Chapter 8. Multiple processor systems

Non-uniform memory access

NUMA

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Agenda

01 **Basic concepts**

Some basic related concepts in multiprocessors

02 **What's NUMA?**

More detail information and characteristics of NUMA

03 **Assessment**

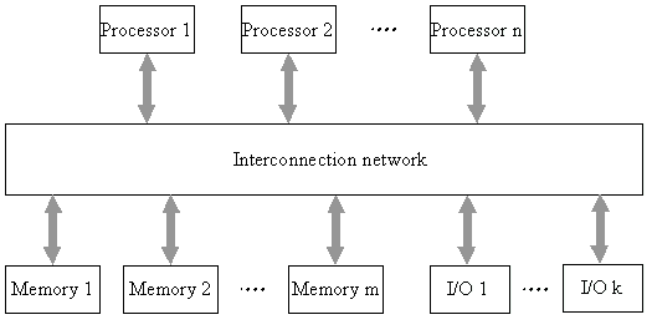
Comparison with UMA; pros & cons, its applications

Basic concepts

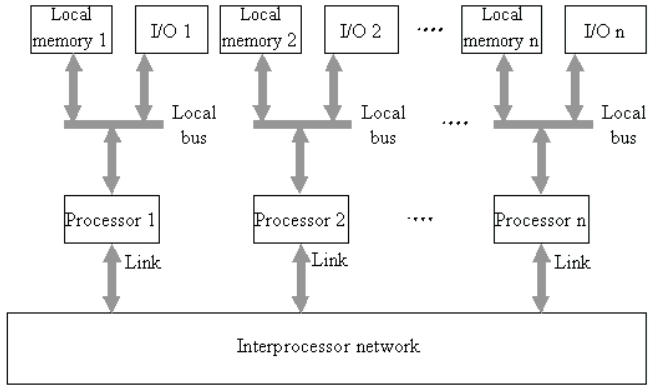
Multiprocessor

A computer system with two or more CPUs share full access to a common RAM.

Boost the system's execution speed



Shared-memory multiprocessor



Distributed memory multiprocessor

3 models

Uniform Memory Access (**UMA**)
Non-uniform Memory Access (**NUMA**)
Cache-only Memory Access (**COMA**)

Property

Every CPU can address all of memory.

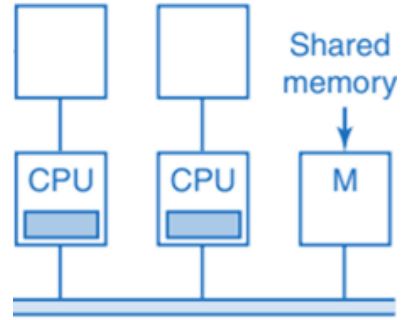
UMA (Uniform Memory Access)

- Single memory, accessed by all the processors
- Bus-based, crossbar switch, multistage switching network

Identical memory access latencies for any processor

Potential overload and becomes a performance **bottleneck**

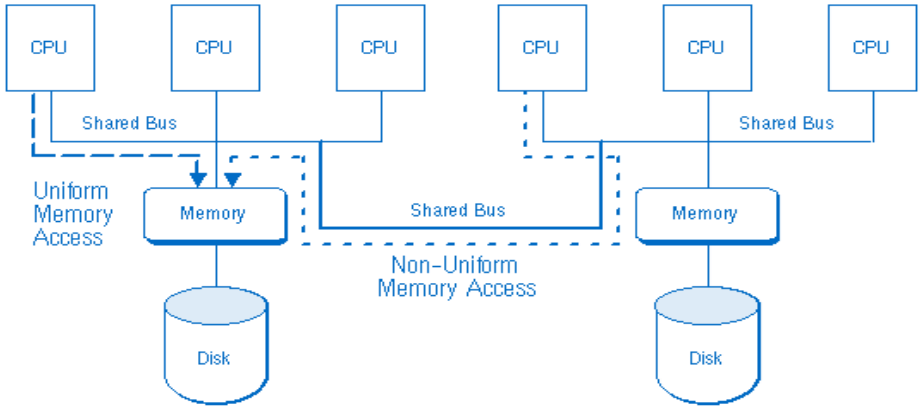
Performance will be **limited** by this memory organization!



