Reliable Adaptable Network RAM

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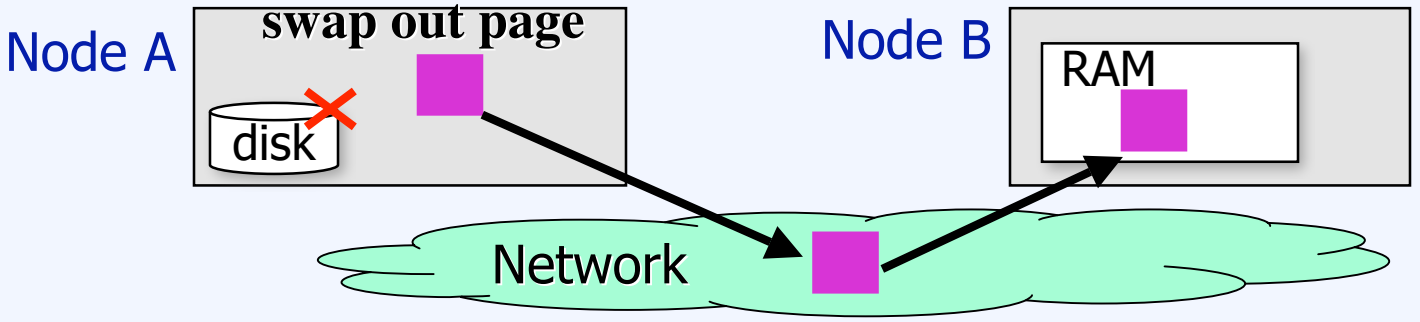
Network RAM

General purpose cluster nodes share each other's idle RAM as a remote swap partition

When one node's RAM is overcommitted, swap its pages out over the network to store in idle RAM of other nodes

+ Avoid swapping to slower local disk
+ Almost always some significant amt idle RAM even when some nodes overloaded



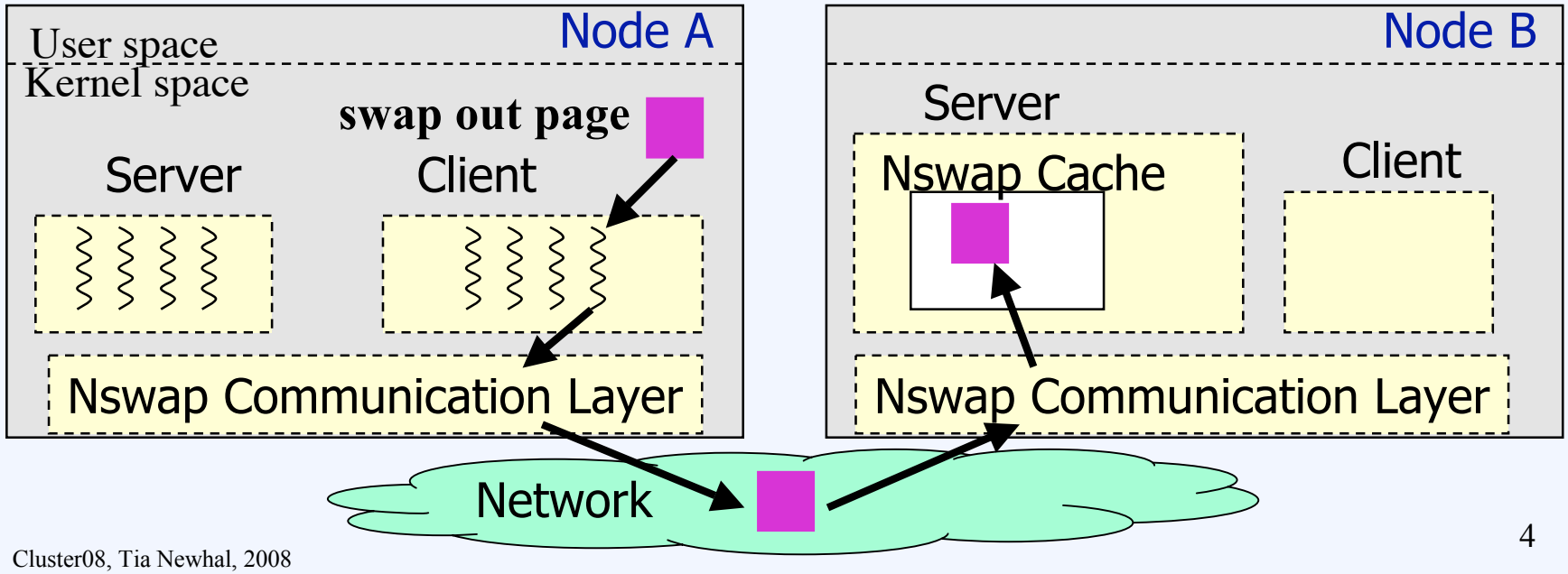
Goals of Network RAM system

- Scalable
  - No central authority
- Adaptable
  - Node's RAM usage varies
  - Don't want remotely swapped page data to cause more swapping on a node

