Server Implementations of HTTP/2 Priority

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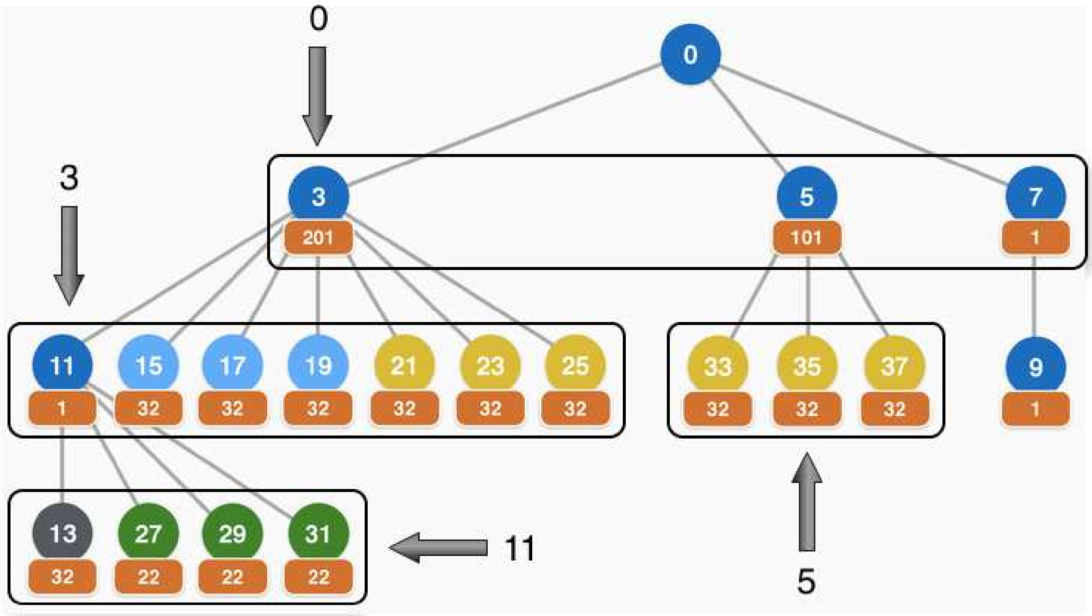
History

- h2o (in C)
  - Kazuho Oku
  - Array of Queue (external)
  - Enqueue O(1), dequeue O(1), delete O(1)
  - Deficit and delete information is managed outside
- nghttp2 (in C)
  - Tatsuhiro Tsujikawa
  - Binary Heap (external)
  - Enqueue O(log N), dequeue O(log N), delete O(log N)
  - Deficit and delete information is managed outside
- Warp (in Haskell)
  - Kazu Yamamoto
  - Random Skew Heap
  - Enqueue O(log N), dequeue O(log N), delete O(N log N)
  - No deficit and delete information

  - Now using PSQ (Priority Search Queue)
  - Enqueue O(log N), dequeue O(log N), delete O(log N)

Today’s topic

- Flat priority queue only
- Nested priority queue can be build over flat ones

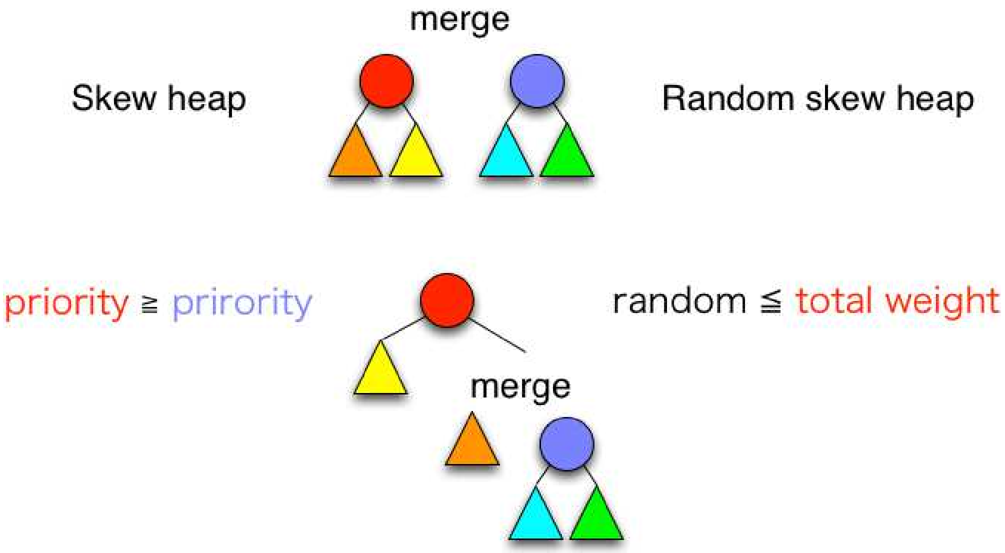


Background

- Using weight as priority of max heap
  - it’s not fair
- Example
  - A for weight 10
  - B for weight 5
  - C for weight 1
- Result sequence
  - A(10), A(9), A(8), A(7), A(6), A(5), B(5), A(4), B(4), ...