Bus-based UMA (SMP) shared-memory

NUMA (Non-uniform Memory Access)

- Each processor connected with the dedicated memory.
- Logically follow in scaling from SMP architectures.
- Increase the available bandwidth to the memory



What's NUMA?

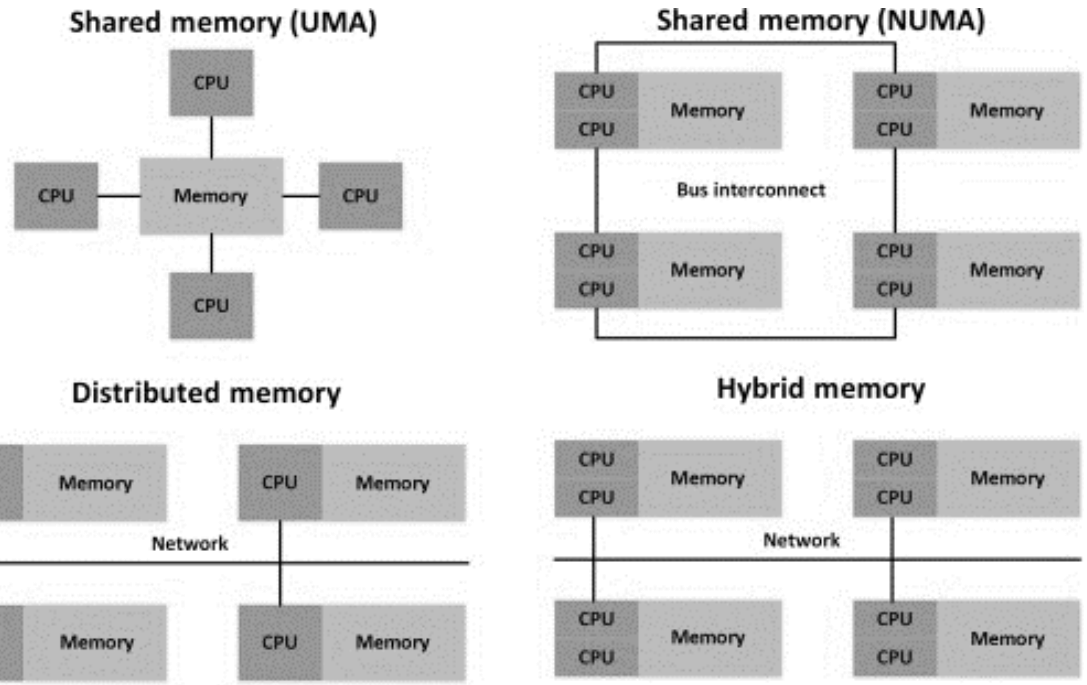
Definition

NUMA is a method of configuring a cluster of microprocessor in a multiprocessing system.

Key characteristics

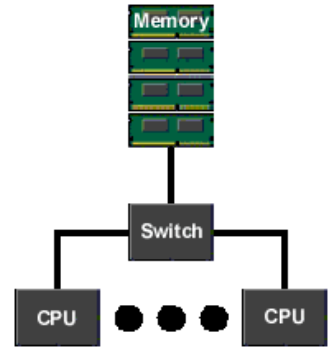
1. There is a single address space visible to all CPUs.
2. Access to remote memory via **LOAD/STORE instructions**.
3. Access local memory faster than remote memory.

→ **Vary memory access latencies**



Node of a NUMA machine

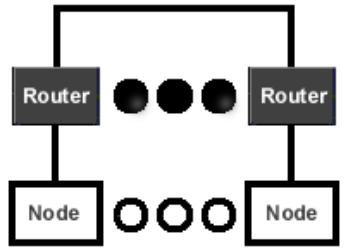
- UMA region – as a **node**.
- Node contains processors, bus, physical memory.
- Each core has a memory controller.



