Distributed System Project Report

Suzuki-Kasami Mutual Exclusion Implementation

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Project Goal

- Implement Suzuki-Kasami's token-based mutual exclusion protocol for Distributed Systems using MPI4PY.
- Record and display the status of different nodes on CLI (user has the option to print the (LN or RN) array and queue state values when he queries it).

Algorithm and Data Structure

Suzuki–Kasami algorithm is a token-based algorithm for achieving mutual exclusion in distributed systems. In token-based algorithms, A site is allowed to enter its critical section if it possesses a unique token. If a process wants to enter its critical section and it does not have the token, it broadcasts a request message to all other processes in the system. The process that has the token, if it is not currently in a critical section, will then send the token to the requesting process. In token-based algorithms, the sequence number is used. Each request for a critical section contains a sequence number. This sequence number is used to distinguish between old and current requests.

The data structure used is:

- **An array of integers RN[1…N]**: A site Si keeps RNi[1…N], where RNi[j] is the largest sequence number received so far through the REQUEST message from site Si.
- **An array of integer LN[1…N]**: This array is used by the token.LN[J] is the sequence number of the request that is recently executed by site Sj.
- **A queue Q**: This data structure is used by the token to keep a record of the ID of sites waiting for the token

Code Execution

Execute code by following cmd:

mpiexec -np `**X**` python3 suzuki-kasami.py `**dirc**`

For `**X**` number of process and pre-existing `**dirc**` directory for logging files.
Message complexity of code : (X – 1) request messages + 1 reply message —> O(X)

Implementation Detail

All the core code related to Suzuki-Kasami has been implemented in the file **suzuki-kasami.py** file. To run the code following modules are required:

- Threading
- Collections
- MPI4PY and Numpy

The following steps have been considered while implementing the code:-

1. To simulate several nodes in a distributed system MPI process has been used in which every process can contact another by message passing. To simulate the critical section, the process goes to sleep when entered in its critical section.

2. A process has the following data structure available:

```
DATA_STRUCTURE = {
    "token_queue": deque(),
    "LN": np.zeros(total_nodes),
    "RN": np.zeros(total_nodes),
    "has_token" : False,
    "in_cs": False,
    "waiting_for_token": False
}
```

3. The following locks were maintained to maintain the mutual exclusion of threads in a process/node:

```
LOCKS = {
    "request": threading.Lock(),
    "send": threading.Lock(),
    "release": threading.Lock(),
    "token": threading.Lock(),
    "cs": threading.Lock(),
    "rn": threading.Lock(),
}
```

4. A process has in total two threads: (i) Simulator/Action thread and (ii) Listener thread. However, for printing status on the CLI for a given process rank, we added another thread for process with rank “0” that serves the purpose of interacting with user.

```
if __name__=="__main__":
    directory = sys.argv[1]
    DATA_STRUCTURE["RN"][0]=1
    # giving a token to start the process 0
    if rank==0:
        print_log("%s: I am %d and have a startup token." % (datetime.now().strftime('%M:%S'), rank))
        sys.stdout.flush()
        DATA_STRUCTURE["has_token"]=True

    try:
        listener_thread = Thread(target=listener)
        listener_thread.start()
    except:
        print_log("Error: unable to start thread!   ")

    if rank==0:
        try:
            print_status_thread = Thread(target=print_node_status)
            print_status_thread.start()
        except:
            print_log("Error: unable to start print status thread!   ")

    while True:
        if not DATA_STRUCTURE["has_token"]:
            sleep(random.uniform(1,3));
            request()
        elif not DATA_STRUCTURE["in_cs"]:
            run_cs()
        while DATA_STRUCTURE["waiting_for_token"]:
            sleep(0.5)
```