  ⇒ relinquish RAM its using to local paging system when needed by local processes, & allocate when idle RAM
- Fault Tolerant: recover remotely swapped page data lost in node crash
  - A single node failure can lose pages from processes running on remote nodes
  - One node's failure can affect unrelated processes on other nodes

Nswap

- Network swapping lkm for Linux clusters
  - Runs entirely in kernel space on unmodified Linux 2.6
- Completely Decentralized
  - Each node runs a multi-threaded client & server
  - Client is active when node swapping
    - Uses local information to find a "good" Server when it swaps-out
  - Server is active when node has idle RAM available

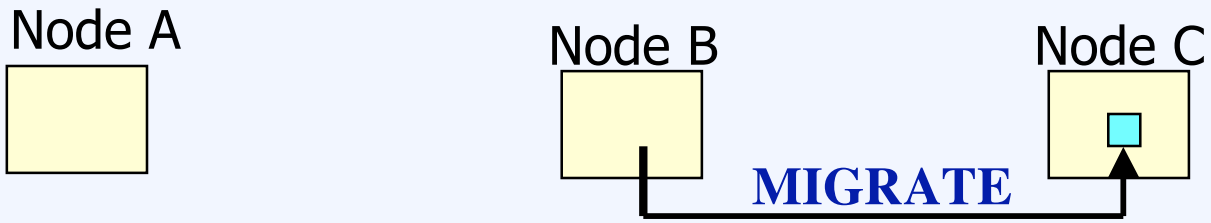


How Pages Move around system

Swap out: from client A to server B

Swap in: from server B to client A (B still is backing store)

Migrate: server B shrinks its Nswap Cache sends pages to server C



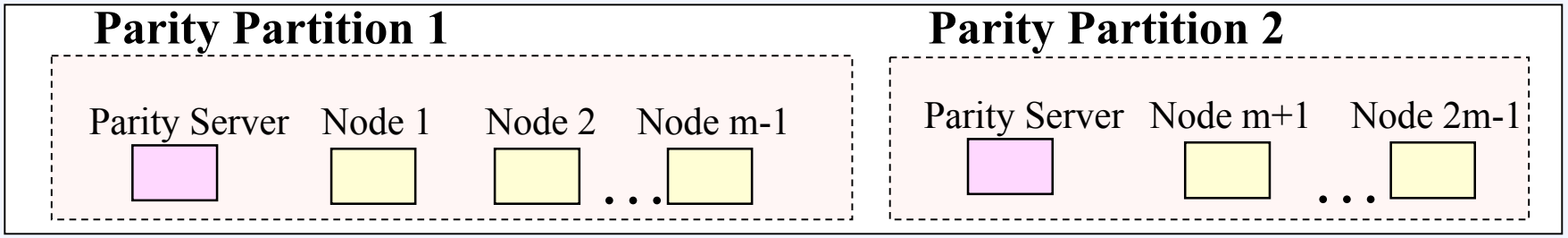
Reliability Algorithms

- Avoid reliability solutions that use disk for reliability
  - ➔ want a RAID-like solution that stripes page & reliability data across cluster-wide idle RAM
- Has to work with Nswap's:
  1. Dynamic resizing of Nswap Cache
  2. Varying Nswap Cache capacity at each node
  3. Support for migrating remotely swapped page data between servers
  - ➔ Reliability solutions that require fixed placement of page and reliability data won't work

