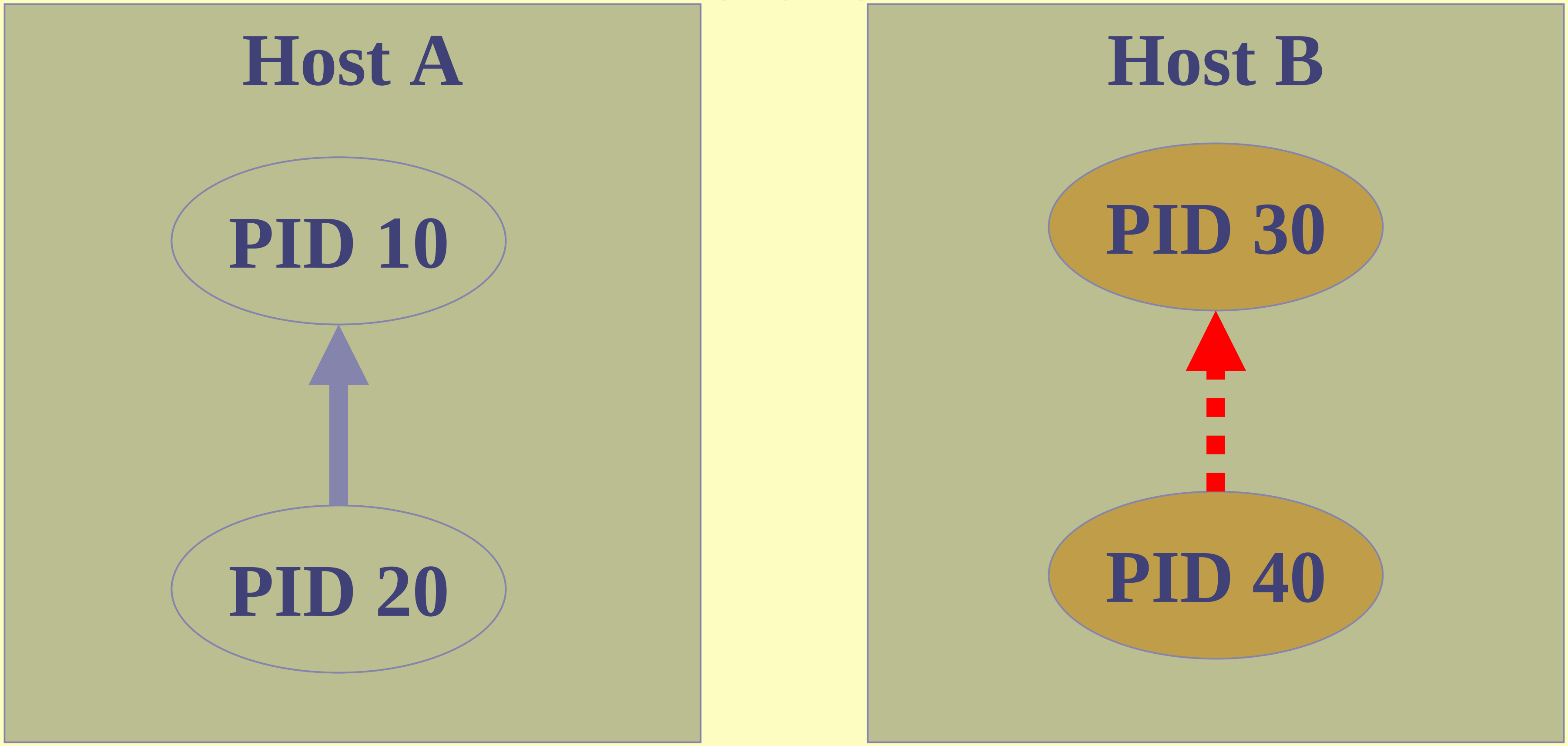
Outline

- Background & Motivation
- Difficulties of Migration
- Zap components
  - Virtualization
  - Migration
- Experimental Results
- Conclusion

