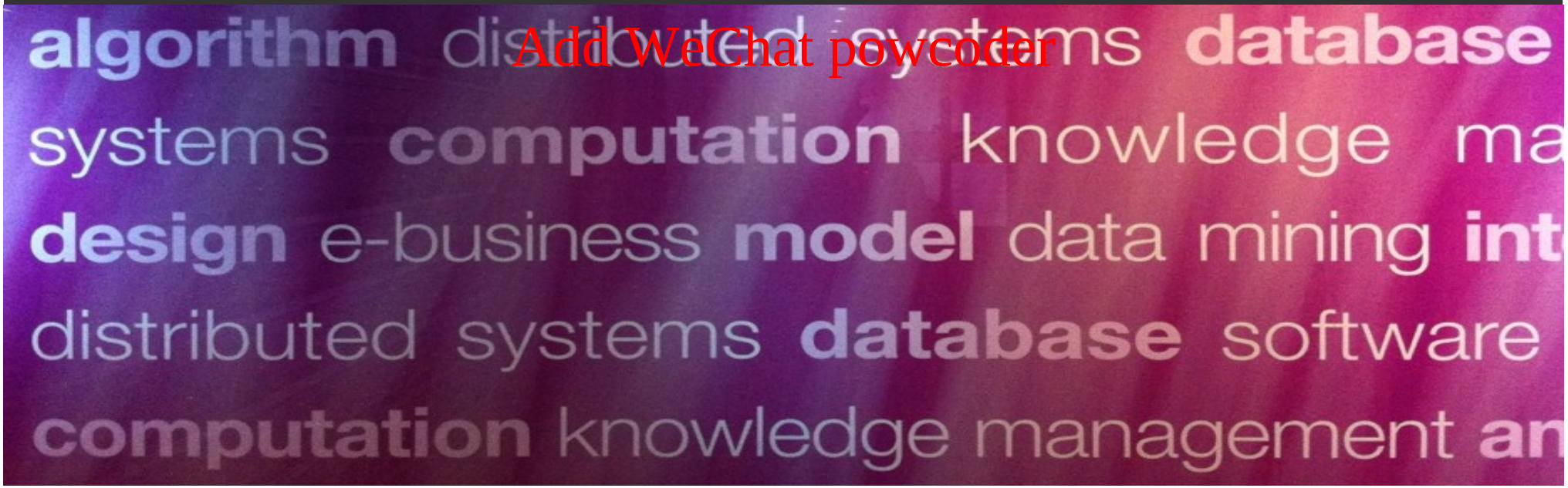
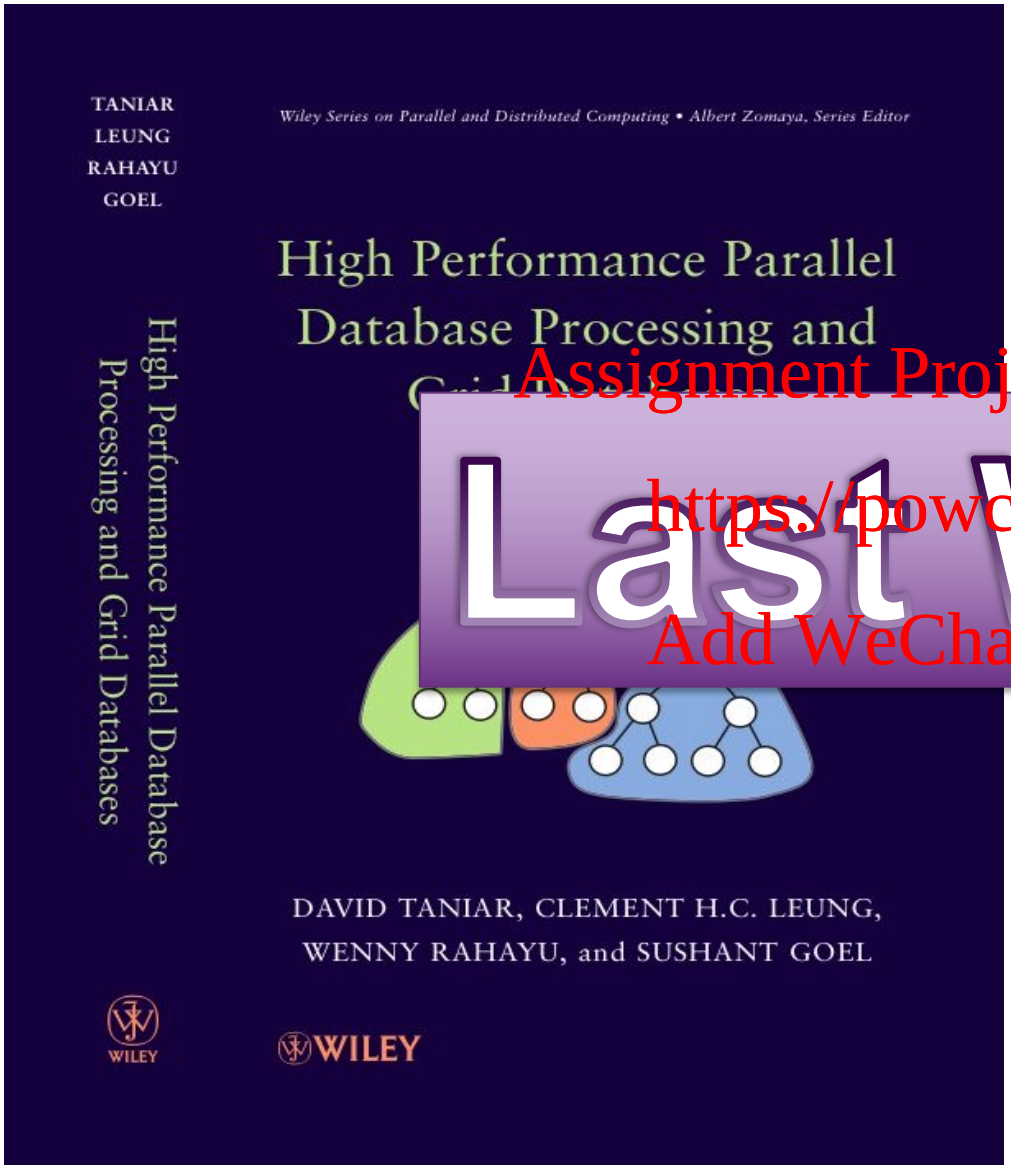
MONASH University

Information Technology

FIT5202 (Volume IV – Sort and Group By)

Week 4a – Parallel Sort





Chapter 5
Parallel Join

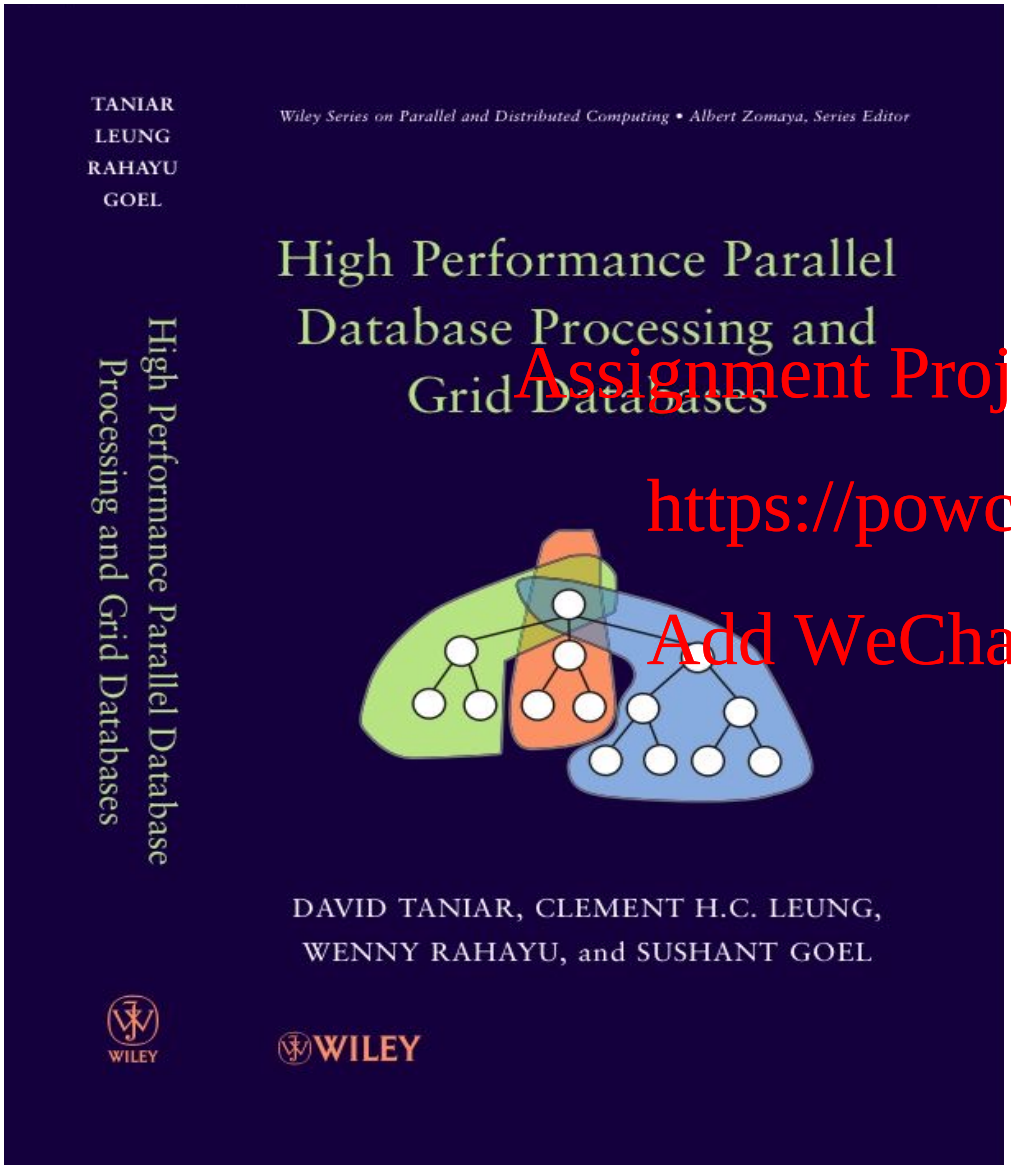
Last Week

Revision

- **Exercise 1 (FLUX Quiz)**
  - Parallel Join algorithms for Inner Join consists of two major phases: Data Partitioning, and Local Join
  - A. TRUE
  - B. FALSE

Revision

- **Exercise 2 (FLUX Quiz)**
  - Parallel Join algorithms for Outer Join queries are:
  - A. ROJA and DOJA
  - B. DER
  - C. OJSO
  - E. only A and B
  - F. A. B and C are correct.