Centralized Dynamic Parity

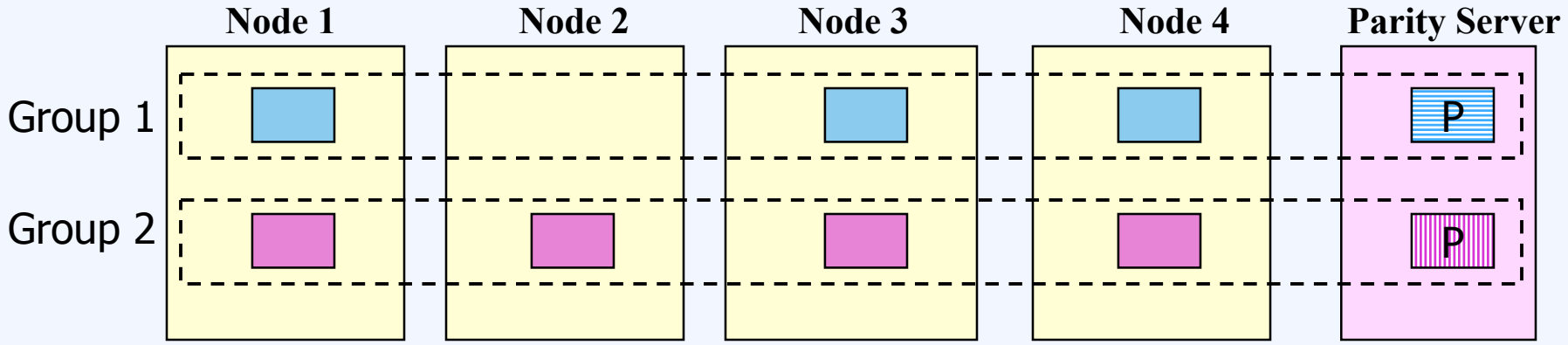
- RAID 4 like
- A single, dedicated, parity server node
  - In large clusters, nodes divided into Parity Partitions, each partition has its own dedicated Parity Server
  - Parity Server stores parity pages and implements page recovery

    + Client & server don't need to know about parity grps



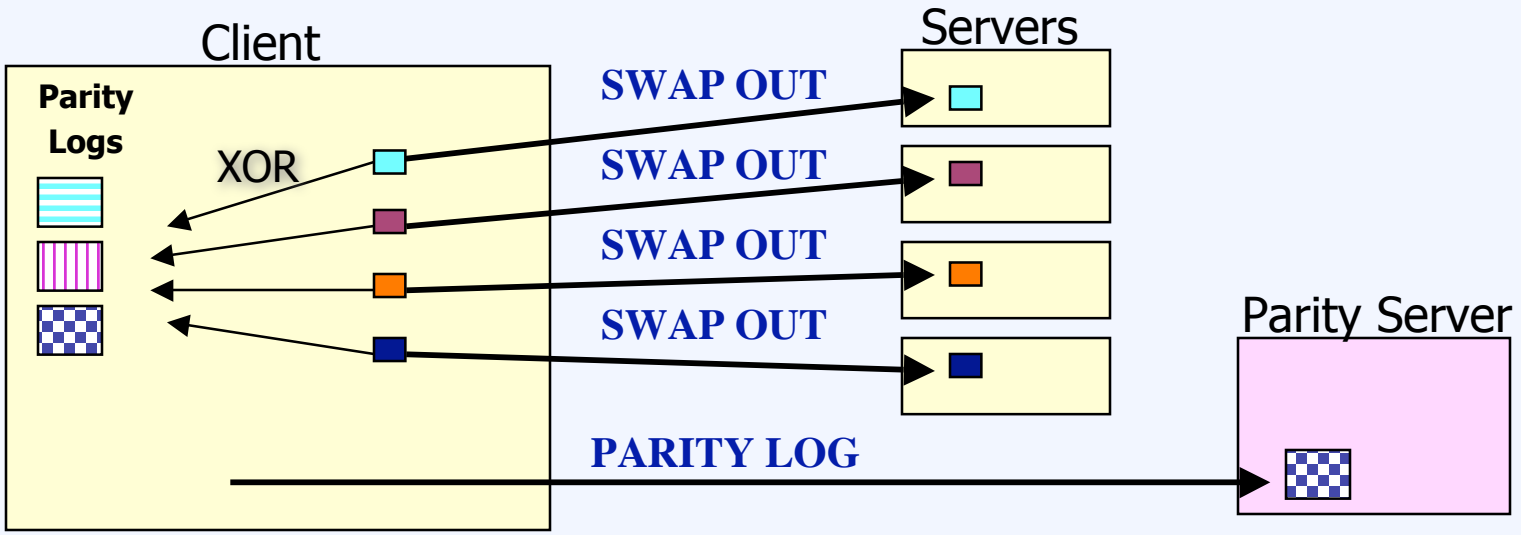
Centralized Dynamic Parity (cont.)

