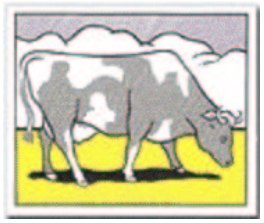
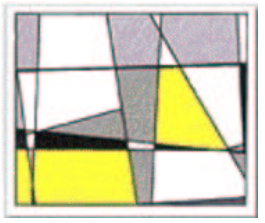
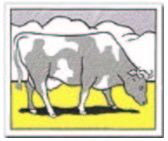




Power Efficient Cache Coherence

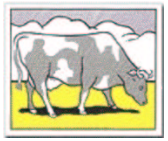
Craig Saldanha

Mikko Lipasti



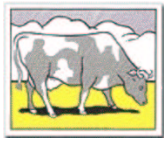
Motivation

- Power consumption becoming a serious design constraint.
- Market demand for faster and more complex servers.
- Complex coherence protocol and interconnect.
- $f_{clock}\uparrow$ + *Complexity*$\uparrow$ = $P_{interconnect}\uparrow$



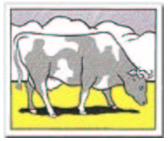
Motivation

- Traditional power saving methodologies ineffective.
- Minimize number of transaction packets.
- At the end-points: *Jetty.*
- At the source: *Serial Snoop.*

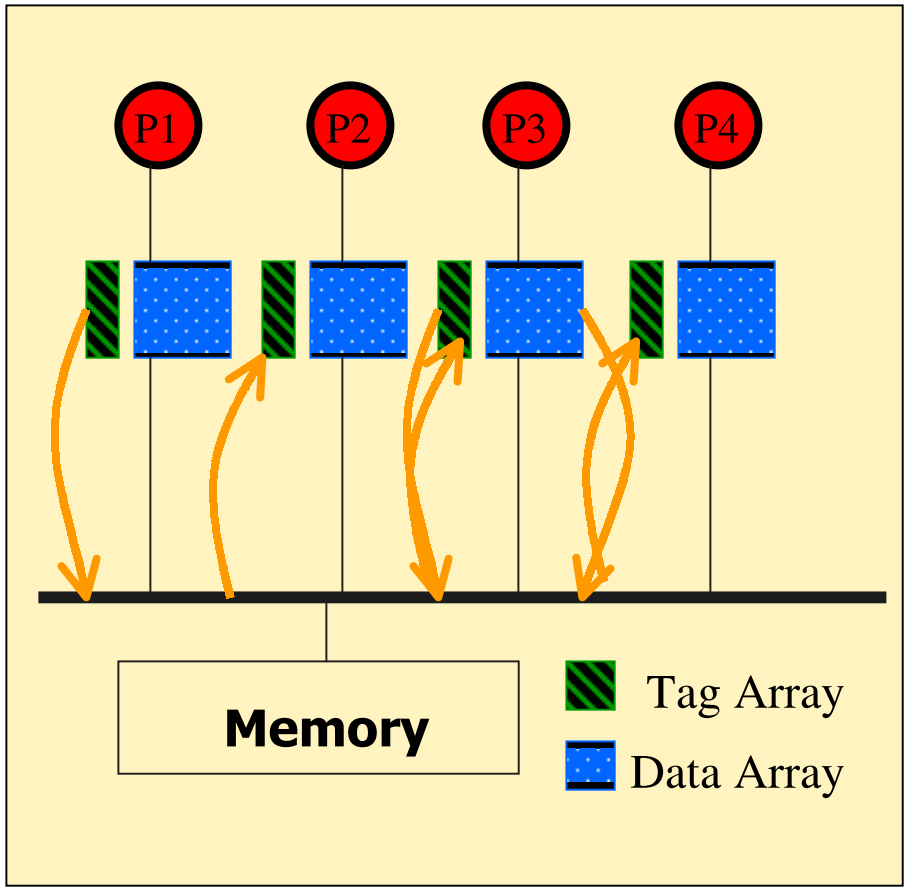


OUTLINE

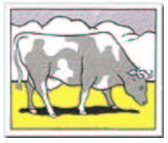
- Overview of Snoop based protocols and opportunity for power savings
- Latency and Power consumption of parallel snooping techniques
- Serial Snooping
- Results
- Conclusions
- Future Work



Snoop Based Coherence



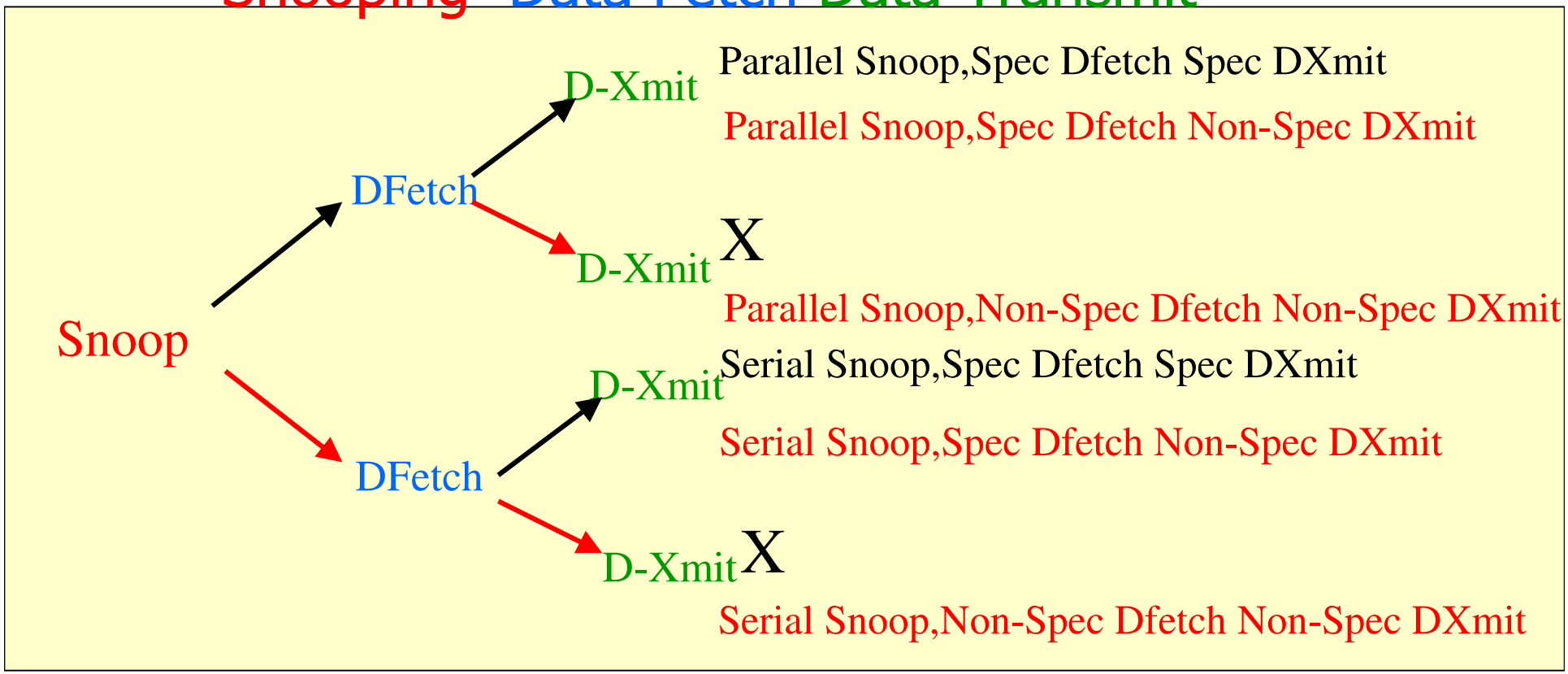
- **Local Node**
  - → Tag Lookup
  - → Bus Arbitration
  - → Snoop Transmission
- **Remote Node**
  - → Tag Lookup
  - → Snoop Response
  - → Combination of Responses
  - → Data Fetch
  - → Data Transmit

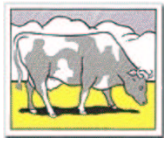


Degrees of Speculation

- 3 Degrees of Freedom to Speculate

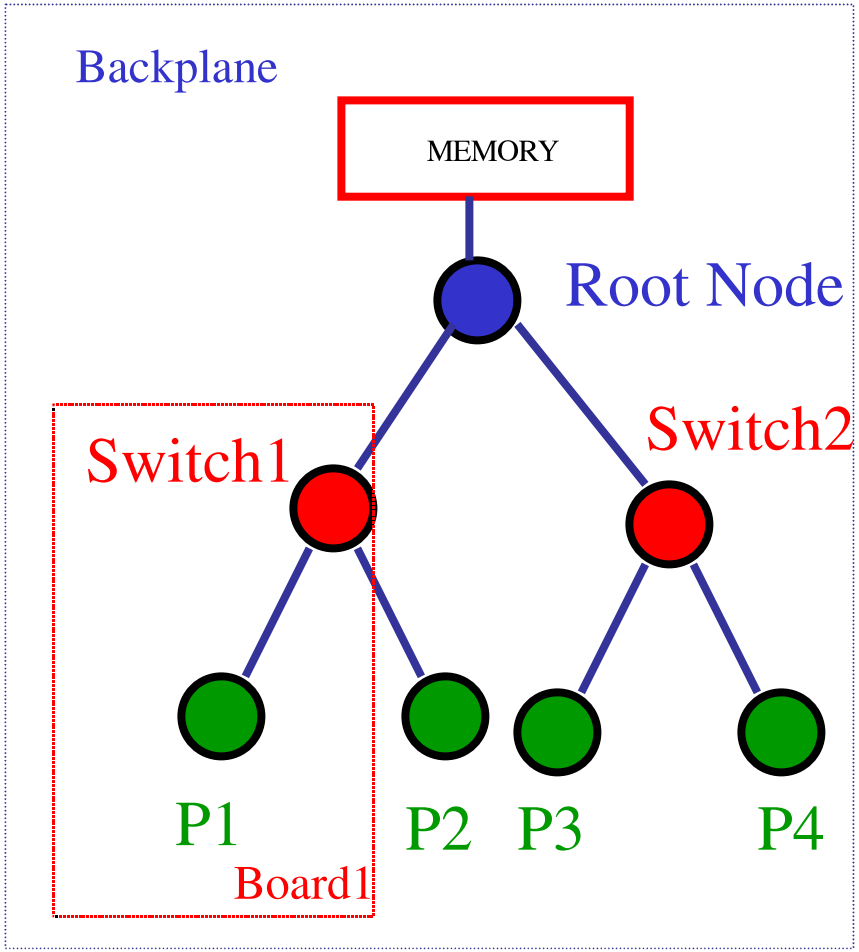
Snooping Data Fetch Data Transmit

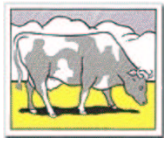




Latency and Power assumptions

- Consider only load misses
- Tree of point-point connections.
- Latency to traverse a link: 1Bus cycle (7ns)
- Tag Look up :1 bus cycle (7ns)
- D-Fetch: 2 bus cycles (14ns)
- DRAM access: 10 bus cycles (70ns)





