Distributed Computer Simulations

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1. Introduction

Can MMORPG Scale?

- MMORPG needs scalability
- Using each user computer, parallel execution is possible
- 2 design questions upon parallel algorithm

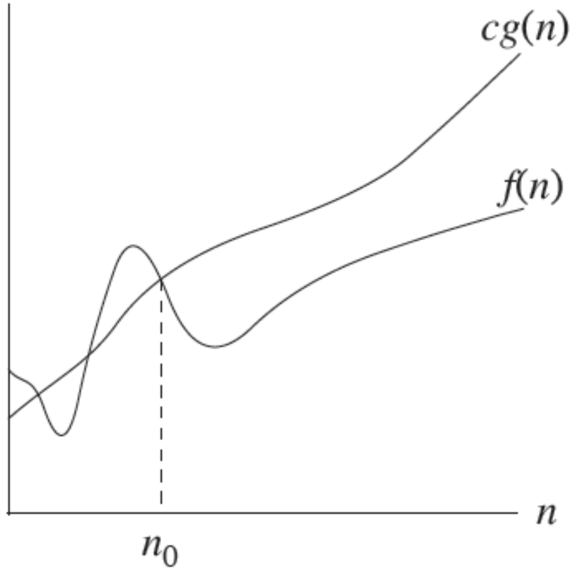
1. Problem has enough parallelism?
2. Data sharing fast enough?

Asymptotic Notation

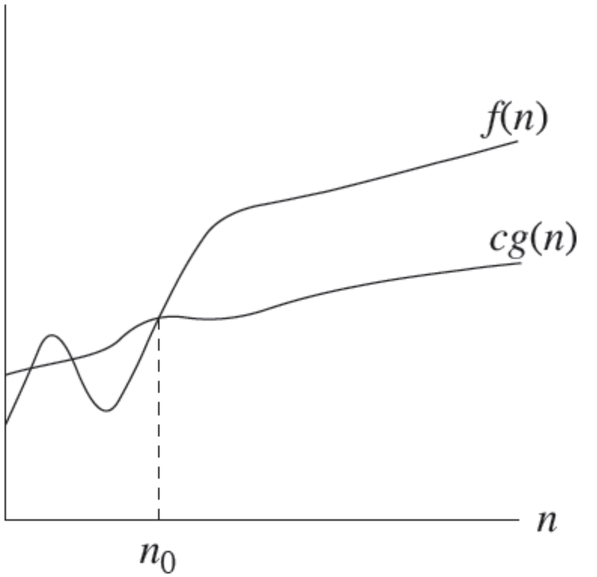
Big O notation: $f(x) = O\big(g(x)\big)$

Big Omega notation: $f(x) = \Omega(g(x))$

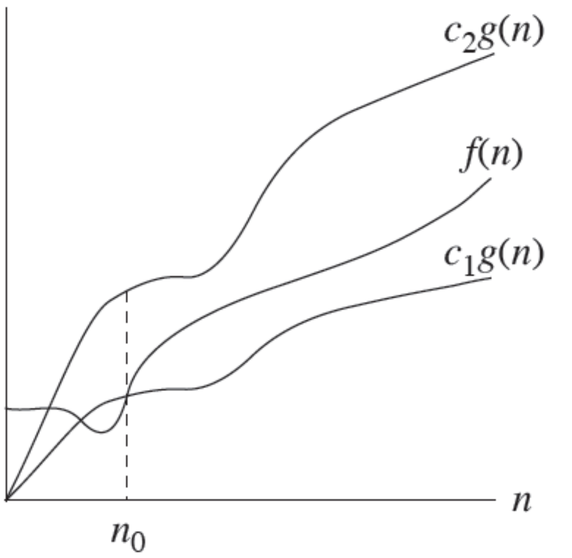
Big Theta notation: $f(x) = \Theta(g(x))$



