JavaOne

Sun's 2001 Worldwide Java Developer Conference

Strong Protection Domains and Resource Control With Java™ Technology

Walter Binder
Software Engineer
CoCo Software Engineering GmbH

Overall Presentation Goal

Learn about the requirements of component execution platforms and see how such systems can be implemented entirely with Java™ technology

Learning Objectives

- As a result of this presentation, you will be able to understand:
  - Why Java™ technology-based components need protection
  - How protection domains can be efficiently implemented entirely with Java technology
  - The design of an efficient communication model
  - How to ensure safe domain termination
  - Techniques for resource control in the Java programming language

Speaker's Qualifications

- Developer using Java technology since 1996
- Research on Java technology-based operating systems since 1997
- Designer and developer of J-SEAL2
- Working on resource control for the Java platform

Agenda: Java™ Component Execution Platforms

- Java™ component execution platforms
- Strong protection domains
- Safe domain termination
- Efficient and mediated communication
- Resource control

Java Components

- Applets
- Servlets
- Enterprise JavaBeans™
- Mobile objects (mobile agents)

Requirements for Component Execution Platforms

- Security
  - Protect platform and components
  - Ensure secrecy
  - Ensure integrity
  - Prevent denial-of-service attacks
  - Prevent resource leaks
- Portability
- High performance

Why Java™ Technology for Components?

- Portable code
- Language safety
  - Type safety
  - Automatic memory management
  - Memory protection
  - Byte-code verification
- Multi-threading
- Class-loader namespaces

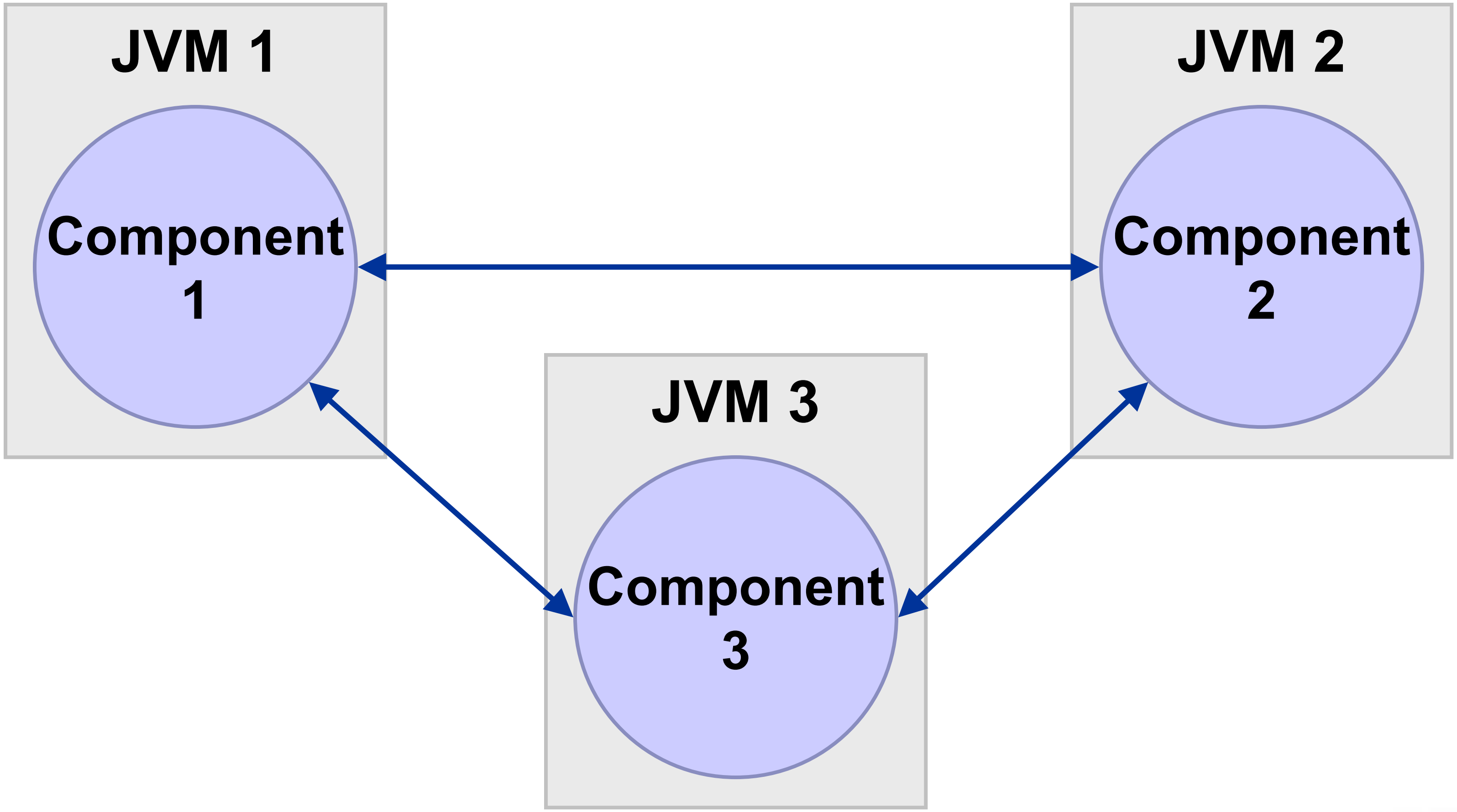
Caveats and Pitfalls

- The JVM™ virtual machine is not an operating system
- No protection domains
- Uncontrolled aliasing
- No ownership information in objects
- Covert channels (e.g., public static variables)
- No resource control
- Single heap

