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Study of Data Structure and Symmetry Properties for Interconnection Network

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Abstract:
Study of Symmetry properties and Data structure is play a key role to analysis connectivity and complexity of interconnection network. Symmetric property allows reverse engineering in connectivity and complexity, that useful for effective design and scaling and synthesis of new interconnection network by modifying the structural properties of architecture. Our approach is based on the data structure for study relation between nodes which helps to reduce the connectivity and complexity.

Keywords:
PDS, PDN, Interconnection Network, Data Structure, Symmetry

Introduction:

The Structural relationship between nodes of interconnection networks plays a key role in the study of performance of parallel and distributed architecture[1,11]. Perfect difference set based architectures is one of the most important interconnection networks that focuses upon the evaluation and applications of parallel and distributed architecture. Difference set-based architectures have received greatly focus over the past decade since they propose a wealthy interconnected structure with a number of attractive properties such as low diameter, degree, high bisection width, smaller complexity and Cost[2,12]. PDN is a one of the most popular difference set based Interconnection network[3]**.** In Parallel computer, the perfect difference network has been broadly used as the interconnection network[4]. However, the number of communication links for each node is a polynomial function of the total number of nodes in PDN[5,13].In this paper data structure and basic of symmetric relation of interconnection network based on the perfect difference based architecture is brief discussed along with their connectivity and complexity. PDN (perfect Difference Network) has better properties in terms of degree, diameter, average latency, routing & communication pattern, network flow throughput, and path diversity[6,13]. It also takes advantage of increasing nodes of scaling process. The comparative study suggests the methods to overcome the above restrictions besides having attractive properties.

Study of Data Structure for Interconnection Network

Let consider a example to calculate a factorization PA = LU. Linear system of the Ax = b?[11,13] Permuting the rows of A and b, we have

PAx = MNx = Pb;

and therefore

$x = N^{-1} M^{-1}Pb$

So we can reduce the problem of finding x to two simpler problems:

1. Solve My = Pb
2. Solve Nx = y

We assume the matrix M is unit lower triangular (diagonal of all ones + lower triangular), and N is upper triangular, so we can solve linear systems with M and N involving forward and

backward substitution. As a concrete example, suppose

$$M = \begin{pmatrix} 1 & 0 & 0 \\ 2 & 1 & 0 \\ 3 & 2 & 1 \end{pmatrix} \qquad N = \begin{pmatrix} 1 \\ 1 \\ 3 \end{pmatrix}$$

To solve a linear system of the form My = d, we process each row in turn to find the value of the corresponding entry of y:

1. Row 1: $y_1 = d_1$
2. Row 2: $2y_1 + y_2 = d_2$, or $y_2 = d_2 - 2y_1$
3. Row 3: $3y_1 + 2y_2 + y_3 = d_3$, or $y_3 = d_3 - 3y_1 - 2y_2$

More generally, the forward substitution algorithm for solving unit lower tri-angular linear systems Ly = d looks like

```
y = d;
for i=2:n
y (i) = d(i) - L(1:i-1) * y(1:i-1)
end
```

Similarly, there is a backward substitution algorithm for solving upper triangular linear systems Ux = d[14,15]

```
x(n) = d(n) / U(n,n);
for i = n - 1: - 1 : 1
x (i) = ( d(i) - U(i+1:n) * x(i+1:n) ) / U(i,i)
end
```

$O(n^2)$ is a time complexity of mention algorithm.

PRAM algorithm for simple matrix multiplication:

Matrix multiplication is a common popular operation in matrix for communication. Here we discuss common matrix multiplication operation with n = nodes in PDN.

```
Begin
    Repeat logn times do
        for all (ordered) pair (i,j,k)
            0 < k ≤ n, 0 < i = j =k ≤ n
            in parallel do
             for all (ordered) pair     (i,j,k)
             0 < k ≤ n, 0 < i = j =k ≤ n
           cij = 0 or sum = 0
          end for
        end for
      for all (ordered) pair (i,j,k)
          0 < k ≤ n, 0 < i = j =k ≤ n
          cij = cij + aik * bkj
          sum = sum + aik * bkj
    end for
    End
```