Big O



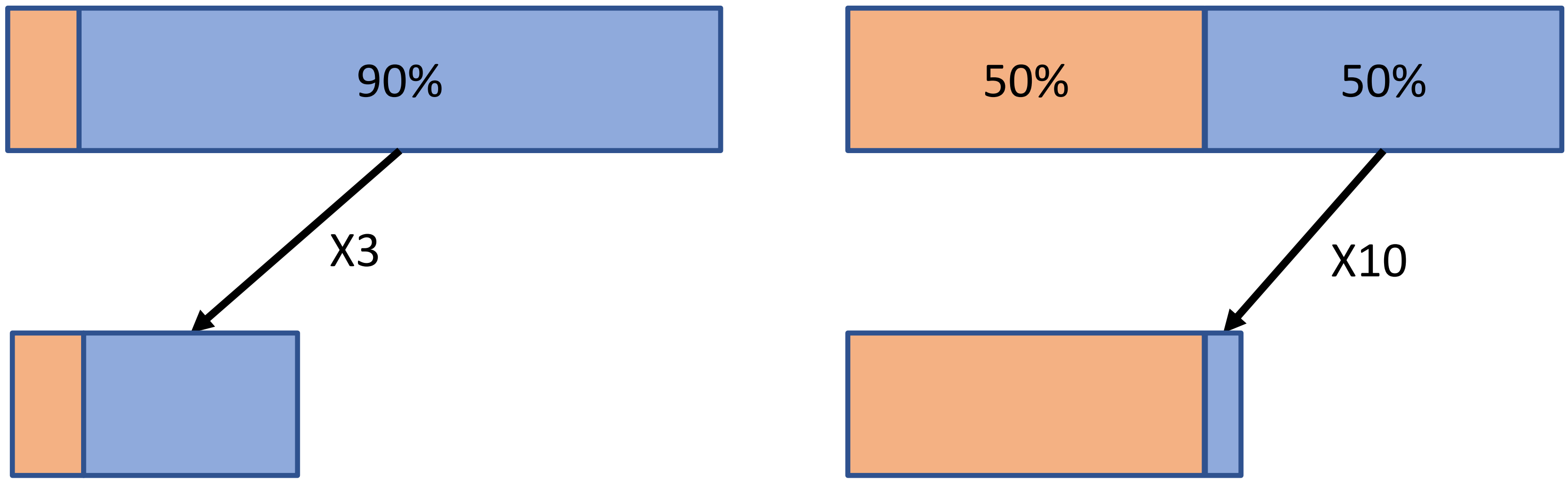
Big Omega



Big Theta

Amdahl's Law

- Speedup is mostly defined by how small is the portion of sequentially executed part