Chapter 4 Parallel Sort and GroupBy

4.1. Sorting, and Serial Sorting

- Serial Sorting – **INTERNAL**
  - The data to be sorted fits entirely into the main memory
- Serial Sorting - **EXTERNAL**
  - The data to be sorted DOES NOT fit entirely into the main memory

4.1. Internal Serial Sorting (cont'd)

- **Bubble Sort**
  - Based on swapping
  - It compares the first two elements, and if the first is greater than the second, it swaps them.
  - It continues doing this for each pair of adjacent elements to the end of the data set.
  - It then starts again with the first two elements, repeating until no swaps have occurred on the last pass.
  - Example: 6 5 3 1 8 7 2 4

4.1. Internal Serial Sorting (cont'd)

6 5 3 1 8 7 2 4

Bubble Sort

4.1. Internal Serial Sorting (cont'd)

- **Insertion Sort** 6 5 3 1 8 7 2 4
  - Based on inserting a new value
  - It works by taking elements from the list one by one and inserting them in their correct position into a new sorted list. In arrays, the new list and the remaining elements can share the array's space, but insertion is expensive, requiring shifting all following elements over by one.
  - Example: 6 5 3 1 8 7 2 4

6 5 3 1 8 7 2 4	Take out 6, and insert it in the previous list	**6** 5 3 1 8 7 2 4
6 **5** 3 1 8 7 2 4	Take out 5, and insert it in the previous list	**5 6** 3 1 8 7 2 4
5 6 **3** 1 8 7 2 4	Take out 3, and insert it in the previous list	**3 5 6** 1 8 7 2 4
3 5 6 **1** 8 7 2 4	Take out 1, and insert it in the previous list	**1 3 5 6** 8 7 2 4
1 3 5 6 **8** 7 2 4	Take out 8, and insert it in the previous list	**1 3 5 6 8** 7 2 4
1 3 5 6 8 **7** 2 4	Take out 7, and insert it in the previous list	**1 3 5 6 7 8** 2 4
1 3 5 6 7 8 **2** 4	Take out 2, and insert it in the previous list	**1 2 3 5 6 7 8** 4
1 2 3 5 6 7 8 **4**	Take out 4, and insert it in the previous list	**1 2 3 4 5 6 7 8**

Finished

4.1. Internal Serial Sorting (cont'd)

- **Quick Sort**
  - Quick Sort is a divide and conquer algorithm which relies on a partition operation: to partition an array an element called a *pivot* is selected.
  - All elements smaller than the pivot are moved before it and all greater elements are moved after it.
  - The lesser and greater sublists are then recursively sorted.
  - The most complex issue in Quick Sort is choosing a good pivot element; consistently poor choices of pivots can result in drastically slower performance
  - Example: 6 5 3 1 8 7 2 4

6 5 3 1 8 7 2 4

4.1. Internal Serial Sorting (cont'd)

- **Quick Sort**
  - Quick Sort is a divide and conquer algorithm which relies on a partition operation: to partition an array an element called a *pivot* is selected.
  - All elements smaller than the pivot are moved before it and all greater elements are moved after it.
  - The lesser and greater sublists are then recursively sorted.
  - The most complex issue in Quick Sort is choosing a good pivot element; consistently poor choices of pivots can result in drastically slower performance
  - Example: 6 5 3 1 8 7 2 4

6 5 3 1 8 7 2 4

Homework: Work out step-by-step this Quick Sort example

4.2. Serial External Sorting

- Sorting is expressed by the ORDER BY clause in SQL
- Duplicate remove is identified by the keyword DISTINCT in SQL

Query 4.1:

```
Select *
From STUDENT
Order By Sdegree;
```


Query 4.3:

```
Select Distinct Sdegree
From STUDENT;
```

4.2. Serial External Sorting (cont'd)

- External sorting assumes that the data does not fit into main memory
- Most common external sorting is sort-merge
- Break the file up into unsorted subfiles, sort the subfiles, and then merge the subfiles into larger and larger sorted subfiles until the entire file is sorted

Algorithm: Serial External Sorting

```
// Sort phase – Pass 0
1. Read B pages at a time into memory
2. Sort them, and Write out a sub-file
3. Repeat steps 1-2 until all pages have been processed

// Merge phase – Pass i = 1, 2, ...
4. While the number of sub-files at end of previous pass
   is > 1
5. While there are sub-files to be merged from
   previous pass
6.    Choose B-1 sorted sub-files from the previous pass
7.    Read each sub-file into an input buffer page
      at a time
8.    Merge these sub-files into one bigger sub-file
9.    Write to the output buffer one page at a time
```

Figure 4.1 External sorting algorithm based on sort-merge

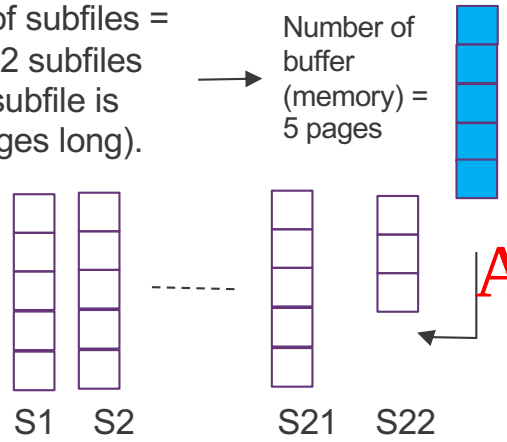
4.2. Serial External Sorting (cont'd)

- **Example**
  - File size to be sorted = 108 pages, number of buffer (or memory size) = 5 pages
  - Number of subfiles = 108/5 = 22 subfiles (the last subfile is only 3 pages long).
  - **Pass 0** (sorting phase): For each subfile, **read from disk**, **sort in main-memory**, and **write to disk** (Note: sorting the data in main-memory can use any fast in-memory sorting method, like Quick Sort)
  - Merging phase: **We use *B*-1 buffers (4 buffers) for input and 1 buffer for output**
  - **Pass 1**: Read 4 sorted subfiles and perform 4-way merging (apply a need *k*-way algorithm). Repeat the 4-way merging until all subfiles are processed. Result = 6 subfiles with 20 pages each (except the last one which has 8 pages)
  - **Pass 2**: Repeat 4-way merging of the 6 subfiles like pass 1 above. Result = 2 subfiles
  - **Pass 3**: Merge the last 2 subfiles
  - Summary: 108 pages and 5 buffer pages require 4 passes

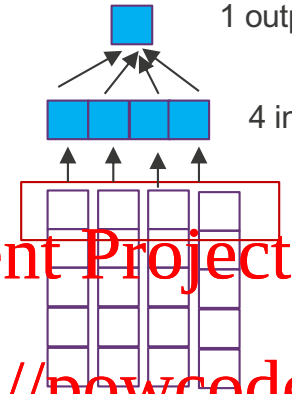
Pass 0 (sorting phase):

Number of subfiles = 108/5 = 22 subfiles (the last subfile is only 3 pages long).

Number of buffer (memory) = 5 pages



Pass 1 (Merging phase):



S1-S4
S5-S8
S9-S12
S13-S16
S17-S20

4-way merging → SS1, SS2, SS3, SS4, SS5 (4 X 5 pages = 20 pages each)

S21 & S22

2-way merging → SS6 (5 + 3 pages = 8 pages)

Pass 2 (Merging phase):

SS1-SS4 —4-way merging→ SSS1 (4 X 20 pages = 80 pages)

SS5 & SS6 —2-way merging→ SSS2 (20 + 8 pages = 28 pages)

Pass 3 (Merging phase):

SSS1 & SSS2 —2-way merging→ SSSS1 (sorted array)

4.2. Serial External Sorting (cont'd)

- **Exercise 3 (FLUX Quiz)**
  - There are 150 data pages to be sorted. The machine that we have has a limited memory, and can only take 8 pages at a time. How many passes will it take to sort the 150 data pages?
  - A. 2
  - B. 3
  - C. 4
  - D. 5

File size to be sorted = 150 pages, number of buffer (or memory size) = 8 pages

Pass 0 (sorting phase):

Number of subfiles = 150/8 = 19 subfiles (the last subfile is only 6 pages long).

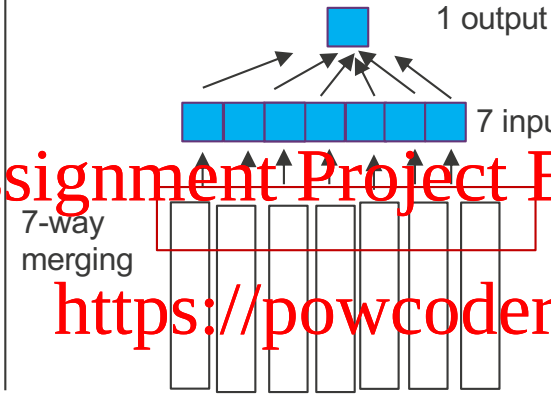
Number of buffer (memory) = 8 pages

Sorted subfiles

8 pages each

S1 S2 ------ S18 S19

Pass 1 (Merging phase):



S1-S7
S8-S14

7-way merging

SS1
SS2

7 X 8 pages = 56 pages each

S15-S18 & S19

5-way merging

SS3

4 X 8 + 6 pages = 38 pages

Pass 2 (Merging phase):

SS1 & SS2 & SS3 → 3-way merging → SSS1 (sorted array)

4.2. Serial External Sorting (cont'd)

- **Example**
  - Buffer size plays an important role in external sort

Table 4.1 Number of passes in serial external sorting as number of buffer increases

R	B = 3	B = 5	B = 9	B = 17	B = 129	B = 257
100	7	4	3	2	1	1
1,000	10	5	4	3	2	2
10,000	13	7	5	4	2	2
100,000	17	9	6	5	3	3
1 million	20	10	7	5	3	3
10 million	23	12	8	6	4	3
100 million	26	14	9	7	4	4
1 billion	30	15	10	8	5	4

4.3. Parallel External Sort

5 different Algorithms

- Parallel Merge-All Sort
- Parallel Binary-Merge Sort
- Parallel Redistribution Binary-Merge Sort
- Parallel Redistribution Merge-All Sort
- Parallel Partitioned Sort

Without data redistribution

With data redistribution

4.3. Parallel External Sort (cont'd)

- **Parallel Merge-All Sort**
  - A traditional approach
  - Two phases: local sort and final merge
  - Load balanced in local sort
  - Problems with merging:
    - Heavy load on one processor
    - Network contention

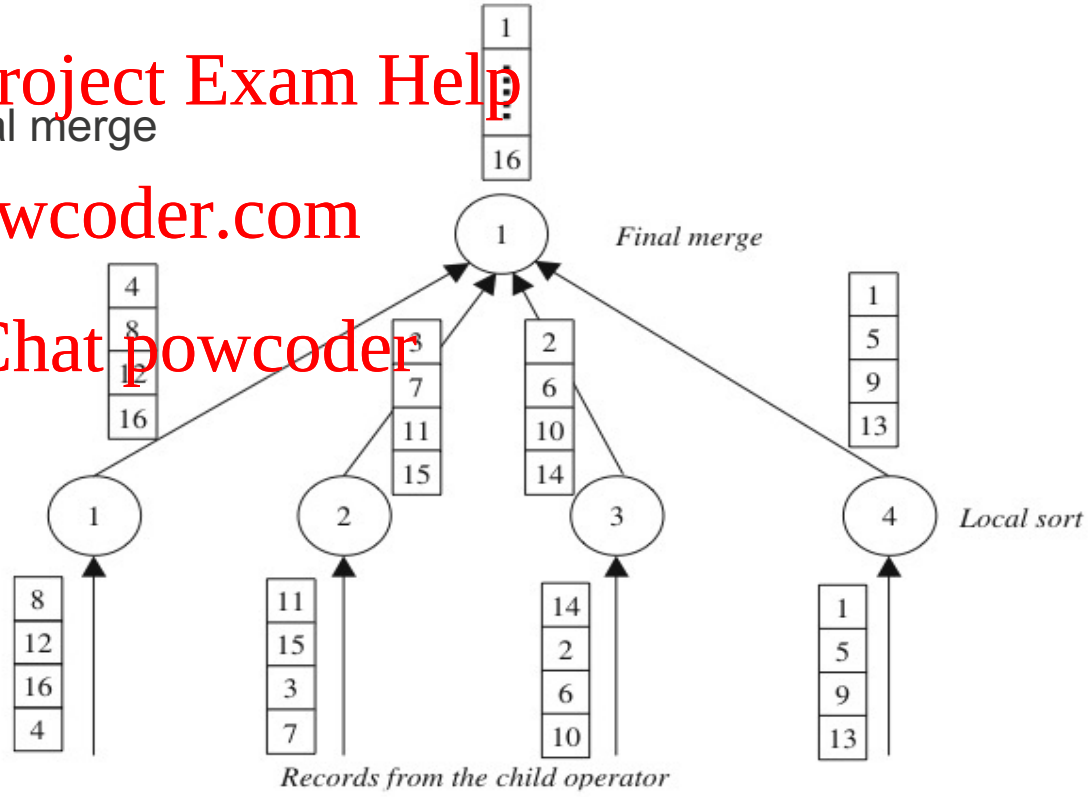


Figure 4.3 Parallel merge-all sort

4.3. Parallel External Sort (cont'd)

- **Parallel Binary-Merge Sort**
  - Local sort similar to traditional method
  - Merging in pairs only
  - Merging work is now spread to pipeline of processors, but merging is still heavy

