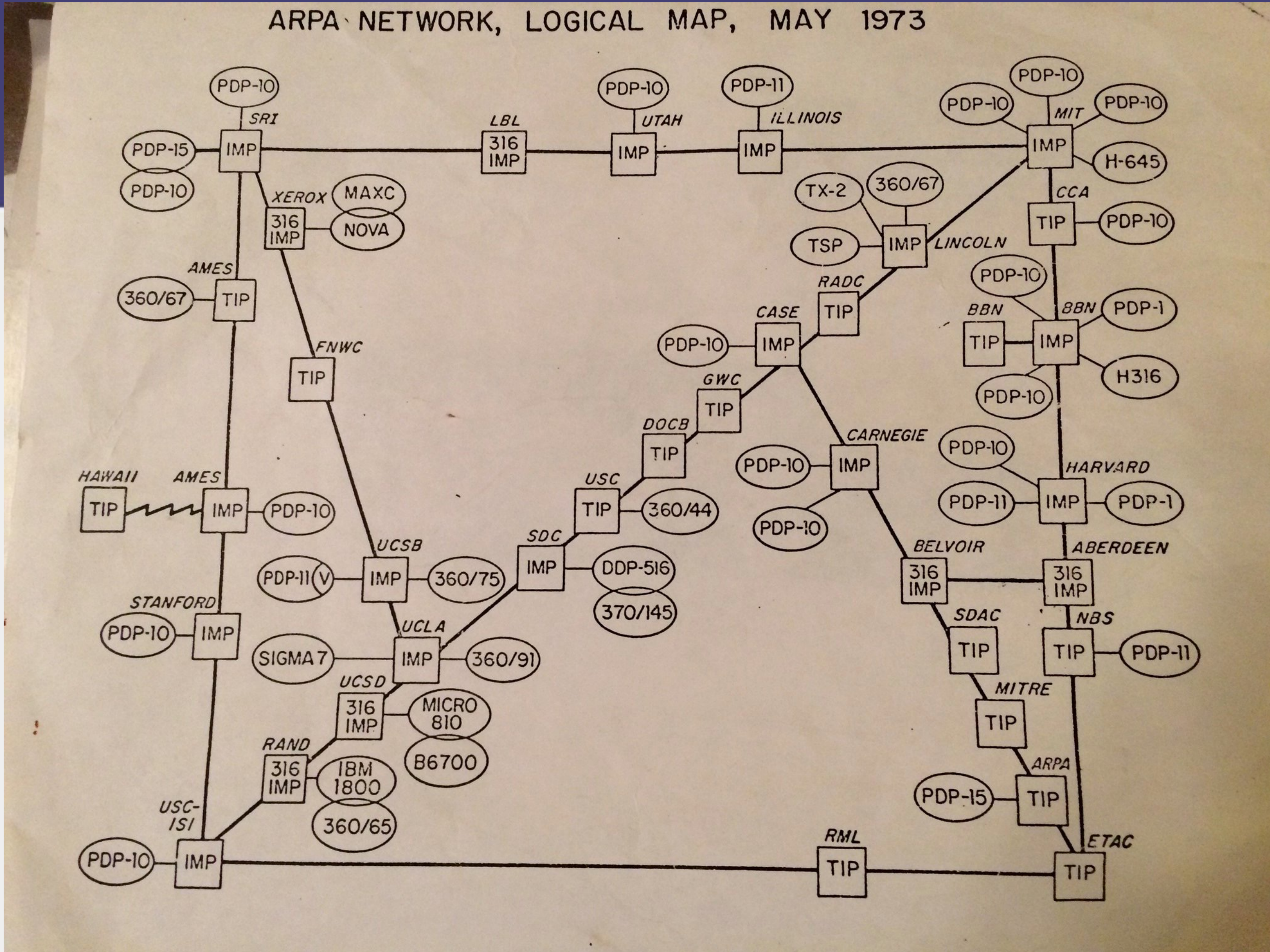
”The Internet” 1973



CS 425 / ECE 428
Distributed Systems
Fall 2022

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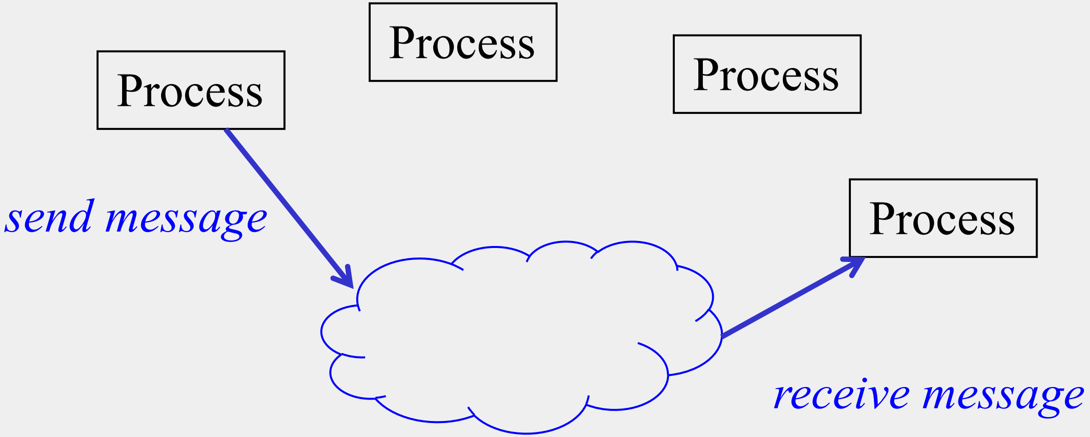
Lecture 24 A: Distributed Shared Memory