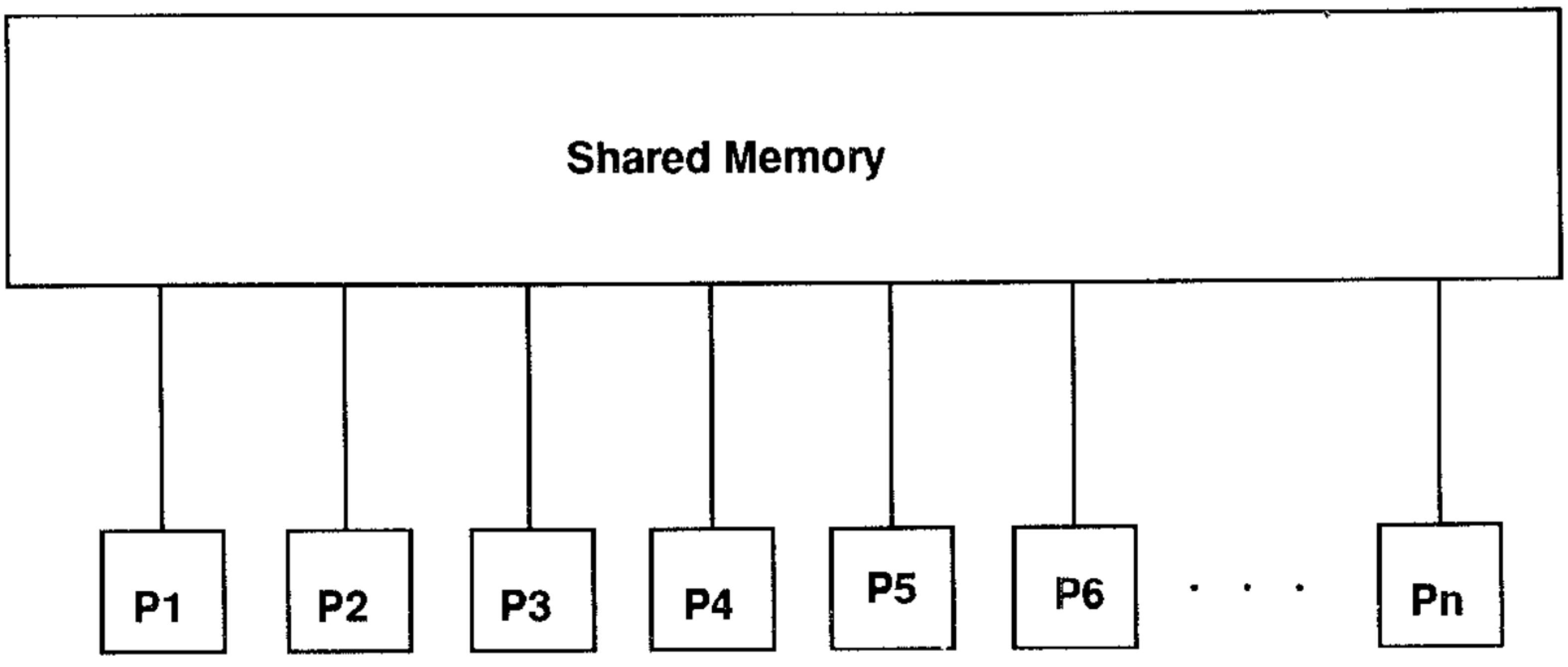
Overall speedup: 2.5

Overall speedup: 1.8

2. Parallel Random Access Machine

Parallel Random Access Machine

- Parallel computation model



(n, m)-PRAM

PRAM Memory – (1)

- Three kinds of PRAM depending on the memory access pattern

1. EREW (exclusive read, exclusive write)
   Only one processor could read or write
2. CREW (concurrent read, exclusive write)
   Only one processor could write, multiple could read
3. CRCW (concurrent read, concurrent write)
   Multiple processor could read or write

PRAM Memory – (2)

- 4 conflict resolution strategy for CRCW PRAM

1. Common CRCW PRAM

   All values should be identical

2. Arbitrary CRCW PRAM

   The value is chosen arbitrary

3. Priority CRCW PRAM

   The value is chosen with the highest priority

4. Combining CRCW PRAM

   Linear combination of all values are written

PRAM Algorithm – (1)

- Cole's parallel merge sort

1. EREW PRAM – $O(\log n)$
   $O(1)$ time on binary tree like approach
   $O(logn)$ time on the depth
2. CRCW PRAM – $O\left(\frac{\log n}{loglog\frac{2p}{n}}\right)$
   $(p: number\ of\ processor,\ 2n \leq p\ \leq n^2)$

PRAM Algorithm – (2)

- Maximum finding

- CRCW PRAM – $O(1)$
  n^2 processors compare every subset of 2 elements and write 1 on one with smaller value. → One with value 0 is maximum