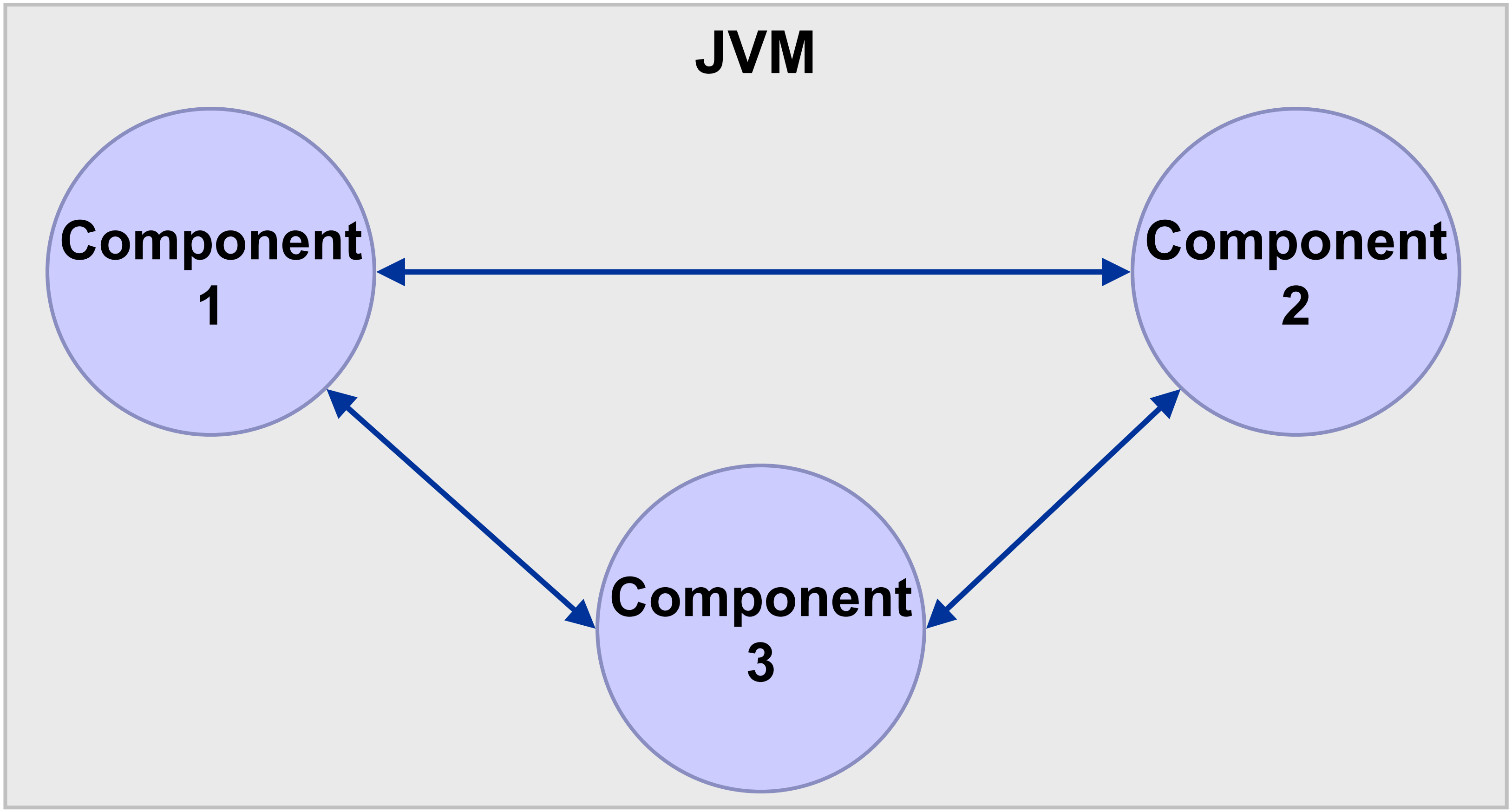
Possible Solutions

- Separate JVM for each component
  – Requires process support in operating system
  – High startup overhead, reloading of JDK™ software-based classes (“JDK classes”)
  – Expensive communication
  – Limited scalability
- Multiple protection domains in single JVM
  – Difficult to implement

Separate JVM™ for Each Component



Multiple Protection Domains in Single JVM™



Design Goals

- Operating system structure
  - Isolated protection domains
  - Safe domain termination
  - Mediated communication
  - Resource control
- Micro-kernel architecture
- Based entirely on Java™ technology
- Efficient implementation techniques

Case Study: The J-SEAL2 Mobile Agent Kernel

- Strong security guarantees
- Formal model: Seal Calculus (Jan Vitek)
- Redesign of the “JavaSeal” project (University of Geneva)
- Small micro-kernel (< 150KB)
- Portable (based entirely on Java technology)
- Flexible and extensible
- Efficient and scalable

Related Work

- Portable (based entirely on Java technology)
  – Project “JavaSeal”
  – J-Kernel
  – (JRes)
- Non-portable (native code, modified JVM™)
  – Alta
  – KaffeOS
  – Luna
  – Nomads

Agenda:
Strong Protection Domains

- Java™ component execution platforms
- Strong protection domains
- Safe domain termination
- Efficient and mediated communication
- Resource control

Requirements

- Isolation of components
- Kernel enforces domain boundaries
- Encapsulation
  - Class-loader
  - Classes
  - Threads
  - Objects
  - Kernel state (e.g., communication queues)

Class-loading

- Shared classes
  - Loaded by system class-loader
  - JDK™ and kernel classes
- Replicated classes
  - Loaded by class-loader of protection domain
  - Libraries and component classes
- Caching of replicated library classes