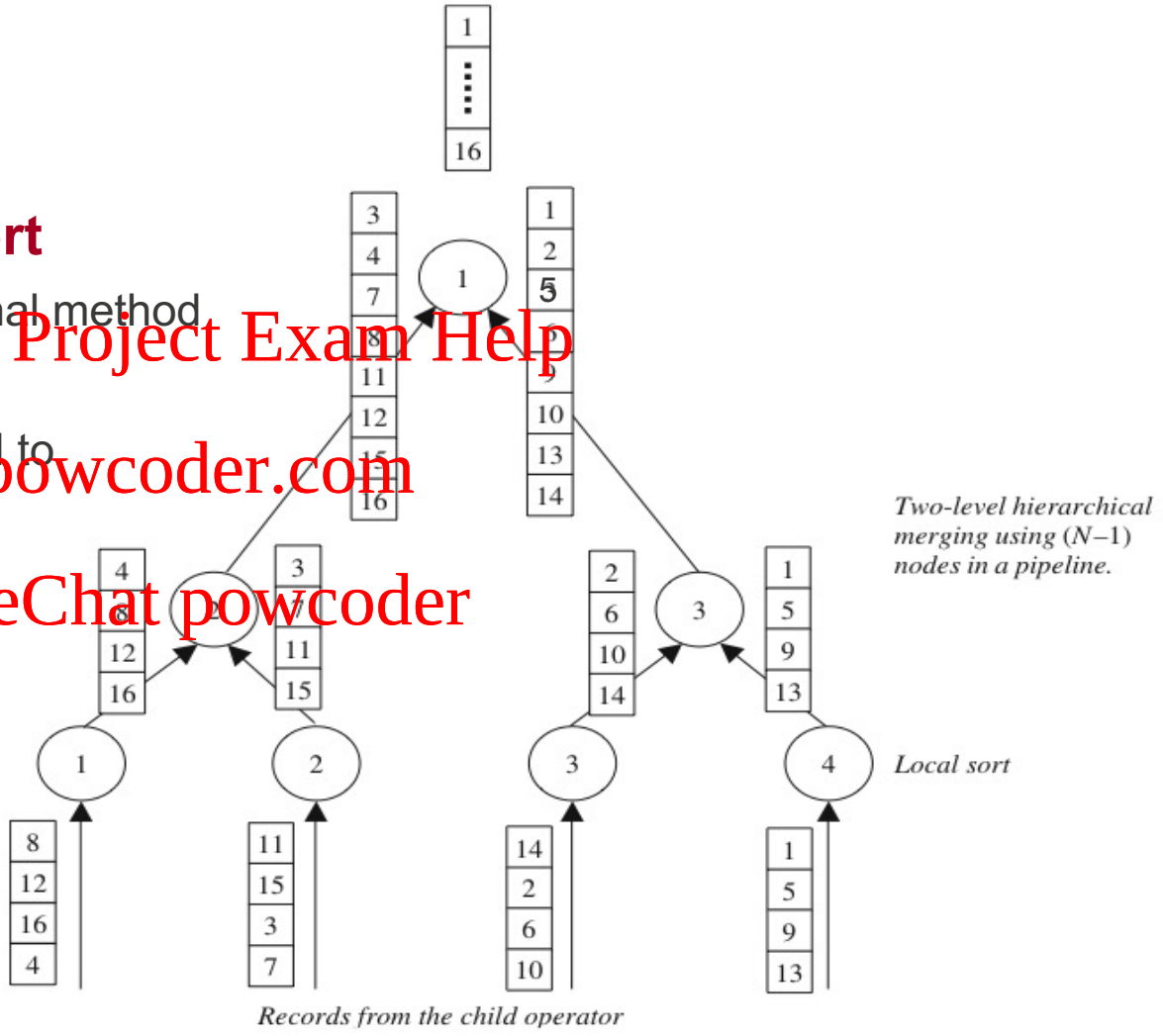
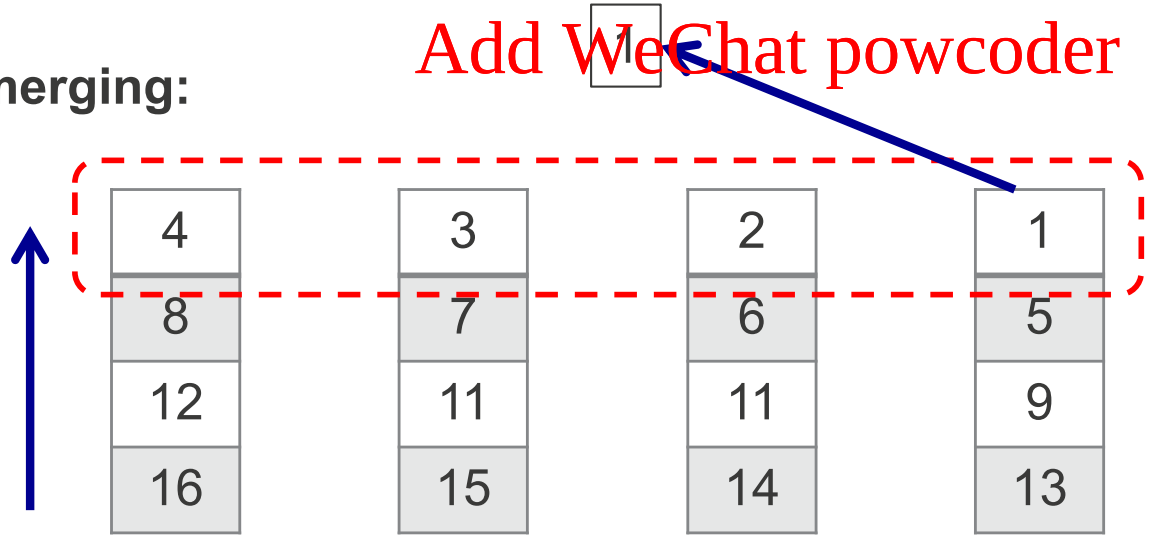


Figure 4.4 Parallel binary-merge sort

4.3. Parallel External Sort (cont'd)

- **Parallel Binary-Merge Sort**
  - Binary merging vs. *k*-way merging
  - In *k*-way merging, the **searching for the smallest value among *k* partitions** is done at the same time
  - In binary merging, it is pairwise, but can be time consuming if the list is long
  - System requirements: ***k*-way merging requires *k* files open simultaneously**, but the pipeline process in binary merging requires extra overheads

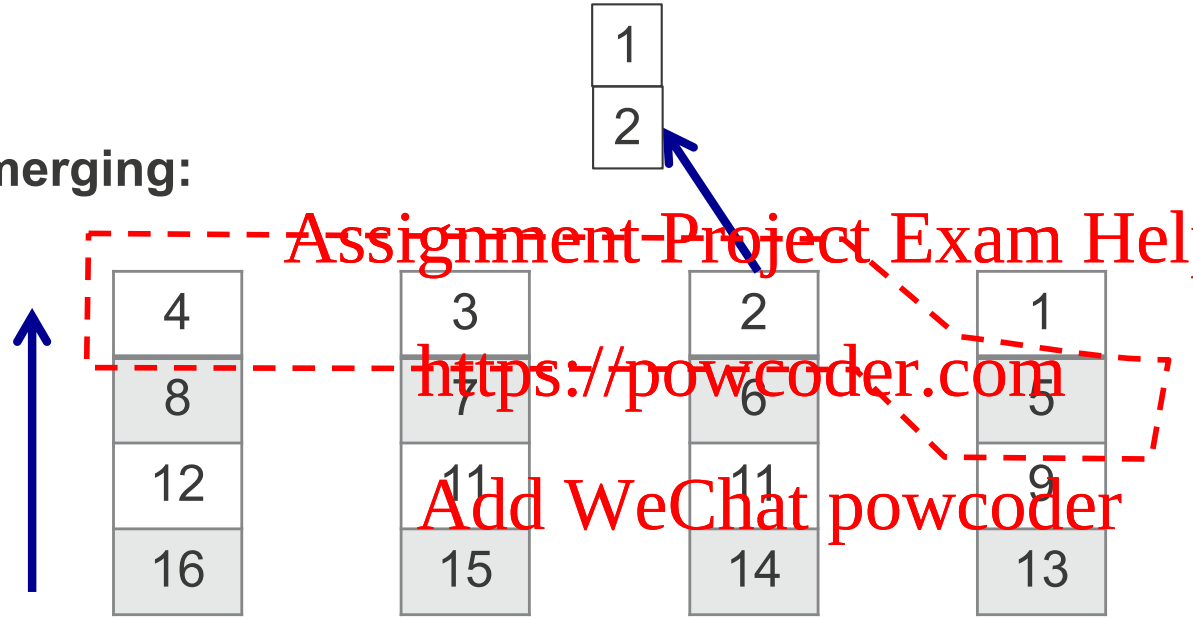
***k*-way merging:**



Searching for the smallest value among the *k* values

4.3. Parallel External Sort (cont'd)

***k*-way merging:**



Searching for the smallest value among the *k* values

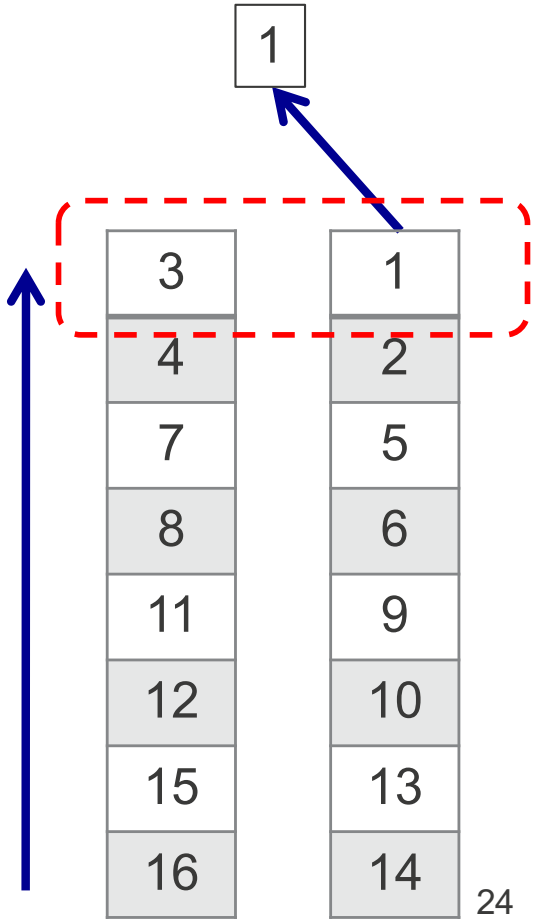
and so on…

4.3. Parallel External Sort (cont'd)

- **Parallel Binary-Merge Sort (Binary Merging step)**
  - Binary merging vs. *k*-way merging
  - In **binary merging**, it is pairwise, but can be time consuming if the list is long
  - System requirements: the pipeline process in binary merging requires extra overheads