Strassen's Matrix :-

Stassen's algorithm is a Divide-and-Conquer algorithm that beat the bound. The usual multiplication of two n x n matrices takes[14,15]

$$A = \begin{pmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \end{pmatrix} B = \begin{pmatrix} b_{11} & b_{12} \\ b_{21} & b_{22} \end{pmatrix}$$

$$C = \begin{pmatrix} c_{11} & c_{12} \\ c_{21} & c_{22} \end{pmatrix}$$

If C = A * B, then we have the following:

$$\begin{pmatrix} c_{11} & c_{12} \\ c_{21} & c_{22} \end{pmatrix} = \begin{pmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \end{pmatrix} * \begin{pmatrix} b_{11} & b_{12} \\ b_{21} & b_{22} \end{pmatrix}$$

Formula for C_{11}, C_{12}, C_{21}, and C_{22} :

$$c_{11} = a_{11}b_{11} + a_{12}b_{21} \quad ,$$

$$c_{12} = a_{11}b_{12} + a_{12}b_{22}$$

$$c_{21} = a_{21}b_{11} + a_{22}b_{21} \quad ,$$

$$c_{22} = a_{21}b_{12} + a_{22}b_{22}$$

Strassen's algorithm is based observation:

$S_1 = (a_{11} + a_{22}) * (b_{11} + b_{22})$
$S_2 = (a_{21} + a_{22}) * (b_{11})$
$S_3 = (a_{11}) * (b_{12} - b_{22})$
$S_4 = (a_{22}) * (b_{21} - b_{11})$
$S_5 = (a_{11} + a_{12}) * (b_{22})$
$S_6 = (a_{21} - a_{11}) * (b_{11} + b_{12})$
$S_7 = (a_{12} - a_{22}) * (b_{21} + b_{22})$

$C_{11} = S_1 + S_4 – S_5 + S_7 = a_{11}\, b_{11} + b_{12}\, b_{21}$

$C_{12} = S_3 + S_5 = a_{11}\, b_{12} + a_{12}\, b_{22}$

$C_{21} = S_2 + S_4 = b_{21}\, b_{11} + a_{22}\, b_{21}$

$C_{22} = S_1 + S_3 – S_2 + S_6 = a_{21}\, b_{12} + a_{22}\, b_{22}$

Sequential algorithm for Straightforward matrix multiplication:

The First Attempt Straightforward from the formulas above (assuming that n is a power of 2):

MMult(A,B, n)

1. If n = 1 Output A × B
2. Else
3. Compute $A_{11},B_{11}, \ldots ,A_{22},B_{22}$ by computing m = n/2
4. $S_1 \leftarrow$ MMult($A_{11}B_{11}$, n/2)
5. $S_2 \leftarrow$ MMult($A_{12}B_{21}$, n/2)
6. $S_3 \leftarrow$ MMult($A_{11}B_{12}$, n/2)
7. $S_4 \leftarrow$ MMult($A_{12}B_{22}$, n/2)
8. $S_5 \leftarrow$ MMult($A_{21}B_{11}$, n/2)
9. $S_6 \leftarrow$MMult($A_{22}B_{21}$, n/2)
10. $S_7 \leftarrow$MMult($A_{21}B_{12}$, n/2)
11. $S_8 \leftarrow$ MMult($A_{22}B_{22}$, n/2)
12. $C_{11} \leftarrow S_1 + S_2$
13. $C_{12} \leftarrow S_3 + S_4$
14. $C_{21} \leftarrow S_5 + S_6$
15. $C_{22} \leftarrow S_7 + S_8$
16. Output C
17. End If

Sparse Matrix:

As we have seen, the LU decomposition[16] of the matrix **RST** is used to solve the linear system of equations **Ax = b** by sequentially solving Equation 1 through Equation 1, which are repeated below.

y = **Pb**
M**c** = **y** …….. (A)
N**z** = **c**
x = **Qz**

Sparsity techniques benefit this process. The algorithms presented in this section assume:

• An LU decomposition of **RST** exists.