5. **Simulator/Active thread**: Actually, simulator thread keep running in infinite loop. When a site Si is running and don't have token, it firstly sleeps for 2-3 seconds then wants to enter the critical section but since it does not have the token it increments its sequence number RNi[i] and sends a request message REQUEST(i, seq), by calling function **request(),** to all other sites in order to request the token. Here seq is update value of RNi[i]. In case, site Si has token and is not executing it's critical section then **run_cs()** function will get executed. Otherwise, it'll wait for requested token.

```
def request():
    global DATA_STRUCTURE
    with LOCKS["request"]:
        if not DATA_STRUCTURE["has_token"]:
            DATA_STRUCTURE["RN"][rank] = DATA_STRUCTURE["RN"][rank] + 1
            print_log("%s: I'm %d and want a token for the %d time." \
                % (datetime.now().strftime('%M:%S'), rank, DATA_STRUCTURE['RN'][rank]))
            sys.stdout.flush()
            DATA_STRUCTURE["waiting_for_token"]=True
            for i in range(total_nodes):
                if rank!=i:
                    comm.send([
                        REQUEST_MESSAGE_TYPE,
                        rank,
                        DATA_STRUCTURE["RN"][rank]
                    ], dest=i)
```

```
def listener():
    global DATA_STRUCTURE
    while True:
        mes = comm.recv(source=MPI.ANY_SOURCE)
        if mes[0] == REQUEST_MESSAGE_TYPE:
            with LOCKS["rn"]:
                rid = mes[1]
                seq = mes[2]
                DATA_STRUCTURE['RN'][rid] = max([seq, DATA_STRUCTURE['RN'][rid]])
                if DATA_STRUCTURE['RN'][rid] > seq:
                    print_log(
                        "%s: Request from %d has expired." % (datetime.now().strftime('%M:%S'), rid))
                    sys.stdout.flush()
                if DATA_STRUCTURE['has_token'] and \
                   not DATA_STRUCTURE['in_cs'] and \
                   DATA_STRUCTURE['RN'][rid] == DATA_STRUCTURE['LN'][rid]+1:
                   DATA_STRUCTURE['has_token'] = False
                   send_token(rid)
        elif mes[0] == TOKEN_MESSAGE_TYPE:
            with LOCKS['token']:
                print_log("%s: I'm %d and I got a token." % (datetime.now().strftime('%M:%S'), rank))
                sys.stdout.flush()
                DATA_STRUCTURE['has_token'] = True
                DATA_STRUCTURE['waiting_for_token'] = False
                DATA_STRUCTURE['LN'] = mes[1]
                DATA_STRUCTURE['token_queue'] = mes[2]
                run_cs()
```

6. **Listener thread**: Listens to two types of messages
    a. REQUEST_MESSAGE_TYPE — When a site Sj receives the request message REQUEST(i, seq) from site Si, it sets RNj[i] to maximum of RNj[i] and seq i.e RNj[i] = max(RNj[i], seq).After updating RNj[i], Site Sj sends the token to site Si if it has token and RNj[i] = LN[i] + 1 by function **send_token()**.

```
def send_token(recipient):
    global DATA_STRUCTURE
    with LOCKS["send"]:
        print_log("%s: I'm %d and sending the token to %d." \
            % (datetime.now().strftime('%M:%S'), rank, recipient))
        sys.stdout.flush()
        comm.send([
            TOKEN_MESSAGE_TYPE,
            DATA_STRUCTURE["LN"],
            DATA_STRUCTURE["token_queue"]
        ], dest=recipient)
```

    b. TOKEN_MESSAGE_TYPE — Site Si executes the critical section if it has acquired the token. And execute function **run_cs().**

```
def run_cs():
    global DATA_STRUCTURE
    with LOCKS["cs"]:
        if DATA_STRUCTURE["has_token"]:
            DATA_STRUCTURE["in_cs"] = True
            print_log("%s: I am %d and execute %d CS." \
                % (datetime.now().strftime('%M:%S'), rank, DATA_STRUCTURE['RN'][rank]))
            sys.stdout.flush()
            sleep(random.uniform(2, 5))
            DATA_STRUCTURE["in_cs"] = False
            print_log("%s: I'm %d and finished %d CS." \
                % (datetime.now().strftime('%M:%S'), rank, DATA_STRUCTURE['RN'][rank]))
            sys.stdout.flush()
            release_cs()
```