Migration Difficulties

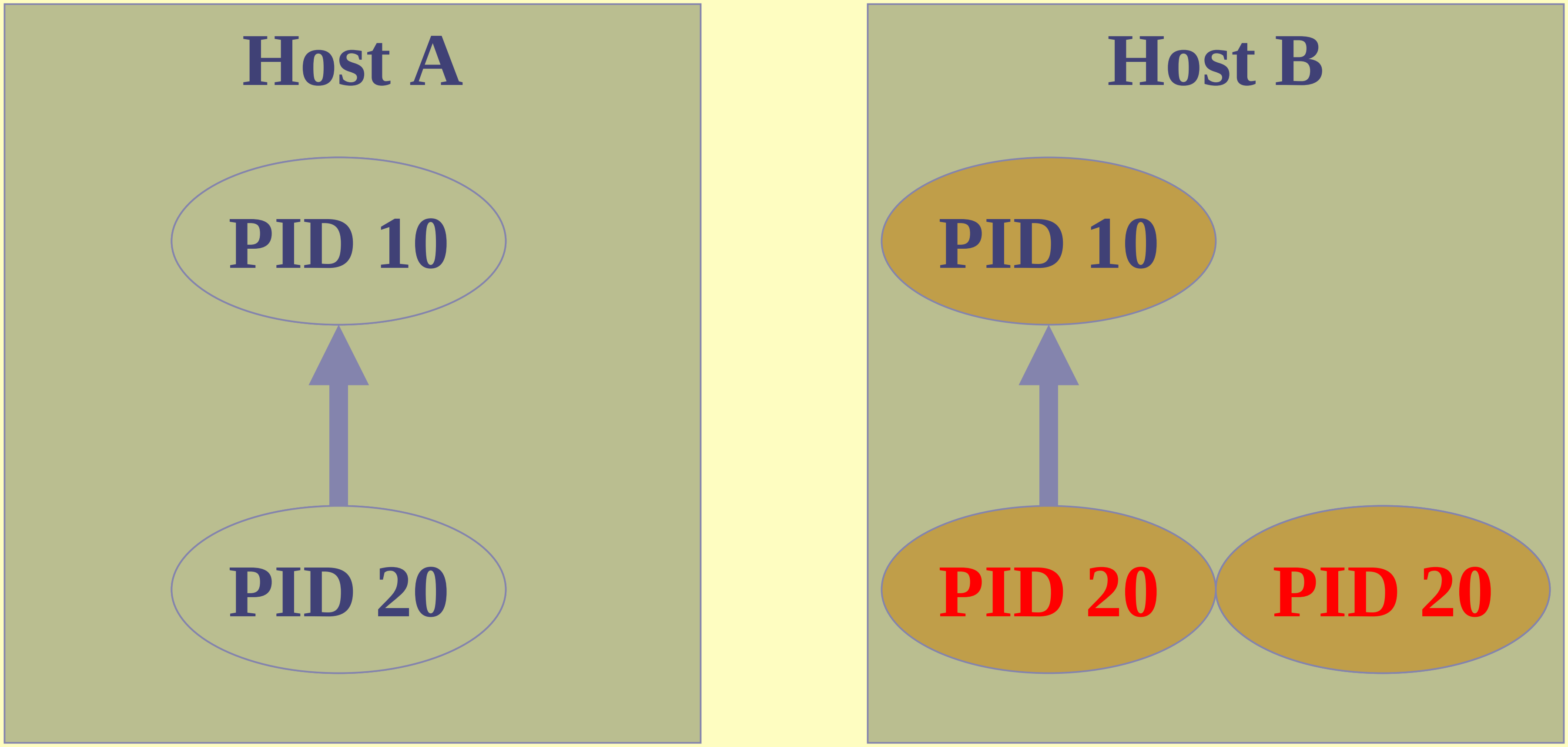
```
int iChildPID;

if (iChildPID=fork()) {
  /* parent does some work */
  waitpid(iChildPID);
} else {
  /* child does some work */
  exit(0);
}
```