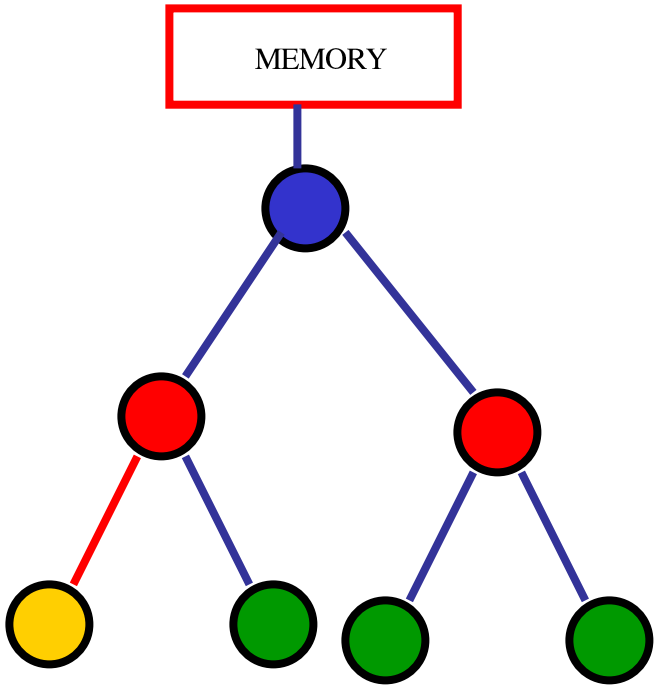
Parallel Snoop Speculative Fetch Speculative Transmit (PS/SF/ST)

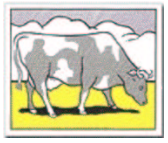
Snoop Broadcast

Latency

Power

Plink





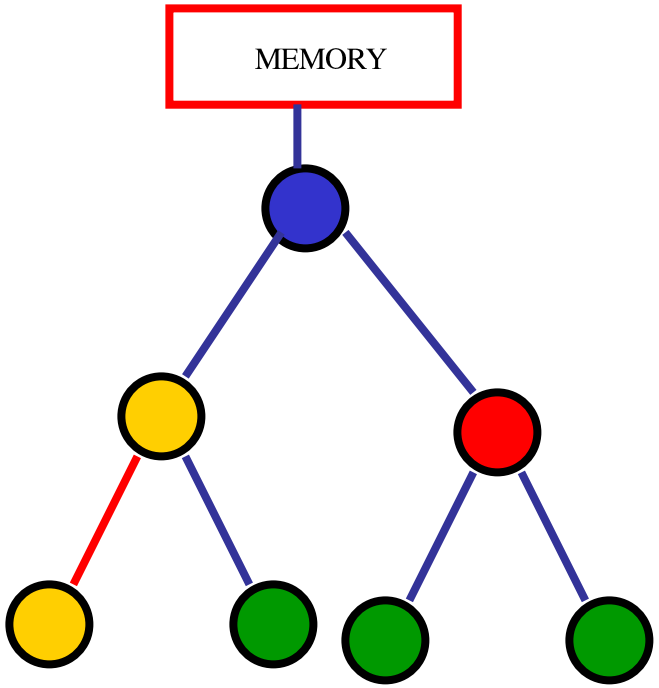
Parallel Snoop Speculative Fetch Speculative Transmit (PS/SF/ST)

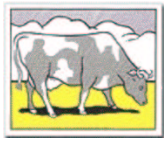
Snoop Broadcast

Latency

Power

Plink+Pswitch

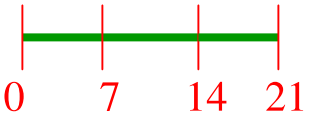


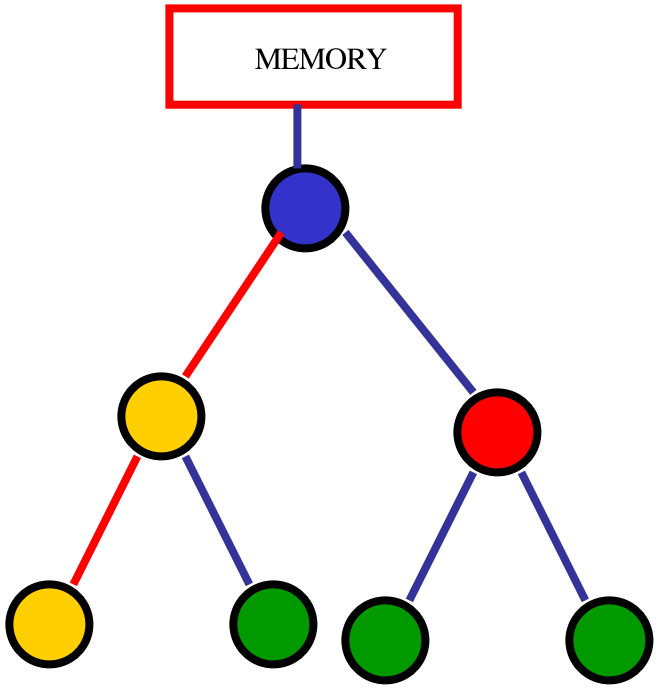


Parallel Snoop Speculative Fetch Speculative Transmit (PS/SF/ST)

Snoop Broadcast

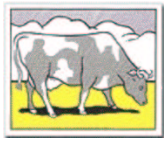
Latency





Power

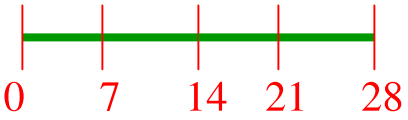
2Plink+Pswitch

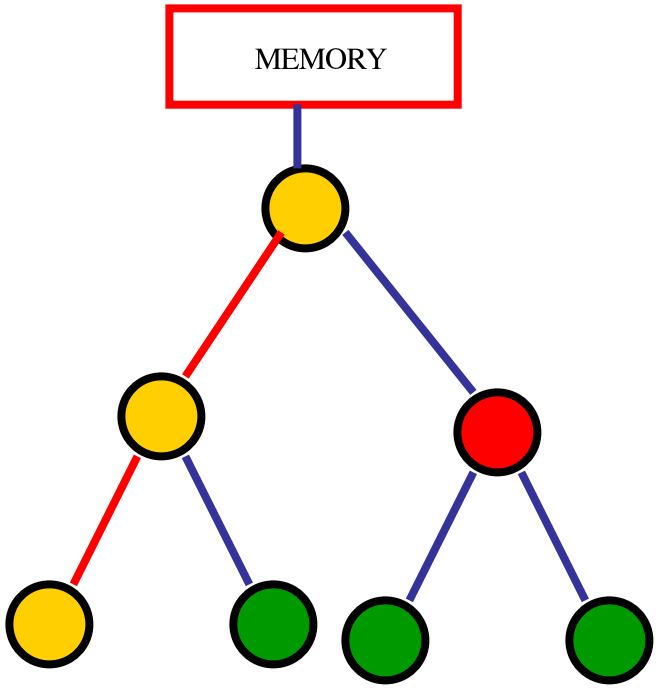


Parallel Snoop Speculative Fetch Speculative Transmit (PS/SF/ST)

Snoop Broadcast

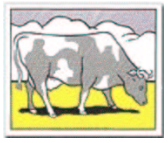
Latency





Power

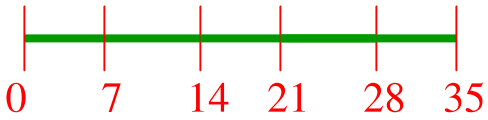
2Plink+2Pswitch



Parallel Snoop Speculative Fetch Speculative Transmit (PS/SF/ST)

