

Staying CALM Beyond Deterministic Queries

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Distributed Consistency Beyond Queries

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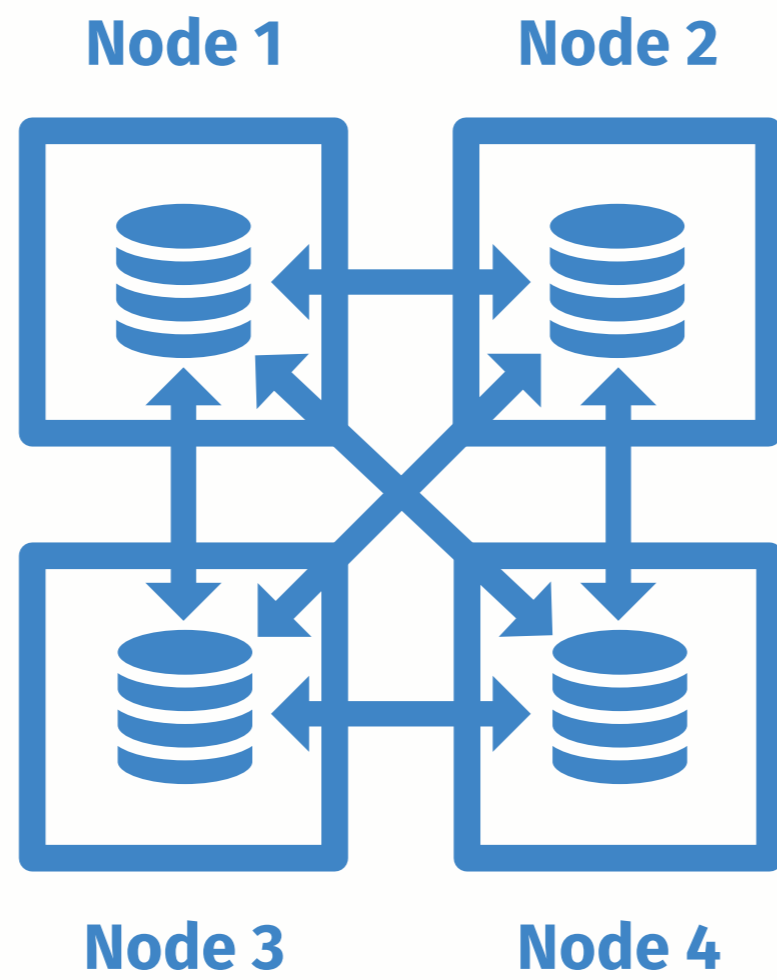
System Assumptions

Shared-Nothing

State is local to each node, communication is achieved through message passing

Asynchronous

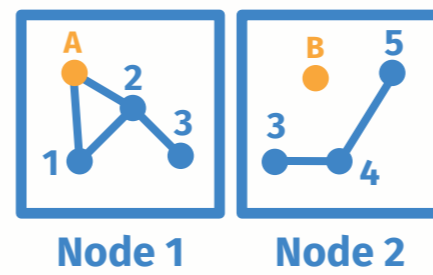
Messages may arrive out-of-order, and with arbitrary (but finite) delay.



Programs and Coordination

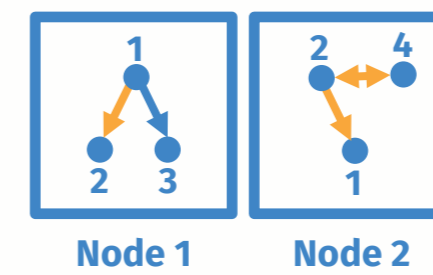
Connection

Is there a path from A to B?



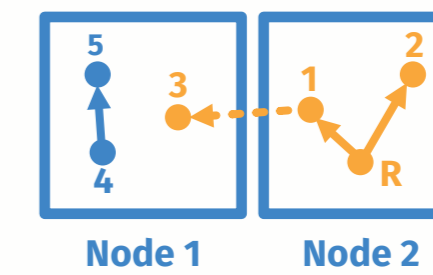
Deadlock Detection^[3]

Is there a cycle in the waits-for graph?