Random Skew Heap

- Selecting a frame based on a random value
  - 1 - 10 for A
  - 11 - 15 for B
  - 16 for C
- To implement O(log N) operations, skew heap is used



Random Skew Heap

- Pros
  - No additional information
- Cons
  - It is hard for me to proof fairness
  - It is difficult to write test cases
  - Pseudo random generators are slow for this purpose
  - delete is O(N log N)

Weighted Fair Queueing

- Inverted weight with min heap
  - New: deficit = min_deficit_in_heap + constant / weight
  - Exist: deficit = last_deficit + constant / weight
- Deficit examples (constant is 65536)
  - A for weight 10, deficit = 6553
  - B for weight   5, deficit = 13107
  - C for weight   1, deficit = 65536
- Result sequence
  - A (6553)
  - A (13106)
  - B (13107)
  - A (19659)
  - A (26212)
  - B (26214)
  - ...

Weighted Fair Queueing

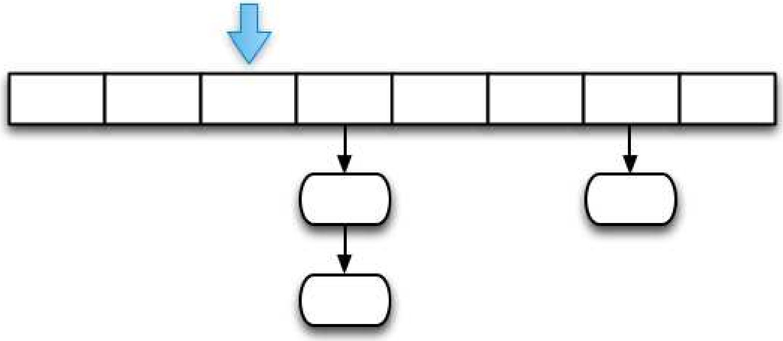
- Pros
  - Fairness is proved already though I don’t understand
  - It’s easy to write test cases
  - All operations could be O(log N)
- Cons
  - Need to memorize deficit for each entry
  - Deficit could be overflowed (but it is unlikely)

Min Heap

- Binary heap
  - Many people knows
  - Perfect balance in arrays
  - O(log N) for enqueue, dequeue and delete
  - The array must be glow if the concurrency is increased
- Okasaki heap
  - Immutable data
  - O(log N) for enqueue and dequeue
  - O(N) for delete
- Priority search queue
  - Immutable data
  - Blend of search tree and heap
  - O(log N) for enqueue, dequeue and delete

Array of Queue

- Emulating heap with an array of queues
  - Behavior is a little bit different
- Deficit and offset
  - Exist: deficit = (last_deficit + constant / weight) % constant2
  - Exist: offset = (last_deficit + constant / weight) / constant2
- An element is queued according to its offset
  - "Find first bit set" in O(1) can be used to find a non empty queue



Array of Queue

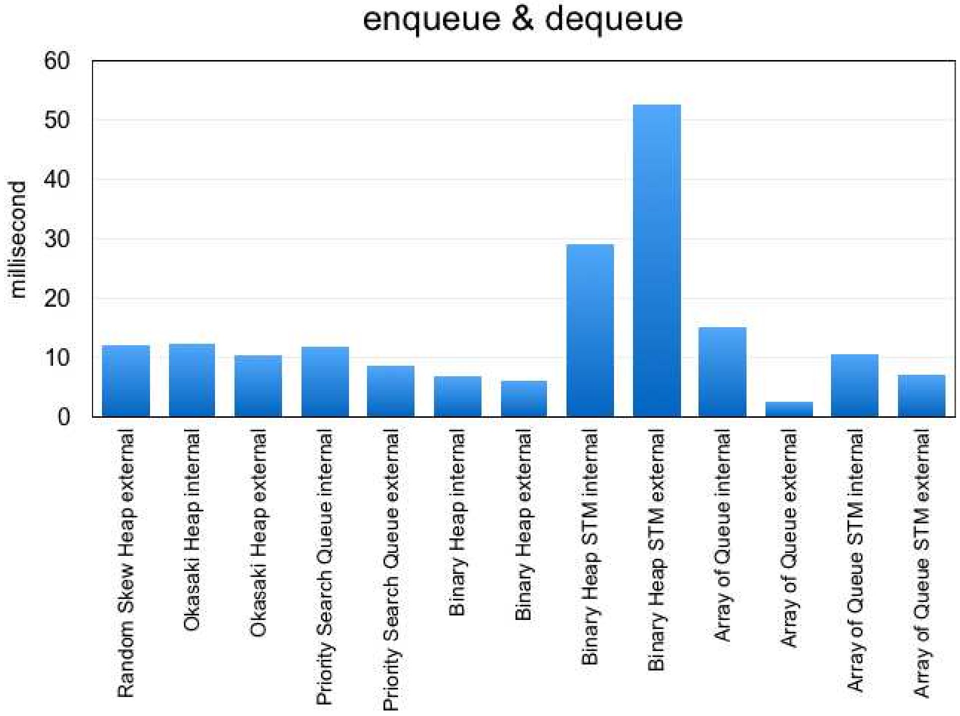
- Pros
  - It’s easy to write test cases
  - All operations could be O(1)
  - Deficit is not overflowed
- Cons
  - Implementation is a little bit complicated