7. **Releasing the critical section**: After finishing the execution Site Si exits the critical section and does following: sets LN[i] = RNi[i] to indicate that its critical section request RNi[i] has been executed. For every site Sj, whose ID is not present in the token queue Q, it appends its ID to Q if RNi[j] = LN[j] + 1 to indicate that site Sj has an outstanding request. After above updation, if the Queue Q is non-empty, it pops a site ID from the Q and sends the token to site indicated by popped ID. If the queue Q is empty, it keeps the token.

```
def release_cs():
    global DATA_STRUCTURE
    with LOCKS["release"]:
        DATA_STRUCTURE["LN"][rank] = DATA_STRUCTURE["RN"][rank]
        for k in range(total_nodes):
            if k not in DATA_STRUCTURE["token_queue"]:
                if DATA_STRUCTURE["RN"][k]== (DATA_STRUCTURE["LN"][k]+1):
                    DATA_STRUCTURE["token_queue"].append(k)
                    print_log("%s: I'm %d and it adds %d to the queue. Queue after adding: %s." % (
                        datetime.now().strftime('%M:%S'), rank, k, str(DATA_STRUCTURE['token_queue'])))
                    sys.stdout.flush()
        if len(DATA_STRUCTURE["token_queue"])!=0:
            DATA_STRUCTURE["has_token"]=0
            send_token(DATA_STRUCTURE["token_queue"].popleft())
```

8. **print_log() and print_node_status()** are the function that are logging and reading latest status of the node/process/site respectively. **print_log()** appends latest status of the of site in a file dedicated to that site/process itself, along with it's LN, RN and token queue understanding. Function **print_node_status()** prints the same on **stdout** when a user enters and node rank on the CLI, which it reads from the log file.

9. Point to note that functions that both Simulator/Action and Listener thread have access: **run_cs(), send_token(), release_cs(), print_log().** However, only Action thread access **request()** and only listener thread access **listen()** function**.**

Example Run

We ran on 2, 3, 5, 8, 15 and 20 processes and made the simulation run for ~ 40 min. Multiple log files have been obtained. For 3 process we get logs as follow:

P0:

41:36: I am 0 and have a startup token.
LN : [0. 0. 0.]
RN : [1. 0. 0.]
Queue Understanding : deque([])
41:36: I am 0 and execute 1 CS.
LN : [0. 0. 0.]
RN : [1. 0. 0.]
Queue Understanding : deque([])
41:38: I'm 0 and I recieved outstanding request from 2.
LN : [0. 0. 0.]
RN : [1. 0. 1.]
Queue Understanding : deque([])
41:38: I'm 0 and I recieved outstanding request from 1.
LN : [0. 0. 0.]
RN : [1. 1. 1.]
Queue Understanding : deque([])
41:40: I'm 0 and finished 1 CS.
LN : [0. 0. 0.]
RN : [1. 1. 1.]
Queue Understanding : deque([])
41:40: I'm 0 and it adds 1 to the queue. Queue after adding: deque([1]).
LN : [1. 0. 0.]
RN : [1. 1. 1.]
Queue Understanding : deque([1])
41:40: I'm 0 and it adds 2 to the queue. Queue after adding: deque([1, 2]).
LN : [1. 0. 0.]
RN : [1. 1. 1.]
Queue Understanding : deque([1, 2])
41:40: I'm 0 and sending the token to 1.
LN : [1. 0. 0.]
RN : [1. 1. 1.]
Queue Understanding : deque([2])

P1:

41:38: I'm 1 and I recieved outstanding request from 2.
LN : [0. 0. 0.]
RN : [1. 0. 1.]

Queue Understanding : deque([])
41:38: I'm 1 and want a token for the 1 time.
LN : [0. 0. 0.]
RN : [1. 1. 1.]
Queue Understanding : deque([])
41:40: I'm 1 and I got a token.
LN : [0. 0. 0.]
RN : [1. 1. 1.]
Queue Understanding : deque([])
41:40: I am 1 and execute 1 CS.
LN : [1. 0. 0.]
RN : [1. 1. 1.]
Queue Understanding : deque([2])
41:43: I'm 1 and finished 1 CS.
LN : [1. 0. 0.]
RN : [1. 1. 1.]
Queue Understanding : deque([2])
41:43: I'm 1 and sending the token to 2.
LN : [1. 1. 0.]
RN : [1. 1. 1.]
Queue Understanding : deque([])

