**1. What are the chief characteristics of an SMP?**

* All processors share the same memory and I/O devices.
* Processors run under a single operating system instance.
* Tasks can be scheduled on any processor (no processor affinity required).
* Processors communicate and synchronize through shared memory.
* Equal access to hardware resources (symmetry).

**2. What are some of the potential advantages of an SMP compared with a uniprocessor?**

1. Improved performance: Multiple processors can handle tasks in parallel.
2. Fault tolerance: If one processor fails, others may continue working.
3. Scalability: Additional processors can increase computing power.
4. Better resource utilization: Tasks can be balanced across processors for efficiency.

**3. What are some of the key OS design issues for an SMP?**

* Synchronization: Managing access to shared resources to avoid conflicts.
* Scheduling: Distributing tasks efficiently among processors.
* Cache coherence: Ensuring consistency of data across multiple caches.
* Deadlock and race conditions: Avoiding issues when multiple processors access the same data.
* Load balancing: Preventing overload on some processors while others are idle.

**4. What is the meaning of each of the four states in the MESI protocol?**

* Modified: The cache line is updated and differs from main memory. Only one processor has it.
* Exclusive: The cache line is the same as in main memory and exists only in one cache.
* Shared: The cache line is the same as in memory and may exist in multiple caches.
* Invalid: The cache line is not valid; it has been modified or removed by another processor.

**5. What are some of the key benefits of clustering?**

* High availability: If one node fails, others can take over.
* Load balancing: Workload can be spread across multiple nodes.
* Scalability: More nodes can be added to increase capacity.
* Fault tolerance: Redundancy and failover mechanisms enhance reliability.
* Performance: Distributed processing improves overall system throughput.

**6. What are the differences among UMA, NUMA, and CC-NUMA?**

* UMA (Uniform Memory Access):
  + All processors access shared memory with equal latency.
  + Suitable for small-scale multiprocessor systems.
* NUMA (Non-Uniform Memory Access):
  + Each processor has its own local memory.
  + Access to local memory is faster than to remote memory.
  + More scalable than UMA, used in large systems.
* CC-NUMA (Cache-Coherent NUMA):
  + A NUMA system with a cache coherence protocol (e.g., MESI).
  + Ensures data consistency between processor caches.
  + Combines performance benefits of NUMA with programming simplicity.