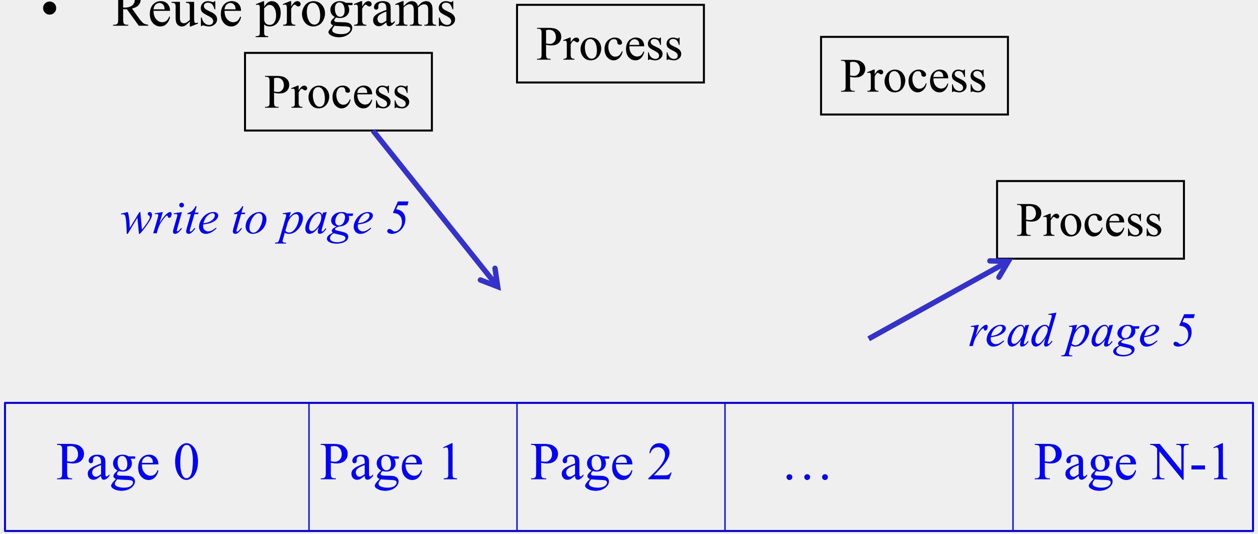
So Far …

- Message passing network



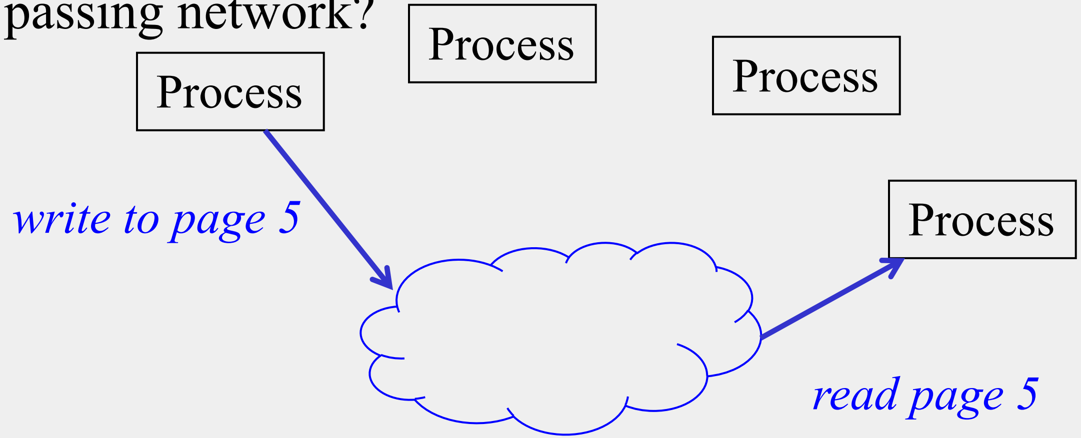
But what if …

- Processes could *share* memory pages instead?
- Makes it convenient to write programs
- Reuse programs



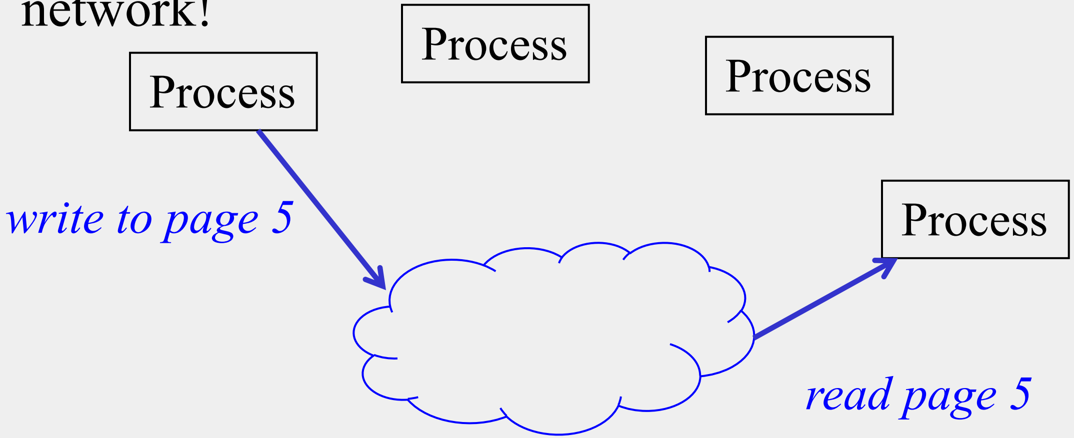
Distributed Shared Memory

- Distributed Shared Memory = processes virtually share pages
- How do you implement DSM over a message-passing network?