• The factorization is maintained in a sparse matrix data structure which supports the scan and get operators.

• The row permutations **P** are represented by a mapping ψ whose domain is a row index in **A** and whose range is the corresponding row index in **RST**.

• The column permutations **Q** are represented by a mapping τ whose domain is a column index in **RST** and whose range is the corresponding column index in **A**. For simplicity of exposition, it is assumed that the vectors **b**, **c**, **x**, **y**, and **z** are stored in linear arrays. However, any data structure that lets you retrieve and update an element of a vector based on its index will suffice[16,17,18].

LU Decomposition of a Sparse Matrix by Doolittle's Method

for $i = 2, \ldots .. , n$

while [j =scan (**A** ,row i, 1, n, a)] ≠ finished

push_scan

$\alpha = a$

m = min ($-1, j-1$)

while [p =scan (**A** ,row i, 1, m, a)] ≠ finished

$b = a$

i f get (**A**, p, j, a) is successful

$\alpha = \alpha - ab$

i f $i > j$

get (**A**, j, j, a)

$\alpha = \alpha$

a

$a = \alpha$

put (**A**, i, j, a)

pop_scan

Perfect Difference Set

As we know from remainder theorem that

Numerator = Remainder + Denominator * Quotient.

The Perfect Difference Set (PDS)[6,7] can be formulated from remainder theorem as an integer (numerator) is equal to the addition of remainder and denominator here quotient is one. Now integer is a member of set of (1, 2, ..., $\delta^2 + \delta$), where δ is a prime or power of prime and the remainder is the difference $S_i – S_j$,

where $i \neq j$, $0 \leq j, j \leq \delta$

So we can write that $(\delta^2 + \delta) = (S_i - S_j) + (\delta^2 + \delta + 1)*Q$

or

$(S_i - S_j) = (\delta^2 + \delta) - (\delta^2 + \delta + 1)*Q$

Definition of Perfect Difference Set: A set {s0, s 1, ……..,sδ} of $\delta + 1$ integers having the property that their $(\delta^2 + \delta)$ differences, $0 \le i, \ne j \le \delta$ are congruent modulo $(\delta^2 + \delta + 1)$, to the integers 1, 2,…….., $\delta^2 + \delta$ in some order is a perfect difference set of order δ[8,9]. Perfect Difference sets [49] are sometimes called simple difference sets, given that they correspond to the special $\delta = 1$ case of difference sets for which each of the possible differences is formed in exactly δ ways, where δ is a prime or power of prime and

$n = (\delta^2 + \delta + 1)$ and $(S_i - S_j) = (\delta^2 + \delta) \bmod n$

Evaluation of PDS: The Perfect Difference Set of each node of the PDN can be evaluated by the remainder theorem i.e.,

N=R+D * Q,

Where N = Numerator, R = Remainder, D and Q = Quotient

The above equation can be written as

Integer = $(S_i - S_j) + (\delta^2 + \delta + 1)*1$

Where integer is a member of the set (l, 2,……., $\delta^2 + \delta$) and $S_i - S_j$ is numerator or the difference set.

So we can write as –

$(S_i - S_j) = (\text{Integer}) \bmod (\delta^2 + \delta + 1)$ [7,10]

Lemma 1: Perfect Difference Network has a half of $(\delta^2 + \delta + 1)^2 + (\delta^2 + \delta + 1)$ symmetric relation with Binary choice.

Sol^n :

As we know PDN has $(\delta^2 + \delta + 1)$ nodes. If we consider δ=2. The node is named as 0,1,2, …, $(\delta^2 + \delta)$.