A Node

NUMA machine

- Multiple nodes are combined to form a NUMA machine.
- Link together via a fast interconnect.



Model of NUMA system

Drawbacks

- Performance of application depends on the number of nodes.

Design goal

- Make the routers as fast as possible, minimize the difference between local and remote memory references.
- Perfect (infinite) memory bandwidth
- Perfect (single-cycle) memory latency

→ **Ideal system**

Cluster computing

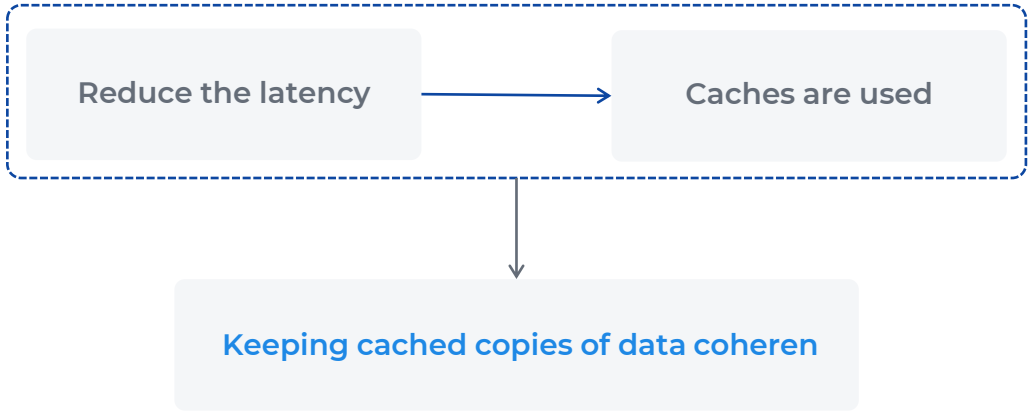
A "cluster in a box"

NUMA as a tightly-coupled form of cluster computing.

Maintain hierarchical view of the data on all the nodes.

Data is moved on the bus between the clusters of a NUMA system using **scalable coherent interface** (SCI) technology.

Problems



Non Cache-coherent NUMA → Simpler model, complex to program

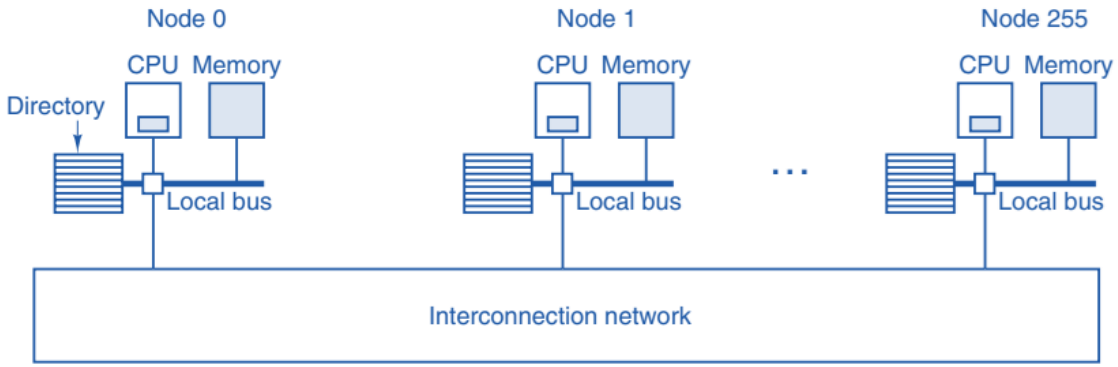
Cache-coherent NUMA → Enhance locality, easier programming

Cache - coherent NUMA

⚠ Complex structure + ⚠ Significant overhead

Solutions

- Keep a consistent memory image
- Allocate processors and memory in NUMA-friendly ways
- SCI define a **directory-based cache coherency protocol** - avoid scalability limitations