Binary merging:

Compare two values only, but lists are longer



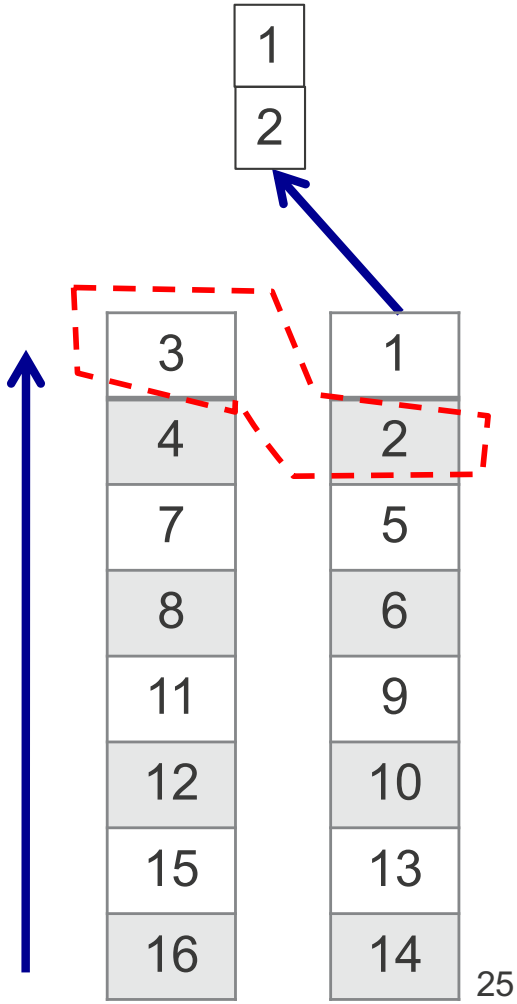
4.3. Parallel External Sort (cont'd)

- **Parallel Binary-Merge Sort (Binary Merging step)**
  - Binary merging vs. *k*-way merging
  - In **binary merging**, it is pairwise, but can be time consuming if the list is long
  - System requirements: the pipeline process in binary merging requires extra overheads

Binary merging:

Compare two values only, but lists are longer

And so on…



Parallel Redistribution Binary-Merge Sort

- Parallelism at all levels in the pipeline hierarchy
- Step 1: local sort
- Step 2: redistribute the results of local sort
- Step 3: merge using the same pool of processors

- Benefit: merging becomes lighter than without redistribution
- Problem: height of the tree

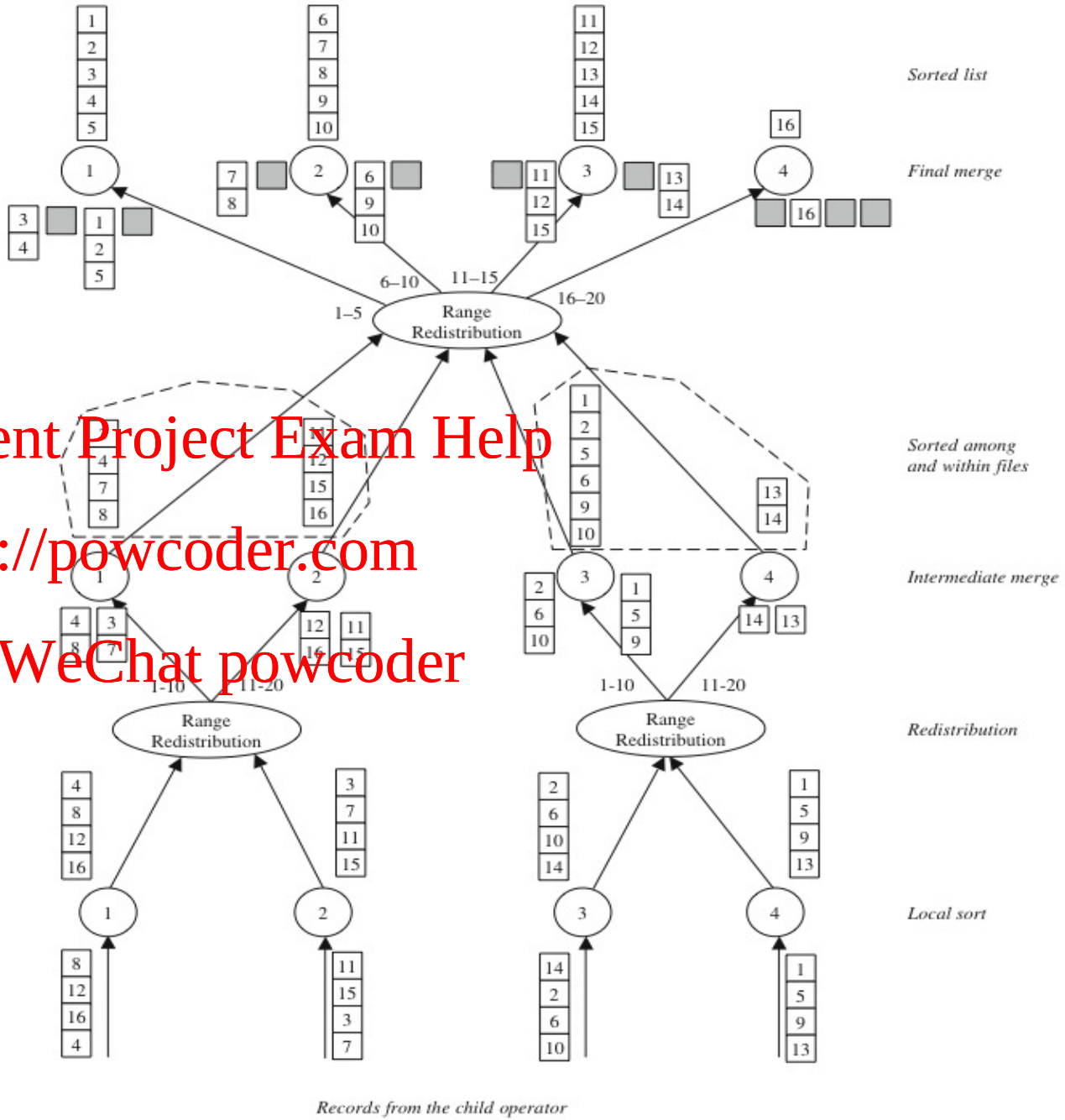


Figure 4.6 Parallel redistribution binary-merge sort

- **Parallel Redistribution Merge-All Sort**
  - Reduce the height of the tree, and still maintain parallelism
  - Like parallel merge-all sort, but with redistribution
  - The advantage is true parallelism in merging
  - Skew problem in the merging

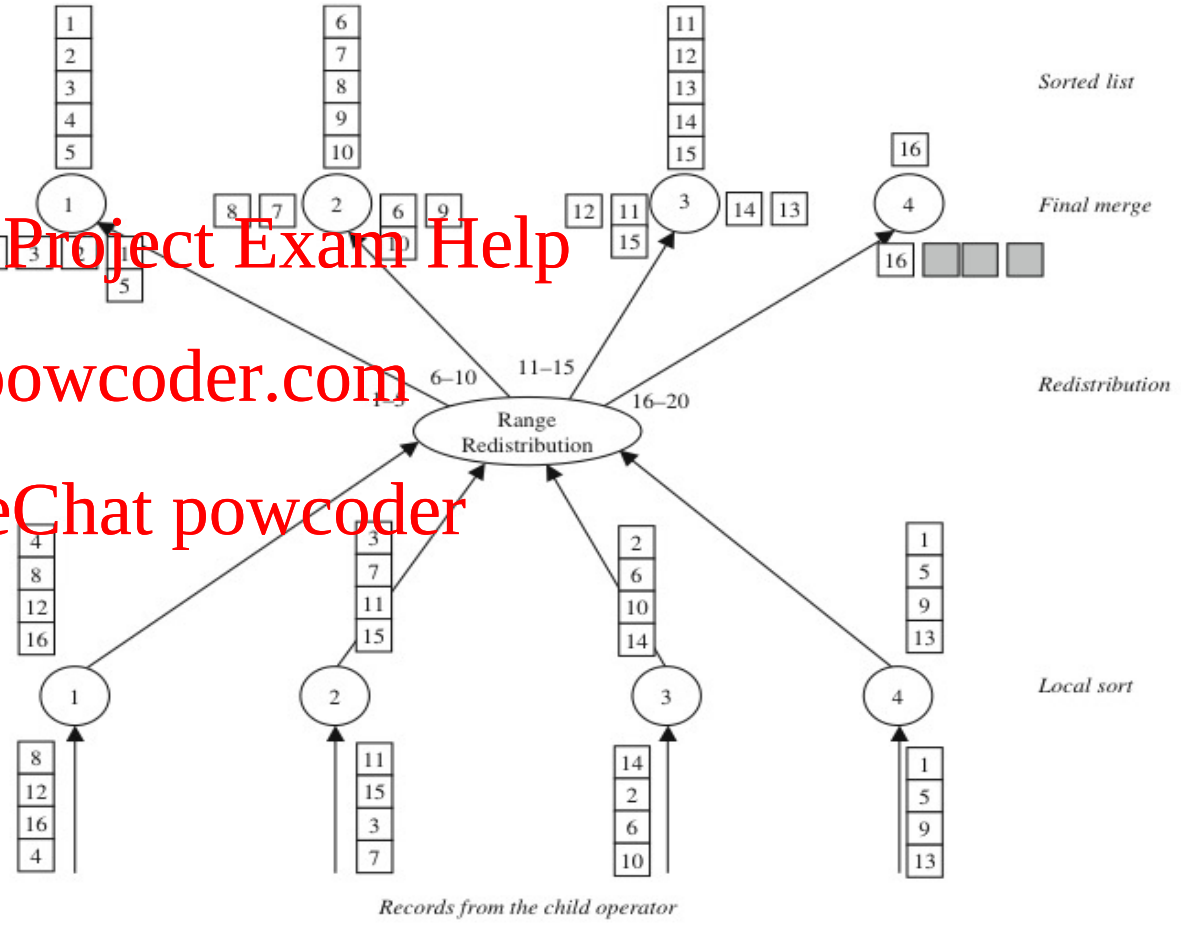


Figure 4.7 Parallel redistribution merge-all sort

Parallel Partitioned Sort

- Two stages: Partitioning stage and Independent local work
- Partitioning (or range redistribution) may raise load skew
- Local sort is done after the partitioning, not before
- No merging is necessary
- Main problem: **Skew** produced by the partitioning