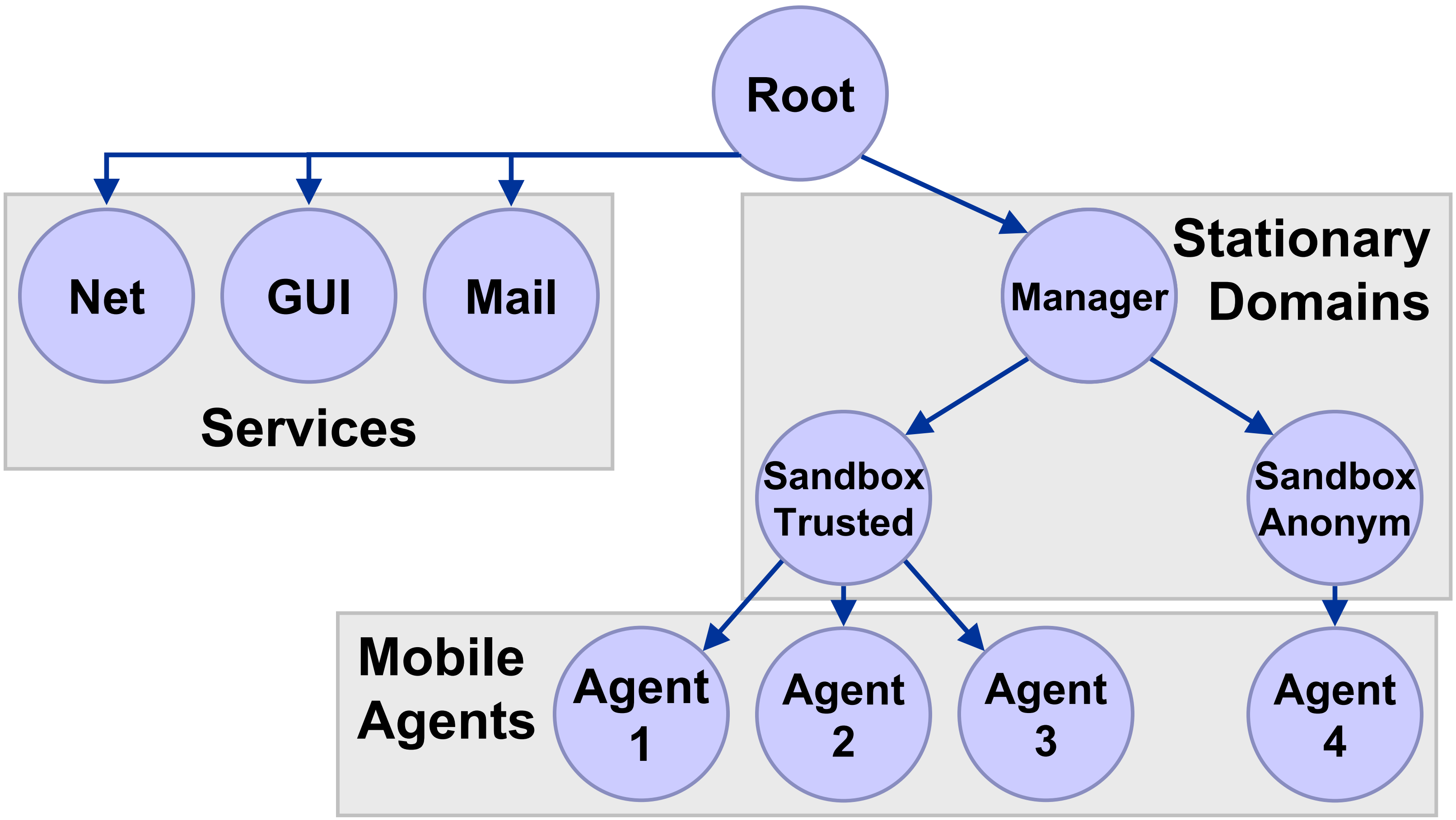
Extended Byte-code Verification

- Limit access to JDK™ classes and kernel
- Configurable verifier directives
  - Restricted access to packages and classes
  - Restricted access to class members
  - Extension restrictions
- Efficient constant-pool verification

Case Study: Nested Protection Domains in J-SEAL2

- Hierarchy of protection domains
- Parent domain controls children
  – Communication control
  – Resource control
  – Termination of sub-hierarchies
- Sandboxes with different privileges

J-SEAL2 System Structure



Agenda: Safe Domain Termination

- Java™ component execution platforms
- Strong protection domains
- Safe domain termination
- Efficient and mediated communication
- Resource control

Requirements

- Immediate resource reclamation
  - Termination of all threads in domain
  - Invalidation of open communication ports
- Ensure consistency of JVM™ and kernel
  - Atomic kernel operations
  - VM operations in kernel (e.g., class-loading)

Code Restrictions

- No finalizers
  - void finalize()
  - void classFinalize()
- No catching of ThreadDeath
- Kernel enforces restrictions
  - Byte-code rewriting
  - Extended byte-code verification

Kernel Mode

- Atomic operations
- Multiple-reader/single-writer lock
  – Domain termination: Write lock (exclusive)
  – Other kernel operations: Read lock (shared)
- Asynchronous class-loading
  – Requires read lock
  – Prevent deadlocks
  – Keep track of threads in kernel-mode

Structure of Kernel Operations

```
boolean excl = ...; // exclusive or shared
Kernel.lock(excl);
// now executing in kernel-mode
try {
   // allocate all objects (worst case)
   ...
   // update kernel state
   ...
}
finally {
   Kernel.unlock(excl);
}
// now back in user-mode
```