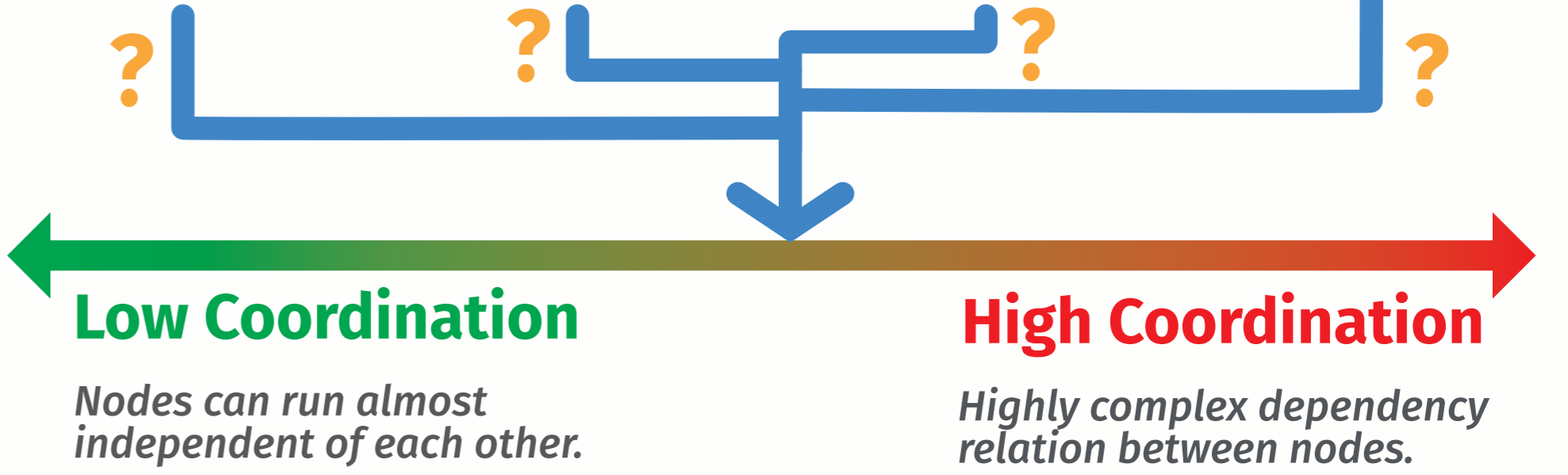
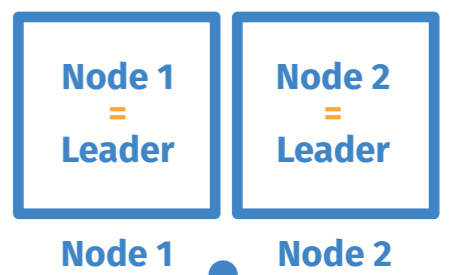
Garbage Collection^[3]

Is a memory object reachable from R?