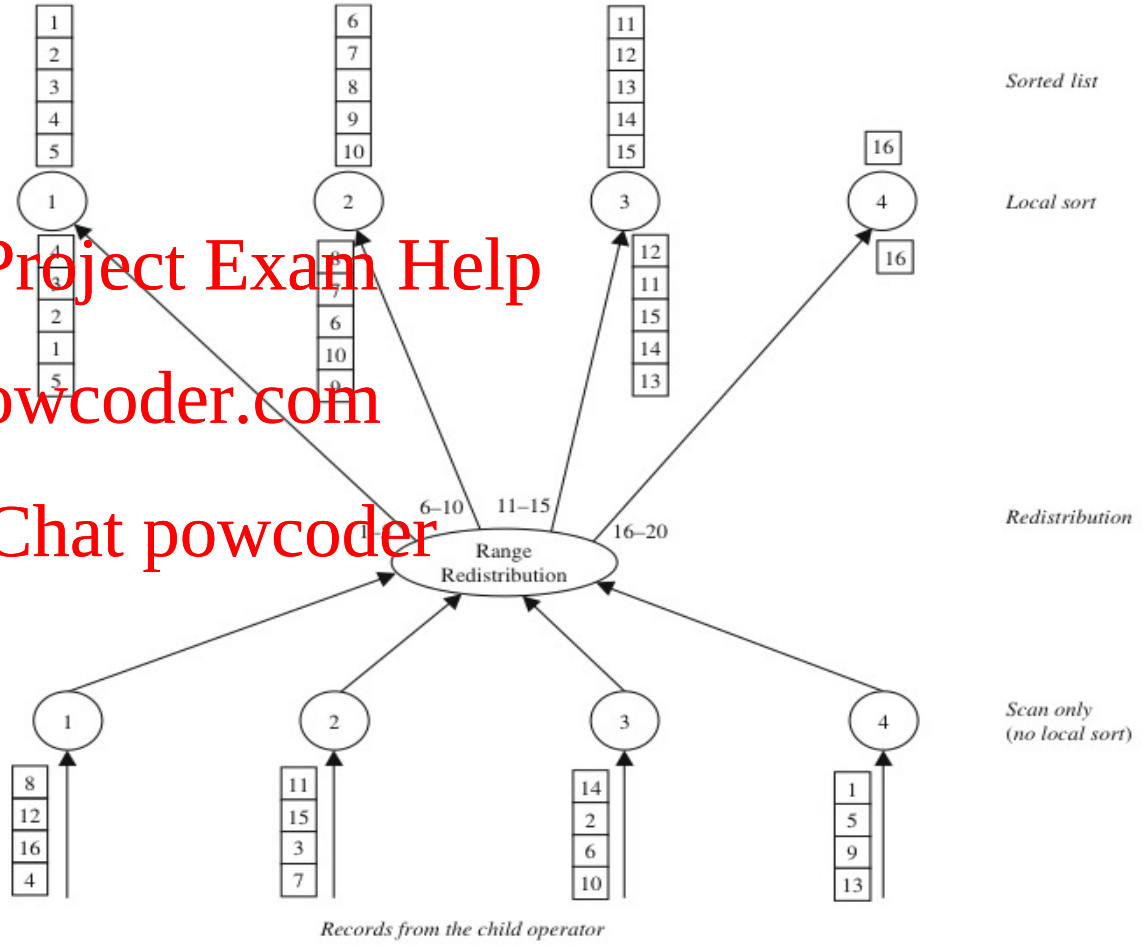


Figure 4.8 Parallel partitioned sort

4.2. Serial External Sorting (cont'd)

- **Exercise 4 (Home Work)**
  - Given a data set *D* = {55; 30; 68; 39; 1; 4; 49; 90; 34; 76; 82; 56; 31; 25; 78; 56; 38; 32; 88; 9; 44; 98; 11; 70; 66; 89; 99; 22; 23; 26} and four processors, show step by step how the **Parallel Partitioned Sort** works.

4.2. Serial External Sorting (cont'd)

- **Exercise 5 (Difficult)**
  - Given the same dataset as in the previous question, and 4 processors, show how **Load Balancing** is achieved in the **Parallel Partitioned Sort**.

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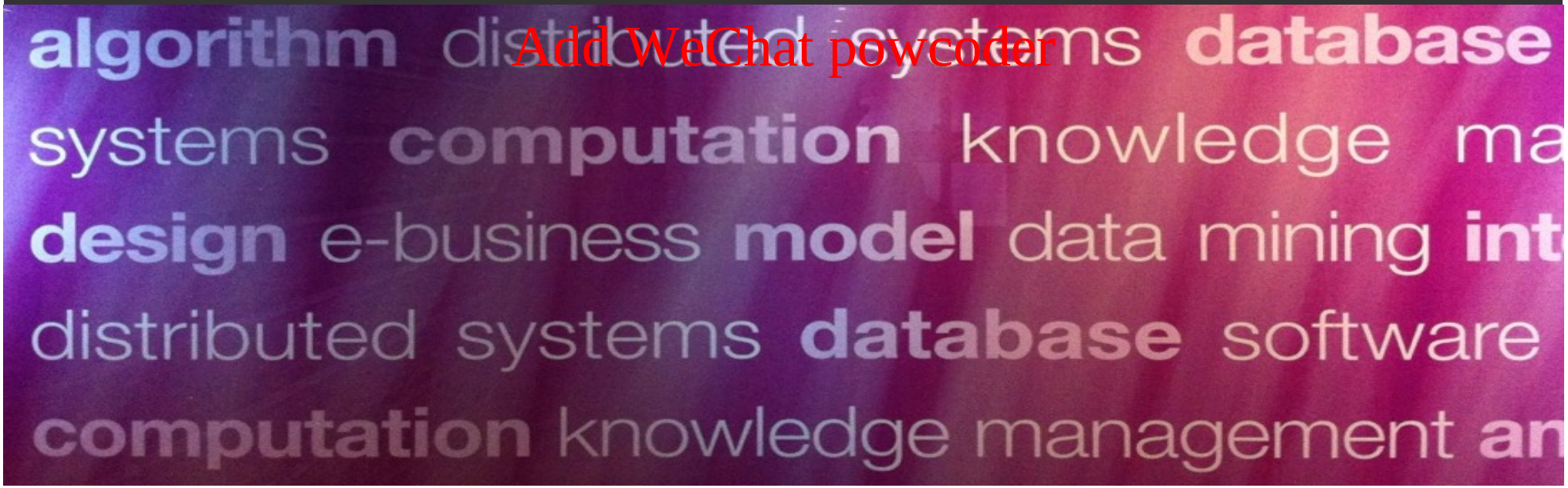
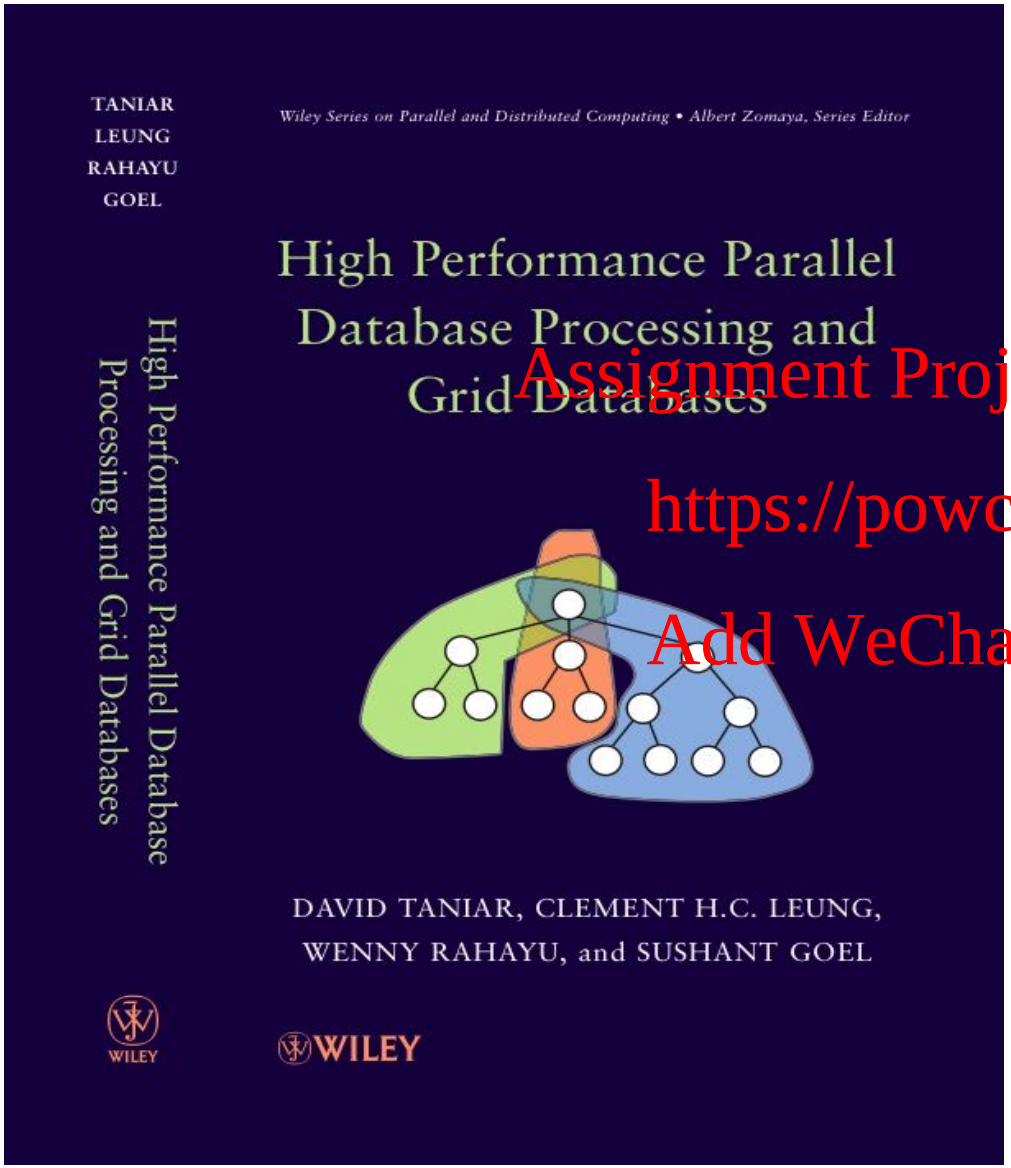
FIT5202 (Volume IV – Sort and Group By)

Week 4b – Parallel Group By





Chapter 4 Parallel Sort and GroupBy

4.1. GroupBy, and Serial GroupBy

```
Select Suburb, Count(*)
From Student
Group By Suburb;
```

Student	Suburb
Adam	Clayton
Ben	Hawthorn
Chris	Doncaster
Daniel	Caulfield
Eric	Kew
Fred	Richmond
Garry	Hawthorn
Harold	Elwood
Irene	Clayton
Jessica	Caulfield
Katie	Malvern
Leonard	Balwyn
Mary	Hawthorn

4.1. Serial GroupBy Processing (cont'd)

```
Select Suburb, Count(*)
From Student
Group By Suburb;
```

Processing Steps:

1. Read the first student record, and hash the suburb to the hash table

Student	Suburb
Adam	Clayton
Ben	Hawthorn
Chris	Doncaster
Daniel	Caulfield
Eric	Kew
Fred	Richmond
Garry	Hawthorn
Harold	Elwood
Irene	Clayton
Jessica	Caulfield
Katie	Malvern
Leonard	Balwyn
Mary	Hawthorn

Hash the record using a certain hash function

Hash Table

1		
2		
3		
4		
5		
6		
7		
8	Clayton	1
9		

4.1. Serial GroupBy Processing (cont'd)

```
Select Suburb, Count(*)
From Student
Group By Suburb;
```

Processing Steps:

1. Read the first student record, and hash the suburb to the hash table
2. Read the second record and hash it

Student	Suburb
Adam	Clayton
Ben	Hawthorn
Chris	Doncaster
Daniel	Caulfield
Eric	Kew
Fred	Richmond
Garry	Hawthorn
Harold	Elwood
Irene	Clayton
Jessica	Caulfield
Katie	Malvern
Leonard	Balwyn
Mary	Hawthorn

Hash Table

1	Hawthorn	1
2		
3		
4		
5		
6		
7		
8	Clayton	1
9		

4.1. Serial GroupBy Processing (cont'd)

```
Select Suburb, Count(*)
From Student
Group By Suburb;
```

Processing Steps:

1. Read the first student record, and hash the suburb to the hash table
2. Read the second record and hash it
3. Read the subsequent records one-by-one and hash them

Student	Suburb
Adam	Clayton
Ben	Hawthorn
Chris	Doncaster
Daniel	Caulfield
Eric	Kew
Fred	Richmond
Garry	Hawthorn
Harold	Elwood
Irene	Clayton
Jessica	Caulfield
Katie	Malvern
Leonard	Balwyn
Mary	Hawthorn