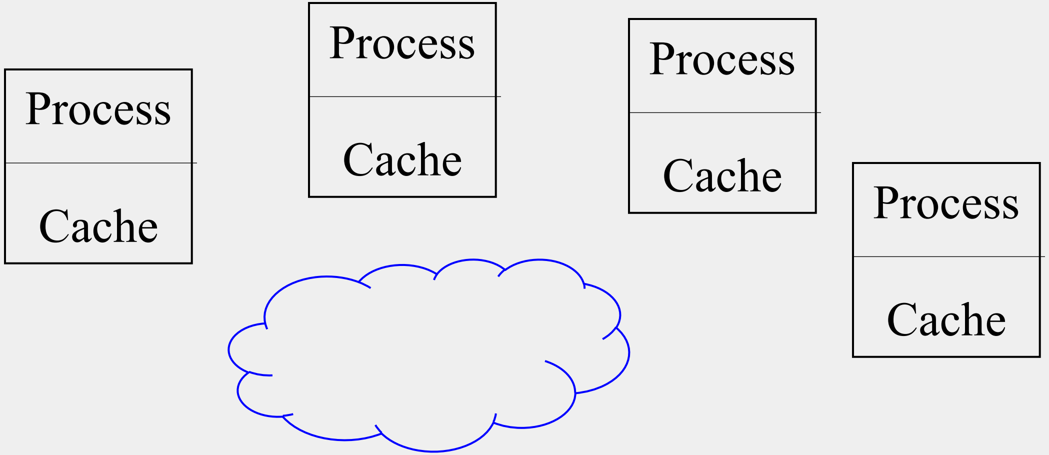
In fact …

1. Message-passing can be implemented over DSM!
   – Use a common page as buffer to read/write messages
2. DSM can be implemented over a message-passing network!



DSM over Message-Passing Network

- ***Cache*** maintained at each process
  - Cache stores pages accessed recently by that process
- Read/write first goes to cache



DSM over Message-Passing Network (2)

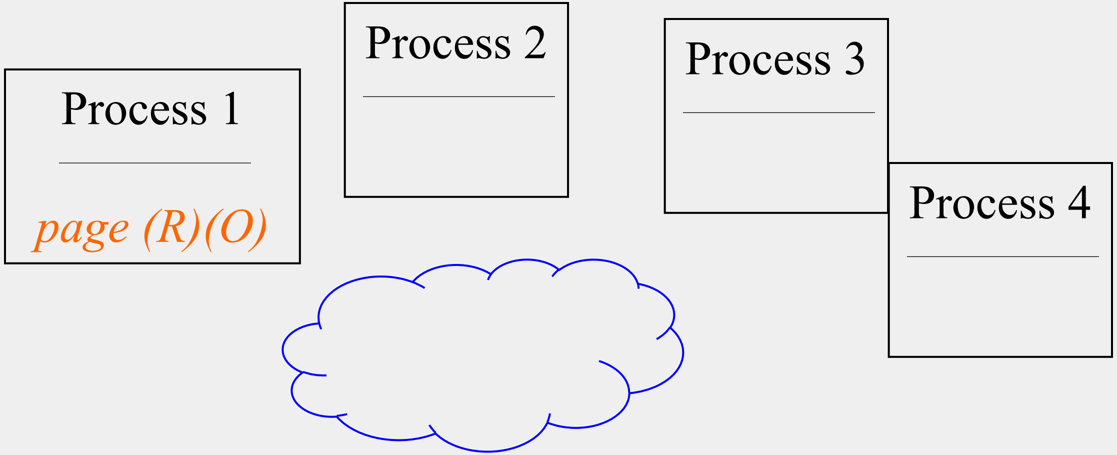
- Pages can be mapped in local memory
- When page is present in memory, page hit
- Otherwise, *page fault* (kernel trap) occurs
  - Kernel trap handler: invokes the DSM software
  - May contact other processes in DSM group, via multicast

DSM: Invalidate Protocol

- Owner = Process with latest version of page
- Each page is in either R or W state
- When page in R state, owner has an R copy, but other processes may also have R copies
  - but no W copies exist
- When page is in W state, only owner has a copy