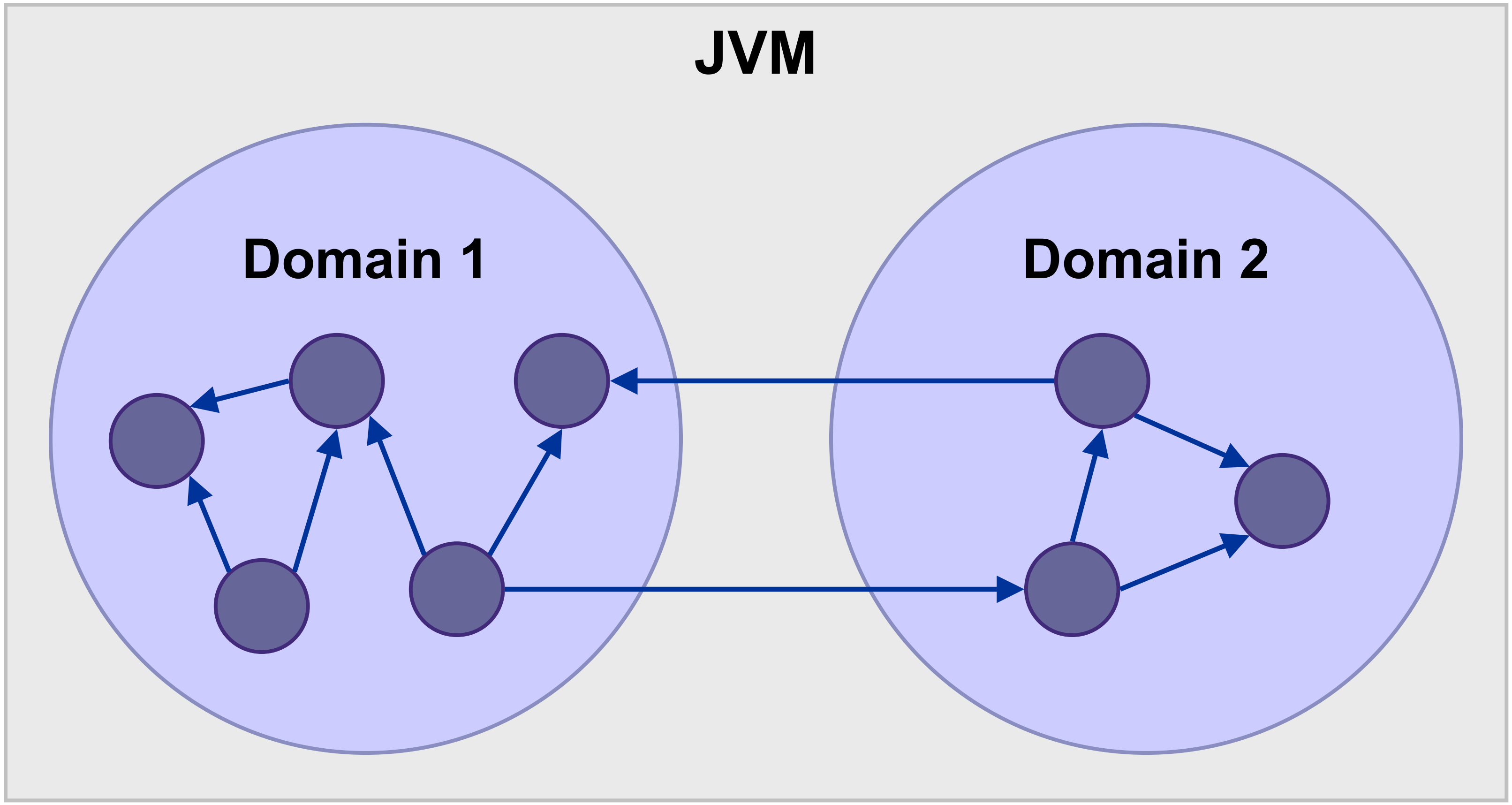
Agenda: Efficient and Mediated Communication

- Java™ component execution platforms
- Strong protection domains
- Safe domain termination
- Efficient and mediated communication
- Resource control

Communication Models

- Direct sharing
  - Java™ technology based references (“Java references”)
  - Special remote pointers (e.g., Luna)
- Indirect sharing (e.g., J-SEAL2, J-Kernel)
- Copying (e.g., project “JavaSeal”, J-SEAL2, J-Kernel)

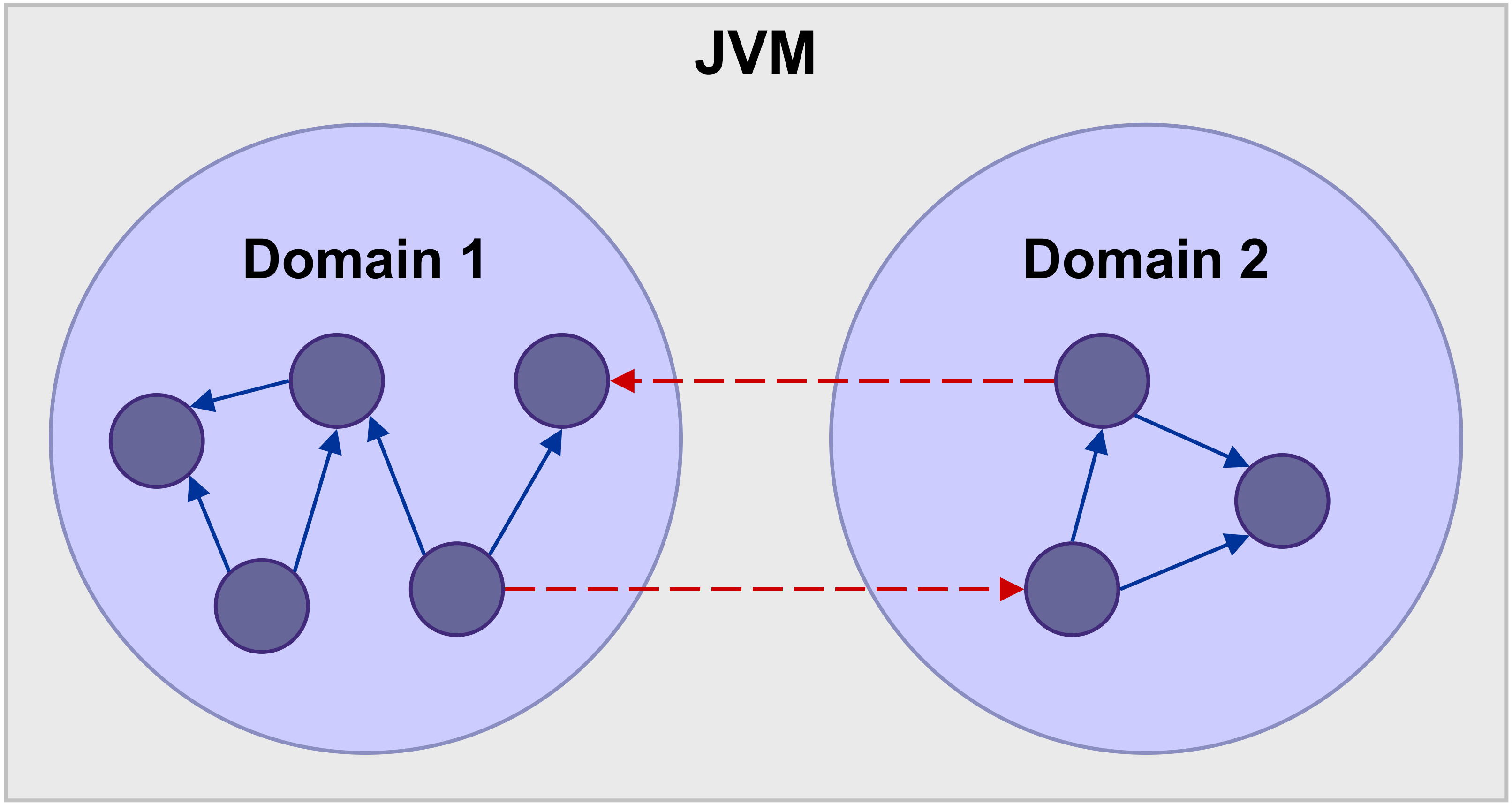
Direct Sharing With Java™ Technology



Direct Sharing With Java™ Technology: Pros and Cons

- Pros
  - Simple
  - Fast (method invocation)
  - Based entirely on Java technology
- Cons
  - Blurs domain boundaries
  - No revocation
  - Domain termination
  - Resource accounting