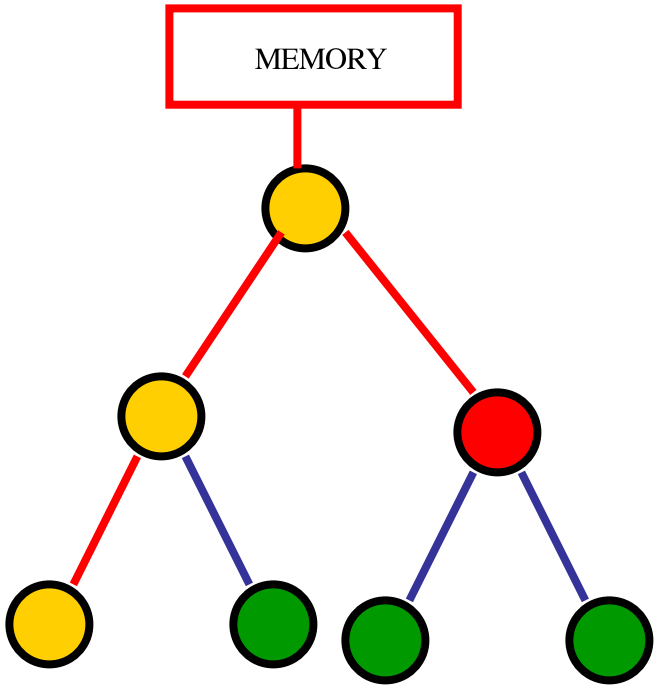
Snoop Broadcast

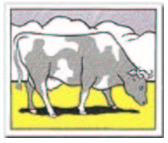
Latency



Power

5Plink+2Pswitch

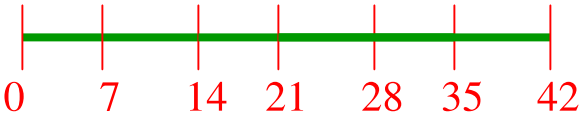


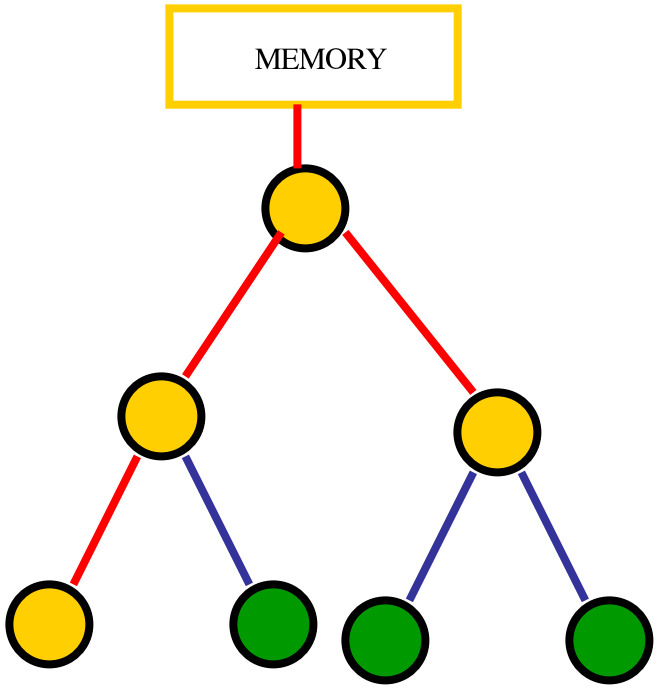


Parallel Snoop Speculative Fetch Speculative Transmit (PS/SF/ST)

Snoop Broadcast

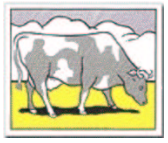
Latency





Power

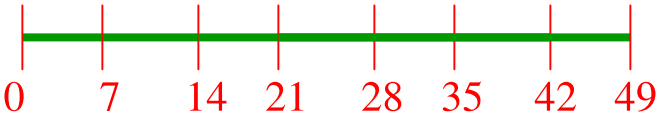
5Plink+4Pswitch



Parallel Snoop Speculative Fetch Speculative Transmit (PS/SF/ST)

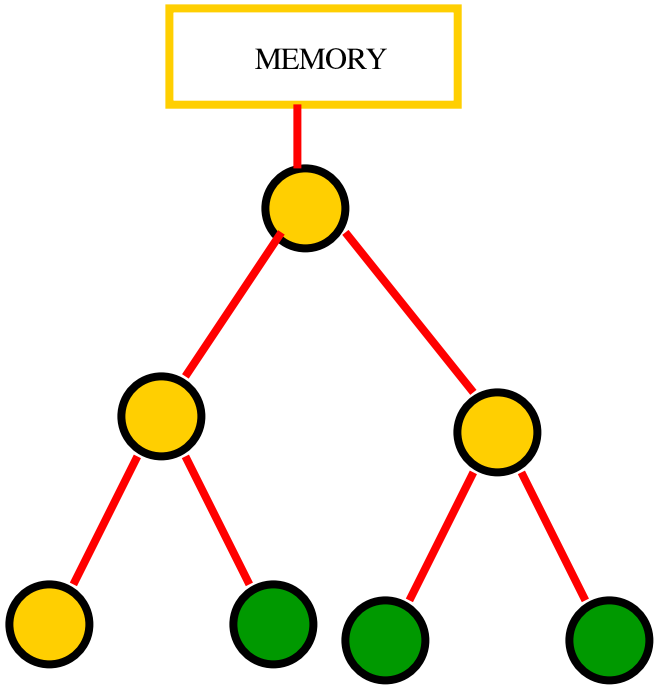
Snoop Broadcast

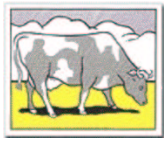
Latency



Power

8Plink+4Pswitch





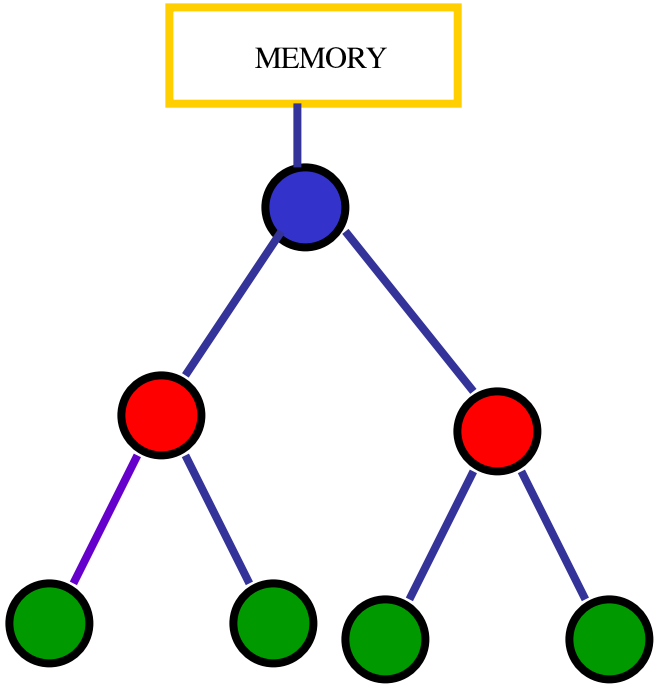
Parallel Snoop Speculative Fetch Speculative Transmit (PS/SF/ST)

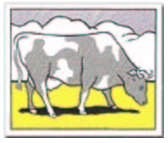
Memory Access :Data Fetch

Latency

Power

Pmem

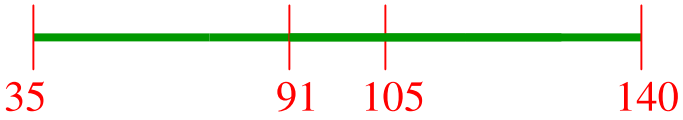


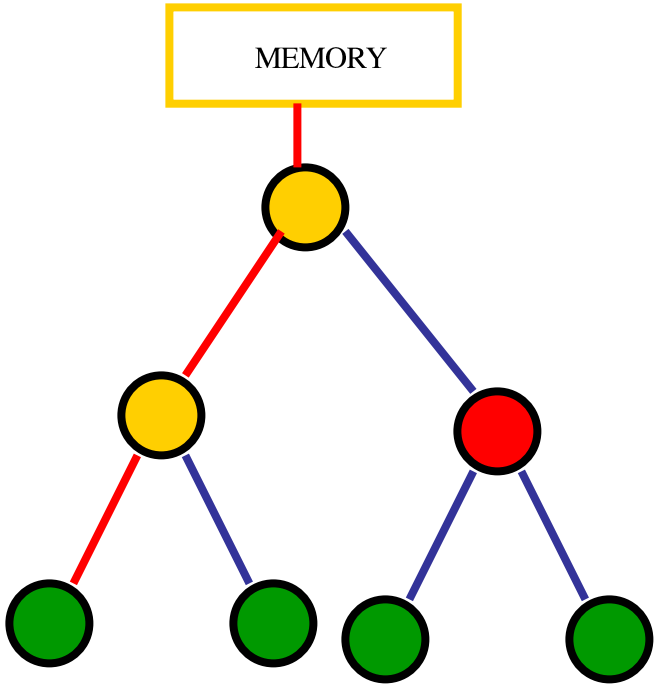


Parallel Snoop Speculative Fetch Speculative Transmit (PS/SF/ST)

Memory Access :Data Transmit

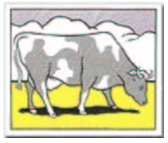
Latency





Power

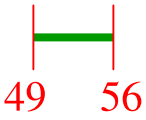
Pmem+3Plink+2Pswitch



Parallel Snoop Speculative Fetch Speculative Transmit (PS/SF/ST)

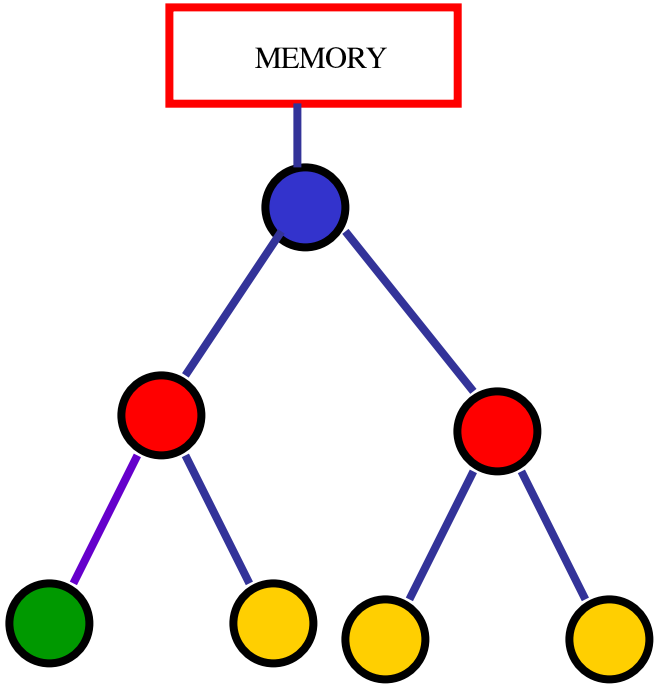
Remote Node: Tag Lookup

Latency



Power

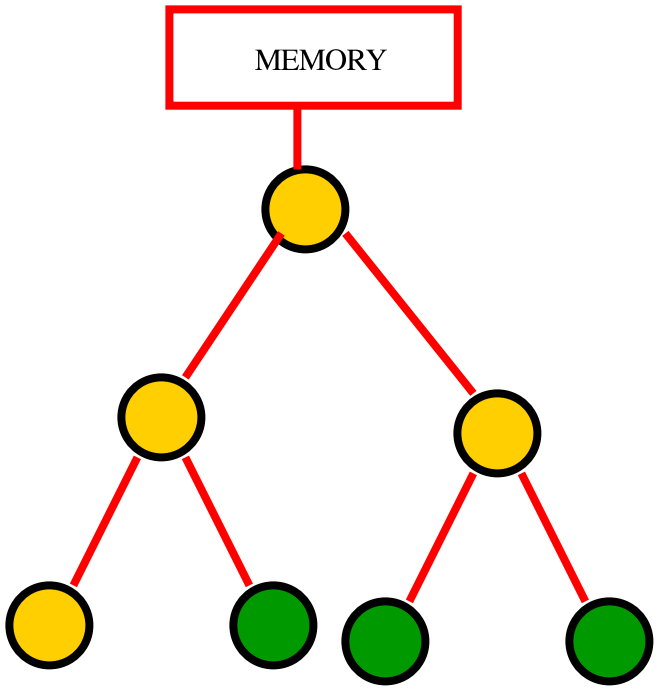
3Ptag



Parallel Snoop Speculative Fetch Speculative Transmit (PS/SF/ST)