Hash Table

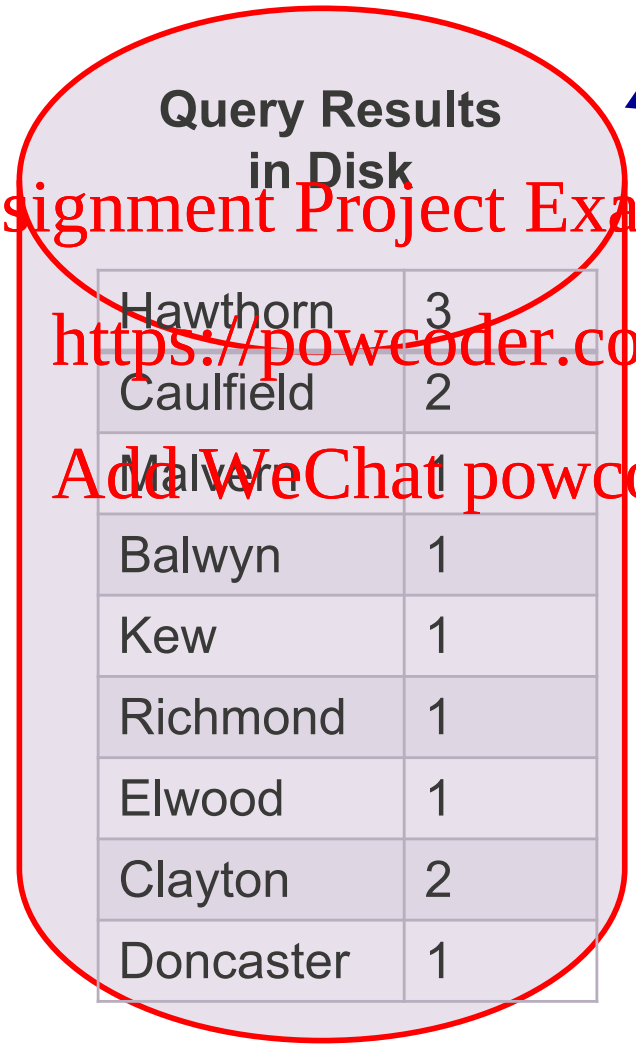
1	Hawthorn	3
2	Caulfield	2
3	Malvern	1
4	Balwyn	1
5	Kew	1
6	Richmond	1
7	Elwood	1
8	Clayton	2
9	Doncaster	1

4.1. Serial GroupBy Processing (cont'd)

Select Suburb, Count(*)
From Student
Group By Suburb;

Processing Steps:

1. Read the first student record, and hash the suburb to the hash table
2. Read the second record and hash it
3. Read the subsequent records one-by-one and hash them
4. Read the Hash Table, and store this in disk as the query results



Hawthorn	3
Caulfield	2
Malvern	1
Balwyn	1
Kew	1
Richmond	1
Elwood	1
Clayton	2
Doncaster	1

Hash Table in Main-Memory

1	Hawthorn	3
2	Caulfield	2
3	Malvern	1
4	Balwyn	1
5	Kew	1
6	Richmond	1
7	Elwood	1
8	Clayton	2
9	Doncaster	1

4.1. Serial GroupBy Processing (cont'd)

```
Select Suburb, Count(*)
From Student
Group By Suburb;
```

Student	Suburb
Adam	Clayton
Ben	Hawthorn
Leonard	Balwyn
Mary	Hawthorn

This will work, if we assume that the main-memory can hold the entire Hash Table.

How about if the Hash Table is so big that it cannot fit into the main-memory.

For example, how about if the main-memory can only hold 4 hash records at a time? How does the Group By processing work?

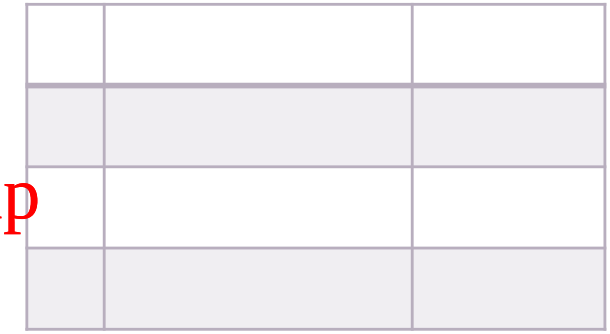
Hash Table

1	Hawthorn	3
2	Caulfield	2
3	Malvern	1
4	Balwyn	1
5	Kew	1
6	Richmond	1
7	Elwood	1
8	Clayton	2
9	Doncaster	1

4.1. Serial GroupBy Processing (cont'd)

Student	Suburb
Adam	Clayton
Ben	Hawthorn
Chris	Doncaster
Daniel	Caulfield
Eric	Kew
Fred	Richmond
Garry	Hawthorn
Harold	Elwood
Irene	Clayton
Jessica	Caulfield
Katie	Malvern
Leonard	Balwyn
Mary	Hawthorn

Hash Table



Assume that the main-memory can hold 4 records in the hash table.

It needs a bigger hash table, but it doesn't have.

Student	Suburb
Adam	Clayton
Ben	Hawthorn
Chris	Doncaster
Daniel	Caulfield
Eric	Kew
Fred	Richmond
Garry	Hawthorn
Harold	Elwood
Irene	Clayton
Jessica	Caulfield
Katie	Malvern
Leonard	Balwyn
Mary	Hawthorn

Hash Data Partitioning based on the **Suburb**

In Main-Memory

Ben	Hawthorn
Daniel	Caulfield
Garry	Hawthorn
Jessica	Caulfield
Mary	Hawthorn

In Disk

Eric	Kew
Fred	Richmond
Katie	Malvern
Leonard	Balwyn

Adam	Clayton
Chris	Doncaster
Harold	Elwood
Irene	Clayton

Ben	Hawthorn
Daniel	Caulfield
Garry	Hawthorn
Jessica	Caulfield
Mary	Hawthorn

In Main-Memory

Eric	Kew
Fred	Richmond
Katie	Malvern
Leonard	Balwyn

Adam	Clayton
Chris	Doncaster
Harold	Elwood
Irene	Clayton

Still in Disk

Hash Table in Main-Memory

Hawthorn	3
Caulfield	2

Query Results in Disk

Hawthorn	3
Caulfield	2

Ben	Hawthorn
Daniel	Caulfield
Garry	Hawthorn
Jessica	Caulfield
Mary	Hawthorn

Flush to Disk

Eric	Kew
Fred	Richmond
Katie	Malvern
Leonard	Balwyn

Load to Main-Memory

Adam	Clayton
Chris	Doncaster
Harold	Elwood
Irene	Clayton

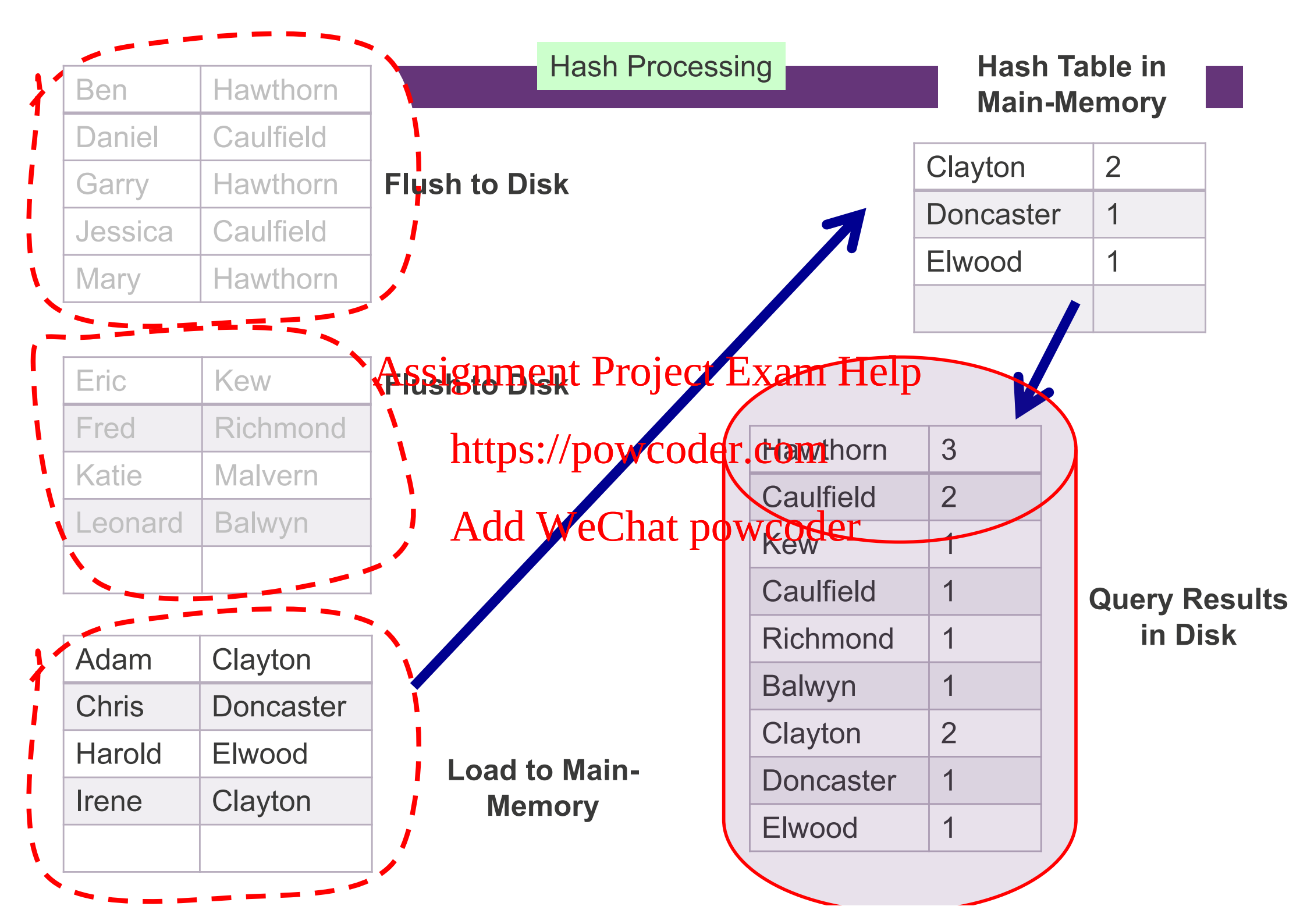
Still in Disk

Hash Table in Main-Memory

Kew	1
Malvern	1
Richmond	1
Balwyn	1

Query Results in Disk

Hawthorn	3
Caulfield	2
Kew	1
Caulfield	1
Richmond	1
Balwyn	1


Hash Processing
Hash Table in Main-Memory
Ben Hawthorn
Daniel Caulfield
Garry Hawthorn
Jessica Caulfield
Mary Hawthorn
Flush to Disk
Clayton 2
Doncaster 1
Elwood 1
Eric Kew
Fred Richmond
Katie Malvern
Leonard Balwyn
Flush to Disk
Assignment Project Exam Help
https://powcoder.com
Add WeChat powcoder
Hawthorn 3
Caulfield 2
Kew 1
Caulfield 1
Richmond 1
Balwyn 1
Clayton 2
Doncaster 1
Elwood 1
Query Results in Disk
Adam Clayton
Chris Doncaster
Harold Elwood
Irene Clayton
Load to Main-Memory

4.4. Parallel GroupBy

- Traditional methods (Merge-All and Hierarchical Merging)
- Two-phase method
- Redistribution method