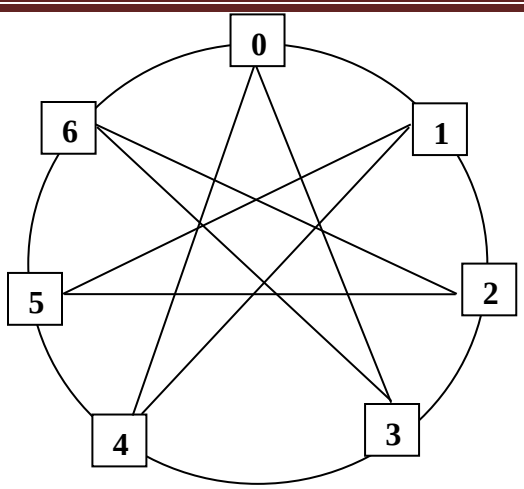


Fig: PDN with δ=2

Here we consider reachability (path) as a relation. In PDN each node has connect to all other nodes. Node i have following connection:

$n_i + 1$

$n_i + S_j \pmod n - 1$

$n_i + S_j \pmod n$

$n_i - S_j \pmod n$

$n_i - S_j \pmod n + 1$

$n_i - 1$

So n_i has $(\delta^2 + \delta)$

Example

Node "0"

	Node	diameter
$n_i + 1$	1	1
$n_i + S_j \pmod n - 1$	2	2
$n_i + S_j \pmod n$	3	1
$n_i - S_j \pmod n$	4	1
$n_i - S_j \pmod n + 1$	5	2
$n_i - 1$	6	1

Node "1"

	Node	Diameter
$n_i + 1$	2	1
$n_i + S_j(\text{mod } n) - 1$	3	2
$n_i + S_j(\text{mod } n)$	4	1
$n_i - S_j(\text{mod } n)$	5	1
$n_i - S_j(\text{mod } n) + 1$	6	2
$n_i - 1$	0	1

Node "$(\delta^2 + \delta)$"

	Node	Diameter
$n_i + 1$	0	1
$n_i + S_j(\text{mod } n) - 1$	1	2
$n_i + S_j(\text{mod } n)$	2	1
$n_i - S_j(\text{mod } n)$	3	1
$n_i - S_j(\text{mod } n) + 1$	4	2
$n_i - 1$	5	1

so, ni has $(\delta 2 + \delta)$ connection + 1 self loop.

Therefore $(\delta 2 + \delta + 1)$ node has $(\delta 2 + \delta+1)2$ connectivity. and $(\delta 2 + \delta + 1)$ self loop.

The total relation (excluding self loop) is exist in PDN is $(\delta 2 + \delta + 1)2 - (\delta 2 + \delta +1)$.

Symmetry relation allow self relation so $(\delta 2 + \delta + 1)$ is in symmetric relation and rest of relation have choice. If there is relation between node1 node2 (1,2) then the relation (2,1) is compulsory . we have binary choice may be or may not be.

$$2^{(\delta 2 + \delta + 1)} * 2^{((\delta 2 + \delta + 1)2 - (\delta 2 + \delta + 1))/2}$$

$$2^{(2(\delta 2 + \delta + 1) + (\delta 2 + \delta + 1)2 - (\delta 2 + \delta + 1))/2}$$

$$2^{\{|(\delta 2 + \delta + 1)2 + (\delta 2 + \delta + 1)|/2\}}$$

$$2^{(\delta 2 + \delta + 1((\delta 2 + \delta + 1)) + 1)/2)}$$

Hence, we may say that Perfect Difference Network has a half of $(\delta 2 + \delta + 1)\, 2 + (\delta 2 + \delta + 1)$ symmetric relation with Binary choice.

We can also proof above lemma by using matrix and set. First of all we are converting the PDN into its equivalent $(\delta 2 + \delta + 1) * (\delta 2 + \delta + 1)$ dense matrix. The diagonal relation show the self connectivity that is $\delta 2 + \delta + 1$ relation. And the upper and lower triangle matrix is depend each other if $(\delta 2 + \delta)$ is connect to 0 than 0 is also connect to $(\delta 2 + \delta)$. The connection matrix(reach ability) of PDN is represent as below:

	0	1	2	3	4	5	6
0	1	1	1	1	1	1	1
1	1	1	1	1	1	1	1
2	1	1	1	1	1	1	1
3	1	1	1	1	1	1	1
4	1	1	1	1	1	1	1
5	1	1	1	1	1	1	1
6	1	1	1	1	1	1	1

For example,

$A = \{1,2,3,4,\ldots, (\delta^2 + \delta)\}$

Universal Relation $A = (\delta^2 + \delta+1)* (\delta^2 + \delta+1)$. let consider $N=(\delta^2 + \delta+1)$

A Total of n^2 Ordered Pair lie in universal Relation on A.