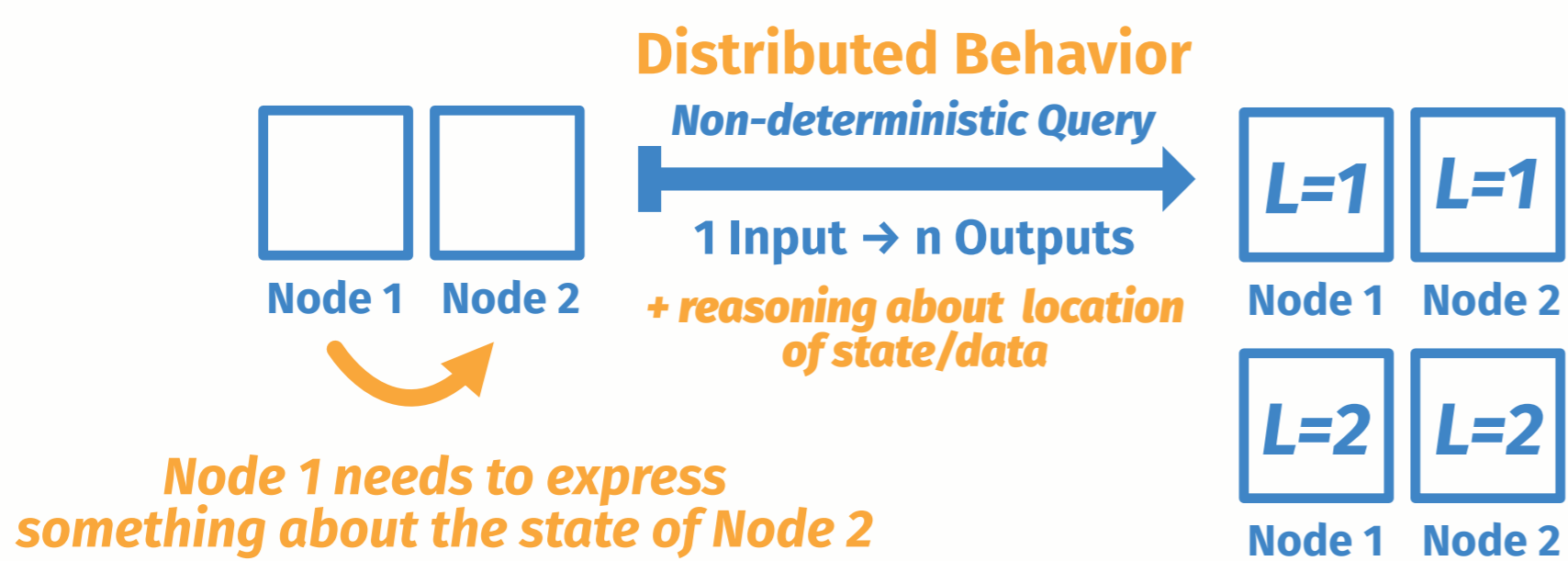
Leader Election

Do all nodes pick the same leader?



Distributed Behaviors

To express Leader Election semantically, we need **non-determinism** and **data placement**.



Modeling Systems With Behaviors

*This list is non-exhaustive, more examples in the full paper.

- Id** Nodes have a unique identity.
- Id+All** Each node knows the unique identity of all other nodes.
- Id+All+Ord** Each node agrees on an order over its stored data.
- Id+Ind** Each node knows part of a distributed index (i.e., the data partitioning strategy)

The CALM Theorem: A Coordination Spectrum

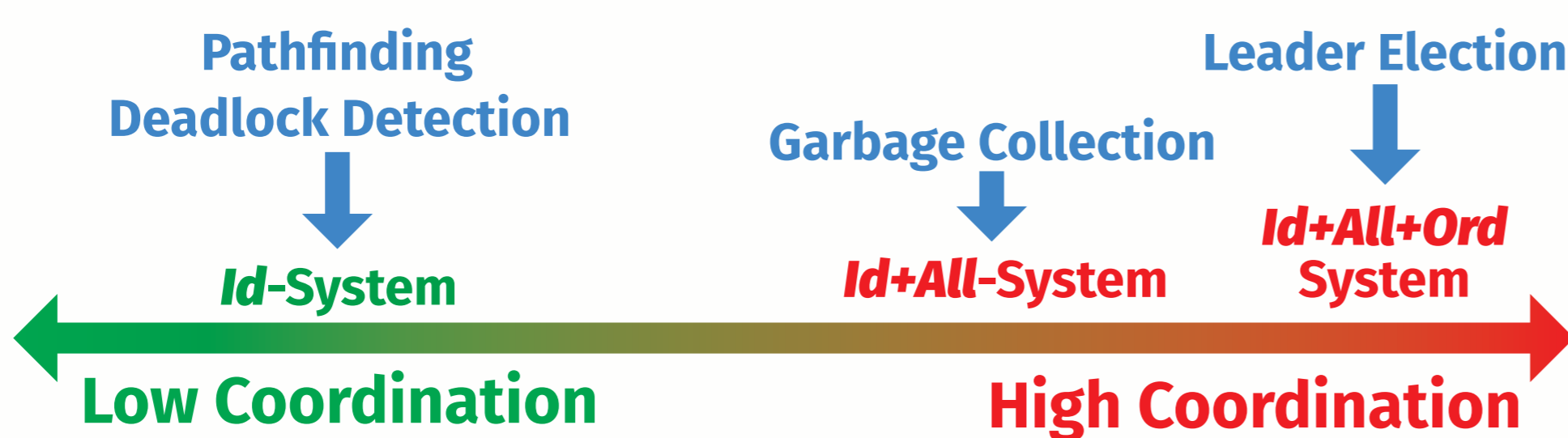
The CALM Theorem^[1,2] (Revisited)



