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A Study of Topological Connectivity with Some Binary Relations Using AND operation in the Hypercube Interconnection Network

Tiwari bhimnarayan[1], Premikar Shrinivash[2], Katare Rakesh Kumar[3]

Department of Computer Science, APS Univrsity, Rewa (MP) india[1]

Department of Computer Science, Govt College Raigaon, Satna (MP) India[2]

Department of Computer Science, APS Univrsity, Rewa (MP)[3]

Email: tiwaribhim18@gmail.com, premikar.cs@gmail.com

Abstract: *This study investigates the topological connectivity with binary relations of the Hypercube interconnection networks, a widely used topological structure through hypercube formations for parallel computing systems. The presents an innovative approach to analyzing network connectivity between processors or nodes through matrix binary relations, specially focusing on binary relations and connectivity using logical AND operations, to establish topological links and sub graph patterns. The describes connectivity binary relations on a combination of Hamming distance and specific Boolean relations, analyzed the connectivity of 1D (Line Segment), 2D (Square), 3D (Cube), etc. hypercube patterns via matrix binary relations. The focuses of this study that used an AND operation to selectively refine connectivity of binary relations, that supports regarding into different topological structures in hypercube networks, vertex symmetric behaviors, and the hypercube formation of disjoint paths under specific topological properties. Additionally, the findings are validated outcomes with modeling the hypercube formations as a relation matrix, evaluating relationship operations, and comparing the resulting structural patterns of connectivity with traditional direct linkage methods association.*

Keywords: Hypercube Interconnection Network, Topological Connectivity & Binary Relations, AND Operation, Relation Matrix, Topological mapping, etc

I. INTRODUCTION

This study focuses on analyzing the topological properties and connectivity patterns within the hypercube interconnection network. The hypercube interconnection network, or binary n-cube, is a foundational parallel topological processing collected of nodes or processors, where each node is labeled with an n-bit binary string. Nodes are connected directly if their binary addresses differ by exactly one bit, offering a low diameter, high fault tolerance, and effective recursive structure for parallel computation. The topological connectivity of these networks is often analyzed by evaluating the relationships between node addresses, specifically using binary logical operations to define adjacency and path finding. It explores specific relationships between node addresses by implementing binary operations, particularly the AND operation, along with others for steering and structural analysis with different patterns. The some aspects of this study contain:

Binary Relations: This research study derives relationships between node addresses to recognize structural patterns in Line Segment (1D), Square (2D), Cube (3D), and Tesseract (4D) hyper-cubes and extends these findings from the n-bit hypercube formation.

AND Logical Operation: This learning uses the AND operation expected in combination with other bitwise operations to investigate specific topological properties and connectivity between nodes or processors.

Topological Mapping: This study maps the hypercube associations to analyze the topological structure, frequently including in the improvement of resourceful relational communication and identifying the reflecting outcome between nodes of the hypercube formation.

Indexing and Addressing: The involving binary gray coding is commonly used toward index nodes or processors align with the Hamming distance property somewhere adjacent nodes are different by a single bit.

Topological Formations of Hypercube

Topological connectivity in a binary hypercube or n-cube interconnection networks are frequently analyzed using binary relations and logical operations on node addresses. The hypercube, consisting of nodes, is defined by a structure where two nodes are connected if their binary representations differ by exactly one bit. The bitwise AND operation is used to identify sub-cubes within a larger hypercube. Through using AND to node addresses, the network can be partitioned into smaller, disjoint, or overlapping sub-cubes. This helps in mapping parallel algorithms onto the architecture. The logical AND operation is a fundamental finding or selection mechanism used to drawing study between processors or nodes/vertices by analyzing their binary relations, logically in the context of routing in the communication within sub-cube structure patterns. So, in a hypercube with 2^n nodes, each node is labeled with a unique n-bit string. Here in this study have been some examples of AND operations diagonally different dimensions:

1D Hypercube (Line Segment): In a hypercube (fig. 1), the AND operation is used to find the intersection of vertices or to determine the "lowest common ancestor" sub-element between two points. Think of each vertex as a binary coordinate, the AND operation compares each bit.