These ordered pairs –$((\delta^2 + \delta + 1) -N)$

Non- Diagonal ordered pair $(((\delta^2 + \delta + 1)^2 - (\delta^2 + \delta + 1))$

We null select ordered pair (2,1) that means if we selected ordered pair (1,2) then ordered pair (2,1) already selected same logic applied for other ordered pair also in upper triangle This implies we can either selected or not selected out of $(n^2 -n) /2$ ordered pair in upper triangle in

$$2^{\frac{(N^2 - N)}{2}}$$

Total number of symmetric relation on set A having n element is equal to

Number of way of selected diagonal ordered pair * number of way of selecting non- diagonal ordered pair

$$= 2^N * 2^{\frac{(N^2 - N)}{2}}$$

$= 2^{N+\frac{(N^2-N)}{2}}$ ex. $\frac{n_+}{1}\ \frac{(N^2-N)}{2}$

$= 2\ \frac{(N^2+N)}{2}$ $\frac{2n+N^2-N)}{2}$

$= 2^{N\frac{(N^2+1)}{2}}$

$= N+N^2$

$= \frac{N^2+N}{2}$

Lemma 2- There are ($\delta^2+\delta$) -2δ node is reachable form node i with two hops.

Proof:- From the definition of PDN, it is clear that PDN has $\delta^2+\delta+1$ node where δ is prime or power of prime each node having circular and chord link

Circular link

Node	Connection
Node 0	1,6
Node 1	2,0
Node 2	3,1
Node 3	4,2
Node 4	5,3
Node 5	6, 4
Node 6	0,5

Chord link

Node 0	4,3
Node 1	5,4
Node 2	6,5
Node 3	0,6
Node 4	1,0
Node 5	2,1
Node 6	3,2

B. Prahami & M. Rakov also Proof earlier [] that the Sum of indegree and outdegree of each node of PDN is 2δ therefore any node is reachable from node is in maximum two hopes.

Example: PDN with δ=2

($\delta^2+\delta$)-2*δ

(2^2+2) – 2*2

6-4 = 2

Node	Two hope nodes
0	2, 5
1	3, 0
2	4, 0
3	5, 1
4	6, 2
5	0,3
6	1,4

Example PDN with δ =3

($\delta^2+\delta$)-2*δ

(3^2+3) -2*3

= 12-6 =6

Node	Two hope node					
0	2	5	6	7	8	11
1	3	6	7	8	9	12
2	4	7	8	9	10	0
3	5	8	9	10	11	1
4	6	9	10	11	12	2
5	7	10	11	12	0	3
6	8	11	12	0	1	4
7	9	12	0	1	2	5
8	10	0	1	2	3	6
9	11	1	2	3	4	7
10	12	2	3	4	5	8
11	0	3	4	5	6	9
12	1	4	5	6	7	10

Hence proved there are ($\delta^2+\delta$) -2δ node is reachable form node i with 2 hops

Conclusion

In this paper, we have studied the issue of data structure and symmetric relation for parallel Computing. PDN is a one of asymptotically optimal interconnection network for connecting a ($\delta^2 + \delta + 1$) node with diameter 2. So that n_i is reachable from any other node n_k which than as a dense matrix. In this paper we have studied basic concept of PDN and data structure with their some properties. Maximum number of symmetry relation in PDN is also presented in the form of lemma. We also discuss the basic concept of strassen's matrix

multiplication and matrix multiplication. In this paper we explain the data structures for supporting data-parallel computing? Reachability matrix of PDN is said to be symmetric due to its square, transpose and other property of PDN.

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