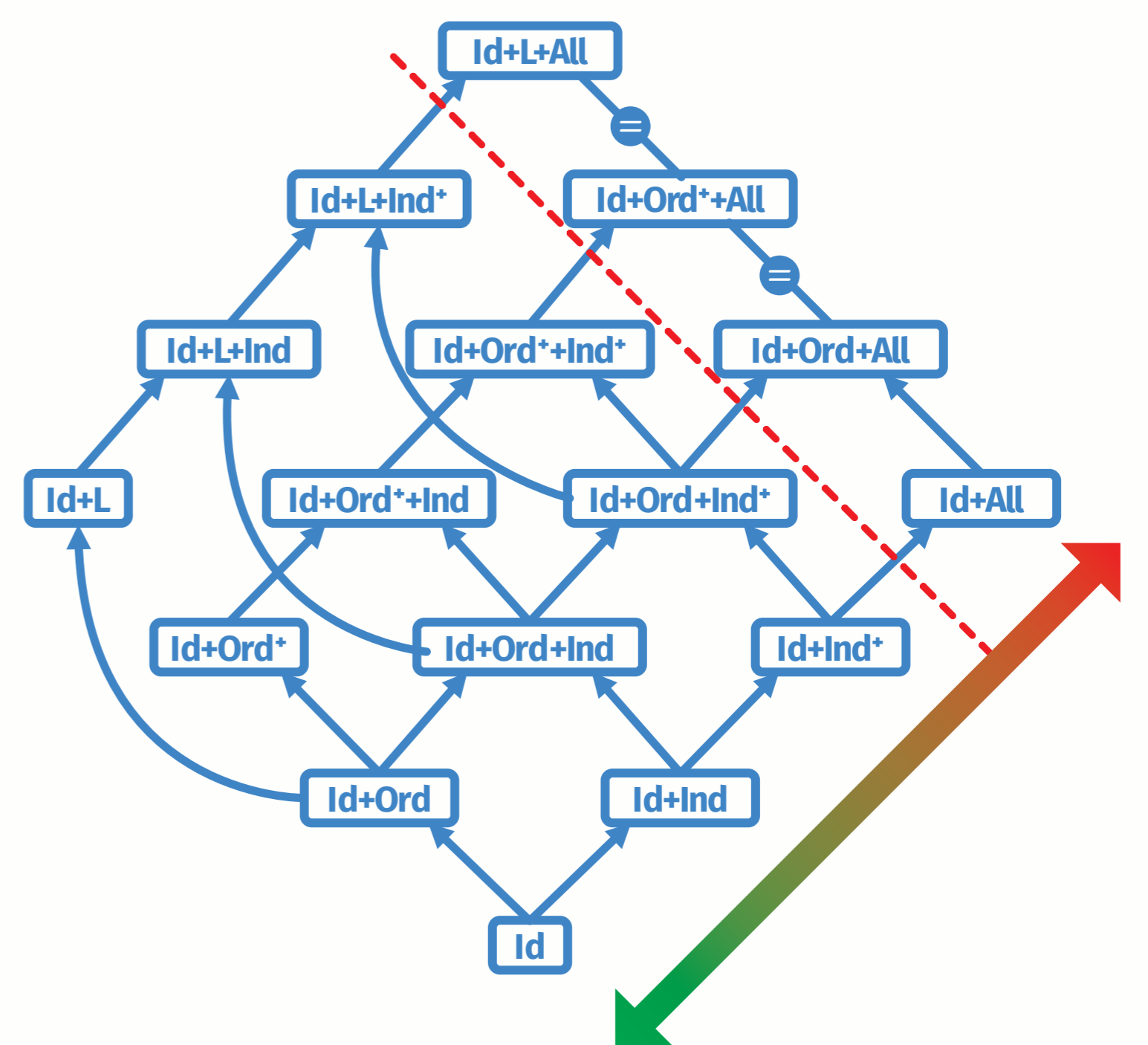
Monotonic Query^[1] **Id-System**^[1] No Coordination^[1]

Semi or Disjoint Monotonic Query^[2] **Id+Ind-System** or **Id+Ind*-System**^[2] Light Coordination^[2]

C-Monotonic Behavior **C-System** Depends on C



Use the system model to define coordination: "A stronger system model implies higher inherent coordination."



[1] Tom J. Ameloot, Frank Neven, and Jan Van den Bussche. 2013. Relational Transducers for Declarative Networking. *J. ACM*. 60, 2, 1-38.

[2] Tom J. Ameloot, Bas Ketsman, Frank Neven, and Daniel Zinn. 2016. Weaker Forms of Monotonicity for Declarative Networking: A More Fine-Grained Answer to the CALM-Conjecture. *ACM Trans. Database Syst.* 40, 4, 1-45.

[3] Joseph M. Hellerstein and Peter Alvaro. 2020. Keeping CALM: When Distributed Consistency is Easy. *Commun. ACM*. 63, 9, 72-81.