P2:

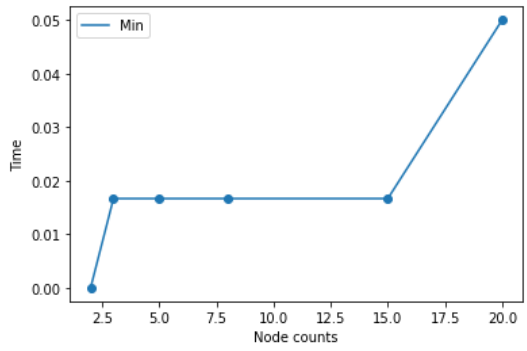
41:38: I'm 2 and want a token for the 1 time.
LN : [0. 0. 0.]
RN : [1. 0. 1.]
Queue Understanding : deque([])
41:38: I'm 2 and I recieved outstanding request from 1.
LN : [0. 0. 0.]
RN : [1. 1. 1.]
Queue Understanding : deque([])
41:42: I'm 2 and I recieved outstanding request from 0.
LN : [0. 0. 0.]
RN : [2. 1. 1.]
Queue Understanding : deque([])
41:43: I'm 2 and I got a token.
LN : [0. 0. 0.]
RN : [2. 1. 1.]
Queue Understanding : deque([])
41:43: I am 2 and execute 1 CS.
LN : [1. 1. 0.]
RN : [2. 1. 1.]
Queue Understanding : deque([])

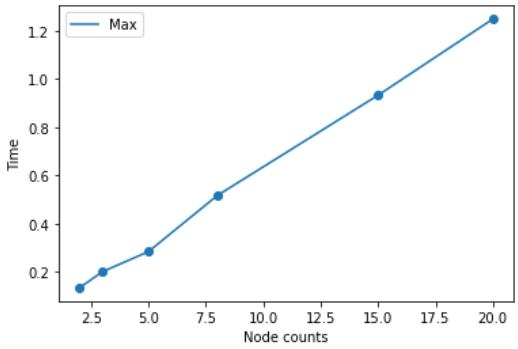
Analysis Done

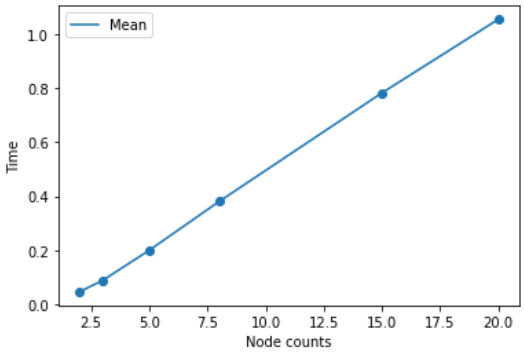
➢ Synchronization delay

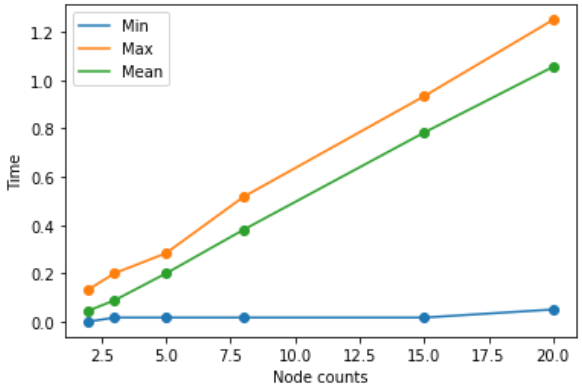
The synchronization delay is the time required after a site exits the CS and before the next site enters the CS. From the Example Run logs given above, we can clearly say that the Synchronization delay is 0.