Resource Consistency Problem



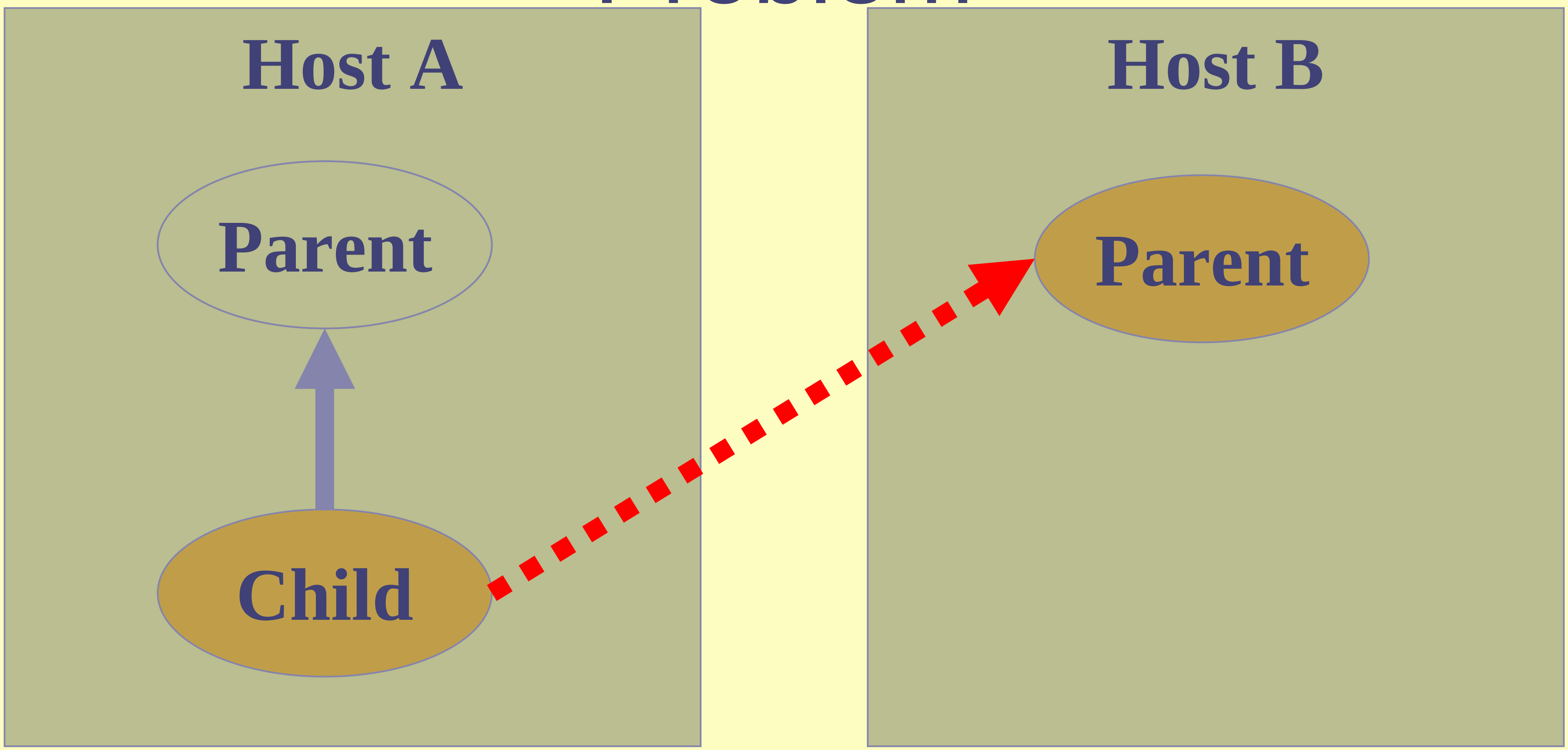
Parent invoked waitpid(20)

Resource Conflict Problem



Resources May Conflict With Other Processes

Resource Dependency Problem



Parent and child depend on each other

Problem Recap

Resource consistency

- Names can’t change

Resource conflict

- Names can’t be duplicates

Resource dependency

- Migration must be complete

Solution

- Group processes into a POD (Process Domain) that has a ***private virtual*** namespace
- PODs can contain one process, one group of processes, or a whole user session
- PODs are migrated as a unit
- Solves
  - Resource consistency problem
  - Resource conflict problem
  - Resource dependency problem

Zap Architecture

Zap combines

- Thin virtualization layer
- Checkpoint/restart mechanism

Checkpoint/restart offers:

- Easier to implement than demand paging
- Leaves nothing behind
- Suspend sessions
- Easily configure and clone environments
- Dynamic system configuration

What Should Zap Virtualize?

- Process identifiers (PIDs)
- Inter-process communication (IPC) keys
- Memory
- File system structure
- Network connections
- Devices

PID and IPC Key Virtualization & Migration

- Create unique namespace for the POD
- Names are virtualized
- When entering a system call, replace POD virtual identifiers with real ones
- When exiting a system call, replace real return values with POD virtual ones
- Mask out identifiers that do not belong to the POD

Memory Virtualization & Migration

- Like IPC, create unique shared memory namespace
- Modern architectures support virtual memory

Thank you modern architectures!

Migration optimization: Move only data pages, code pages can be remapped

File System Virtualization & Migration

- Some filenames can’t conflict:

/var/run/httpd.pid

- Some directories have unique configuration:

/etc

- Some directories depend on the current processes

/proc

File System Virtualization & Migration

- Create a directory structure for POD
- Use network file systems
- Create private POD directories
  - Good for /tmp, /var & POD specific configuration
- Private /proc directory
- Private /dev directory

File System Example

Host FS

- bin
- etc
- pod
  - bin → NFS:/pods/bin
  - dev → Dynamic
  - proc → Dynamic
  - tmp → Private POD