Benefits

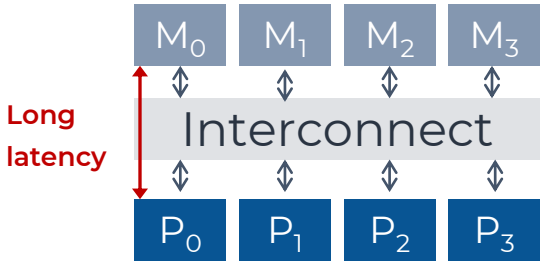
Migration: lower latency + more bandwidth

Replication: data being replicated to reduce latency + contention

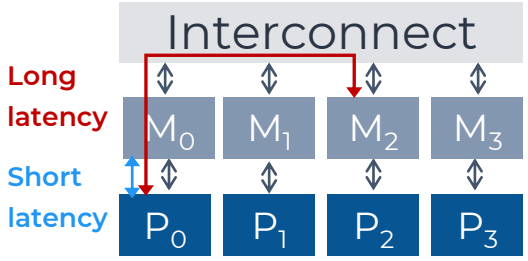
Assessment

Comparison with UMA

BASIS	UMA	NUMA
Basic	Single memory controller	Multiple memory controller
Bus type	Single, multiple and crossbar	Tree and hierarchical
Memory access latencies	Equal	Changes according to the distance of microprocessor
Suitable for	General-purpose & time-sharing applications	Real-time & time-critical applications
Speed	Slower	Faster
Bandwidth	Limited	More than UMA



UMA



NUMA

Conclusion

NUMA has improved the performance as compared to UMA architecture.

Advantages

- Share memory locally.
- Improving performance and ability of the system is expanded.
- Faster movement of data, less replication, easier programming.

Disadvantages

- If many remote node accesses, performance begins to break down.
- Synchronization
- Memory Consistency
- More complex hardware is needed.

Applications

Data mining

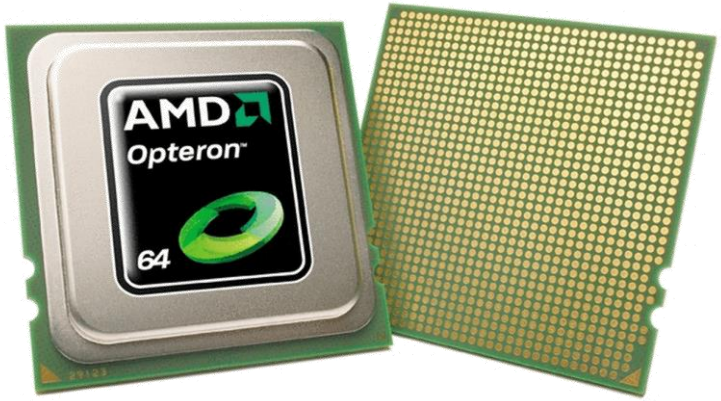
Database

Virtual machine

OpenMP Pthreads

Example

AMD64 Opteron



Processors are connected with high- speed **HyperTransport**.

The **Opteron** CPU directly supports up to an 8-way configuration.

As of 2011, CC-NUMA systems are multiprocessor systems based on the AMD Opteron processor.

Compare to Intel chip-set

The **Opteron** architecture has demonstrated better multi-processor scaling than the **Intel Xeon.**

Intel migrated to a memory architecture similar to the Opteron's for **Intel Core i7** family of processors and their Xeon derivatives.