- Like RAID 4
  - Parity group pages striped across cluster idle RAM
  - Parity pages all on single parity server
- with some differences
  - Parity group size and assignment is not fixed
  - Pages can leave and enter a given parity group (garbage collection, migration, merging parity grps)



Page Swap-out, case 1: new page swap

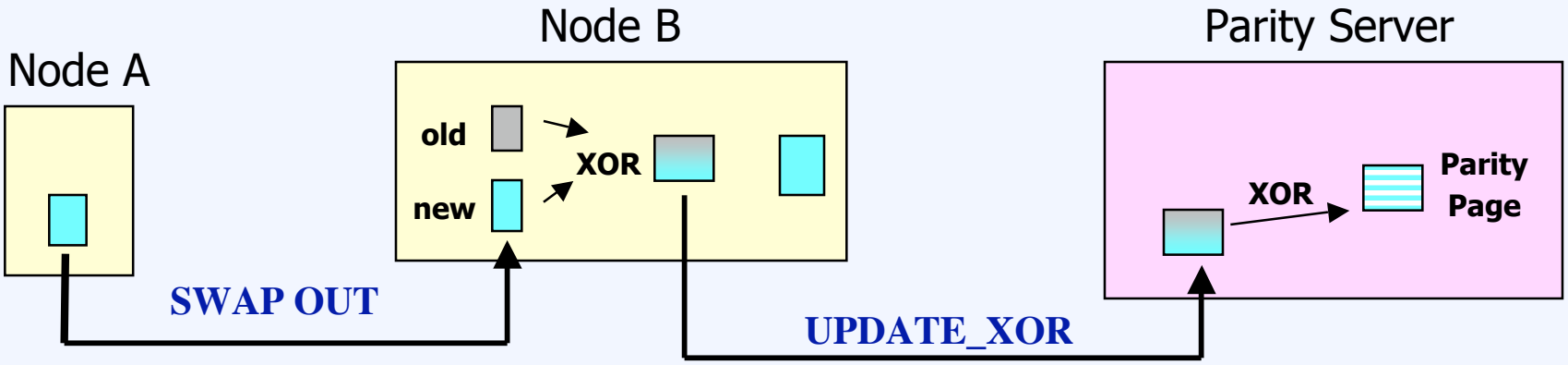
- Parity Logging:
  - client stores a set of in-progress parity pages
  - As page swapped out it is added to a parity log
    - minor computation overhead on client (XOR of 4K pages)
  - As parity logs fill, they are sent to the Parity Server
    - One extra page send to parity server every ~N swap-outs



Page Swap-out, case 2: overwrite

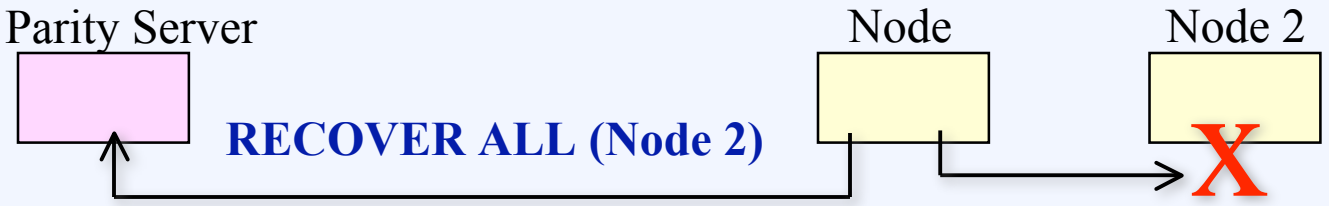
Server has old copy of swapped out page:

- Client sends new page to server
  - No extra overhead on client side vs. non-reliable Nswap
- Server computes the XOR of the old and new version of the page and sends it to the Parity Server before overwriting the old version with the new



