ECE1755 Assignment 2
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This report will target the following two sections: a) the description of my MSI protocol and its optimization MESI; b) a diagram of the state machine of these two protocols.

Section I

MSI 3-hop:

States and message types this MSI 3-hop are guided from [1]. All the simulation results use the assumption of 3 processors in the system.

Message Traffic:

The baseline version is the MSI 3-hop involves three virtual channels (VCs) VC2, VC1, and VC0, ranking from highest priority to least significant. These three VCs are the key to message networks to prevent deadlock. Any initial request from the processor (i.e., GetM) will have the lowest priority and send to the HomeNode (Memory) via VC0. The reply to these requests (i.e., Data) is usually sent through VC2 except the put requests (i.e., PutAck) since PutAck will force the state of the processor back to Invalid and cause deadlock.

State Coherence:

One unique part of the MSI protocol compare to the sample two-state protocol is the ack (cnt in two-state.m) is that its value of sharers can be negative. The interconnect network can reorder the message and result in an acknowledged message (i.e., InvAck from sharer) that may receive before the actual data message that specifies the number of acks to be expected from sharers. For instance, when the Directory is at S-state and receives a GetM request from one of the processors, the requesting processor is expected to receive 2 InvAcks from the sharer processor. Therefore, the Directory will send this Data message containing the data value and ack of 2 to the requesting processor at VC2. However, because the message network can reorder all the messages at VC2, this Data message from the Directory may be delivered after the requesting processor has received serval InvAck messages from the sharers. To address this issue, the ack counter can support negative values; whenever the processor receives an InvAck, the ack of the processor will decrease by one and eventually add the number of acks from the Data message. When the value ack returns to zero, it means the processor has received all the InvAck from sharers and is ready to shift to a stable state when the ack equals zero.

Proof of Correctness:

To prove the protocol matches the design needs, I implement several rules and invariances to test the protocol, including memory coherence check using Lastwrite. In general, the protocol passed all the invariances, having 21451 states and 99274 rules simulated using $Mur\varphi$.

```
Status:

        No error found.

State Space Explored:

        21451 states, 99274 rules fired in 2.02s.

Analysis of State Space:

        There are rules that are never fired.
        If you are running with symmetry, this may be why.  Otherwise,
        please run this program with "-pr" for the rules information.
        The maximum size for the multiset "HomeNode.sharers" is: 3.
        The maximum size for the multiset "Net[HomeType]" is: 4.
        The maximum size for the multiset "Net[Proc_1]" is: 4.
        The maximum size for the multiset "Net[Proc_2]" is: 4.
        The maximum size for the multiset "Net[Proc_3]" is: 4.
```

MESI Optimization:

Summary:

The MESI protocol is the optimized version based on the MSI with an extra Exclusive state. The processor at Exclusive state can modify the value silently without requesting additional written permission from the Directory.

The majority of the MESI protocol is inherited from MSI 3-hop and has 3 VCs to prevent deadlock. One of the key differences is that the Directory will upgrade to H_E when there is only one sharer processor and when an extra sharer processor is joining in, the Directory will require the clean data from the previous owner processor.

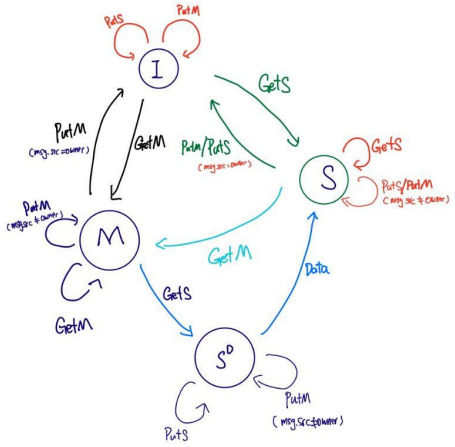
Proof of Correctness:

In addition to the same rules and invariances in the MSI protocol, extra invariants such as the sharer list are empty at E state. No error has appeared in the Mur with 24998 states and 116326 rules.

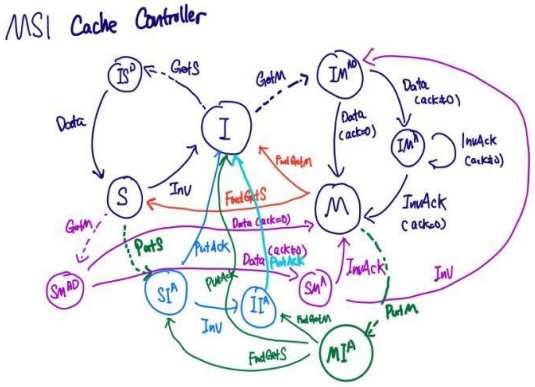
```
Status:

        No error found.

State Space Explored:

        24998 states, 116326 rules fired in 2.08s.

Analysis of State Space:

        There are rules that are never fired.
        If you are running with symmetry, this may be why.  Otherwise,
        please run this program with "-pr" for the rules information.
        The maximum size for the multiset "HomeNode.sharers" is: 3.
        The maximum size for the multiset "Net[HomeType]" is: 4.
        The maximum size for the multiset "Net[Proc_1]" is: 4.
        The maximum size for the multiset "Net[Proc_2]" is: 4.
        The maximum size for the multiset "Net[Proc_3]" is: 4.
ug70:~/Desktop/M/ece1755_sample%
```

Section II

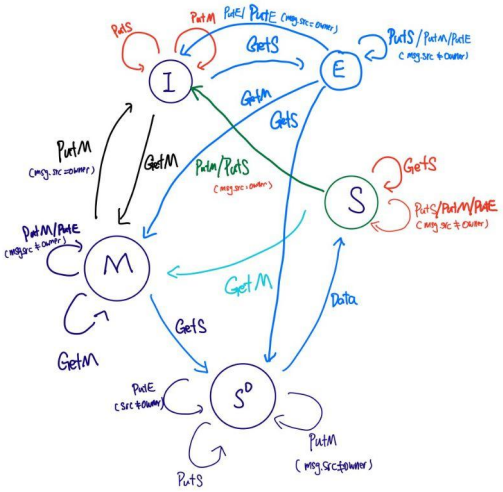
MSI & MESI: State Diagram



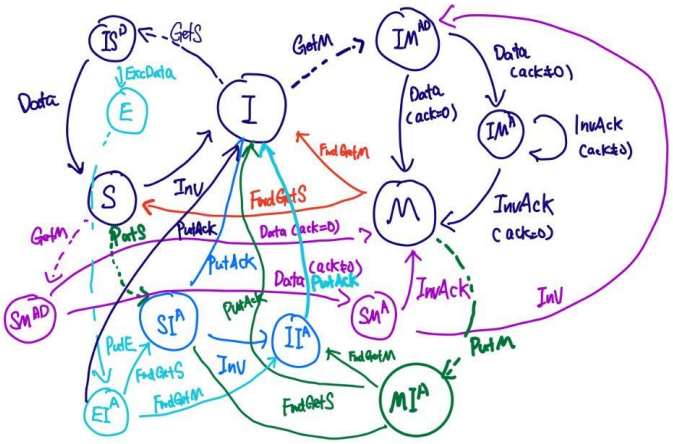
Directory MSI



Cache Controller MSI



Directory MESI



Cache Controller MESI

Reference:

[1] D. J. Sorin, M. D. Hill, and D. A. Wood, *A Primer on memory consistency and cache coherence*. San Rafael, Calif.: Morgan & Claypool Publishers, 2011.