Direct Sharing in Luna

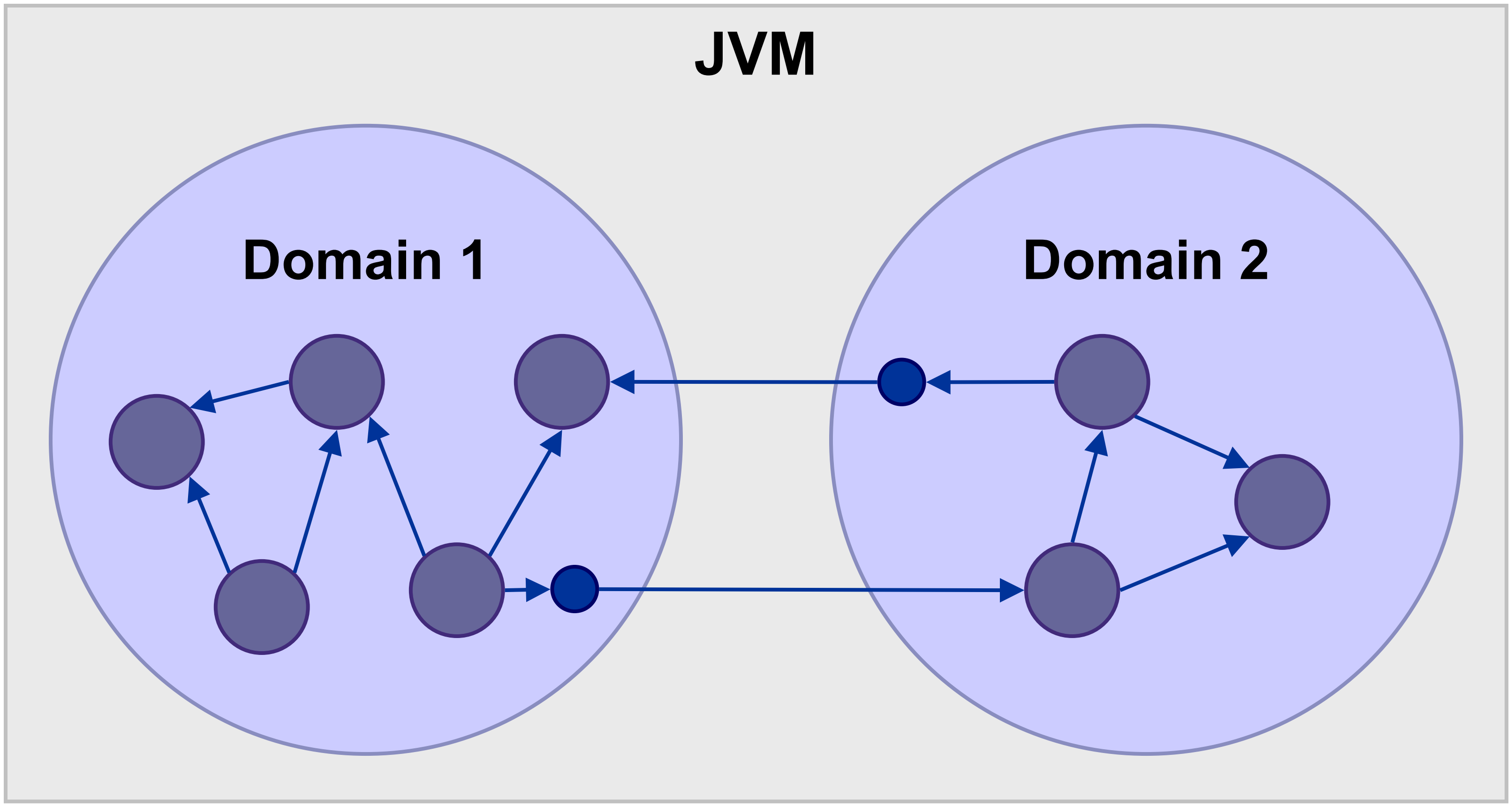


Direct Sharing in Luna: Pros and Cons

- Pros
  - Fast (method invocation)
  - Revocation
  - Domain termination
  - Resource accounting
- Cons
  - Requires modified JVM™

