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 enqueuers.

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 (and in reality, there are about $5 * \log n$ remote operations), which is very expensive.

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 enqueuers. 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 enqueuer's local SPSC.

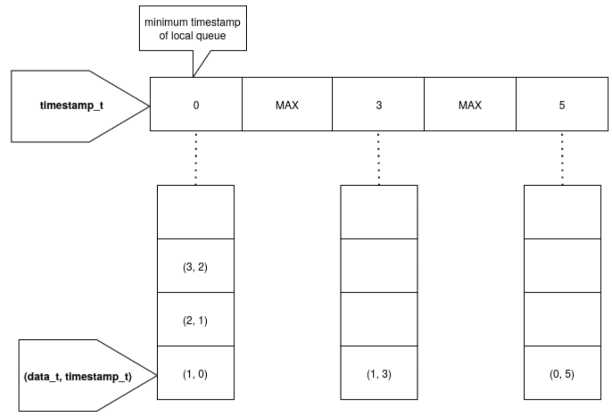

Figure 1: Basic structure of slot queue

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`

```
if (Last + 1 == First)
    return false
Data[Last] = v
Last = (Last + 1) % Capacity
return true
```

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

```
if (First == Last) return ⊥
res = Data[First]
First = (First + 1) % Capacity
return res
```

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

```
if (First == Last)
    return ⊥
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 enqueuers
`spscs`: An array of `spsc_t` with the number of entries equal the number of enqueuers
`counter`: `uint64_t`

Initialization

Init all local SPSCs.
Init `slots` entries to `MAX`.

The enqueue operations are given as follows:

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

```
timestamp = FFA(counter)
value = (v, timestamp)
res = spsc_enqueue(spscs[rank], value)
if (res && spsc_readFront(spscs[rank]) == value)
    propagateEnqueue(rank, timestamp)
return res
```

Procedure 5: `propagateEnqueue(rank: int, ts: timestamp_t)`

```
slots[rank] = ts
```

The dequeue operations are given as follows:

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

```
rank = readMinimumRank()
if (rank == DUMMY || slots[rank] == MAX)
    return ⊥
res = spsc_dequeue(spscs[rank])
if res == ⊥ return ⊥
propagateDequeue(rank)
return res
```

Procedure 7: `readMinimumRank()` **returns** `int`

```
rank = length(slots)
min-timestamp = MAX
for index in 0..length(slots)
  timestamp = slots[index]
  if min-timestamp < timestamp
    rank = index
    min-timestamp = timestamp
old-rank = rank
for index in 0..old-rank
  timestamp = slots[index]
  if min-timestamp < timestamp
    rank = index
    min-timestamp = timestamp
return rank == length(slots) ? DUMMY : rank
```

Procedure 8: `propagateDequeue(rank: int)`

```
old-timestamp = slots[rank]
front = spsc_readFront(spscs[rank])
new-timestamp = front == ⊥ ? MAX : front.timestamp
if (front != ⊥)
  slots[rank] = new-timestamp
  return
CAS(&slots[rank], old-timestamp, new-timestamp)
```

4. Linearizability

5. Wait-freedom

6. 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.