A 1D hypercube has $\mathbf{2^1 = 2}$ nodes, labeled n1(**0**) and n2(**1**) in fig. 1.

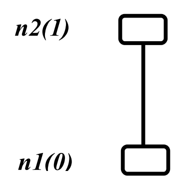

Fig.1 One cube (Line Segment: $2^1 = 2$)

S. No.	node	n1	n2	Relation	Summary
1.	n1	0	1	1	R-> n1 = n2
2.	n2	1	0	1	R-> n2 = n1
	Each nodes shows only one binary relation (connectivity)				

Table1. Topological connectivity relationship

Operation: 1 AND 1 = 1 otherwise the result always is 0.

Here vertices: n1(0) and n2(1)

then n1 AND n2 = 0 (only one relation between one to another)

The AND operation between any node and the node n(0) result in n(0) .

2D Hypercube (Square): This it understand, if you take the top-right corner and the bottom-right corner their shared bitwise component is the bottom-right corner itself.

A 2D hypercube has $\mathbf{2^2 = 4}$ nodes, typically labeled n1(00), n2(01), n3(10), n4(11) in Fig. 2.

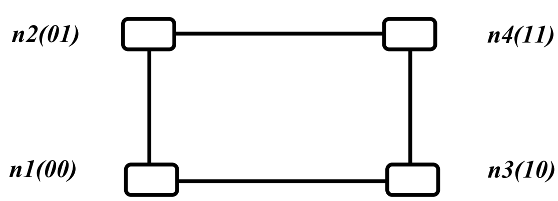

Fig.1 Two cube (Square: $2^2 = 4$)

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S. No.	node	n1	n2	n3	n4	Relation	Summary
	n1	0	1	1	0	2	R-> n1 = n2,n3
	n2	1	0	0	1	2	R-> n2 = n1,n4
	n3	1	0	0	1	2	R-> n3 = n1,n4
	n4	0	1	1	0	2	R-> n4 = n2,n3
Each nodes shows two binary relation (connectivity)							

Table2. Topological connectivity relationship

Here vertices: n1(00), n2(01), n3(10), n4(11)

Logical AND operation: n3(10) AND n4(11) = n3(10)

Logical AND operation: n2(01) AND n3(10) = n1(00)

Find nodes where the first bit is 1 AND the second bit is 1" n4(11). The node n4(11) is the intersection of the edges originating from n2(01) and n3(10) in a higher-order operation.

3D Hypercube (Cube): In a three-cube structure, node n1(000) may communicate with n4(011) (from n1 to n3 to n4 or from n1 to n2 to n4). It should cross at least three links to communicate from node n1(000) to node n8(111).

A 3D hypercube has $\mathbf{2^3 = 8}$ nodes like n1(000) through n8(111) ex. Fig.3.

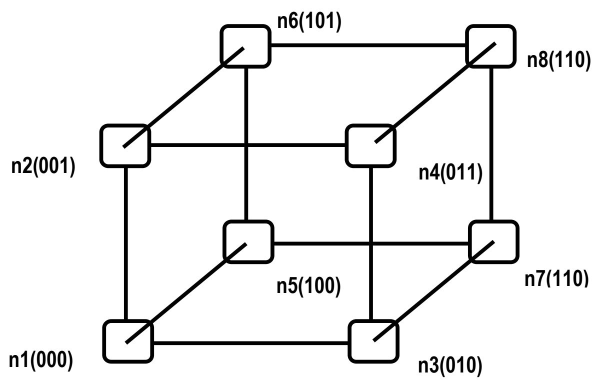

Fig.2 Three cube (Cub: $2^3 = 8$)