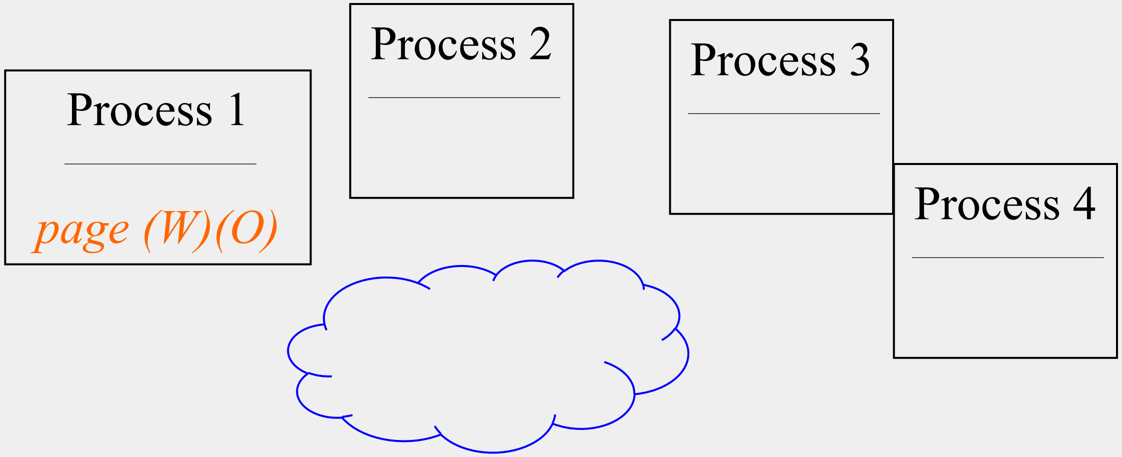
Process 1 Attempting a Read: Scenario 1

- Process 1 is owner *(O)* and has page in R state
- *Read from cache. No messages sent.*



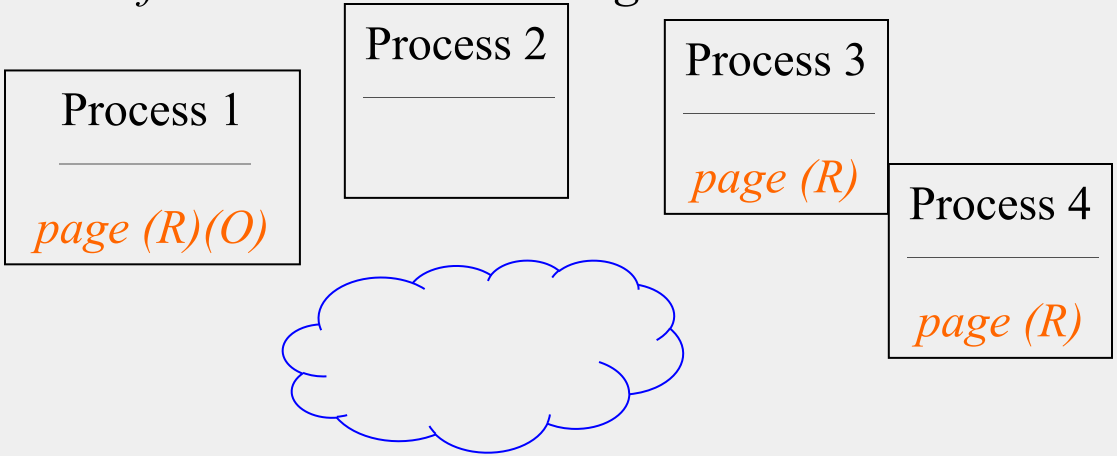
Process 1 Attempting a Read: Scenario 2

- Process 1 is owner *(O)* and has page in W state
- *Read from cache. No messages sent.*



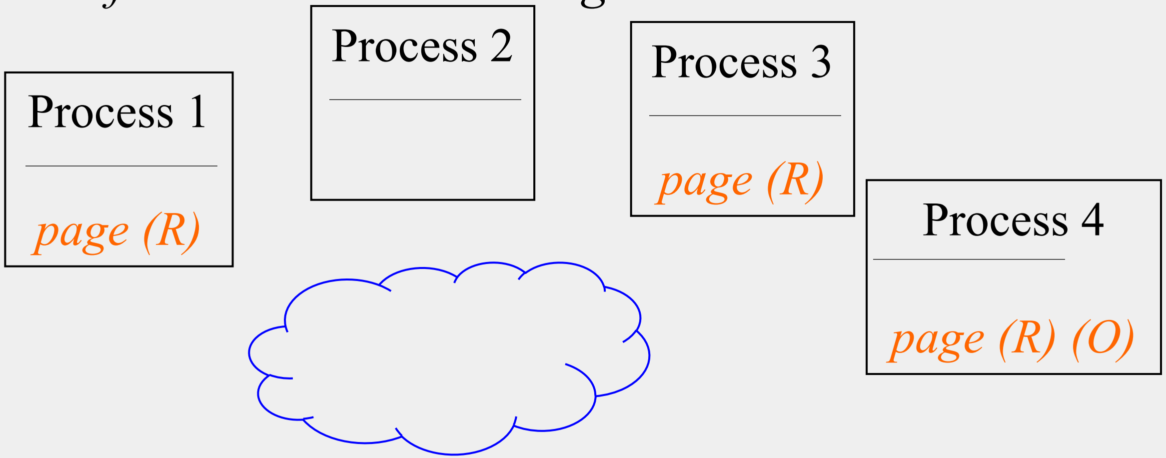
Process 1 Attempting a Read: Scenario 3

- Process 1 is owner *(O)* and has page in R state
- Other processes also have page in R state
- *Read from cache. No messages sent.*