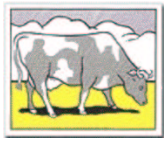
Remote Node :Snoop Response

Latency



Power

3Ptag+3*(Pswitch+2Plink)+Plink+2Pswitch+2Plink



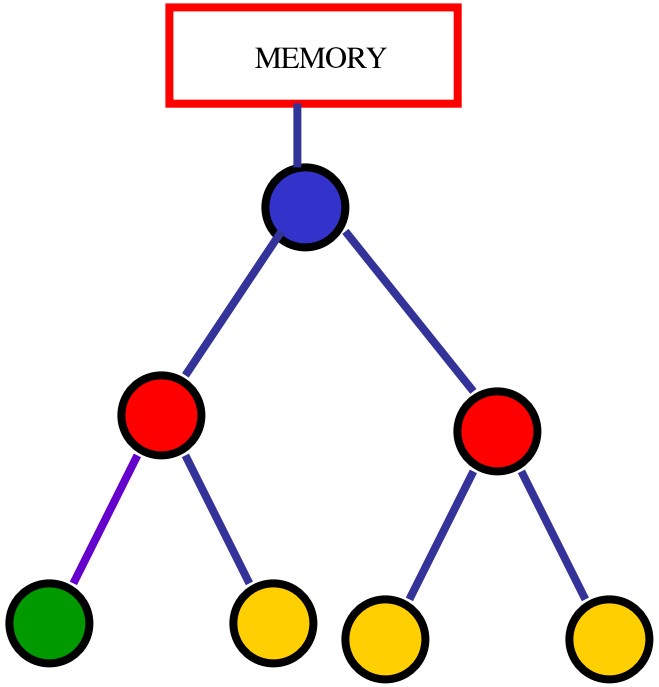
Parallel Snoop Speculative Fetch Speculative Transmit (PS/SF/ST)

Remote Node: Data Fetch

Latency

Power

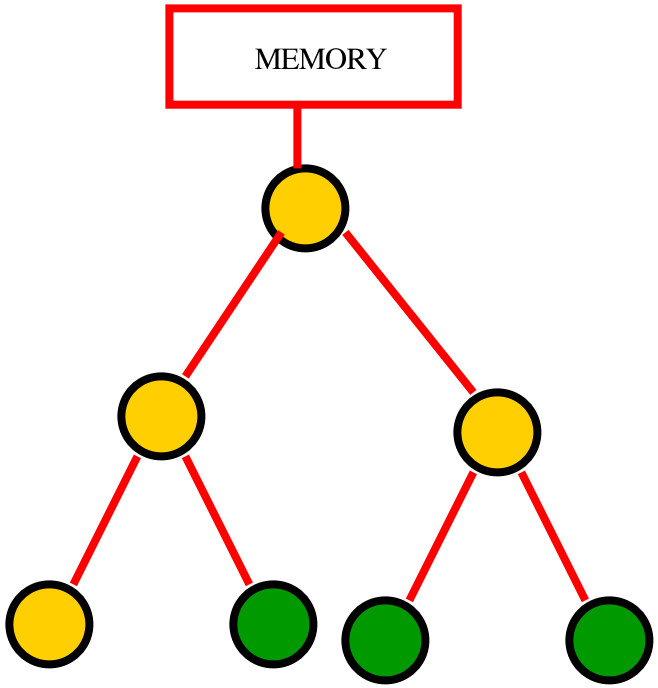
3Pcache



Parallel Snoop Speculative Fetch Speculative Transmit (PS/SF/ST)

Remote Node :Data Transmit

Latency

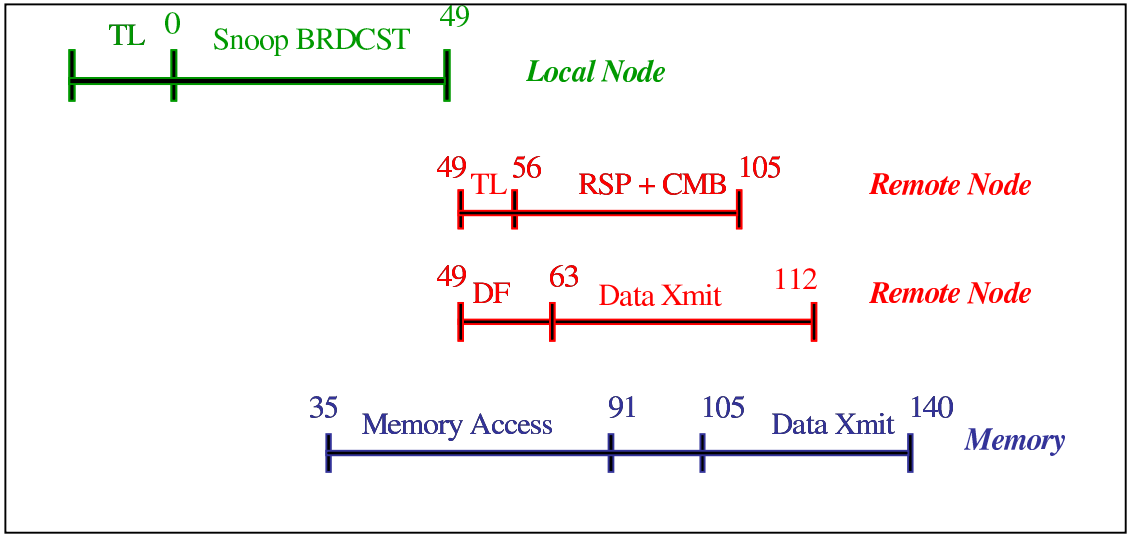


Power

3Ptag+3*(4Plink+3Pswitch)

Parallel Snoop Speculative Fetch Speculative Transmit (PS/SF/ST)

Latency



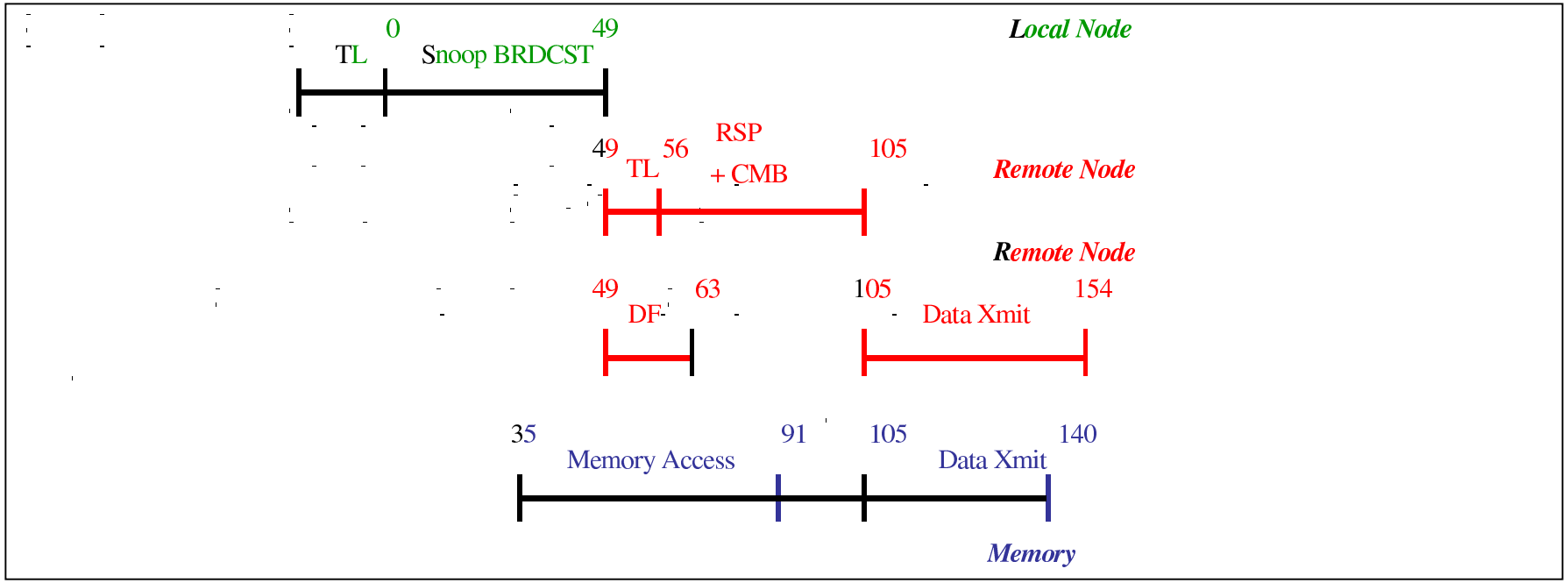
Power

Remote Node supplies the data 29Plink+18Pswitch+3Ptag+3Pcache+Pmem

Memory supplies the data 20Plink+11Pswitch+3Ptag+3Pcache+Pmem

Parallel Snoop Speculative Fetch Non-Speculative Transmit (PS/SF/NT)