JavaOne™

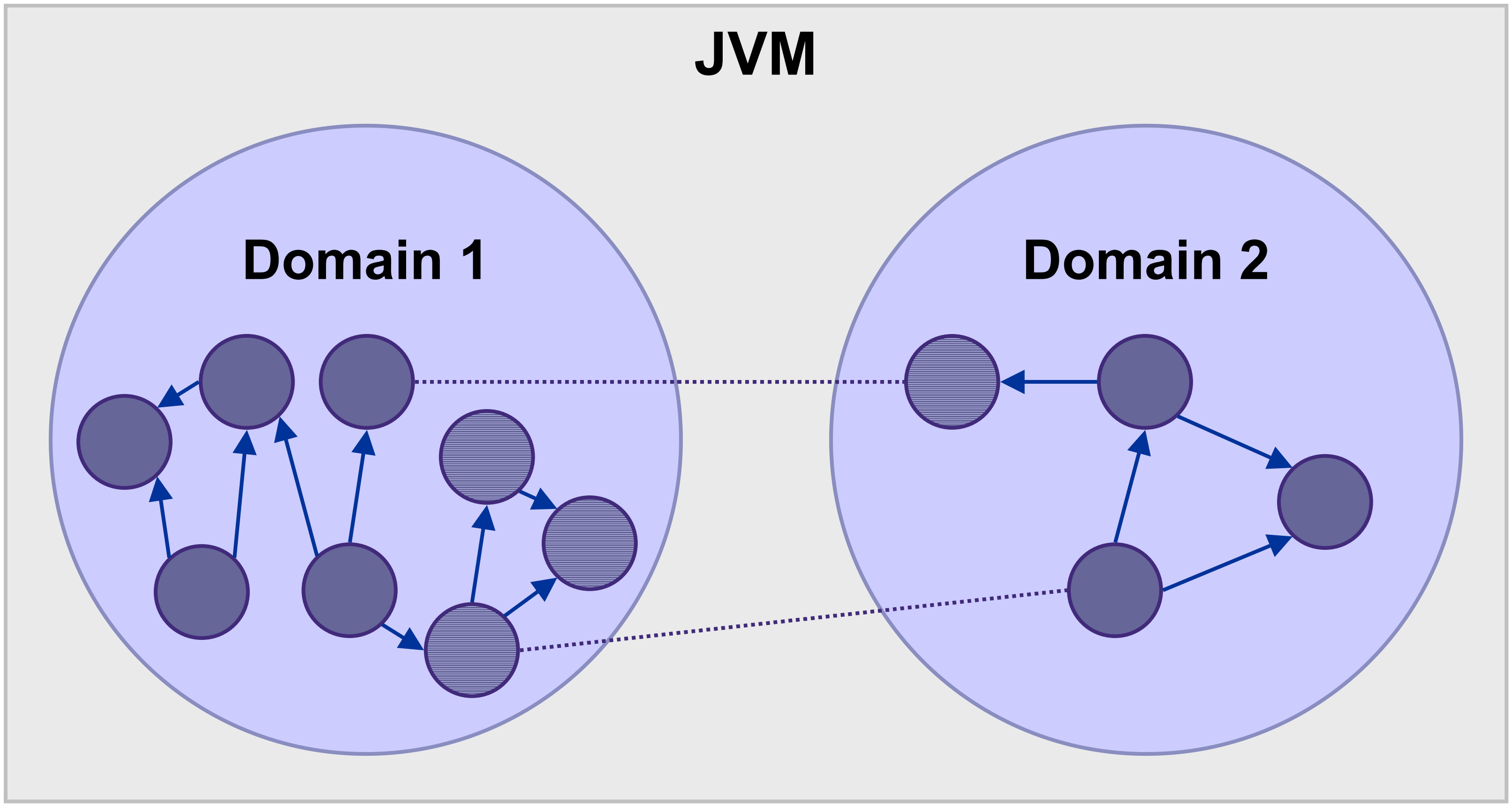
Indirect Sharing



Indirect Sharing: Pros and Cons

- Pros
  - Revocation
  - Domain termination
  - Resource accounting
  - Based entirely on Java technology
- Cons
  - Overhead (indirection)

Copying



Copying: Pros and Cons

- Pros
  - Revocation not necessary
  - Domain termination
  - Resource accounting
  - Based entirely on Java technology
- Cons
  - High overhead for large object graphs (memory and CPU)
  - Serialization restrictions