Node Failure

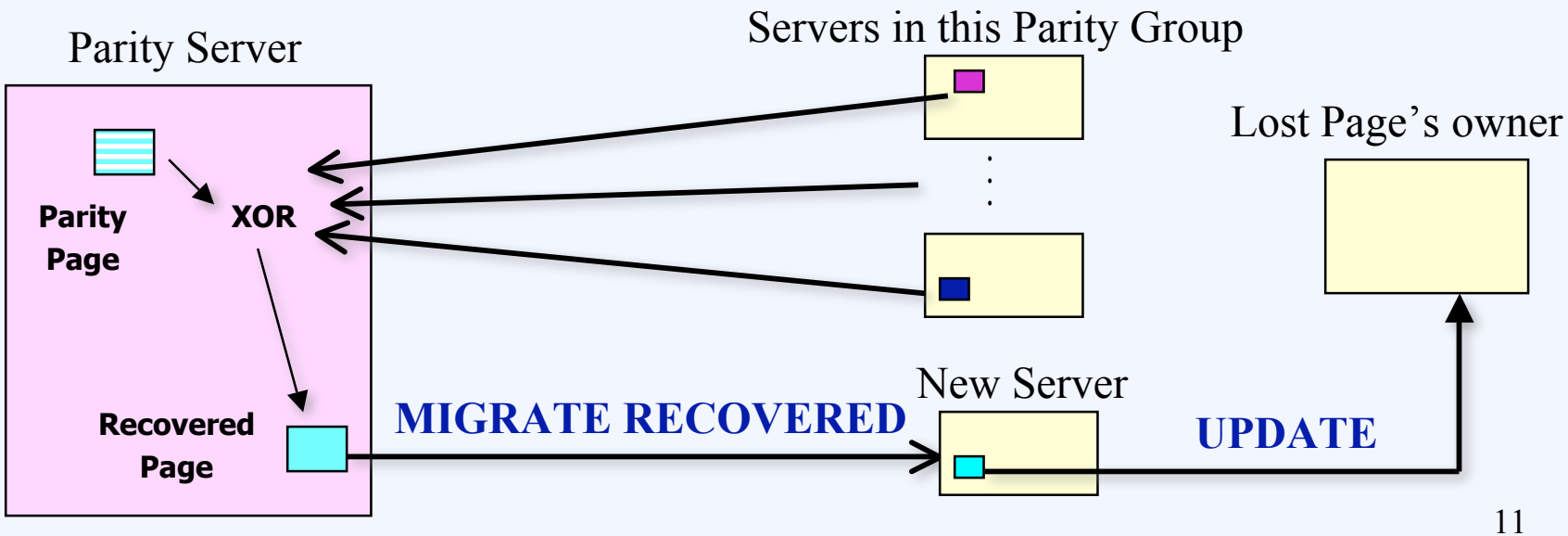
Detecting node sends a RECOVER ALL message to Parity server



Parity Server rebuilds all pages that were stored at the crashed node

As it recovers each page, it migrates it to a non-failed Nswap Server
page may stay in same parity group or be added to a new one

The server receiving the recovered page tells client of its new location



Soln 3: Decentralized Dynamic Parity

- Like RAID 5:
  - No dedicated parity server
  - Data pages and Parity pages striped across Nswap Servers

  \+ not limited by Parity Server's RAM capacity nor Parity Partitioning

  \- every node is now Client, Server, Parity Server
- Store with each data page its parity server & P-group ID
  - For each page, need to know its parity server and to which group it belongs
  - A page's parity group ID and parity server can change due to migration or merging of two small parity groups
    - First set by client on swap-out when parity logging
    - Server can change when page is migrated or parity groups are merged
- Client still does parity logging
  - Finds a node to take the parity page as it starts a new parity group
  - One extra message per parity group to find a server for parity page
- Every Nswap server has to recover lost pages that belong to parity groups whose parity page it stores.

  +/- Decentralized recovery

Kernel Benchmark Results

Workload	Swapping to Disk	Nswap (No Reliability)	Nswap (Centralized Parity)
(1) Sequential R&W	**220.31**	**116.28** (speedup 1.9)	**117.10** (1.9)
(2) Random R&W	**2462.90**	**105.24** (23.4)	**109.15** (22.6)
(3) Random R&W & File I/O	**3561.66**	**105.50** (33.8)	**110.19** (32.3)

8 node Linux 2.6 cluster (Pentium 4, 512 MB RAM, TCP/IP over 1 Gbit Ethernet, 80 GB IDE (100MB/s))

Workloads:

(1) Sequential R & W to large chunk of memory (best case for disk swapping)

(2) Random R & W to memory (more disk arm seeks w/in swap partition)

(3) 1 large file I/O, 1 W2 (disk arm seeks between swap & file partitions)

Parallel Benchmark Results

Workload	Swapping to Disk	Nswap (No Reliability)	Nswap (Centralized Parity)
Linpack	**1745.05**	**418.26** (speedup 4.2)	**415.02** (4.2)
LU	**33464.99**	**3940.12** (8.5)	**109.15** (8.2)
Radix	**464.40**	**96.01** (4.8)	**97.65** (4.8)
FFT	**156.58**	**94.81** (1.7)	**95.95** (1.6)

8 node Linux 2.6 cluster (Pentium 4, 512 MB RAM, TCP/IP over 1 Gbit Ethernet, 80 GB IDE (100MB/s))

Application Processes running on half of the nodes (clients of Nswap), the other half are not running benchmark processes and are acting as Nswap servers.