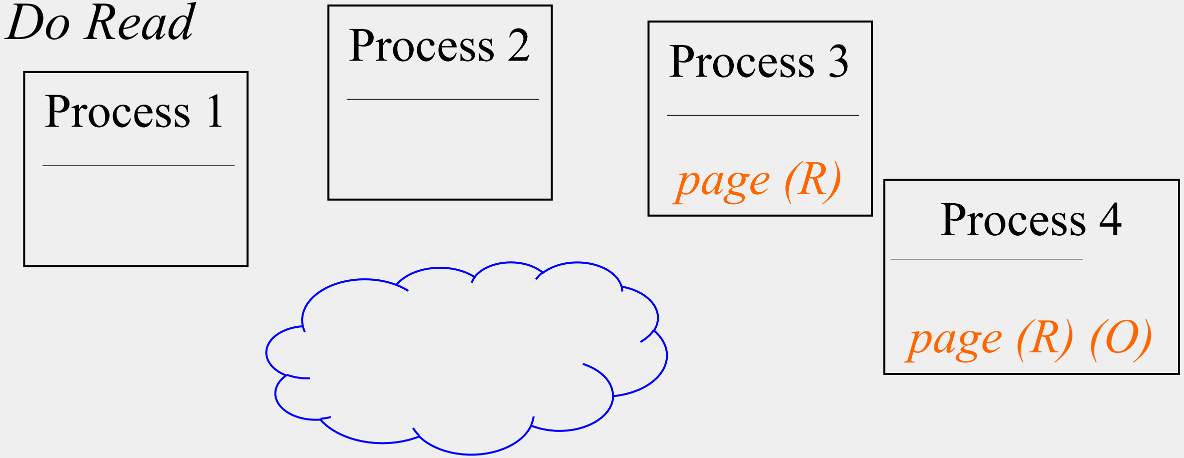
Process 1 Attempting a Read: Scenario 4

- Process 1 has page in R state
- Other processes also have page in R state, and someone else is owner
- *Read from cache. No messages sent.*



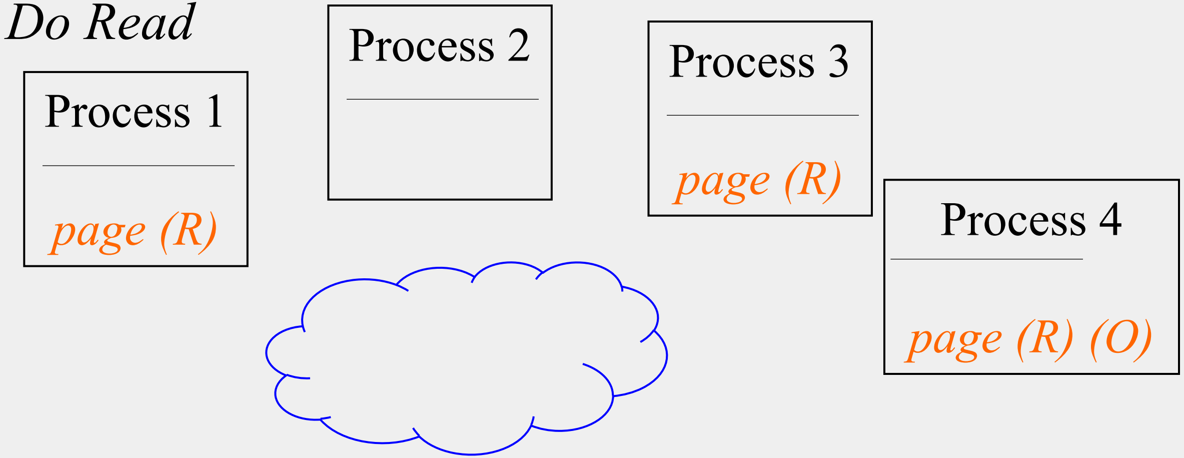
Process 1 Attempting a Read: Scenario 5

- Process 1 does not have page
- Other process(es) has/have page in (R) state
- *Ask for a copy of page. Use <u>multicast</u>.*
- *Mark it as R*
- *Do Read*



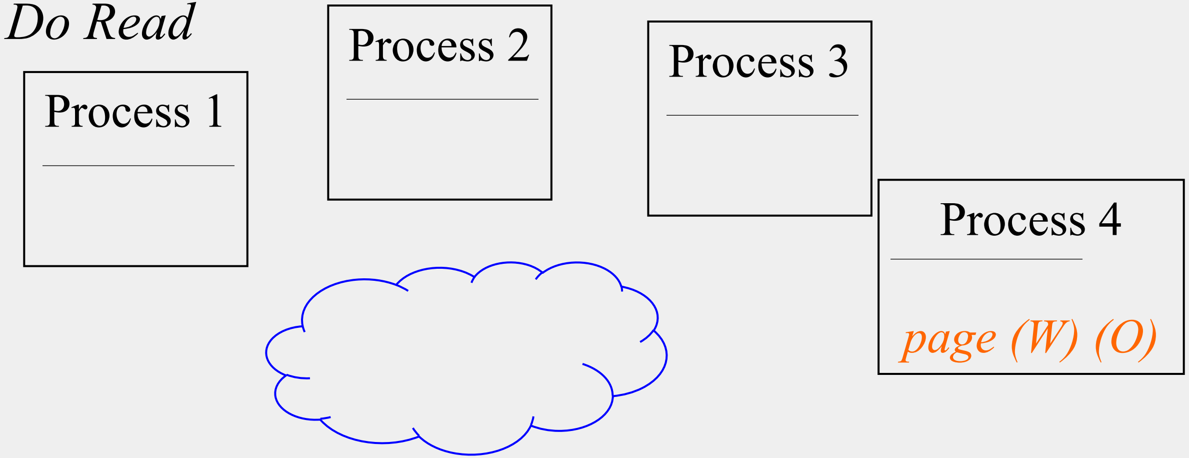
End State: Read Scenario 5

- Process 1 does not have page
- Other process(es) has/have page in (R) state
- *Ask for a copy of page. Use <u>multicast</u>.*
- *Mark it as R*
- *Do Read*



