Disco

CS380L: Mike Dahlin

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"Disco: A bad idea from the 70's, and it's back!"
Mendel Rosenblum (tongue in cheek)

1 Preliminaries

1.1 Review

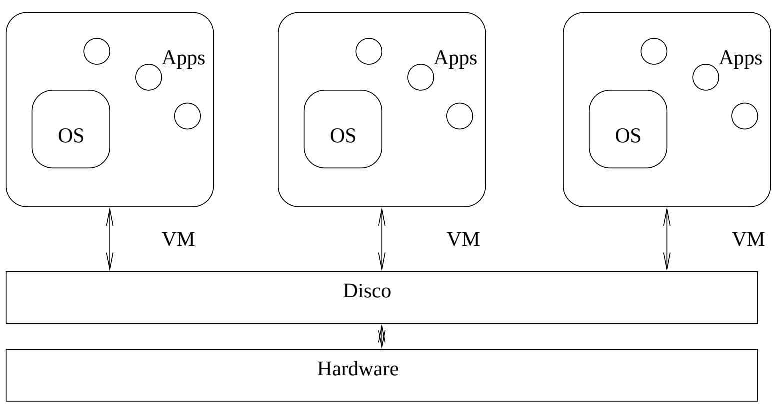
1.2 Outline

1.3 Preview

- This week: Disco and Exokernel. One lesson: "If at first you don't succeed, try try again"

2 Overview

- Disco motivation



  - Background: Stanford FLASH
    - SMP
    - NUMA
      - performance (e.g., memory locality)
      - scale (bottlenecks; NUMA enables larger scale than SMP)
      - fault tolerance (isolation; NUMA enables larger scale and less tight coupling than SMP – some need for/hope for isolation)
  - Want: convert a large SMP into a collection of virtual machines that run concurrently

- Existing commcercial OSs dont do well on FLASH (thanks to NUMAness)
  - Hard to modify them
    - Traditional view: "Software flexible, HW inflexible"
    - Reality: processor architectures respun every 3-5 years, OS architectures respun never
    - → Reality: Software inflexible
    - Why? (One theory: HW has narrow interface; OS interface gets broader and broader)
  - The VMs will hopefully share resources better than the big OS can
    - locality – VM small ← can be hand-tuned "like a parallel program
    - bottlenecks – hierarchical mgmt – Guest OS/VM
    - isolation – OS runs in different address spaces "distributed system"
  - Mix OSs, especially commercial ones with specialized ones
  - Fault containment
  - Economics: if you are a commercial operating system vendor, where spend time: adding features to commodity OS that sells millions of copies per year or porting and maintaining 50M-line OS to run on a few hundred high-end machines?

- Basic goals
  - Support commodity OS with no modification
    - Disco: 13000 lines of code
    - v. Exokernel goal: absolute max performance

- Basic solution
  - Disco
    - Virtualize the hardware
    - Guest OS's have no idea that multipexing is happening
    - Core challenge: virtualize hardware without breaking existing OS
  - (v. Exokernel)
    - Export the hardware
    - LibOS's are active accomplices in virtualizing hardware
    - Core challenge: balance cooperation v. protection for max performance

- Challenges for VM's
  - Overhead of virtualizing hardware
    - Emulate key instructions (IO, interrupts, memory management, ...)
    - Space overhead: many copies of OS, binaries, etc in memory
  - Difficult to manage resources w/o OS participation
    - When is cpu idle?
      - Disco guest OS gives hint for idle loop (give up a bit of transparancy...)
    - When is memory free?
  - Lack of sharing across VM's

    * Interprocess communication on IBM VM: Connect virtual card punch of VM1 to virtual card reader of VM2.
  - Lack of ccNUMA support

3 Virtualizing a machine

- Most instructions execute at hardware speed
- Privleged instructions?
  - Trap to VM; VM emulates
  - Example: What is pseudo-code for "handle process in guest OS TLB miss (for SW filled TLB)?"
- Exceptions and interrupts?
- "Virtualizable machine"