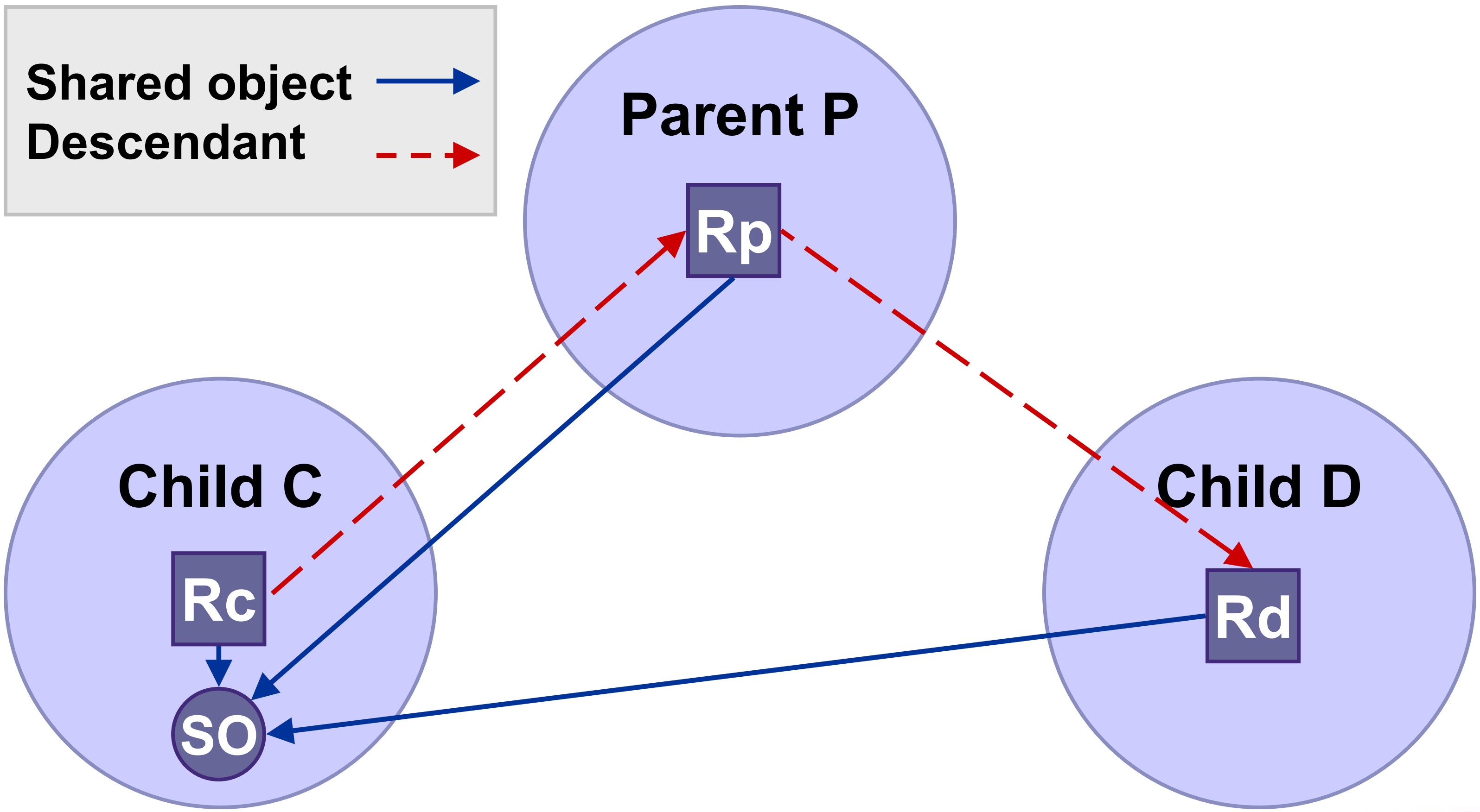
Case Study: Communication in J-SEAL2

- Channels (copying)
  - Name, location (self, parent, child name)
  - Only between neighbor domains
  - Synchronous send/receive (Seal Calculus)
  - Optional timeouts
  - Asynchronous send
- External references (indirect sharing)
  - Cross-domain method invocation
- Inter Agent Method Calling (IAMC)

Communication Values

- Copying and indirect sharing
- Capsule: Serialized object graph
- Special treatment of external references
- Copying optimizations
  - Primitive types
  - Arrays of primitive types
  - Strings

External References



Agenda: Resource Control

- Java component execution platforms
- Strong protection domains
- Safe domain termination
- Efficient and mediated communication
- Resource control

JavaOne

Requirements

- Prevention against denial-of-service attacks
- Resource control
  - Resource accounting
  - Enforcing restrictions
- Physical resources (e.g., CPU, memory, net)
- Logical resources (e.g., threads, domains)

Implementation

- Accountability (objects belong to 1 domain)
- Byte-code rewriting
  - CPU: Count byte-code instructions
  - Memory: Check before allocation (JRes)
- Compensation for native code
  - Class-loading
  - Deserialization
  - Reflection
  - Object cloning

Memory Account (Simplified)

- Memory limit for multiple threads
- Synchronization
- Weak references to allocated objects

```
public final class MemAccount {
   public void setLimit(int limit);
   public void checkAllocation(int size)
          throws ResourceOveruseException;
   public void register(Object o);
}
```

CPU Account

- Separate account for each thread
- No synchronization
- Periodic scheduler thread (high priority)

```
public final class CPUAccount {
   public volatile int usage;
}
```

Passing Accounting Objects

- Unmodified method

```
Object f(int x) {
   if (x < 0) return null;
   else return new Foo(g(x));
}
```

- Added accounting objects

```
Object f(int x, MemAccount mem, CPUAccount cpu) {
   if (x < 0) return null;
   else return new Foo(g(x, mem, cpu), mem, cpu);
}
```

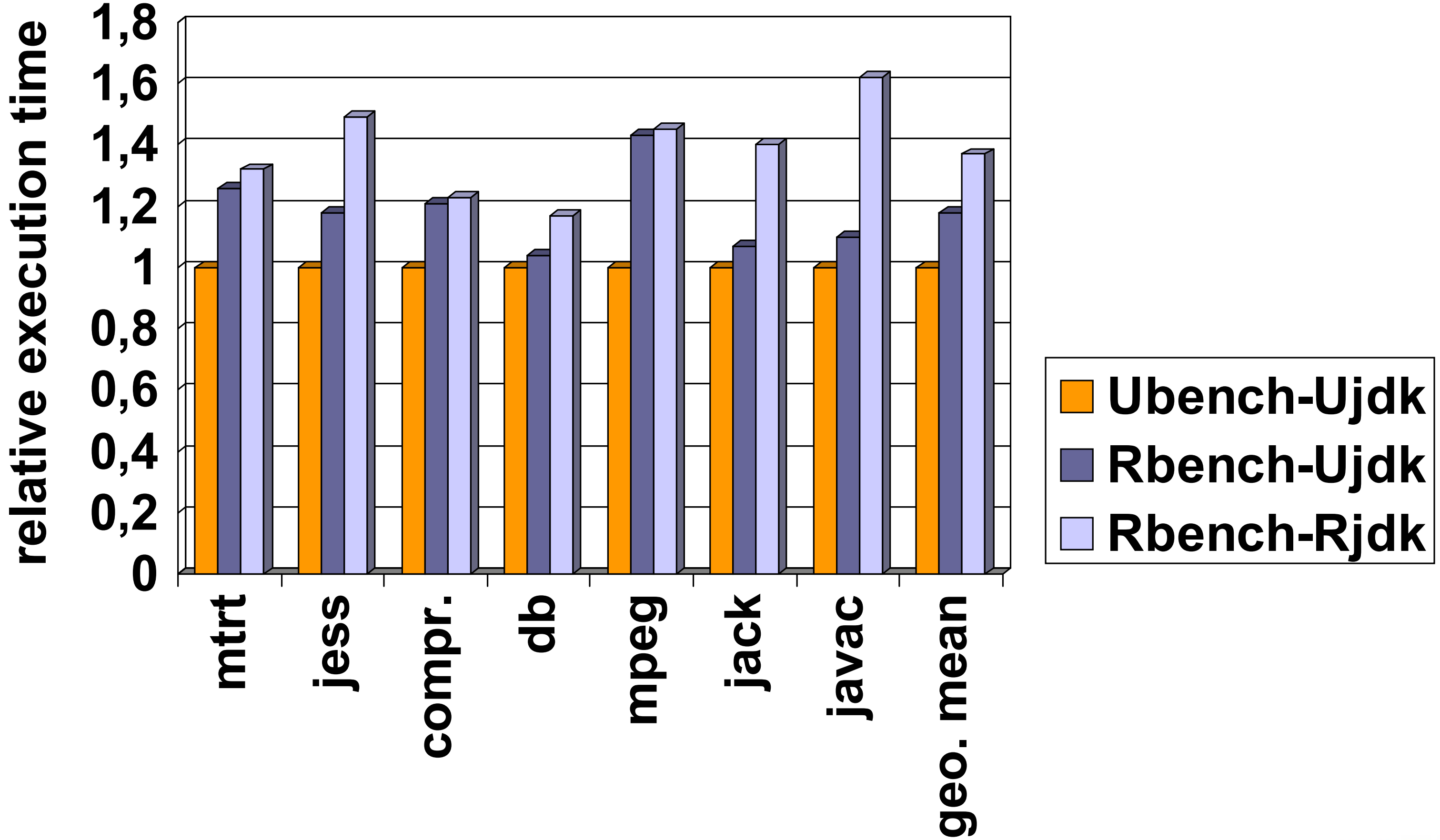
Rewriting for Memory Accounting (Simplified)

```
Object f(int x, MemAccount mem, CPUAccount cpu) {
   if (x < 0) return null;
   else {
      int y = g(x, mem, cpu);
      mem.checkAllocation(SIZEOF_FOO);
      Object o = new Foo(y, mem, cpu);
      mem.register(o);
      return o;
   }
}
```