Latency



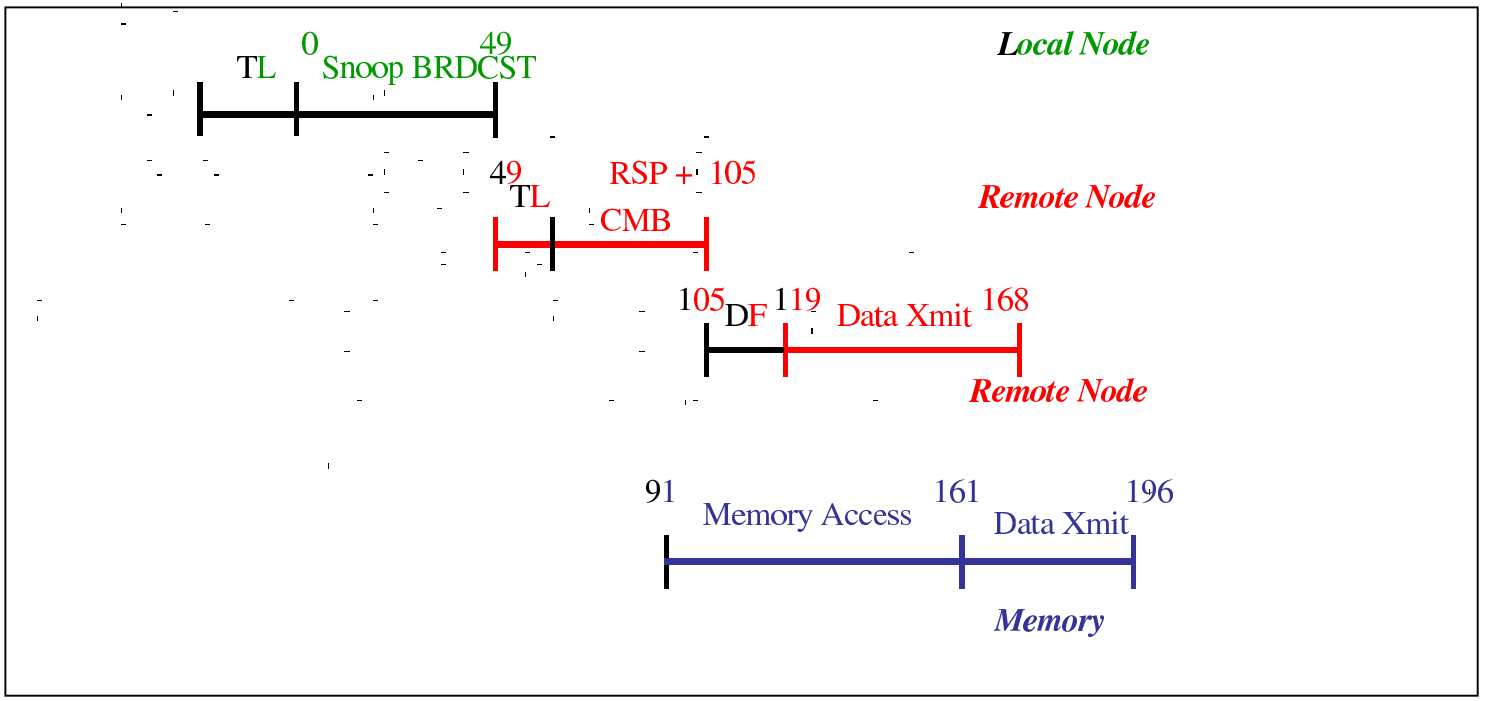
Power

Remote Node supplies the data — 21Plink+12Pswitch+3Ptag+Pcache+Pmem

Memory supplies the data — 20Plink+11Pswitch+3Ptag+3Pcache+Pmem

Parallel Snoop Non-Speculative Fetch Non-Speculative Transmit (PS/NF/NT)

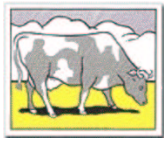
Latency



Power

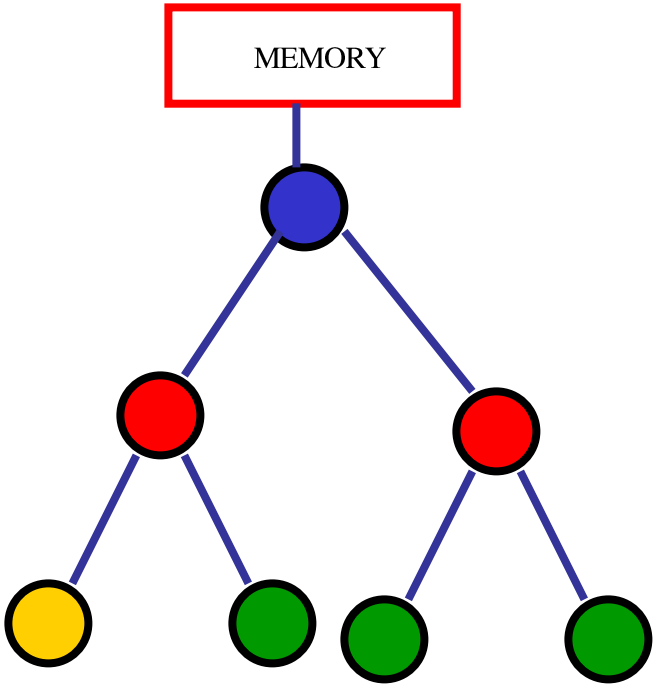
Remote Node supplies the data — 21Plink+12Pswitch+3Ptag+Pcache

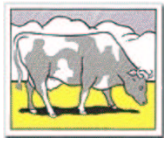
Memory supplies the data — 20Plink+11Pswitch+3Ptag+Pmem



Serial Snooping

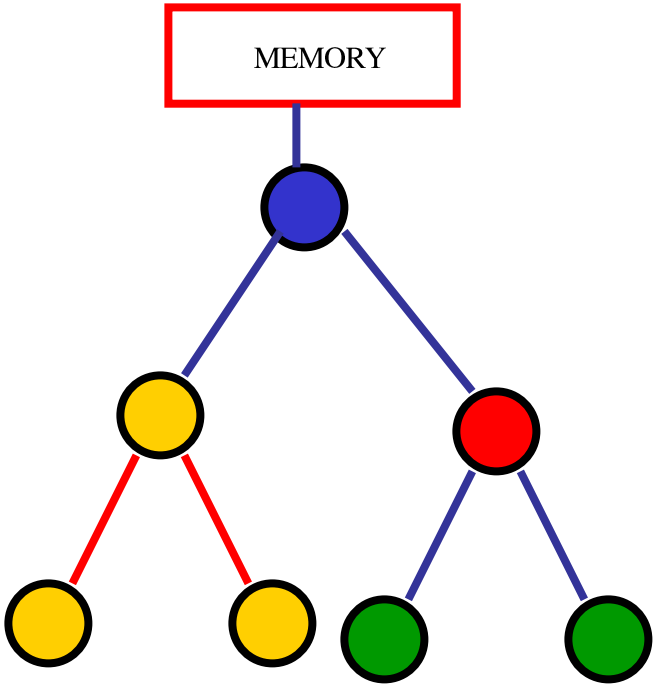
- Avoids Speculative transmission of Snoop packets.

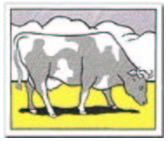




Serial Snooping

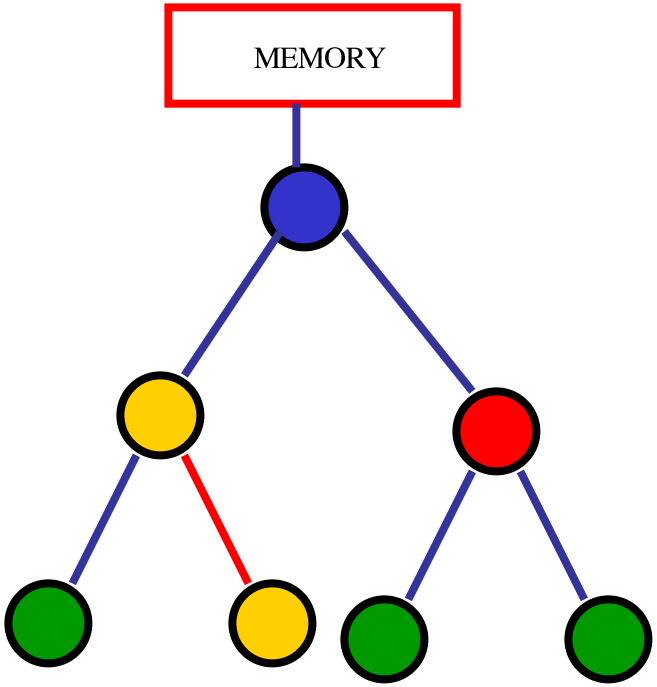
- Avoids Speculative transmission of Snoop packets.
- Check the nearest neighbor
- Data supplied with minimum latency and power