Comparison

- 13 implementations
  - Random Skew Heap <- old Warp
  - Okasaki Heap (internal)
  - Okasaki Heap (external)
  - Priority Search Queue (internal) <- new Warp
  - Priority Search Queue (external)
  - Binary Heap (internal)
  - Binary Heap (external) <- nghttp2
  - Binary Heap STM(Software Transactional Memory) (internal)
  - Binary Heap STM (external)
  - Array of Queue (internal)
  - Array of Queue (external) <- h2o
  - Array of Queue STM (internal)
  - Array of Queue STM (external)
- Information managed internally or externally
  - Deficit
  - Deletion hints
- "internal" means abstract data type

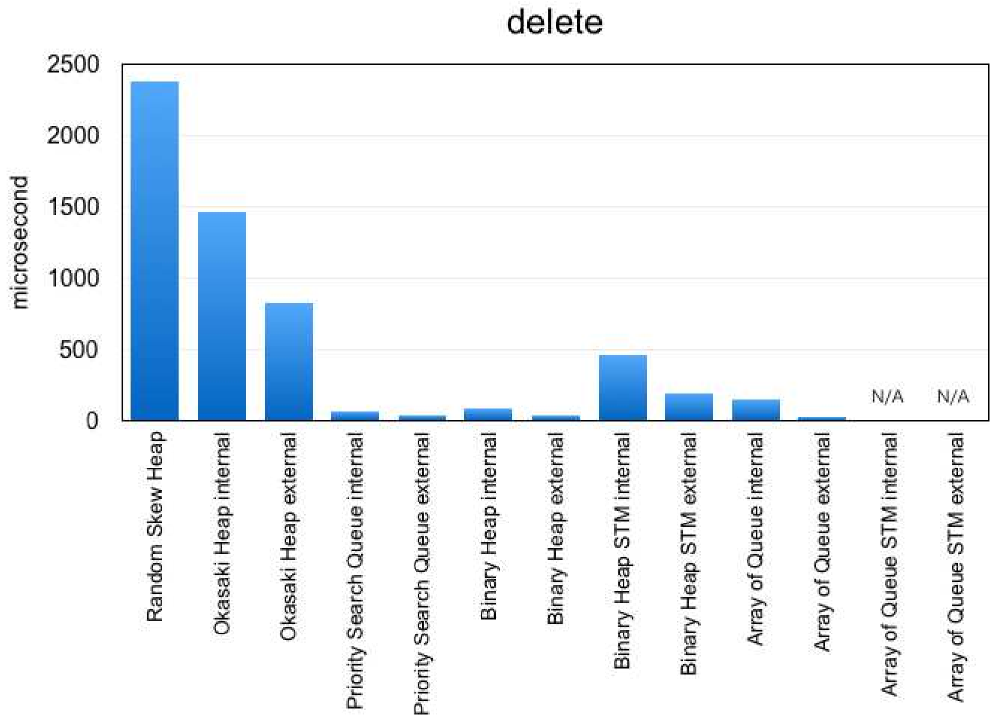
Benchmark on enqueue & dequeue

- Repeating 10000 enqueue & dequeue with 100 streams



Benchmark of delete

- Deleting 100 streams



Conclusion

- Binary Heap would be the first choice for most programming language
    - nghttp2
- Array of Queue would be the next choice if you are not satisfied with the performance
    - h2o
- Priority Search Queue is recommended for highly concurrent programming language
    - Warp