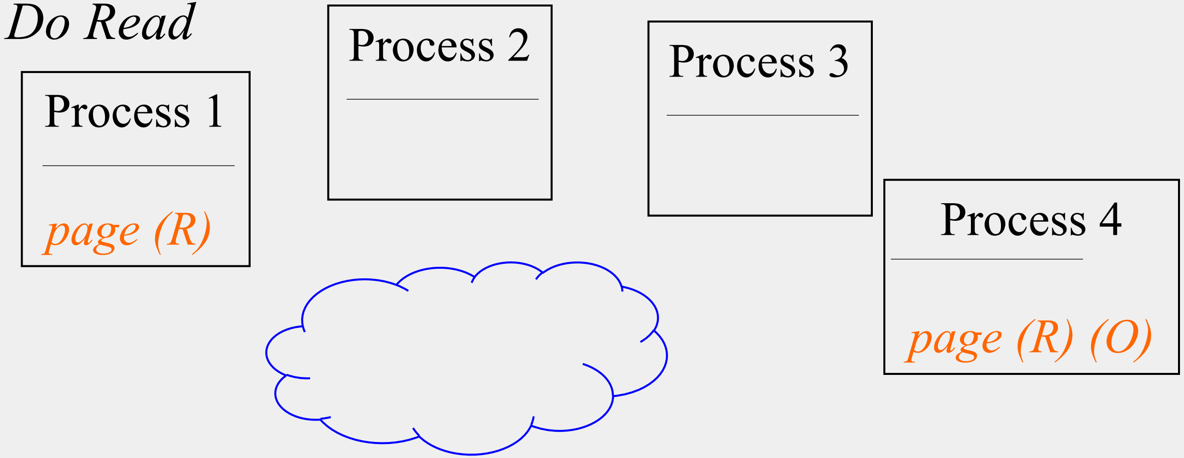
Process 1 Attempting a Read: Scenario 6

- Process 1 does not have page
- Another process has page in (W) state
- *Ask other process to degrade its copy to (R). Locate process via multicast*
- *Get page; mark it as R*
- *Do Read*



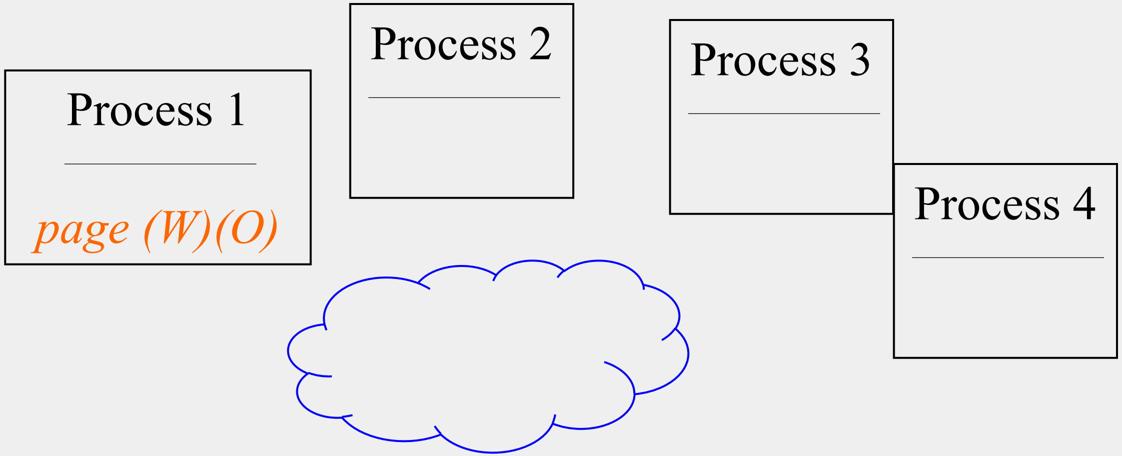
End State: Read Scenario 6

- Process 1 does not have page
- Another process has page in (W) state
- *Ask other process to degrade its copy to (R). Locate process via multicast*
- *Get page; mark it as R*
- *Do Read*



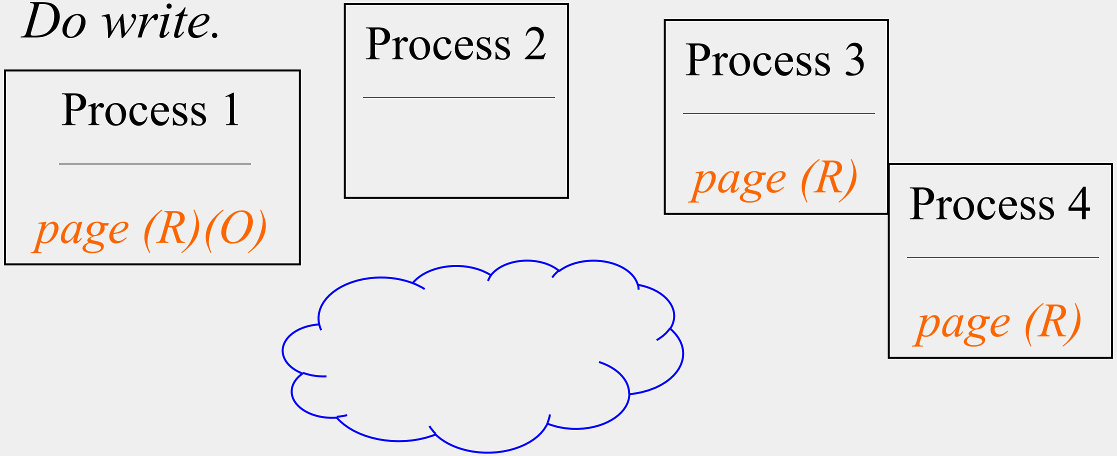
Process 1 Attempting a Write: Scenario 1