S. No.	Node	n1 (000)	n2 (001)	n3 (010)	n4 (011)	n5 (100)	n6 (101)	n7 (110)	n8 (111)	Relation (degree)	Summary
	n1	0	1	0	1	0	1	0	0	3	R-> n1 = n2,n4,n6
	n2	1	0	1	0	1	0	0	0	3	R-> n2 = n1,n3,n5
	n3	1	0	0	1	0	0	1	0	3	R-> n3 = n1,n4,n7
	n4	1	0	1	0	0	0	0	1	3	R-> n4 = n1, n3,n8
	n5	0	1	0	0	0	1	1	0	3	R-> n5 = n2,n6,n7
	n6	1	0	0	0	1	0	0	1	3	R-> n6 = n1, n5,n8
	n7	0	0	1	0	1	0	0	1	3	R-> n7 = n3,n5,n8
	n8	0	0	0	1	0	1	1	0	3	R-> n8 = n4,n6,n7

Each node shows three binary relations (connectivity).

Table3. Topological connectivity relationship

Here vertices: n1(000) from first to last n8(111).

Logical AND operation: n7(110) AND n3(010) = (010)

Logical AND operation: n8(111) AND n6(101) = (101)

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This selects a 1D sub-cube (edge) consisting of 011 and 111 (node where last two bits are 1). The AND operation allows finding the intersection of faces or identifying specific neighbors in a 3D grid.

4D Hypercube (Tesseract): In a 4D hypercube, the **AND operation** is primarily used in the context of Boolean hypercube networks and binary addressing, where each of the 16 vertices is represented by a 4-bit binary string. The AND operation (A^B) is applied bitwise, resulting in a new vertex that exists within the same 4D network.

A 4D hypercube has 2^6 = 16 nodes n(0000 through n(1111).

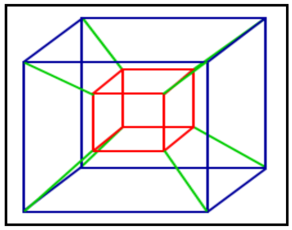

Fig.4 Example of 4D Hypercube

For example:

Let A = n(1011) and Let B = n(1100)

Result with AND operation: A ^ B = n(1000). *(Only the first bit remains active)*

Let A = n(1011) and Let B = n(1100)

Result with AND operation: A ^ B is = n(1000). *(Only the first bit remains active)*

The above operations are important for routing communication in a 4D parallel computer. This defines a 2D sub-cube (square) consisting of nodes n(1000), n(1001), n(1100), n(1101) (Nodes where 1st bit is 1 AND 3rd bit is 0). So, 4D hyper cubes are often used in parallel processing, where node addresses are used to compute efficient data routing paths, such as checking if two nodes share a specific cube facet in 4D space.

Topological Connectivity Through AND Operation

Topological connectivity in a binary hypercube interconnection network using AND, binary relations refers to analyzing the structure, node adjacency, and communication paths by applying logical AND operations to the n-bit binary addresses of the processing nodes. The hypercube consists of n nodes or processors, where two nodes are connected if their addresses differ by exactly one bit. Hypercube has considers some significant topological connectivity via AND binary operations such as Adjacency and Binary Relation, logical AND operation Sub-cube recognition, Connectivity Patterns, Path Calculation etc.

II. CONCLUSION AND FUTURE WORK

The outcome of this study that analyzed topological connectivity between node (processor) with the help of binary relationship matrix using AND operations in the hypercube interconnection network. Table1, 2 and 3 has showing maximum possible connectivity between nodes through Fig. 1, Fig. 2, and Fig. 3 (1D, 2D and 3D). Hypercube formation 1D, showing only one connectivity of binary relation (table1) in each node, 2D, showing two maximum connectivity of binary relation (table2) in each nodes and 3D, showing maximum three connectivity of binary relation (table3) in each nodes. Its retains most of the properties both the balanced hypercube formation and analyzed different topological binary relations with better experience. The future scope for analysis complexity and topological connectivity can use AND based binary relations in hypercube interconnection networks focuses on enhancing fault tolerance, improving routing efficiency, decompositions and reducing complexity in extensive parallel systems.

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