Rewriting for CPU Accounting

```
Object f(int x, MemAccount mem, CPUAccount cpu) {
   cpu.usage += 8;
   if (x < 0) {
      cpu.usage += 8;
      return null;
   }
   else {
      cpu.usage += 26;
      int y = g(x, mem, cpu);
      mem.checkAllocation(SIZEOF_FOO);
      Object o = new Foo(y, mem, cpu);
      mem.register(o);
      return o;
   }
}
```

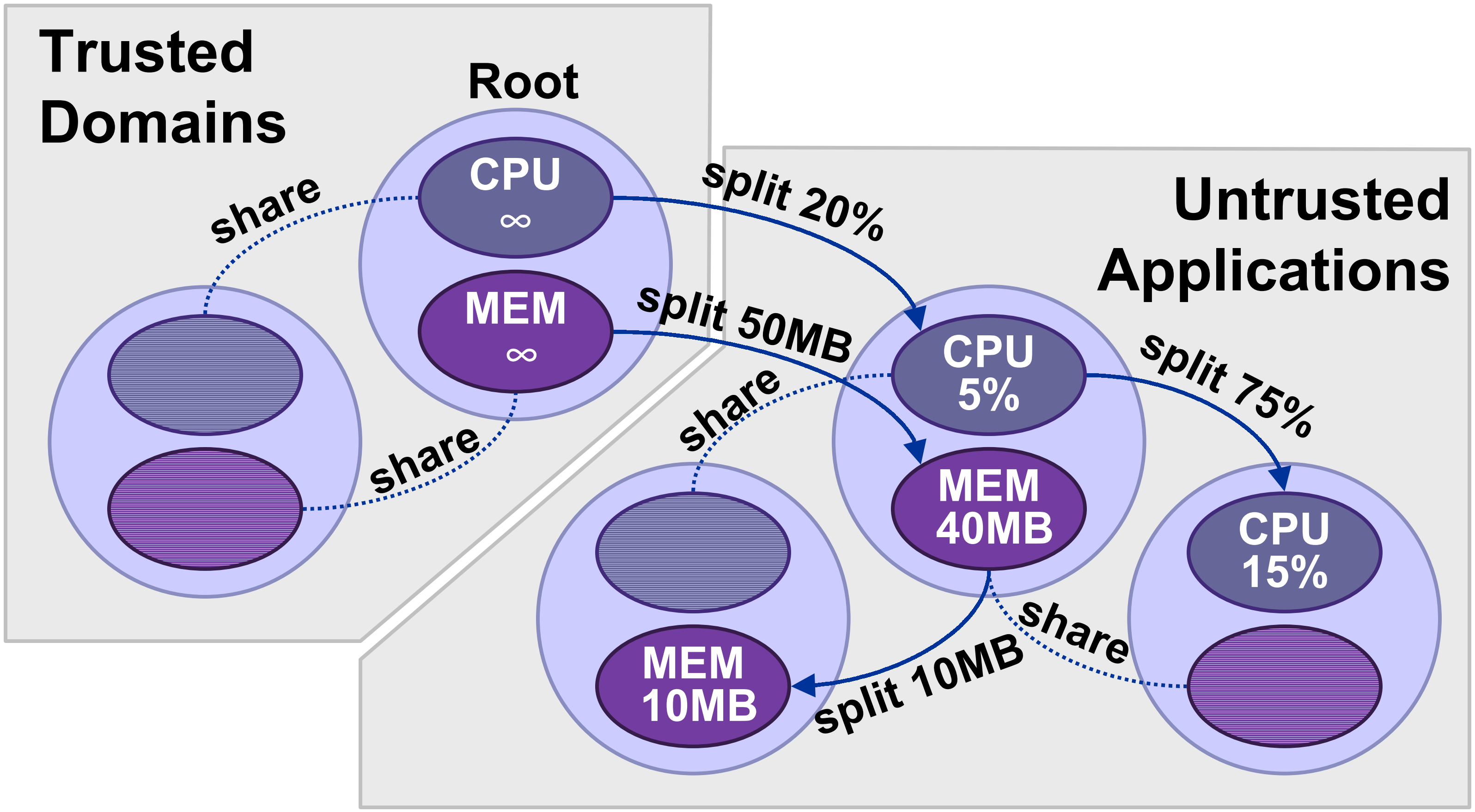
Overhead of CPU Accounting



Case Study: Hierarchical Resource Control in J-SEAL2

- Startup
  - Root domain owns all resources
- Subdomain creation
  - Parent may donate resources to child
  - Parent may share resources with child

Resource Donation and Sharing in J-SEAL2



Summary

- Component execution platform requirements
  - Security
  - Portability
  - High performance and scalability
- Operating system functionality for the Java™ platform
  - Protection domains
  - Safe domain termination
  - Mediated communication
  - Resource control

Get More Information!

- Email to w.binder@coco.co.at
  - Articles
  - Thesis
  - Background information
  - Specific questions
  - Collaboration
  - Research and evaluation versions of J-SEAL2

Q&A

Question

- Which restrictions does the protection model impose on components?

Answer

- ‘Dangerous’ JDK™ software functionality
- Restructure applications for security
- Use of service components
- Automatic transformation of components

JavaOne[SM]

Sun's 2001 Worldwide Java Developer Conference*