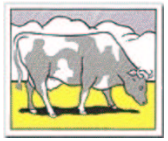




Serial Snooping

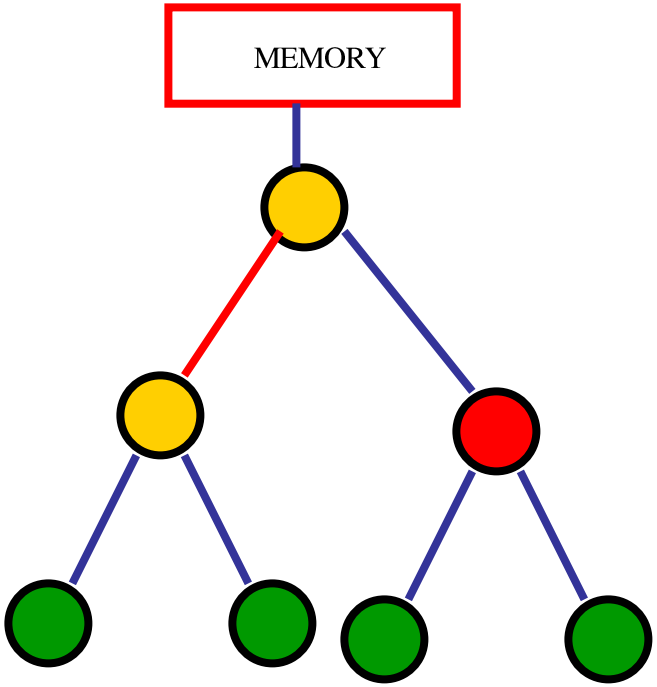
- Forward snoop to next level

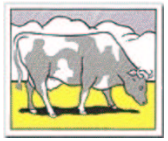




Serial Snooping

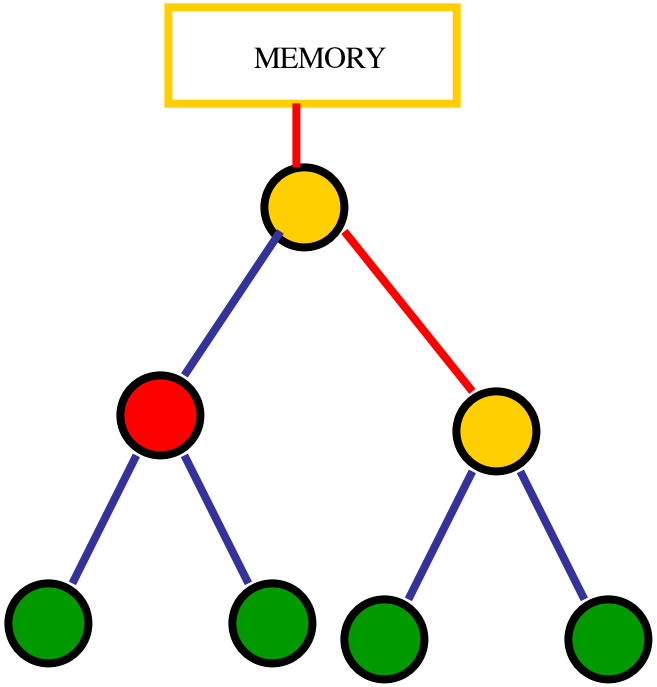
- Forward snoop to next level

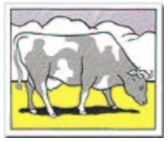




Serial Snooping

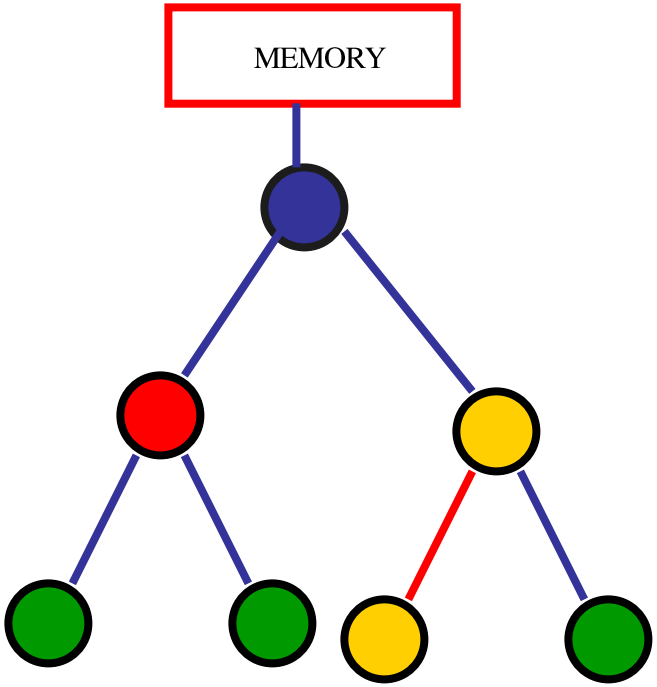
- Search other half of tree

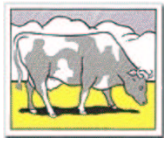




Serial Snooping

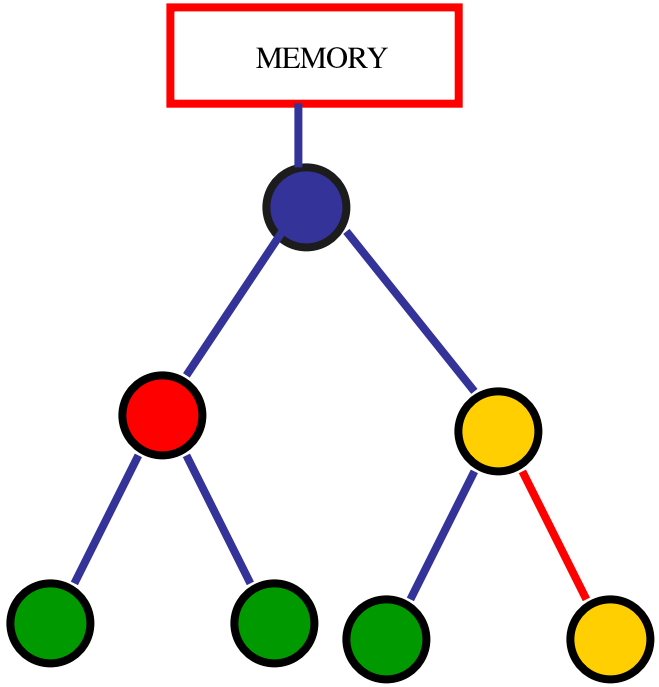
- Search other half of tree
- Search leaf nodes serially

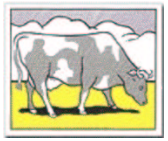




Serial Snooping

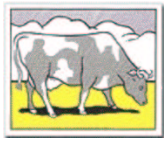
- Search other half of tree
- Search leaf nodes serially





Serial Snooping : Features

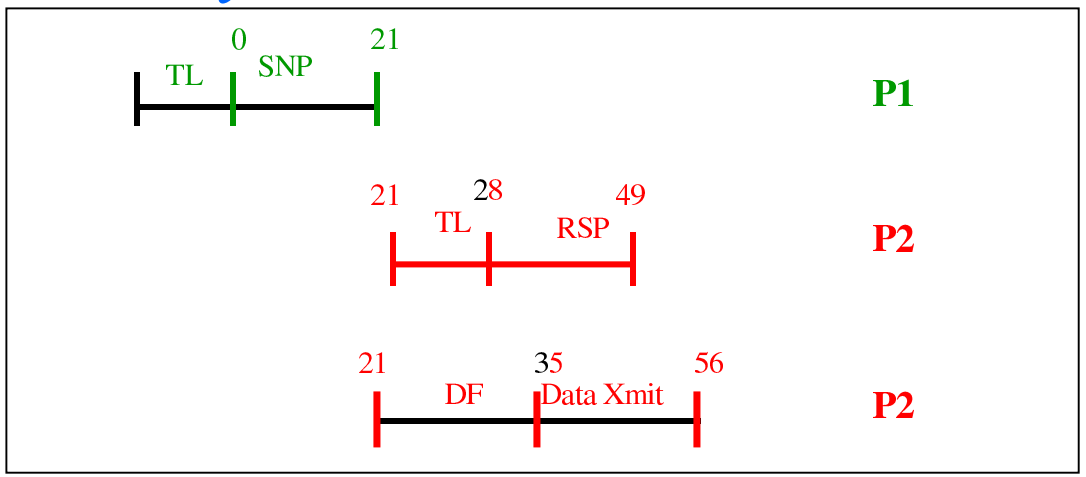
- Latency to satisfy a request dependent on distance from requestor.
- Data resident at the nearest neighbor supplied with the lowest latency and power.
- Requests visible to memory controller only at root node.
- Latency is adversely affected when requested data present at the farthest node
- Worst case power consumption is still less than the parallel snooping.

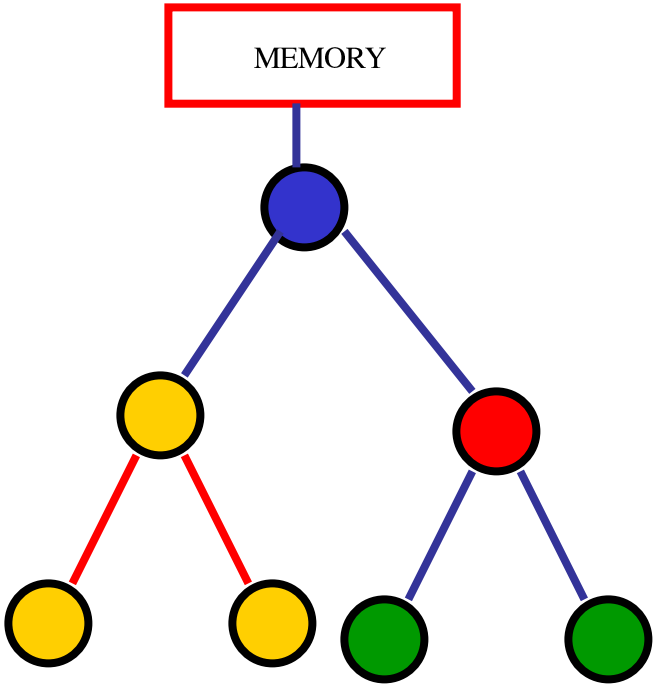


Serial Snooping :