Without data redistribution

With data redistribution

4.4. Parallel GroupBy (cont'd)

- **Traditional Methods**
  - Step 1: local aggregate in each processor
  - Step 2: global aggregation
  - May use a Merge-All or Hierarchical method
  - Need to pay a special attention to some aggregate functions (AVG) when performing a local aggregate process

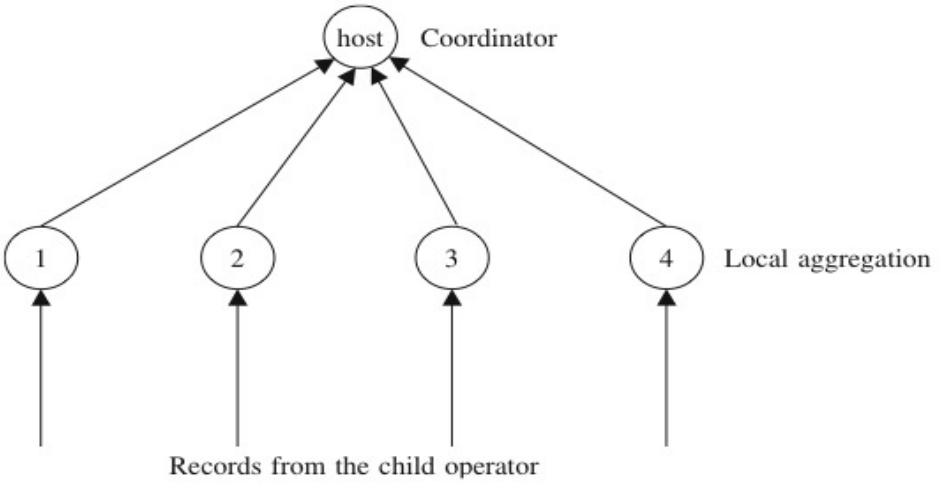


Figure 4.10 Traditional method

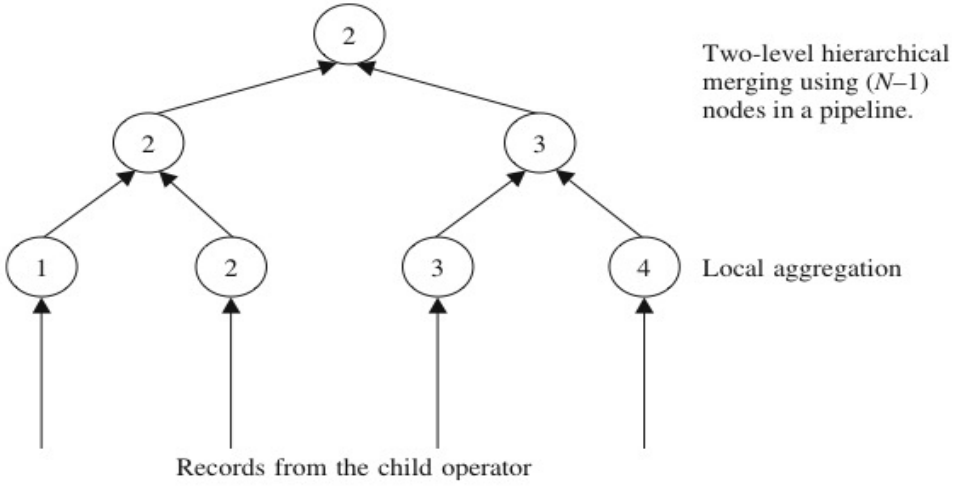
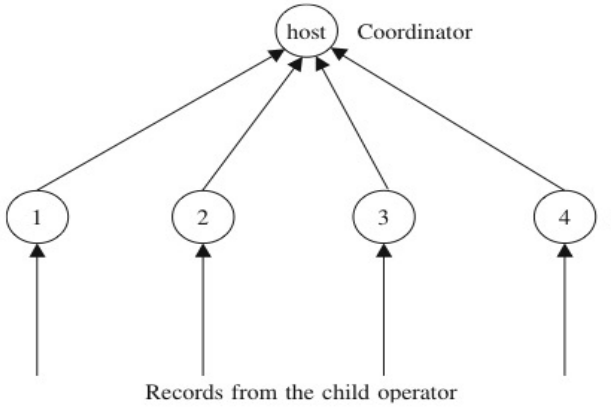


Figure 4.11 Hierarchical merging method

4.4. Parallel GroupBy (cont'd)

- **Traditional Method: Merge All**



Processor 1	
Adam	Clayton
Ben	Clayton
Chris	Caulfield
Dennis	Malvern
Eric	Vermont

Processor 2	
Fred	Hawthorn
George	Richmond
Harold	Elwood
Irene	Malvern
Jessica	Kew

Processor 3	
Kelly	Balwyn
Lesley	Hawthorn
Megan	Kew
Naomi	Richmond
Oscar	Vermont

Processor 4	
Peter	Elwood
Quin	Kew
Roger	Balwyn
Sarah	Malvern
Tracy	Clayton

4.4. Parallel GroupBy (cont'd)

- **Traditional Method: Merge All**

Clayton	2
Caulfield	1
Malvern	1
Vermont	1

Hawthorn	1
Richmond	1
Elwood	1
Malvern	1
Kew	1

Balwyn	1
Hawthorn	1
Kew	1
Richmond	1
Vermont	1

Elwood	1
Kew	1
Balwyn	1
Malvern	1
Clayton	1

Local Aggregation Phase

Processor 1 **Processor 2** **Processor 3** **Processor 4**

Adam	Clayton
Ben	Clayton
Chris	Caulfield
Dennis	Malvern
Eric	Vermont

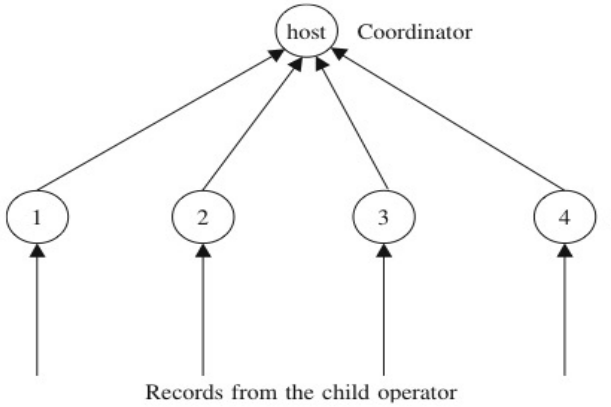
Fred	Hawthorn
George	Richmond
Harold	Elwood
Irene	Malvern
Jessica	Kew

Kelly	Balwyn
Lesley	Hawthorn
Megan	Kew
Naomi	Richmond
Oscar	Vermont

Peter	Elwood
Quin	Kew
Roger	Balwyn
Sarah	Malvern
Tracy	Clayton

4.4. Parallel GroupBy (cont'd)

- **Traditional Method: Merge All**



Clayton	2
Hawthorn	1
Balwyn	1
Elwood	1
…	…
…	…
Vermont	1
Clayton	1

Global Aggregation Phase

Clayton	2
Caulfield	1
Malvern	1
Vermont	1

Processor 1

Hawthorn	1
Richmond	1
Elwood	1
Malvern	1
Kew	1

Processor 2

Balwyn	1
Hawthorn	1
Kew	1
Richmond	1
Vermont	1

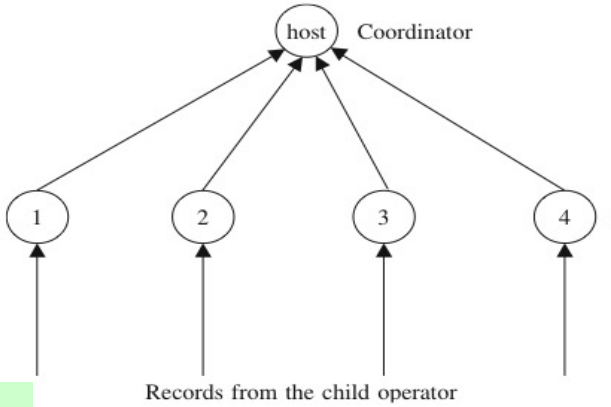
Processor 3

Elwood	1
Kew	1
Balwyn	1
Malvern	1
Clayton	1

Processor 4

4.4. Parallel GroupBy (cont'd)

- **Traditional Method: Merge All**



Clayton	3
Hawthorn	2
Balwyn	2
…	…
…	…
Vermont	2

Final results

Clayton	2
Hawthorn	1
Balwyn	1
Elwood	1
…	…
…	…
Vermont	1
Clayton	1

Global Aggregation Phase

Exercise 6 (FLUX Quiz)

- The limitations of the Traditional Approach (Merge All) to process a Group By query are:

- A. Global aggregation is carried out by one processor
- B. Network bottleneck when sending the local aggregation results to the coordinator
- C. No parallelism in the global aggregation phase
- D. All of the above
- E. Some of the above

4.4. Parallel GroupBy (cont'd)

- **Two-Phase Method**
  - Step 1: local aggregate in each processor. Each processor groups local records according to the groupby attribute
  - Step 2: global aggregation where all temp results from each processor are redistributed and then final aggregate is performed in each processor

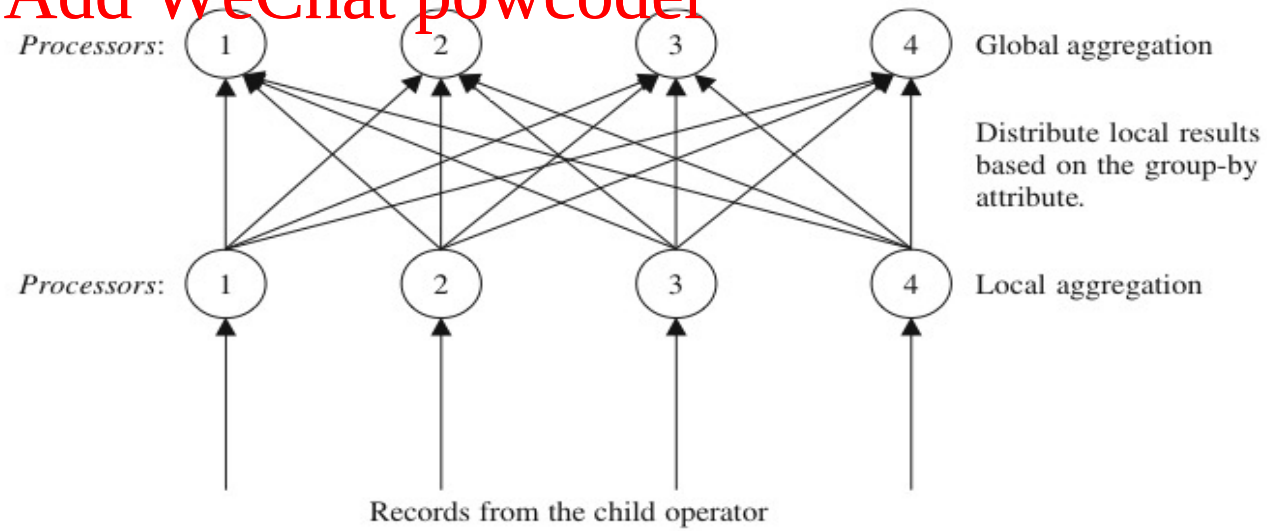
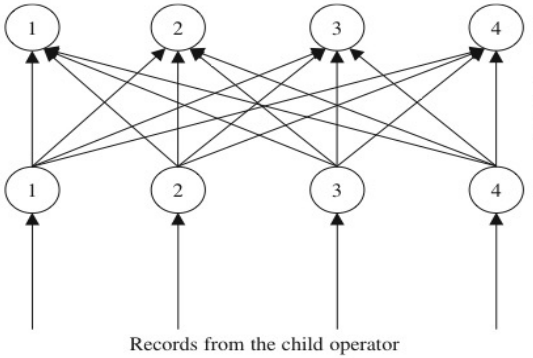