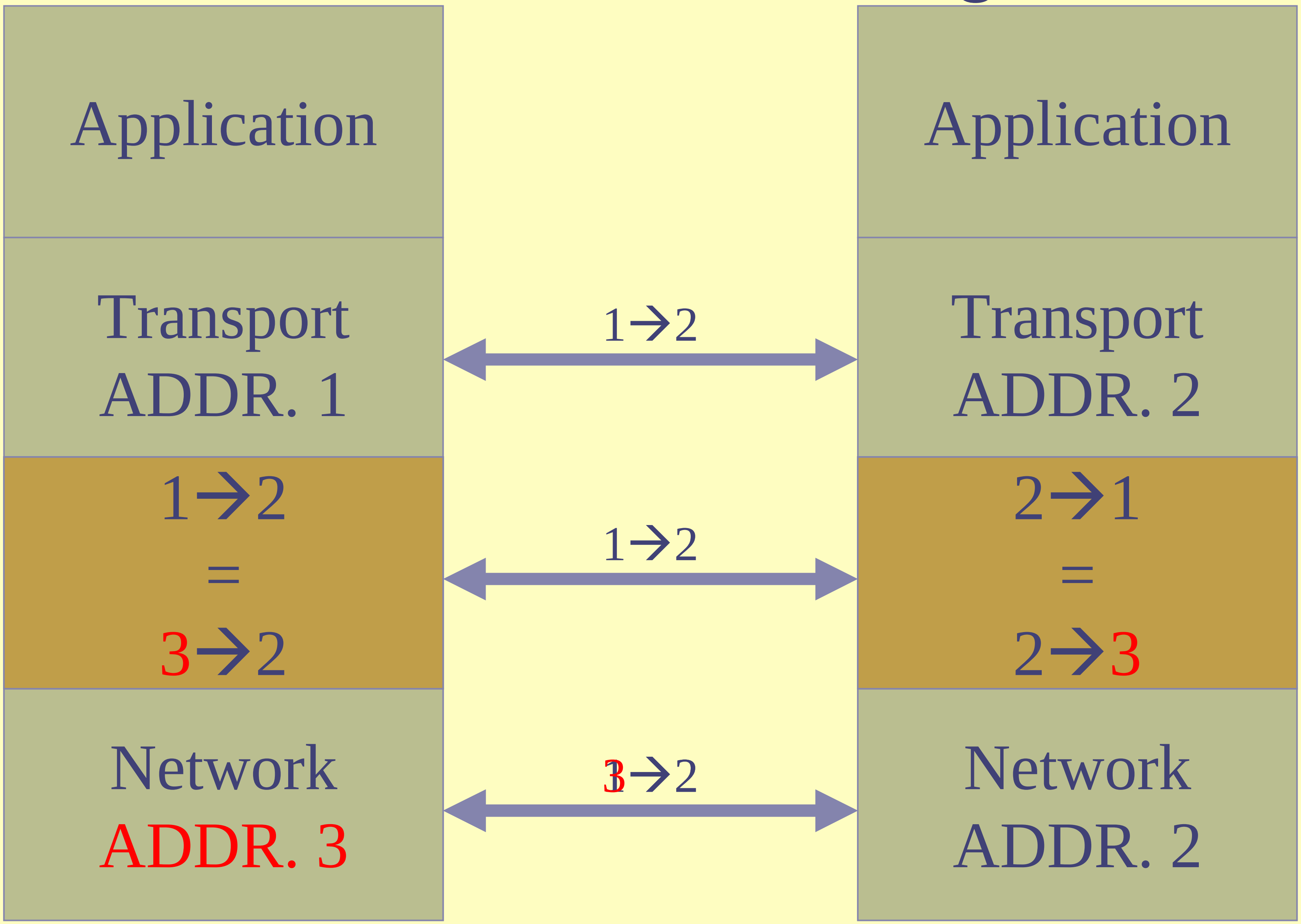
POD FS

Use chroot() to map POD root directory

Networking Virtualization & Migration

- Two network addresses:
  - Persistent internal address
  - Host-dependent external address
- For connection migration:
  - Transport layer sees virtual address
  - Network layer sees real address
  - Transport layer independent
  - Initial virtual address is real address

Virtual Networking



Device Virtualization & Migration

Device migration is hard

- Pseudo Terminal
- Sound Device
- CDRW During a Recording Session
- Electron Microscope