- Process 1 is owner *(O)* and has page in W state
- *Write to cache. No messages sent.*



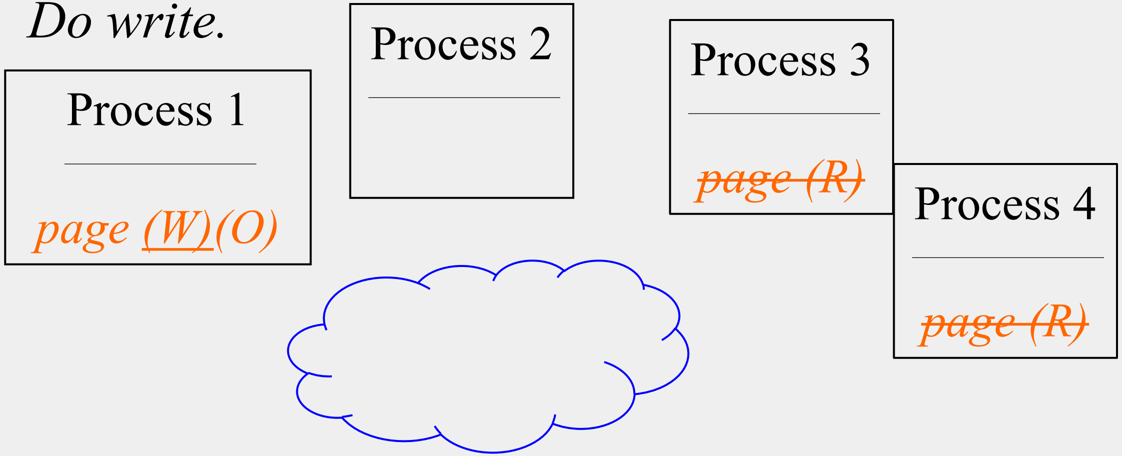
Process 1 Attempting a Write: Scenario 2

- Process 1 is owner *(O)* has page in R state
- Other processes may also have page in R state
- *Ask other processes to <u>invalidate</u> their copies of page. Use multicast.*
- *Mark page as (W).*
- *Do write.*



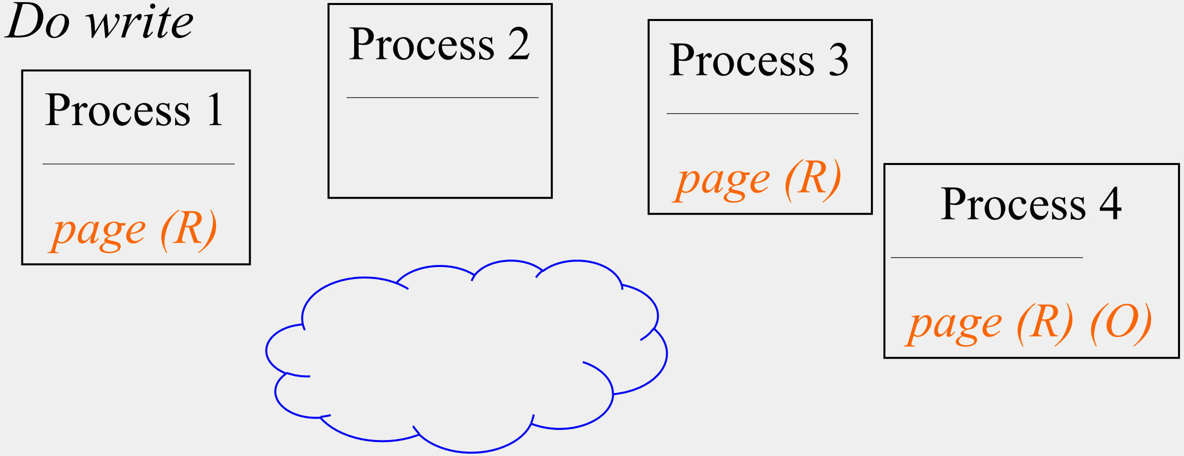
End State: Write Scenario 2

- Process 1 is owner *(O)* has page in R state
- Other processes may also have page in R state
- *Ask other processes to invalidate their copies of page. Use multicast.*
- *Mark page as (W).*
- *Do write.*



Process 1 Attempting a Write: Scenario 3

- Process 1 has page in R state
- Other processes may also have page in R state, and someone else is owner
- *Ask other processes to invalidate their copies of page. Use multicast.*
- *Mark page as (W), <u>become owner</u>*
- *Do write*



End State: Write Scenario 3

- Process 1 has page in R state
- Other processes may also have page in R state, and someone else is owner
- *Ask other processes to invalidate their copies of page. Use multicast.*
- *Mark page as (W), <u>become owner</u>*
- *Do write*

Process 1

page (W) (O)