Recovery Results

- Timed execution of applications with and without concurrent page recovery (simulated node failure and the recovery of pages it lost)
  - Concurrent recovery does not slow down application
- Measured the time it takes for the Parity Server to recover each page of lost data
  - ~7,000 pages recovered per second
  - When parity group size is ~5: 0.15 ms per page
  - When parity group size is ~6: 0.18 ms per page

Conclusions

- Nswap's adaptable design makes adding reliability support difficult
- Our Dynamic Parity Solutions solve these difficulties, and should provide the best solutions in terms of time and space efficiency
- Results testing our Centralized Solution, support implementing the Decentralized Solution
  - + more adaptable
  - + no dedicated Parity Server or its fixed-size RAM limitations
  - - more complicated protocols
  - - more overlapping, potentially interfering operations
  - - each node now a Client, Server, and Parity Server

Acknowlegments

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More information:

http://www.cs.swarthmore.edu/~newhall/nswap.html

Nswap's Design Goals

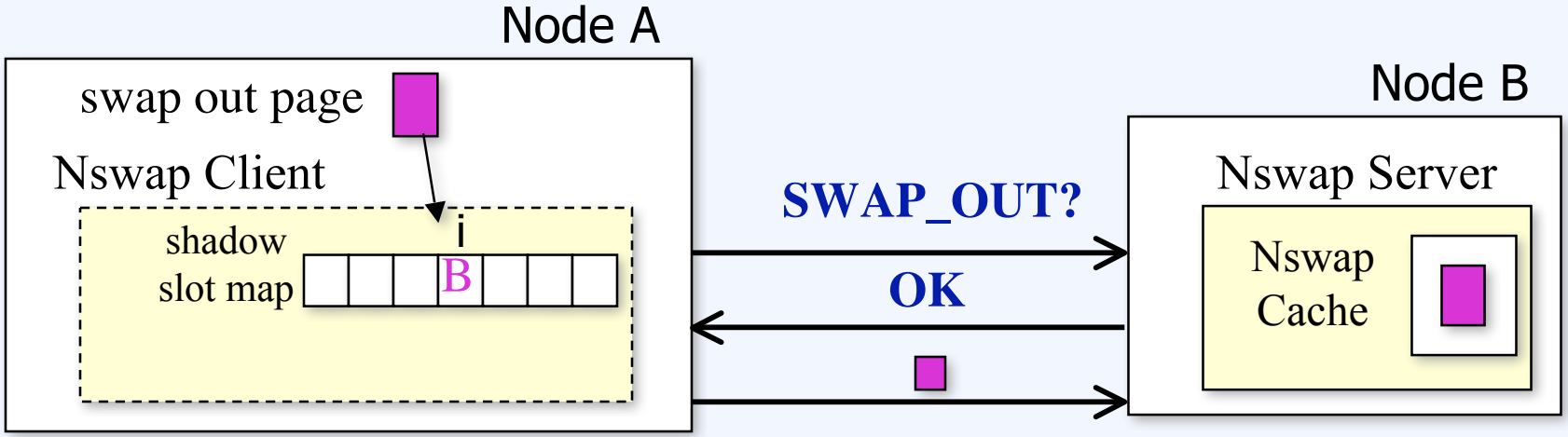
- Transparent
  - User should not have to do anything to enable swapping over NW
- Adaptable
  - A Network RAM system that constantly runs on cluster must adjust to changes in local node's memory usage
  - Local processes should get local RAM before remote processes do
- Efficient
  - Should be fast swapping in and out
  - Should use a minimal amount of local memory state
- Scalable
  - System should scale to large sized clusters (or networked systems)
- Reliable
  - A crash of one node should not effect unrelated processes running on other nodes