Device Migration & Virtualization

Pseudo Terminal → Virtual device configuration+data

Sound Device → Virtual device configuration

Recording CDRW → Migrate later

Electron Microscope → Communicate with original host

Device Migration & Virtualization

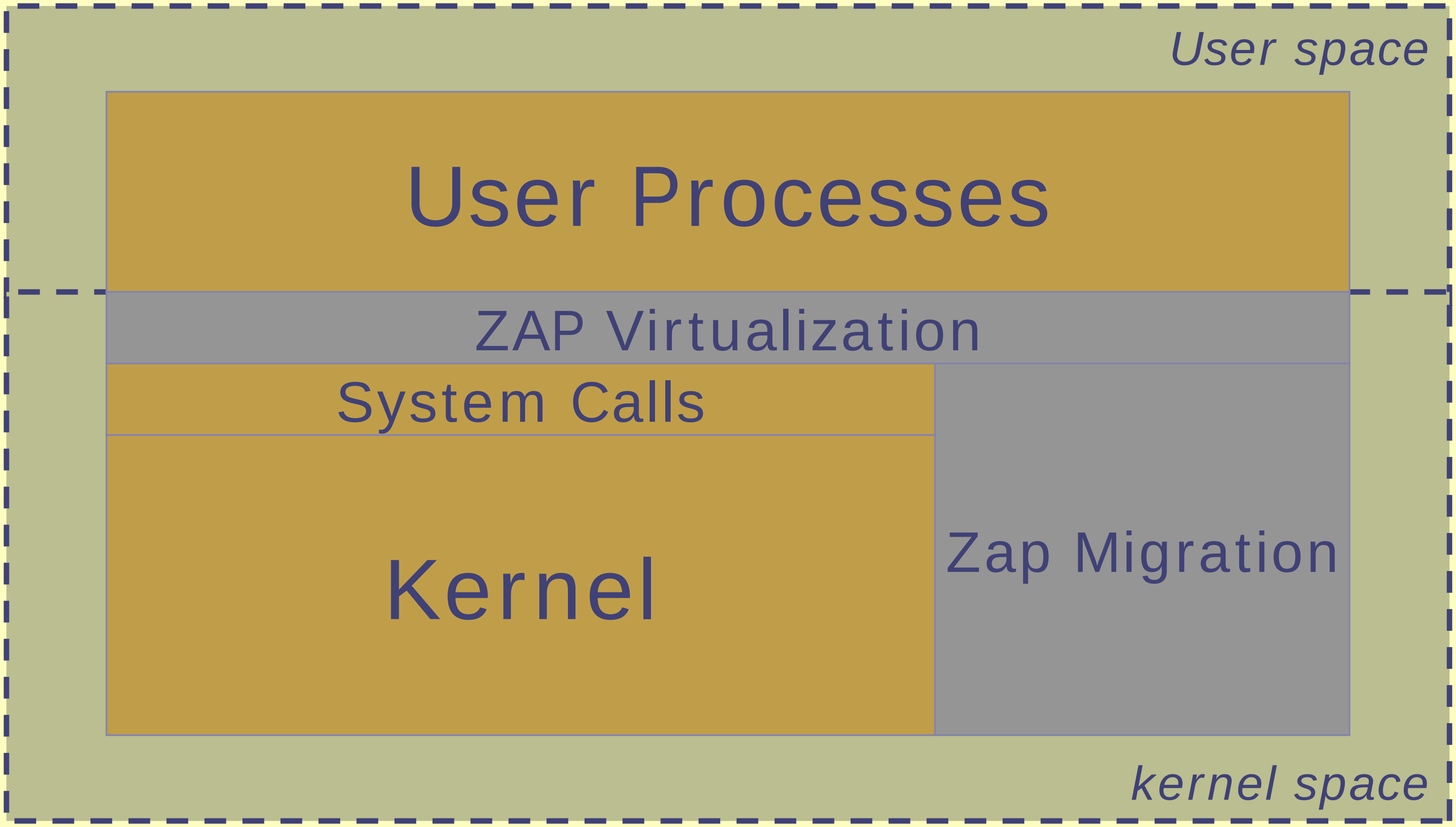
Unsupported devices do not appear in a POD's /dev

Zap currently supports pseudo terminals, ensuring their names are consistent after migration (e.g. /dev/pts/2)

Zap Implementation

- Developed for Linux 2.4
- Zap design enables
  - Loadable kernel module
  - No need to rebuild the kernel
- Intercept system calls for virtualization