Request satisfied by Nearest Node

Latency





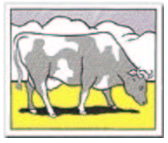
Power

Xmit Snoop: 2Plink + Pswitch

P2 Tag access and snoop response: Ptag + 2Plink + Pswitch

P2 Data Fetch and Xmit: Pcache +2Plink + Pswitch

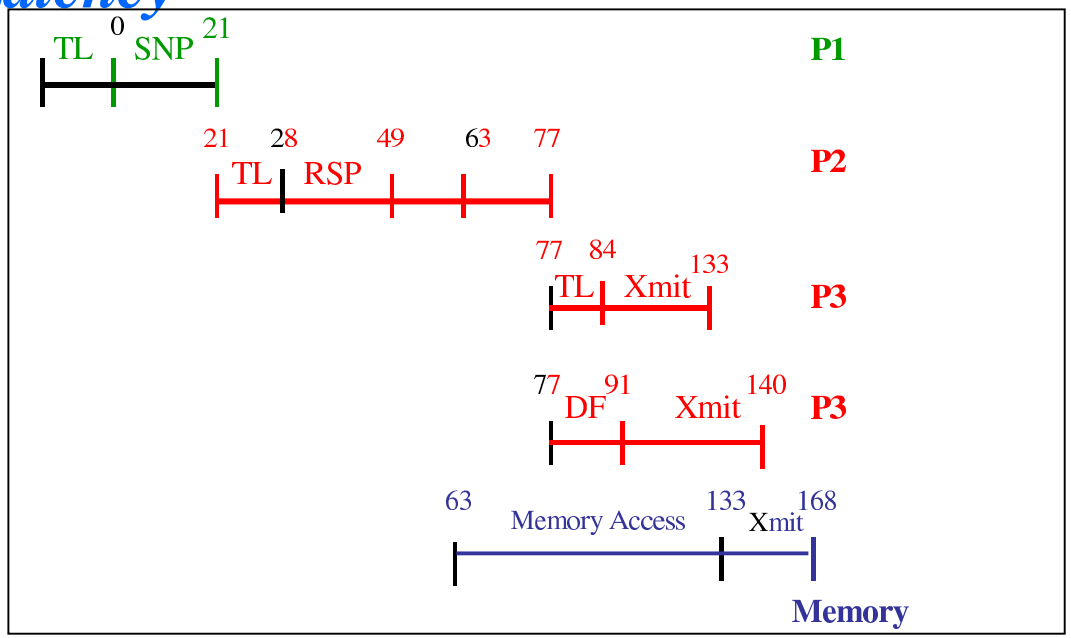
Ptotal= 6Plink+3Pswitch+Ptag+Pcache

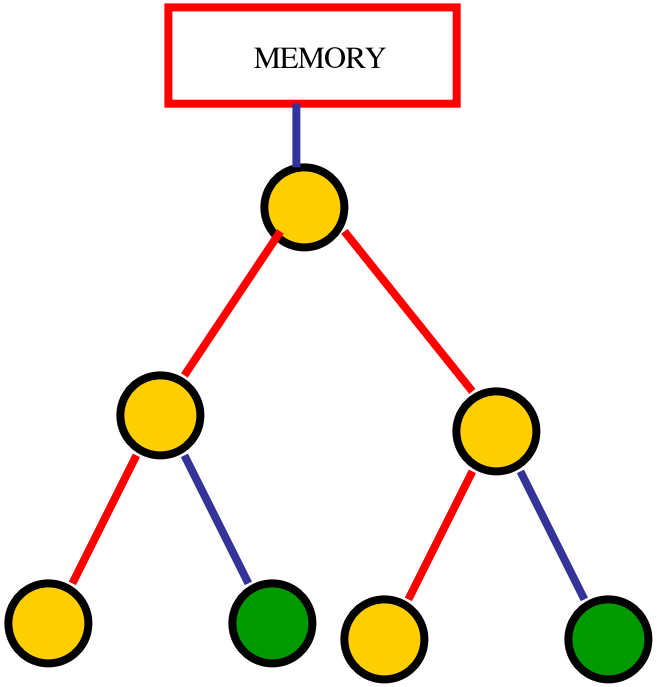


Serial Snooping :

Request satisfied by Next-Nearest Neighbor

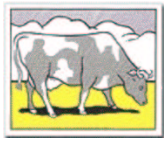
Latency





Power

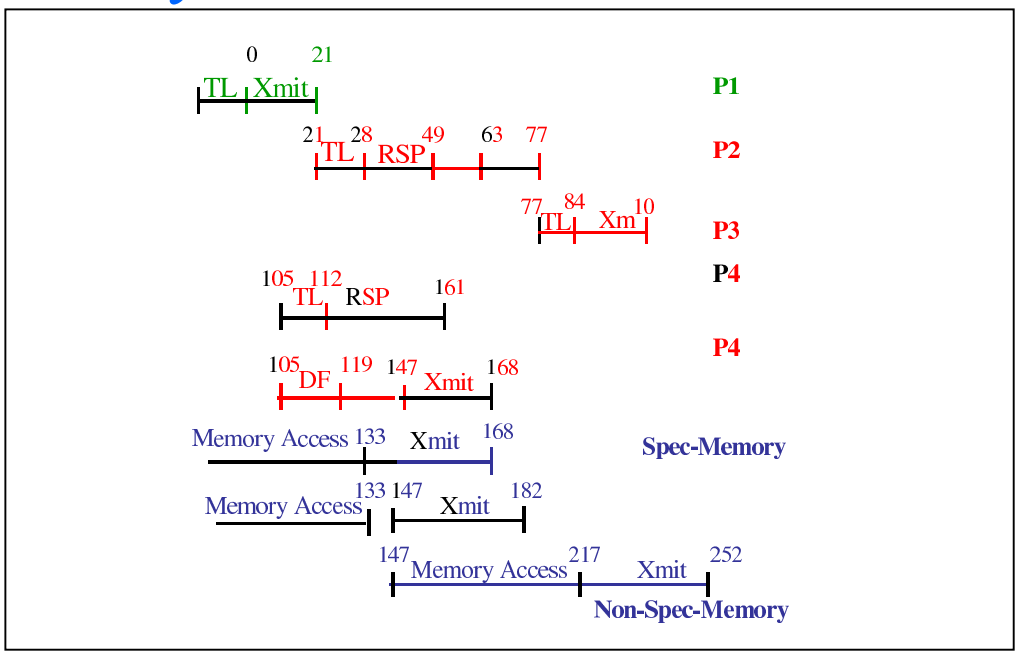
16Plink+10Pswitch+2Ptag+Pcache

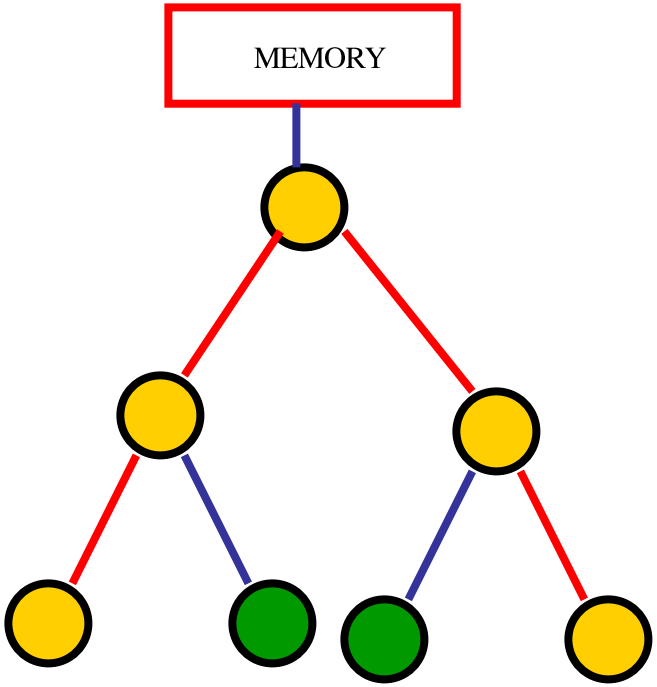


Serial Snooping :