Process 2

Process 3

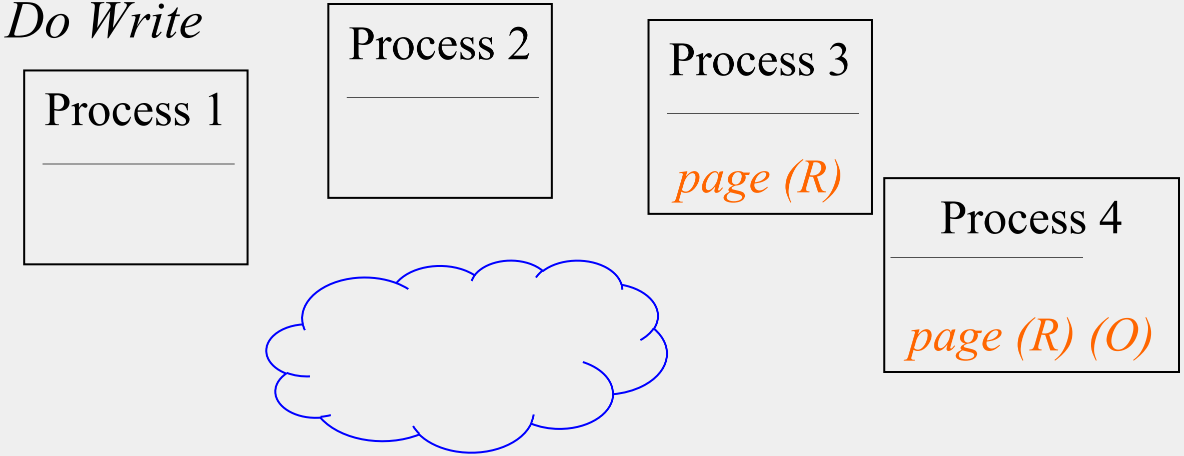
~~*page (R)*~~

Process 4

~~*page (R) (O)*~~

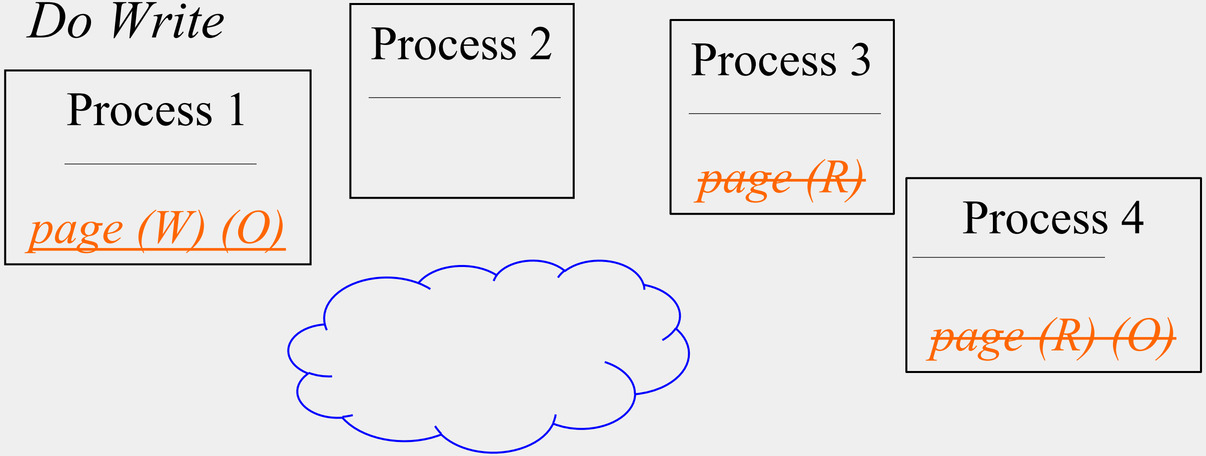
Process 1 Attempting a Write: Scenario 4

- Process 1 does not have page
- Other process(es) has/have page in (R) or (W) state
- *Ask other processes to invalidate their copies of the page. Use multicast.*
- *Fetch all copies; use the latest copy; mark it as (W); become owner*
- *Do Write*



End State: Write Scenario 4

- Process 1 does not have page
- Other process(es) has/have page in (R) or (W) state
- *Ask other processes to invalidate their copies of the page. Use multicast.*
- *Fetch all copies; use the latest copy; mark it as (W); become owner*
- *Do Write*



Invalidate Downsides

- That was the invalidate approach
- If two processes write same page concurrently
  - Flip-flopping behavior where one process invalidates the other
  - Lots of network transfer
  - Can happen when unrelated variables fall on same page
  - Called false sharing
- Need to set page size to capture a process' *locality of interest*
- If page size much larger, then have false sharing
- If page size much smaller, then too many page transfers => also inefficient

An Alternative Approach: Update

- Instead: could use Update approach
  - Multiple processes allowed to have page in W state
  - On a write to a page, multicast newly written value (or part of page) to all other holders of that page
  - Other processes can then continue reading and writing page
- Update preferable over Invalidate
  - When lots of sharing among processes
  - Writes are to small variables
  - Page sizes large
- Generally though, Invalidate better and preferred option

Consistency

- Whenever multiple processes share data, consistency comes into picture
- DSM systems can be implemented with:
  - Linearizability
  - Sequential Consistency
  - Causal Consistency
  - Pipelined RAM (FIFO) Consistency
  - Eventual Consistency
  - (Also other models like Release consistency)
  - These should be familiar to you from the course!
- As one goes down this order, speed increases while consistency gets weaker

Is it Alive?

- DSM was very popular over a decade ago
- But may be making a comeback now
  - Faster networks like Infiniband + SSDs => Remote Direct Memory Access (RDMA) becoming popular
  - Will this grow? Or stay the same as it is right now?
  - Time will tell!

Summary

- DSM = Distributed Shared Memory
  - Processes share pages, rather than sending/receiving messages
  - Useful abstraction: allows processes to use same code as if they were all running over the same OS (multiprocessor OS)
- DSM can be implemented over a message-passing interface
- Invalidate vs. Update protocols