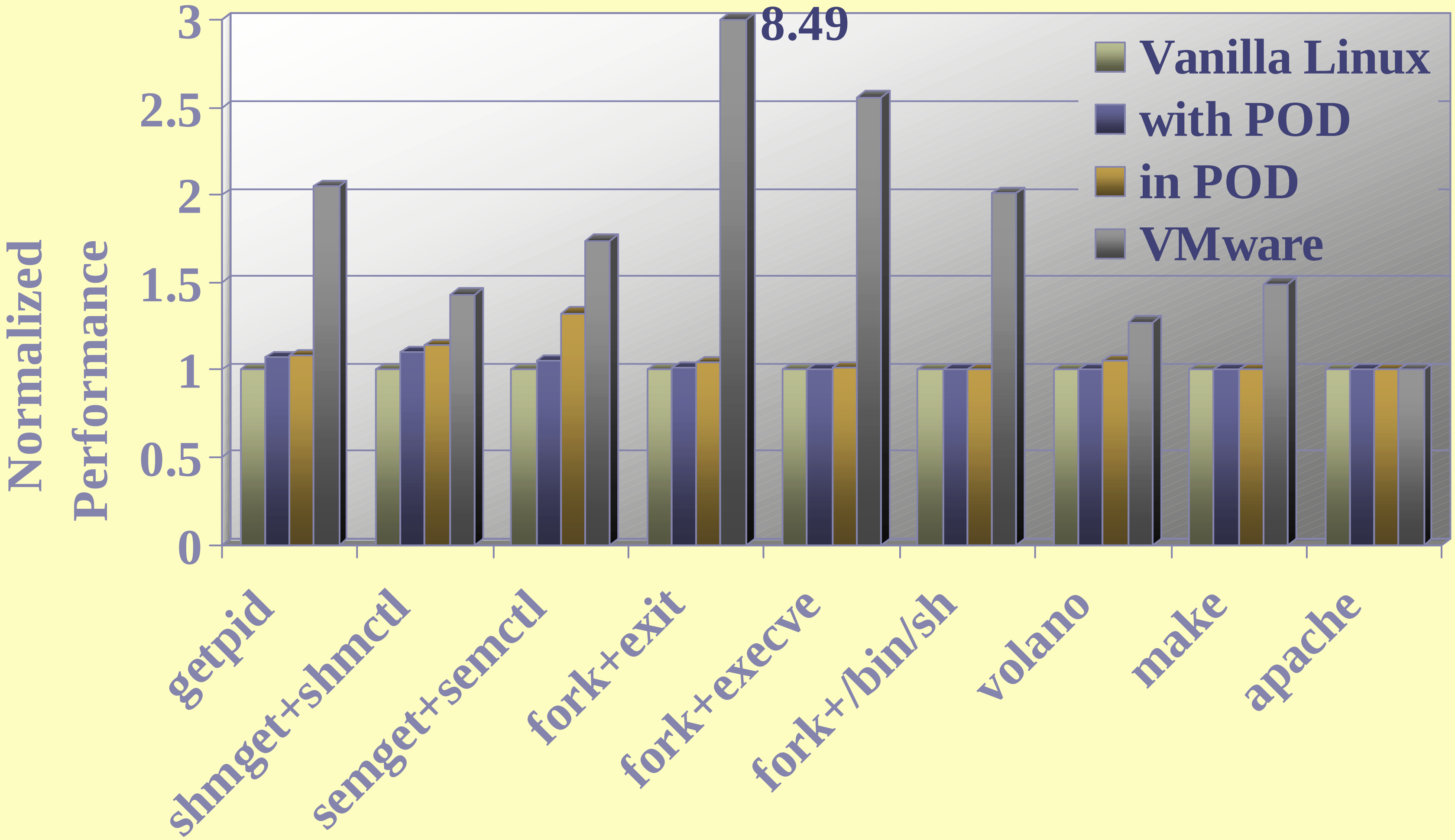
Zap Implementation



Virtualization Cost

- Created micro-benchmarks
  - PID calls (getpid)
  - IPC calls (shmget/ctl, semget/ctl)
  - Process creation calls (fork, execve, exit)
- Used macro-benchmarks
  - Apache
  - Build Linux kernel
  - Volano