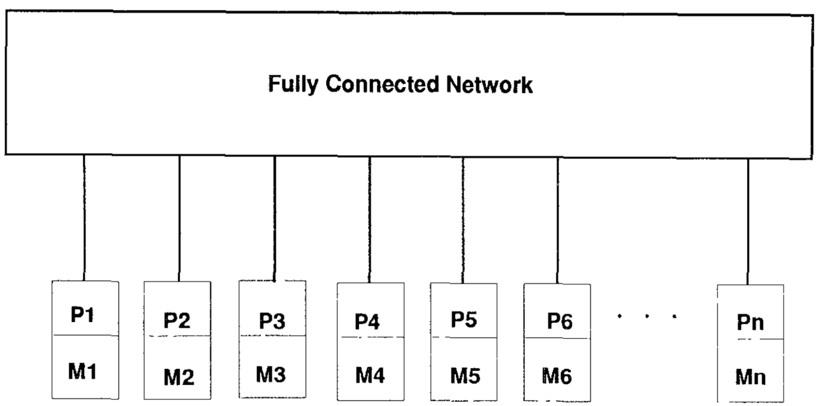
3. PRAM Problems

PRAM Simulation Problem

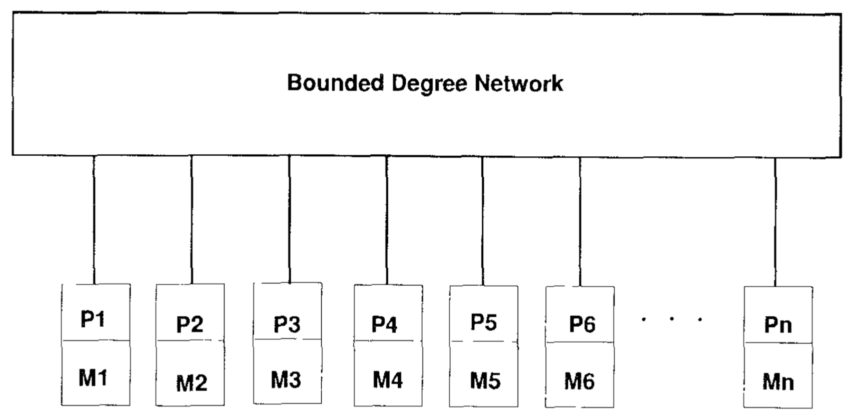
- Problem exist in order to apply PRAM to realistic machine
- No shared memory shared by numerous processor
  → realistic model used instead
- PRAM simulation problem: amount of slowdown on a simulation of a CRCW PRAM to realistic parallel machine

Subproblems of PRAM Simulation Problem - (1)

CRCW PRAM → EREW PRAM →
model parallel computer → bounded degree network



model parallel computer



bounded degree network

Subproblems of PRAM Simulation Problem - (2)

- Concurrent access problem
  – CRCW PRAM → EREW PRAM

- Memory management problem
  – EREW PRAM → MPC

- Routing/interconnection problem
  – MPC → BDN

Quality of PRAM

- Slowdown : number of additional steps by simulation
  → T step on CRCW, f(n)T step on realistic parallel machine → f(n) slowdown

- Efficiency: ratio of time according to the number of processors
  → Optimally efficient simulation: ratio is 1

Concurrent Access Problem – (1)

- CRCW PRAM → EREW PRAM
- Optimal slowdown algorithm → 3 step

1. Sort memory request by (requested memory address, requesting processor)
   $\Omega(\log n)$ on a EREW PRAM.

2. Handle concurrent access on same memory location
   Use binary tree approach
   $O(\log n)$ to check all concurrent access

Concurrent Access Problem – (2)

3. Multibroadcast for read
$O(\log n)$ on a parallel computer

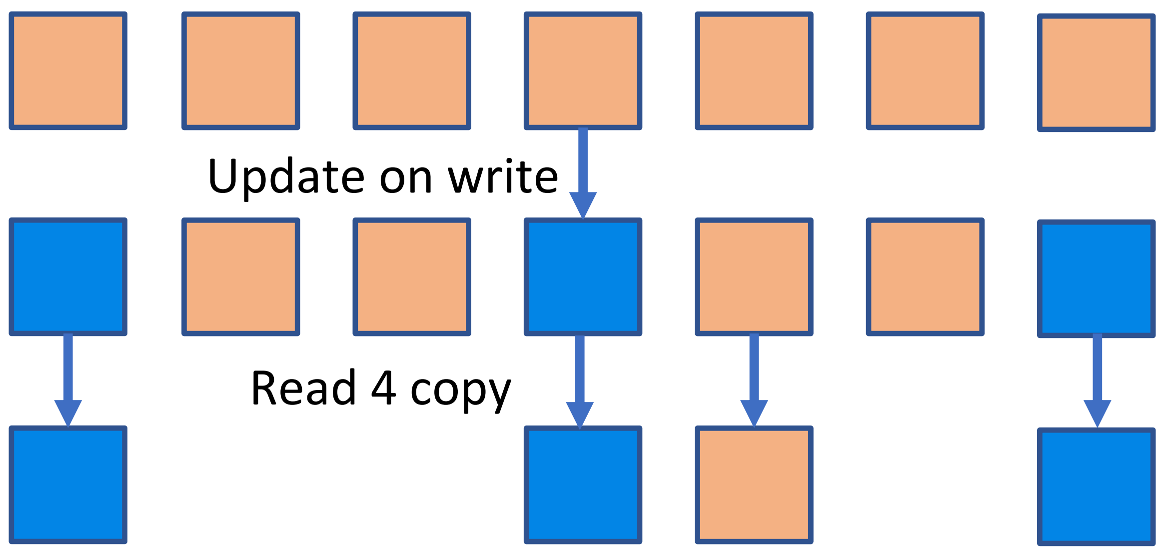
→ Simulating CRCW PRAM on EREW PRAM
includes $\Theta(\log n)$ slowdown

This is the end of part 1

4. Deterministic Simulations

Memory Management Problem – (1)

- Simplest solution: Copy every data
  Read – $O(1)$ Write – $O(n)$
- More efficient solution: Update only majority of the copied data w/ timestamp



