

Slot-queue - An optimized wait-free distributed MPSC

1. Motivation

A good example of a wait-free MPSC has been presented in [1]. In this paper, the authors propose a novel tree-structure and a min-timestamp scheme that allow both enqueue and dequeue to be wait-free and always complete in $\Theta(\log n)$ where n is the number of enqueueers.

We have tried to port this algorithm to distributed context using MPI. The most problematic issue was that the original algorithm uses load-link/store-conditional (LL/SC). To adapt to MPI, we have to propose some modification to the original algorithm to make it use only compare-and-swap (CAS). Even though the resulting algorithm pretty much preserve the original algorithm's characteristic, that is wait-freedom and time complexity of $\Theta(\log n)$, we have to be aware that this is $\Theta(\log n)$ remote operations, which is very expensive. We have estimated that for an enqueue or a dequeue operation in our initial LTQueue version, there are about $2 * \log n$ to $10 * \log n$ remote operations, depending on data placements and the current state of the LTQueue.

Therefore, to be more suitable for distributed context, we propose a new algorithm that's inspired by LTQueue, in which both enqueue and dequeue only perform a constant number of remote operations, at the cost of dequeue having to perform $\Theta(n)$ local operations, where n is the number of enqueueers. Because remote operations are much more expensive, this might be a worthy tradeoff.

2. Structure

Each enqueue will have a local SPSC as in LTQueue [1] that supports dequeue, enqueue and readFront. There's a global queue whose entries store the minimum timestamp of the corresponding enqueueer's local SPSC.



Figure 1: Basic structure of slot queue

3. Pseudocode

3.1. SPSC

The SPSC of [1] is kept in tact, except that we change it into a circular buffer implementation.

Types

```
data_t = The type of data stored
spsc_t = The type of the local SPSC

record
    First: int
    Last: int
    Capacity: int
    Data: an array of data_t of capacity
    Capacity
end
```

Shared variables

```
First: index of the first undequeued entry
Last: index of the first unenqueued entry
```

Initialization

```
First = Last = 0
Set Capacity and allocate array.
```

The procedures are given as follows.

Procedure 1: `spsc_enqueue(v: data_t)` **returns** `bool`

```

1 if (Last + 1 == First)
2   | return false
3 Data[Last] = v
4 Last = (Last + 1) % Capacity
5 return true

```

Procedure 2: `spsc_dequeue()` **returns** `data_t`

```

6 if (First == Last) return  $\perp$ 
7 res = Data[First]
8 First = (First + 1) % Capacity
9 return res

```

Procedure 3: `spsc_readFront` **returns** `data_t`

```

10 if (First == Last)
11   | return  $\perp$ 
12 return Data[First]

```

3.2. Slot-queue

The slot-queue types and structures are given as follows:

Types

data_t = The type of data stored
 timestamp_t = `uint64_t`
 spsc_t = The type of the local SPSC

Shared variables

slots: An array of `timestamp_t` with the number of entries equal the number of enqueueers
 spscs: An array of `spsc_t` with the number of entries equal the number of enqueueers
 counter: `uint64_t`

Initialization

| Initialize all local SPSCs.

| Initialize slots entries to MAX.

The enqueue operations are given as follows:

Procedure 4: `enqueue(rank: int, v: data_t)` **returns** `bool`

```

1 timestamp = FFA(counter)
2 value = (v, timestamp)
3 res = spsc_enqueue(spsc_s[rank], value)
4 if (!res) return false
5 if (!refreshEnqueue(rank, timestamp))
6   | refreshEnqueue(rank, timestamp)
7 return res

```

Procedure 5: `refreshEnqueue(rank: int, ts: timestamp_t)` **returns** `bool`

```

8 old-timestamp = slots[rank]
9 front = spsc_readFront(spsc_s[rank])
10 new-timestamp = front ==  $\perp$  ? MAX : front.timestamp
11 if (new-timestamp != ts)
12   | return true
13 return CAS(&slots[rank], old-timestamp, new-timestamp)

```

The dequeue operations are given as follows:

Procedure 6: `dequeue()` **returns** `data_t`

```

14 rank = readMinimumRank()
15 if (rank == DUMMY || slots[rank] == MAX)
16   | return  $\perp$ 
17 res = spsc_dequeue(spsc_s[rank])
18 if (res ==  $\perp$ ) return  $\perp$ 
19 if (!refreshDequeue(rank))
20   | refreshDequeue(rank)
21 return res

```

Procedure 7: readMinimumRank() returns int

```

22 rank = length(slots)
23 min-timestamp = MAX
24 for index in 0..length(slots)
25   timestamp = slots[index]
26   if (min-timestamp < timestamp)
27     rank = index
28     min-timestamp = timestamp
29 old-rank = rank
30 for index in 0..old-rank
31   timestamp = slots[index]
32   if (min-timestamp < timestamp)
33     rank = index
34     min-timestamp = timestamp
35 return rank == length(slots) ? DUMMY :
    rank

```

Procedure 8: refreshDequeue(rank: int) returns bool

```

36 old-timestamp = slots[rank]
37 front = spsc_readFront(spsc[rank])
38 new-timestamp = front ==  $\perp$  ? MAX :
    front.timestamp
39 if (front !=  $\perp$ )
40   slots[rank] = new-timestamp
41 return true
42 return CAS(&slots[rank], old-timestamp,
    new-timestamp)

```

4. ABA problem

Noticeably, we use no scheme to avoid ABA problem in Slot-queue. In actuality, ABA problem cannot happen in our algorithm, except in the extreme case that the 64-bit global counter overflows, which is unlikely.

5. Linearizability

6. Wait-freedom

7. Memory-safety

References

- [1] P. Jayanti and S. Petrovic, “Logarithmic-time single deleter, multiple inserter wait-free queues and stacks,” 2005, *Springer-Verlag*. doi: 10.1007/11590156_33.