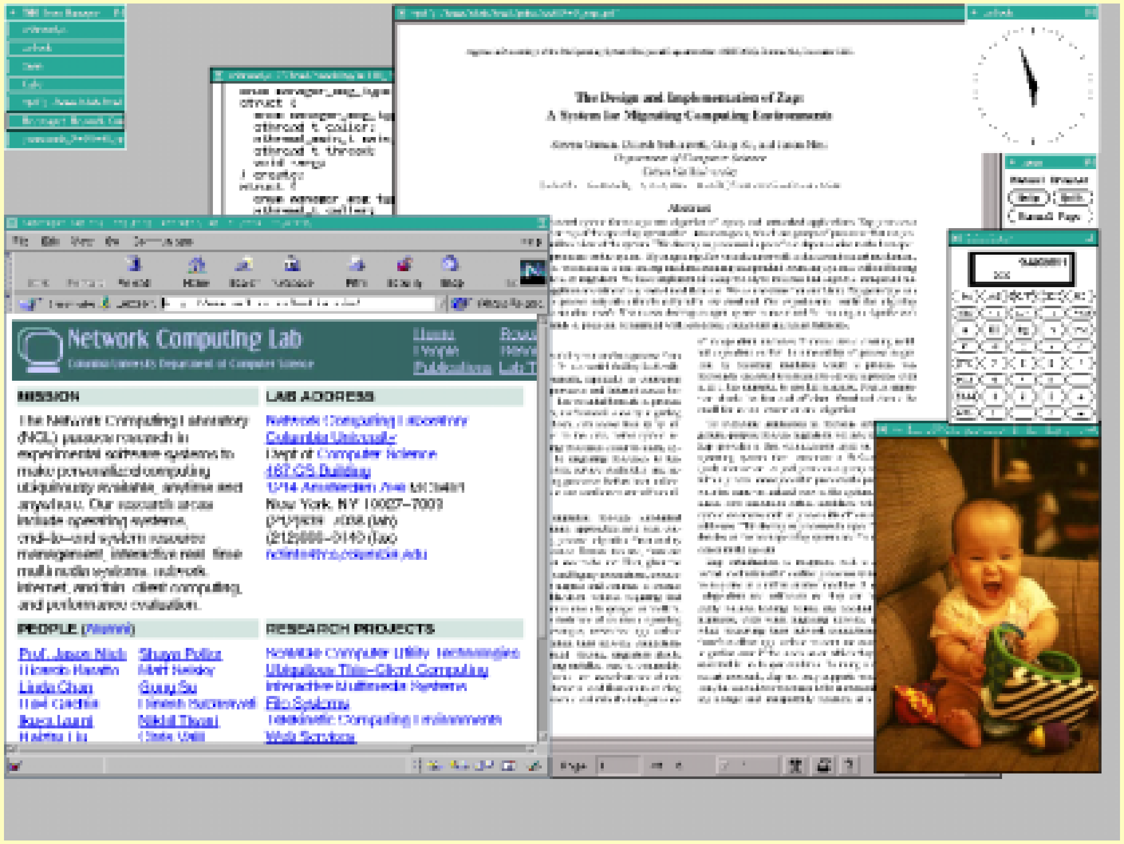
Virtualization Results



Virtualization Results

- Zap incurs low overhead

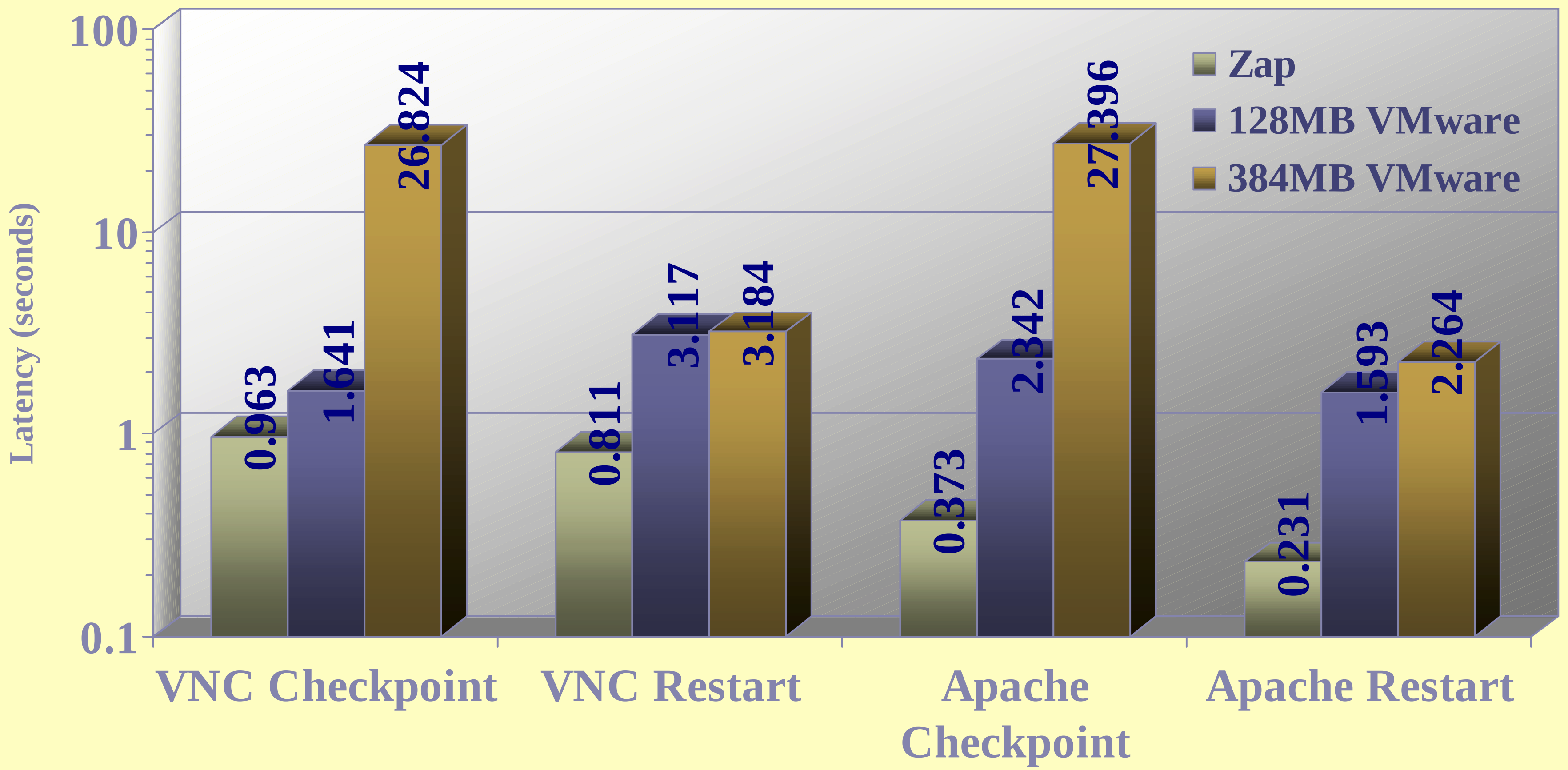
Migration Cost – VNC Session



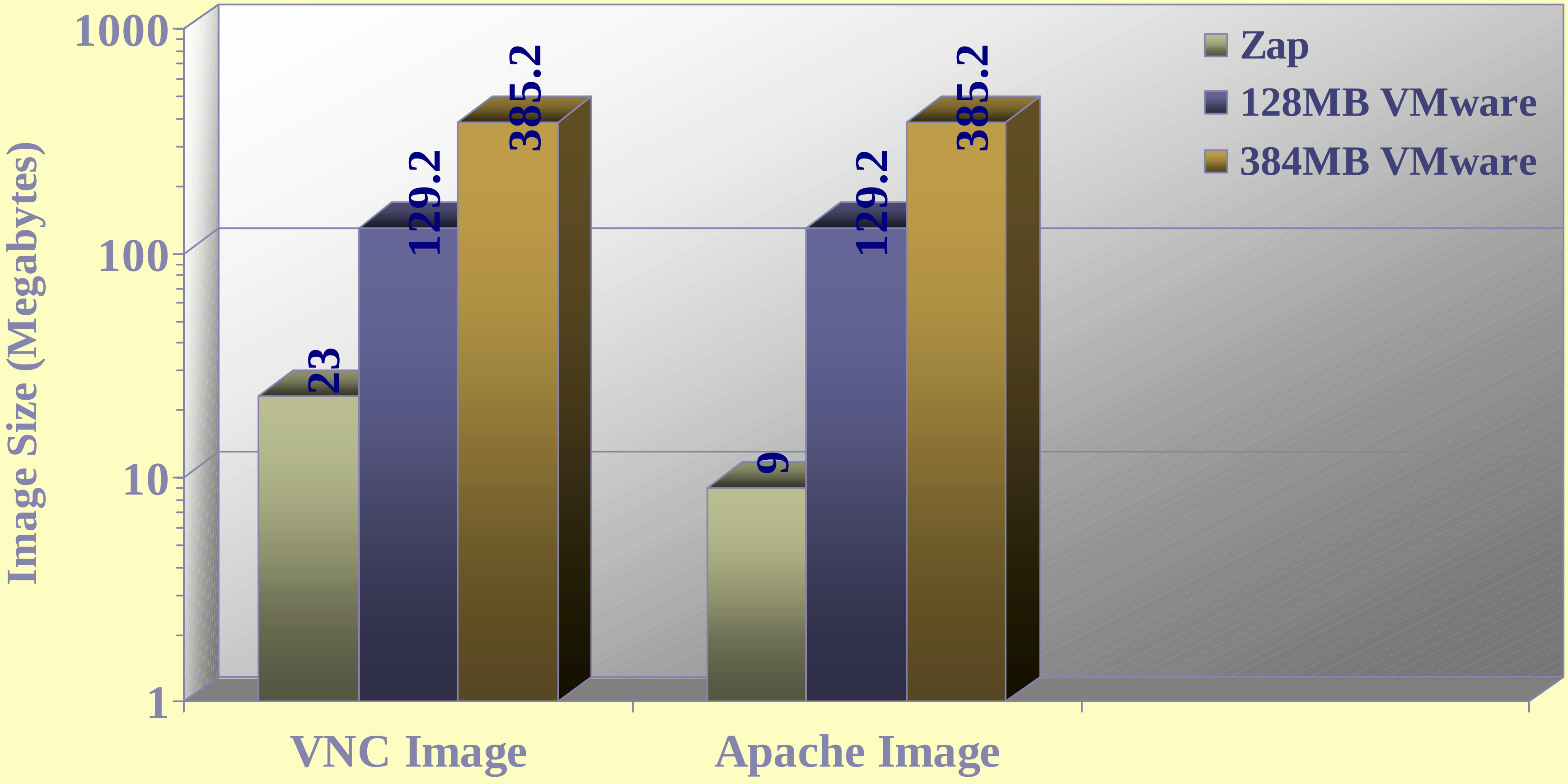
Migration Cost – Apache

- Apache 2.0.35
- Default configuration

Migration Cost – Time



Migration Cost – Space



Migration Cost

- Zap can be fast
- <1 second checkpoint/restart times
- Includes Zap networking round-trip

Zap

- Offers transparent migration of legacy and network applications
- Introduces PODs
  - Consistency
  - Conflict free
  - Avoids Unwanted dependencies
- Leaves nothing behind
- Fast and lightweight

For more information…

- Zap computing

http://www.ncl.cs.columbia.edu/research/migrate

- Network Computing Laboratory

http://www.ncl.cs.columbia.edu/

Future Work

- Secure migration
  - Trusted images, POD sandbox, etc.
- Generalized device support
- Migration policies
- Heterogeneity
- Contextualization
- Resource management