References

[1] Modern Operating System ebook, Tanenbaum 4th edition, Chap 8.1

[2] Computer Science 246 slides, Prof. David Brooks (2010)

[3] Non-uniform memory access - wikipedia.org

[4] Non-uniform memory access, Bruce Jacon (2008) - sciencedirect.com

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[6] Difference between UMA & NUMA (2019) - geeksforgeeks.org

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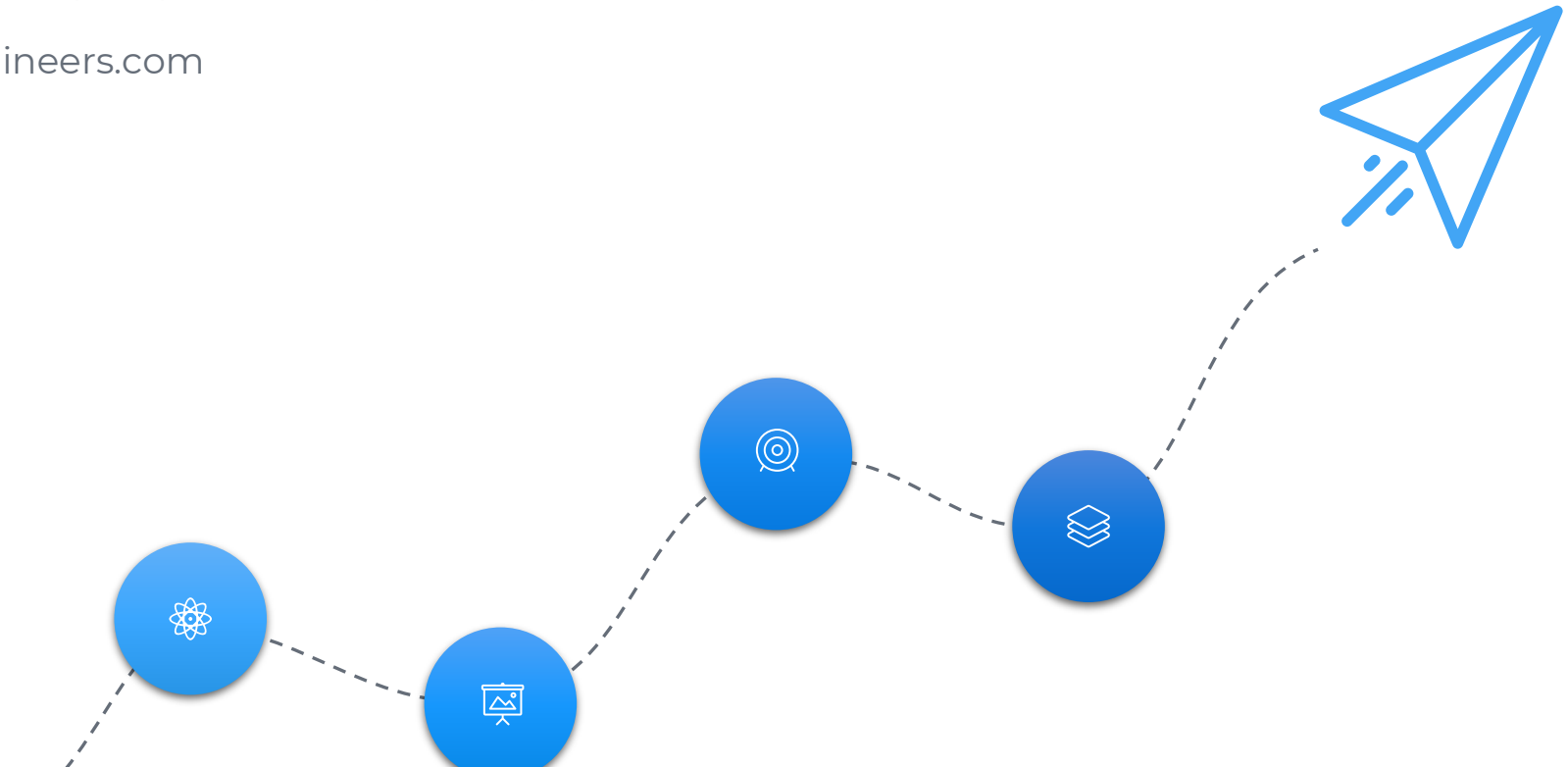

Thank you!

Goodbye!

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