Complications

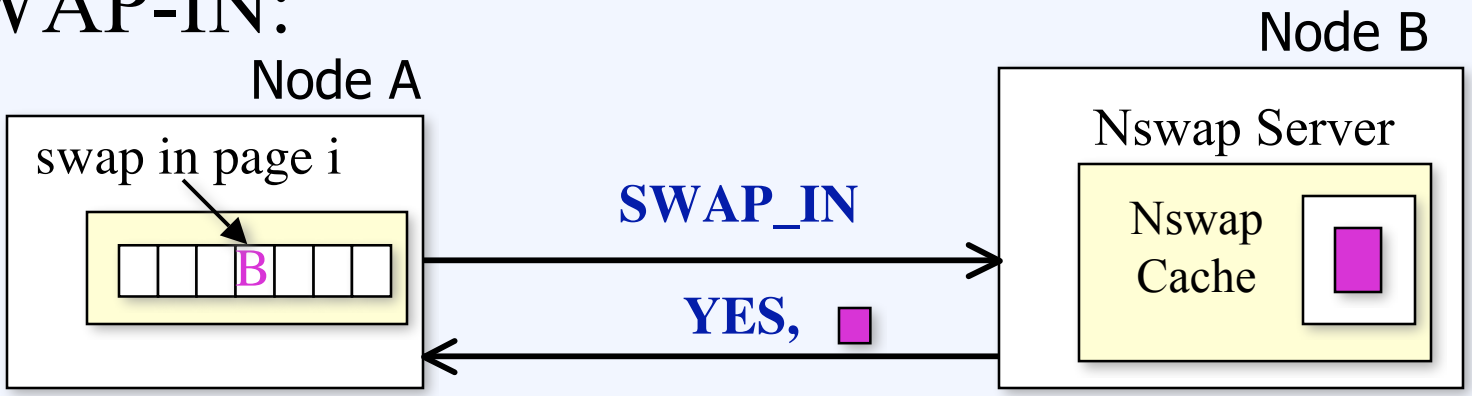
- Simultaneous Conflicting Operations
  - Asynchrony and threads allows for fast, multiple ops at once, but some overlapping ops can conflict ex. Migration and new swap-out for same page
- Garbage Pages in the System
  - When process terminates we need to remove its remotely swapped pages from servers
  - Swap interface doesn't contain call to device to free slots since this isn't a problem for disk swap
- Node failure
  - Can lose remotely swapped page data

How Pages Move Around the System

- SWAP-OUT:

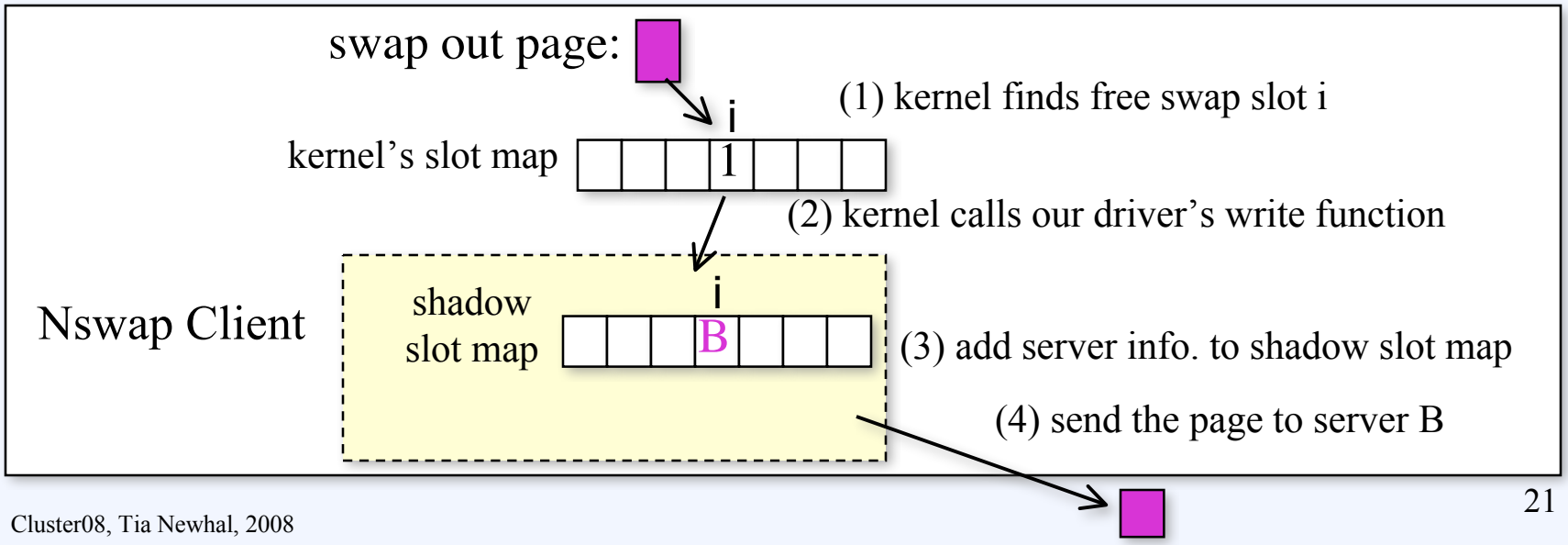


- SWAP-IN:

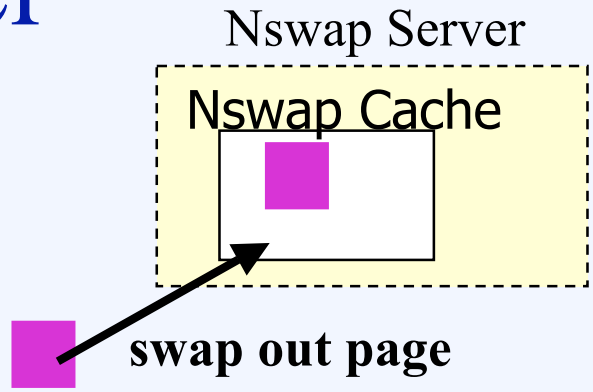


Nswap Client

- Implemented as device driver and added as a swap device on each node
  - Kernel swaps pages to it just like any other swap device
- Shadow slot map stores state about remote location of each swapped out page
  - Extra space overhead that must be minimized



Nswap Server

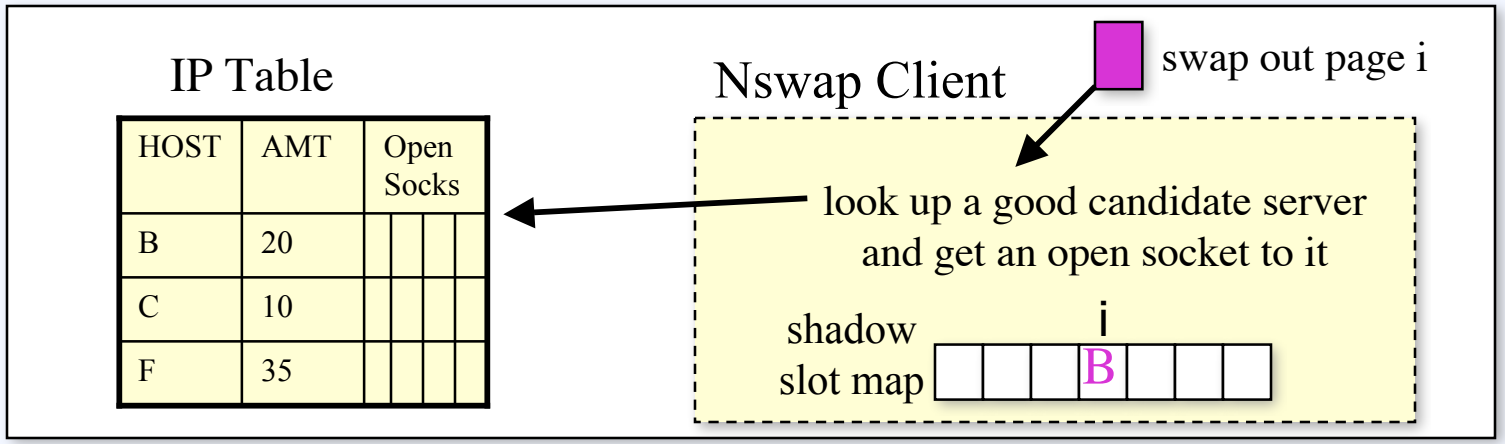


- Manages local idle RAM currently allocated for storing remote pages
- Handles swapping requests
  - Swap-out: allocate page of RAM to store remote page
  - Swap-in: fast lookup of page it stores
- Grows and Shrinks the amount of local RAM available based on the node's local memory usage
  - Acquire pages from paging system when there is idle RAM
  - Release pages to paging system when they are needed locally
  - Remotely swapped page data may be migrated to other servers

Finding a Server to take a Page

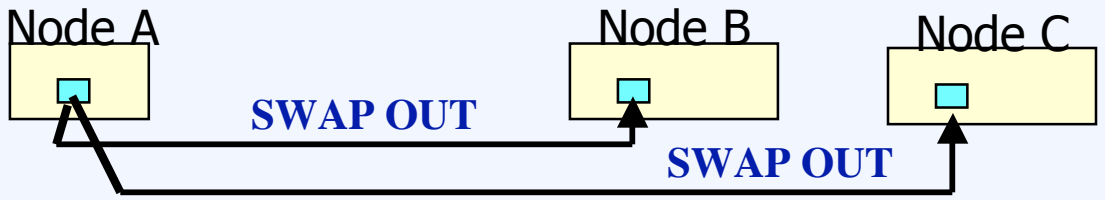
- Client uses local info. to pick "best" server
  - Local IP Table stores available RAM for each node
    - Servers periodically broadcast their size values
    - Clients update entries as they swap to servers
  - IP Table also caches open sockets to nodes

+ No centralized remote memory server



Soln 1: Mirroring

On Swap-outs: send page to primary & back-up servers



On Migrate: if new Server already has a copy of the page

it will not accept the MIGRATE request and old server picks another candidate

+ Easy to Implement
- 2 pages being sent on every swap-out
- Requires 2x as much RAM space for pages
- Increases the size of the shadow slot map