Request satisfied by farthest node

Latency



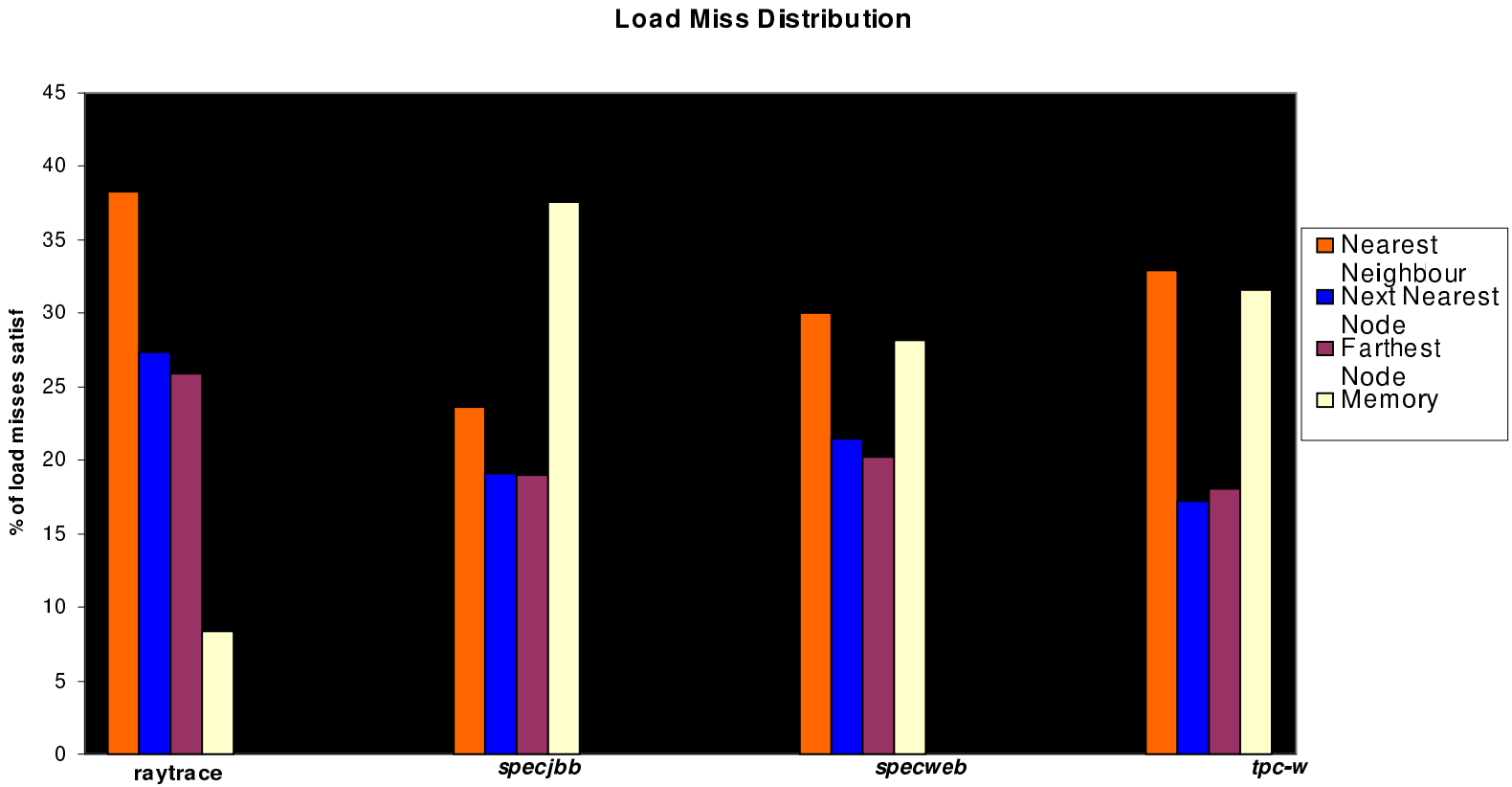


Power

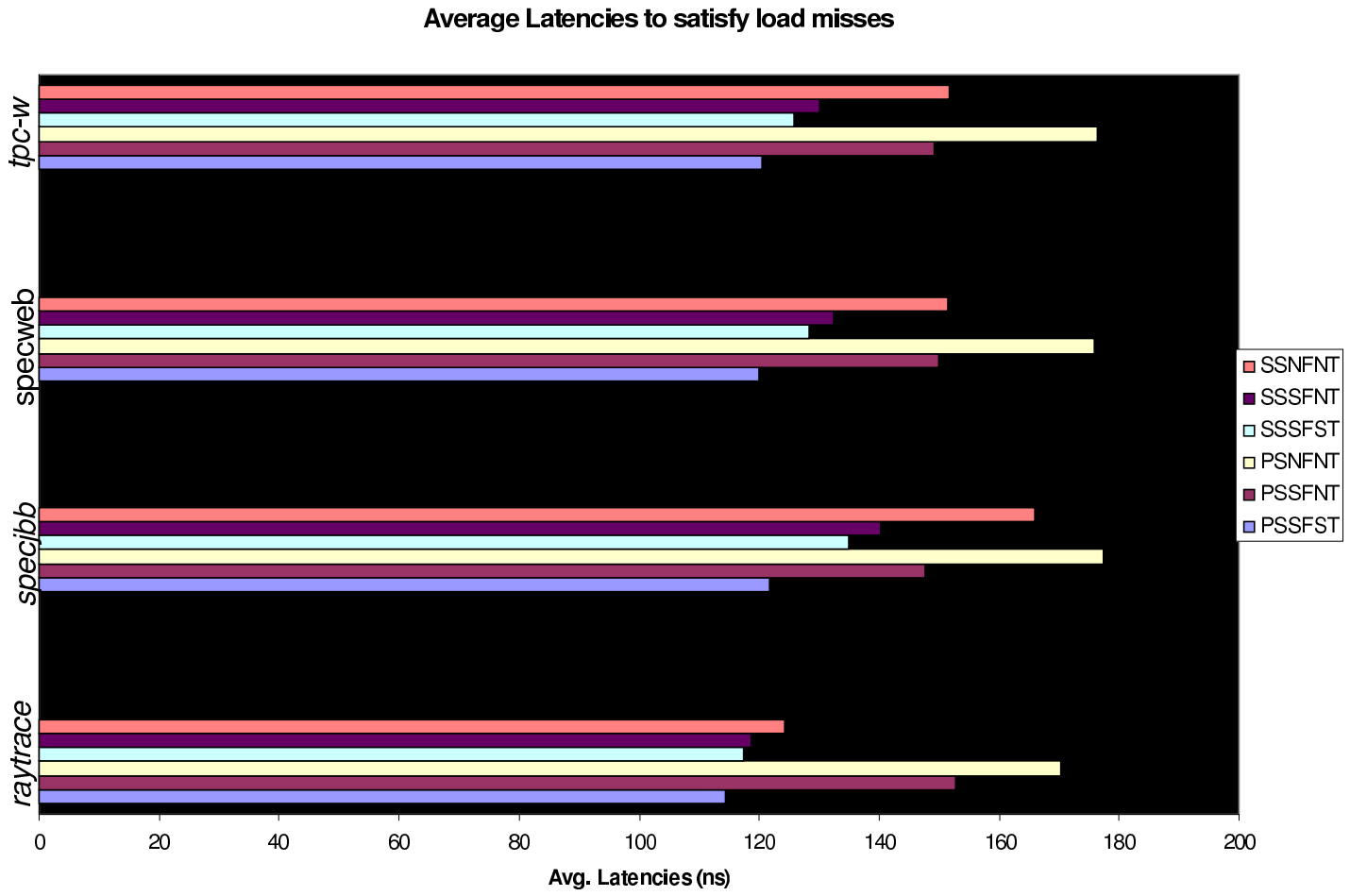
Remote Node supplies the data 18Plink+11Pswitch+3Ptag+Pcache

If Memory supplies the data 17Plink+10Pswitch+3Ptag+Pmem

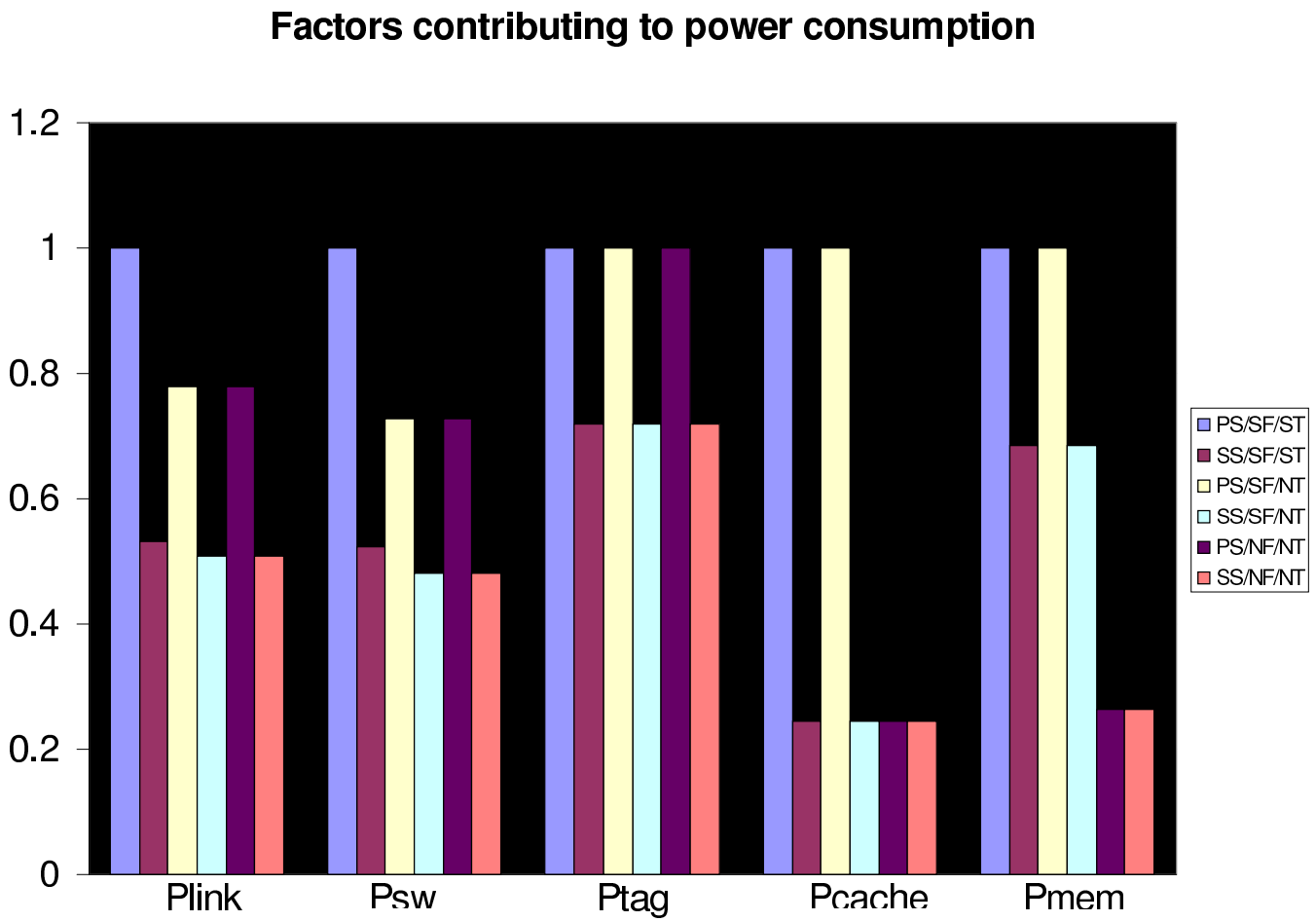
RESULTS : Load Miss Distributions

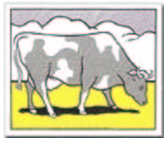


RESULTS: Average Latencies to satisfy load misses



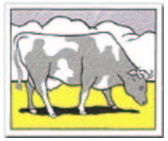
RESULTS: Relative Power Savings





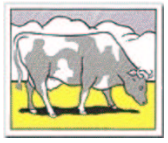
CONCLUSIONS

- Reducing degree of speculation has potential for significant power savings
- Performance degradation is minimal for the set of benchmarks studied.
- Serial Snooping with speculative memory fetch provides optimal latency and power consumption.



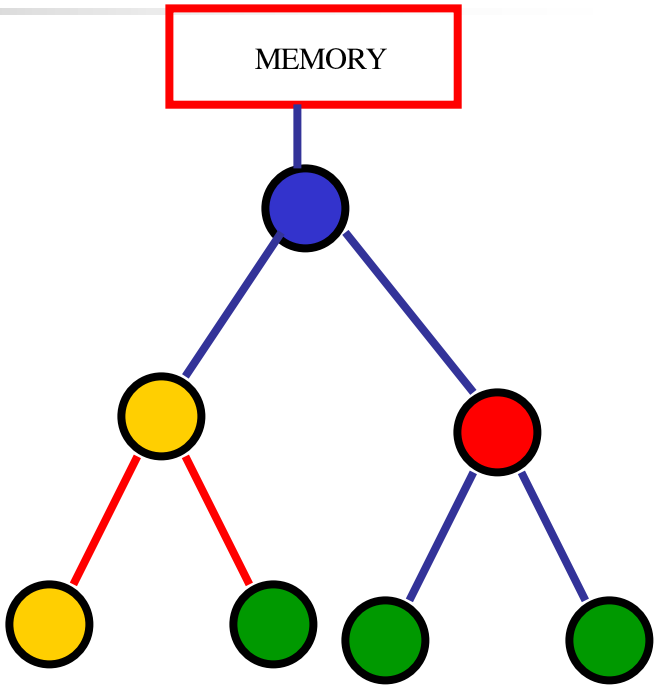
Future Work

- Develop detailed execution-driven Power Model
- Explore different interconnect topologies.
- Examine the viability of adaptive mechanisms for protocol policy.

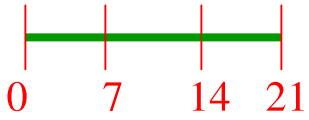


Serial Snooping

Nearest Neighbor

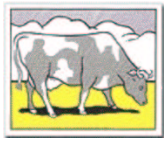


Latency

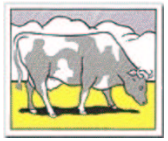


Power

2Plink+Pswitch



Questions



Parallel Snoop Speculative Fetch Speculative Transmit (PS/SF/ST)

Local Node