➢ Time period between request for token and getting the token vs number of process/node/site







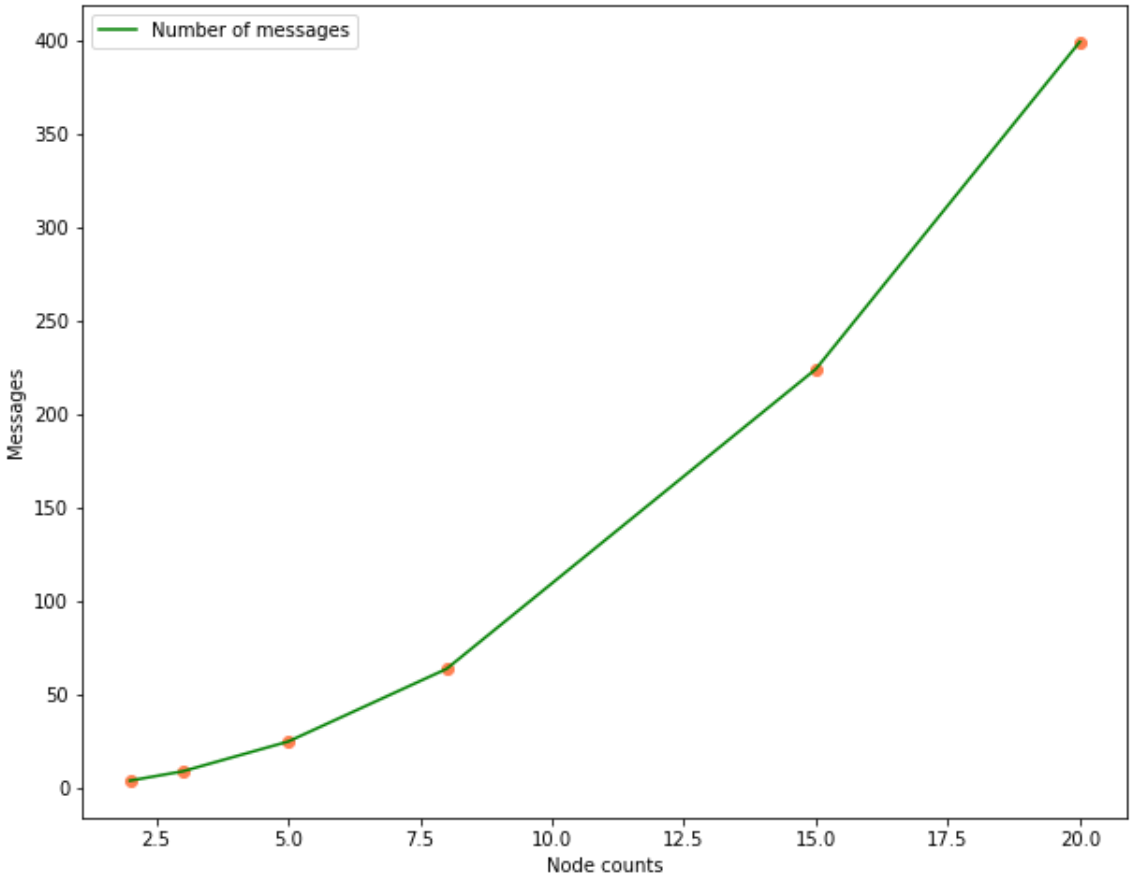


The explanation for the following are:

1. Mean-time vs number of nodes: As more processes compete for the same token, the average time it takes for a token request completion should increase as N increases.
2. Max-time vs number of nodes: Maximum time would be taken for process P_i's request completion, if it is present at the end of Q, and each of the processes (who do not have the token) also have their request in Q ahead of P_i's request. Since, the number of processes are N, max-time = N-1 units = O(N).
3. Min-time vs number of nodes: The minimum request time happens when Q is empty, The process with token executes the CS for ~ (2,5) seconds, so due to

the random nature of token requests by the processes in our system, the minimum-time request should reach the token-holding process just after it completes executing CS. Hence, min-time ~ 0 seconds.

➢ Total number of messages to complete 1 critical section by each process vs number of processes



From the plot, we can see that: number of messages a ≈ N^2 (where, N=number of processes). Here, we count the number of messages as total messages required for each process to enter a critical section (CS) once.
The equality to N^2 is because for executing CS, each process must:

1. Send CS entry request messages to each of the N-1 processes.
2. Receive a message (token) from the process which previously had the token.

Thus, each process sends N messages for executing 1 CS, and
total messages = N processes ✕ N messages per process = N^2 messages.

Video

Attached is a video describing the working of our algorithm along with a few user inputs.