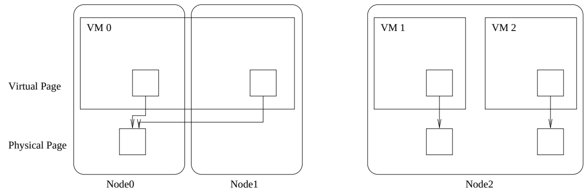
4 Admin

- Project
- hamming paper

5 Key subsystems

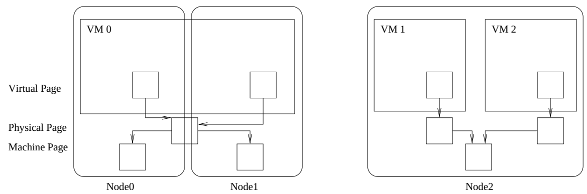
5.1 Virtual memory

- GuestOS sees only "virtual physical addresses"
  - When GuestOS tries to update TLB, VM remaps virtual PA to real PA
  - GuestApp only sees virtual addresses – it cannot detect the "lie"
  - GuestOS sees GuestApp virtual addresses and virtual physical addresses – it cannot detect the "lie"
  - **QUESTION:** Why does Disco relink the OS?
  - **QUESTION:** What does disco need internally to do this? How do you handle TLB miss? How do you take a page away from a VM? How do you migrate a page within a VM? How do you give a page to a VM? Why does Disco not virtualize ASIDs?
  - Disco intercepts disk requests for blocks already cached and gives the requesting VM a read-only mapping to the page (if the request is a multiple of the page size). This leads to transparent sharing of root disk.
  - But how do we do this trick when OSes are sharing mutale file systems via NFS? A virtual network device with unlimited MTU. Change IRIX mbuf implementation to not write buffer memory and change bcopy to monitor's remap
  - OS tells monitor when a page will not be reclaimed (break abstraction)
- Virtual Memory on ccNUMA (pre-disco)



- Shared virtual address space across nodes – where to locate data?
- Disjoint virtual address space within a node – replicate identical data (e.g., "/bin")

- Virtual Memory on ccNUMA (Disco)



  - Transparent replication and migration for shared virtual pages on different machine nodes
  - Transparent sharing of machine pages that are virtually different on same machine node
  - **QUESTION**: Given pmap, how share a page between VMs? How replicate a (read only) page within a VM on multiple processors?

5.2 File system

- Virtually distinct disks
- Optimization: Identical data on virtually distinct disks
  - Copy-on-write sharing
  - Read-only disk file system sharing
  - Write sharing via NFS
- Optimization: Copy-on-write + rollback → useful for debugging, test, etc.

5.3 Devices

- Option 1: Trap all programmed I/O and emulate
- Option 2: Add fake Disco-aware device drivers
- Ranges from transparent to not-so-transparent
- Ranges from slow to fast

5.4 Fast communication

- VM370: Virtual card writer to virtual card reader
- Disco: Fake virtual subnet
  - Use TCP/NFS to connect virtual machines
  - Zero copying by sharing underlying VMM buffers

5.5 Resource allocation

- Simple time-sharing scheduler among VM's
  - Guest OS hints for idle loop
- ccNUMA-aware management (e.g., affinity scheduling)
  - How to do gang scheduling?
  - How to do real time applications?

6 Disco evaluation

- More complete than the original UNIX paper...they measure compilation of GNU chess
- What are they trying to prove? What should they be trying to prove (what are key questions about VMM approach?) Taking their experiments at face value, should you be convinced?
- Discussion
  - IRIX memlock was a total disaster and no OS has a problem that big today
  - NUMA scalability experiment compares to optimal (UMA)

7 Questions

- Research question: Is Disco simple enough to allow formal verification of correctness?
  - Can you add "performance hints" interface that does not hurt correctness argument?
- What lessons (if any) for structuring OS's?
- How much complexity belongs in "virtual machine" and how much in OS? As we add more to virtual machine, can we simplify OS?
- What is the right layering? (What layering does Disco end up using?)
- What is the right HAL interface?

8 Evaluation: Disco v. Exo v. Micro

- Extensibility
  - - Microkernel: experiment with new subsystems
  - - Exokernel: some of the most interesting apps are specialized appliances, but how much protection do you need?
  - - Disco: specialized OS for novel machines
- Concurrent personality
  - Microkernel: by hopefully sharing some underlying subsystems
  - Exokernel: concurrent secure sharing of low level resource by different personalities
  - Exokernel: the most interesting personalities (apps) do not necessarily have to be concurrent
  - Disco: excellent support for concurrent personality but how many VMM subsystems can you share?
- Modularity
  - Microkernel: easier to foster good s/w engineering discipline
  - Exokernel: ouch
  - Disco: OS/HAL, no more modular than that
- Dstributed system support
  - Microkernel: moving subsystems over the net
  - Exokernel: N/A
  - Disco
    - Aggressive copy-on-write is cool
    - The opposite–distributed system support enables the communication of VMs
    - Its a strange idea to turn an expensive SMP into a dumb cheap cluster
- Security
  - Microkernel: smaller trust base, hopefully
  - Exokernel
    - Exokernel itself is smaller so this is good
    - But unclear with all the code injection and tight interactions with apps
    - But maybe protection doesnt matter that much for specialized appliances
  - Disco
    - Nice opportunity of fault containment of VMs on SMPs
- Portability
  - Microkernel: subsystems are easier to port
  - Exokernel: ouch
  - Disco:
    - HAL in modern OS makes this easy
    - Small tweaks of OS can make it more efficient