Memory Management Problem – (2)

- Time complexity of updating majority of the copy
  $\Omega\left(\left(\frac{m}{n}\right)^{\frac{1}{2r}}\right) (r: number\ of\ copies)$
  $O(logn)$ w/ copy of $\Omega\left(\frac{\log\frac{m}{n}}{loglogn}\right)$

- Optimal slowdown of $O(\frac{\log n}{loglog\ n})$ w/ copy of $O(\frac{\log m}{loglog\ m})$

Routing/Interconnection Problem

- In reality, CPUs are much faster than network
- Bad worst case performance due to hotspot
- Sorting network – slowdown of $O(\log n)$

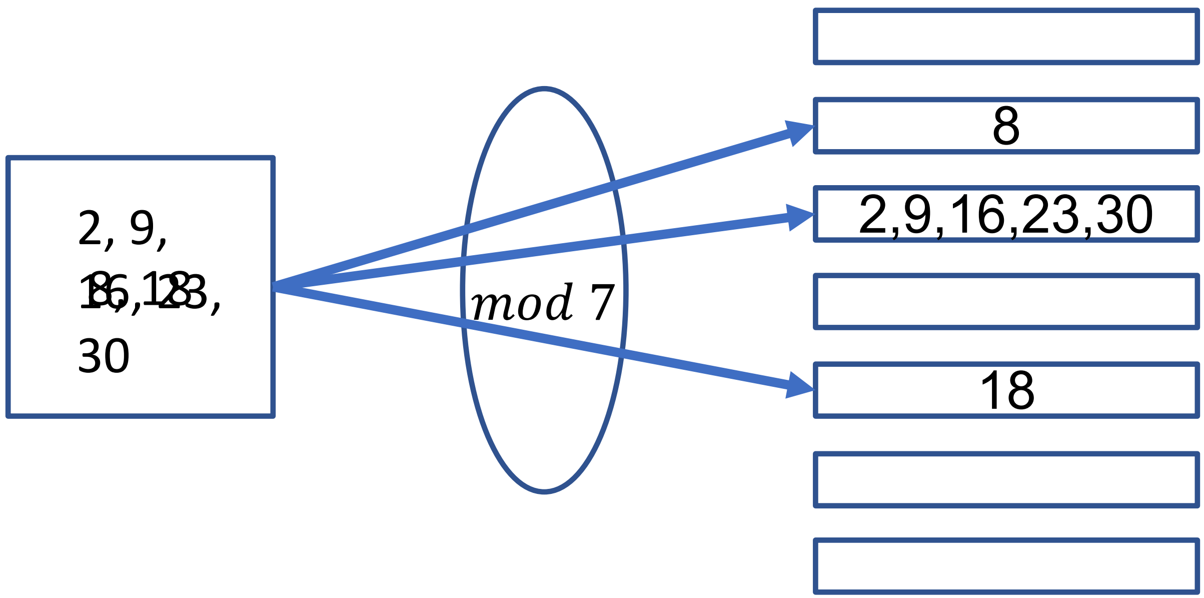
Overall Slowdown

- Concurrent access problem – $\Theta(\log n)$
- Memory management problem – $O\left(\frac{\log n}{\log \log n}\right)$
- Routing/interconnection problem – $O(\log n)$
- Memory management problem and routing/interconnection problem not independent
- Total slowdown – $O(\frac{log^2 n}{\log \log n})$

5. Random Simulations

Memory Management Problem

- Use hash function



- Optimal slowdown – $O(log \log n \, log^* n)$

Routing/Interconnection Problem

- Two-phase random routing – send packet to random stopover before original destination
- Slowdown – $\Omega(\log n)$ (optimal)

Overall Slowdown

- Concurrent access problem – $\Theta(\log n)$
- Memory management problem – $O(\log \log n \, log^{*} n)$
- Routing/interconnection problem – $\Theta(\log n)$
- Total slowdown – $\Theta(\log n)$

Conclusion

- PRAM model
- Types of PRAM
- PRAM simulation problem
- Subproblems of PRAM simulation problem
- Slowdown of $O(\frac{log^2 n}{\log\log n})$ using deterministic simulation, $\Theta(\log n)$ using random simulation

Q & A

Acknowledgment

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- PRAM maximum finding algorithm. https://homes.cs.washington.edu/~arvind/cs424/notes/l2-6.pdf