Figure 4.12 Two-phase method

4.4. Parallel GroupBy (cont'd)

- **Two-Phase Method**



Initial Data Placement

Processor 1	
Adam	Clayton
Ben	Clayton
Chris	Caulfield
Dennis	Malvern
Eric	Vermont

Processor 2	
Fred	Hawthorn
George	Richmond
Harold	Elwood
Irene	Malvern
Jessica	Kew

Processor 3	
Kelly	Balwyn
Lesley	Hawthorn
Megan	Kew
Naomi	Richmond
Oscar	Vermont

Processor 4	
Peter	Elwood
Quin	Kew
Roger	Balwyn
Sarah	Malvern
Tracy	Clayton

4.4. Parallel GroupBy (cont'd)

- **Two-Phase Method**

Clayton	2
Caulfield	1
Malvern	1
Vermont	1

Hawthorn	1
Richmond	1
Elwood	1
Malvern	1
Kew	1

Balwyn	1
Hawthorn	1
Kew	1
Richmond	1
Vermont	1

Elwood	1
Kew	1
Balwyn	1
Malvern	1
Clayton	1

Local Aggregation Phase

Processor 1

Adam	Clayton
Ben	Clayton
Chris	Caulfield
Dennis	Malvern
Eric	Vermont

Processor 2

Fred	Hawthorn
George	Richmond
Harold	Elwood
Irene	Malvern
Jessica	Kew

Processor 3

Kelly	Balwyn
Lesley	Hawthorn
Megan	Kew
Naomi	Richmond
Oscar	Vermont

Processor 4

Peter	Elwood
Quin	Kew
Roger	Balwyn
Sarah	Malvern
Tracy	Clayton

4.4. Parallel GroupBy (cont'd)

- **Two-Phase Method**

Clayton	2
Balwyn	1
Elwood	1
Caulfield	1
Elwood	1
Balwyn	1
Clayton	1

Hawthorn	1
Hawthorn	1
Kew	1
Kew	1
Kew	1

Malvern	1
Malvern	1
Malvern	1

Richmond	1
Vermont	1
Richmond	1
Vermont	1

Distribute Local Aggregation Results Phase

Clayton	2
Caulfield	1
Malvern	1
Vermont	1

Hawthorn	1
Richmond	1
Elwood	1
Malvern	1
Kew	1

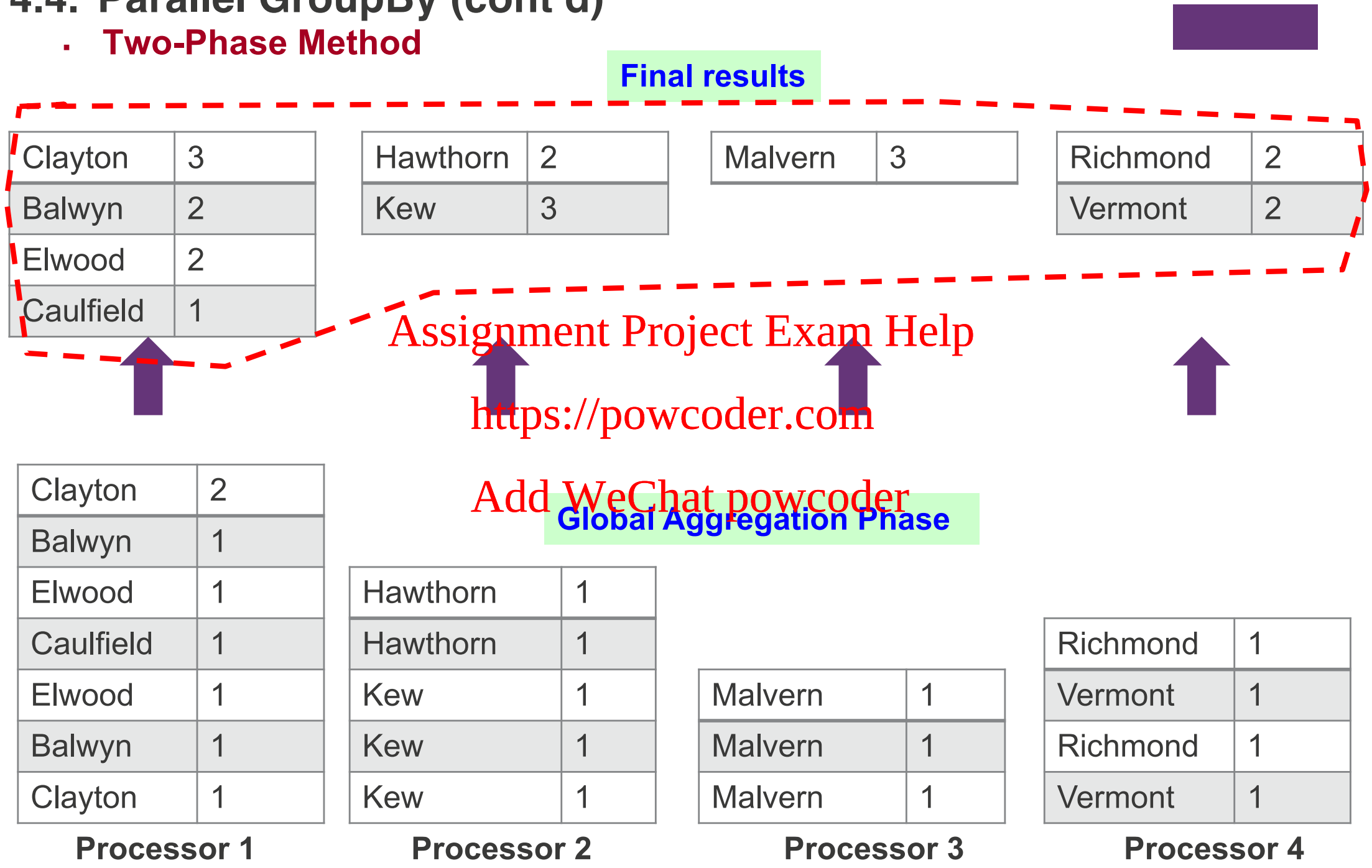
Balwyn	1
Hawthorn	1
Kew	1
Richmond	1
Vermont	1

Elwood	1
Kew	1
Balwyn	1
Malvern	1
Clayton	1

Processor 1 **Processor 2** **Processor 3** **Processor 4**

4.4. Parallel GroupBy (cont'd)

- **Two-Phase Method**



4.4. Parallel GroupBy (cont'd)

- **Redistribution Method**
  - Step 1 (Partitioning phase): redistribute raw records to all processors
  - Step 2 (Aggregation phase): each processor performs a local aggregation

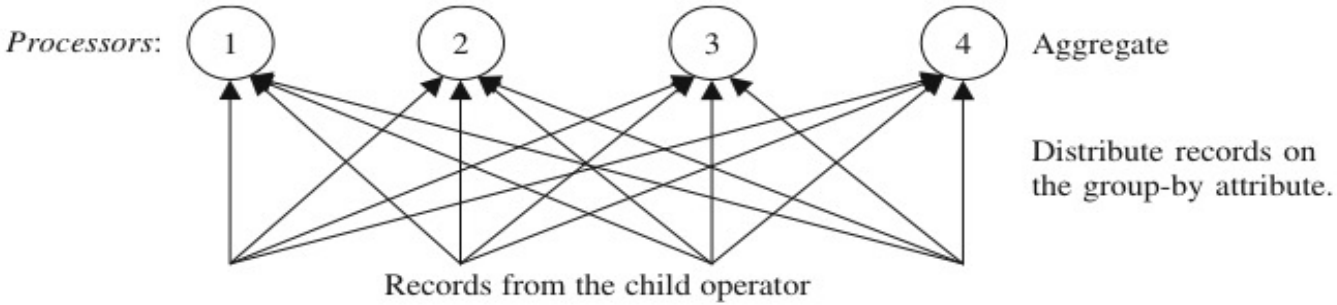
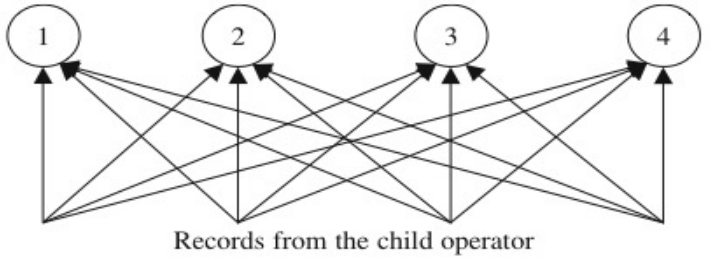


Figure 4.13 Redistribution method

4.4. Parallel GroupBy (cont'd)

- **Redistribution Method**



Initial Data Placement

Processor 1	
Adam	Clayton
Ben	Clayton
Chris	Caulfield
Dennis	Malvern
Eric	Vermont

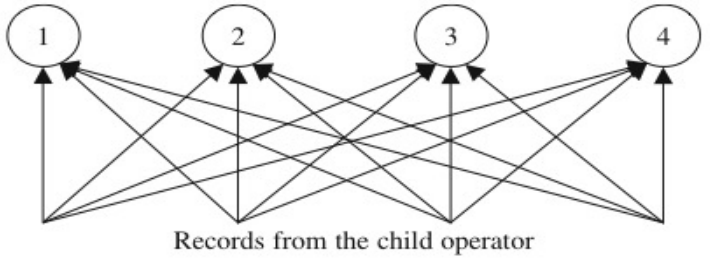
Processor 2	
Fred	Hawthorn
George	Richmond
Harold	Elwood
Irene	Malvern
Jessica	Kew

Processor 3	
Kelly	Balwyn
Lesley	Hawthorn
Megan	Kew
Naomi	Richmond
Oscar	Vermont

Processor 4	
Peter	Elwood
Quin	Kew
Roger	Balwyn
Sarah	Malvern
Tracy	Clayton

4.4. Parallel GroupBy (cont'd)

- **Redistribution Method**



Partitioning Phase

Adam	Clayton
Kelly	Balwyn
Peter	Elwood
Ben	Clayton
Chris	Caulfield
Harold	Elwood
Roger	Balwyn
Tracy	Clayton

Fred	Hawthorn
Lesley	Hawthorn
Quin	Kew
Megan	Kew
Jessica	Kew

Dennis	Malvern
Irene	Malvern
Sarah	Malvern

George	Richmond
Naomi	Richmond
Eric	Vermont
Oscar	Vermont

Processor 1

Adam	Clayton
Ben	Clayton
Chris	Caulfield
Dennis	Malvern
Eric	Vermont

Processor 2

Fred	Hawthorn
George	Richmond
Harold	Elwood
Irene	Malvern
Jessica	Kew

Processor 3

Kelly	Balwyn
Lesley	Hawthorn
Megan	Kew
Naomi	Richmond
Oscar	Vermont

Processor 4

Peter	Elwood
Quin	Kew
Roger	Balwyn
Sarah	Malvern
Tracy	Clayton

4.4. Parallel GroupBy (cont'd)

- **Redistribution Method**

Final results

Clayton	3
Balwyn	2
Elwood	2
Caulfield	1

Hawthorn	2
Kew	3

Malvern	3

Richmond	2
Vermont	2

Aggregation Phase

Adam	Clayton
Kelly	Balwyn
Peter	Elwood
Ben	Clayton
Chris	Caulfield
Harold	Elwood
Roger	Balwyn
Tracy	Clayton

Fred	Hawthorn
Lesley	Hawthorn
Quin	Kew
Megan	Kew
Jessica	Kew

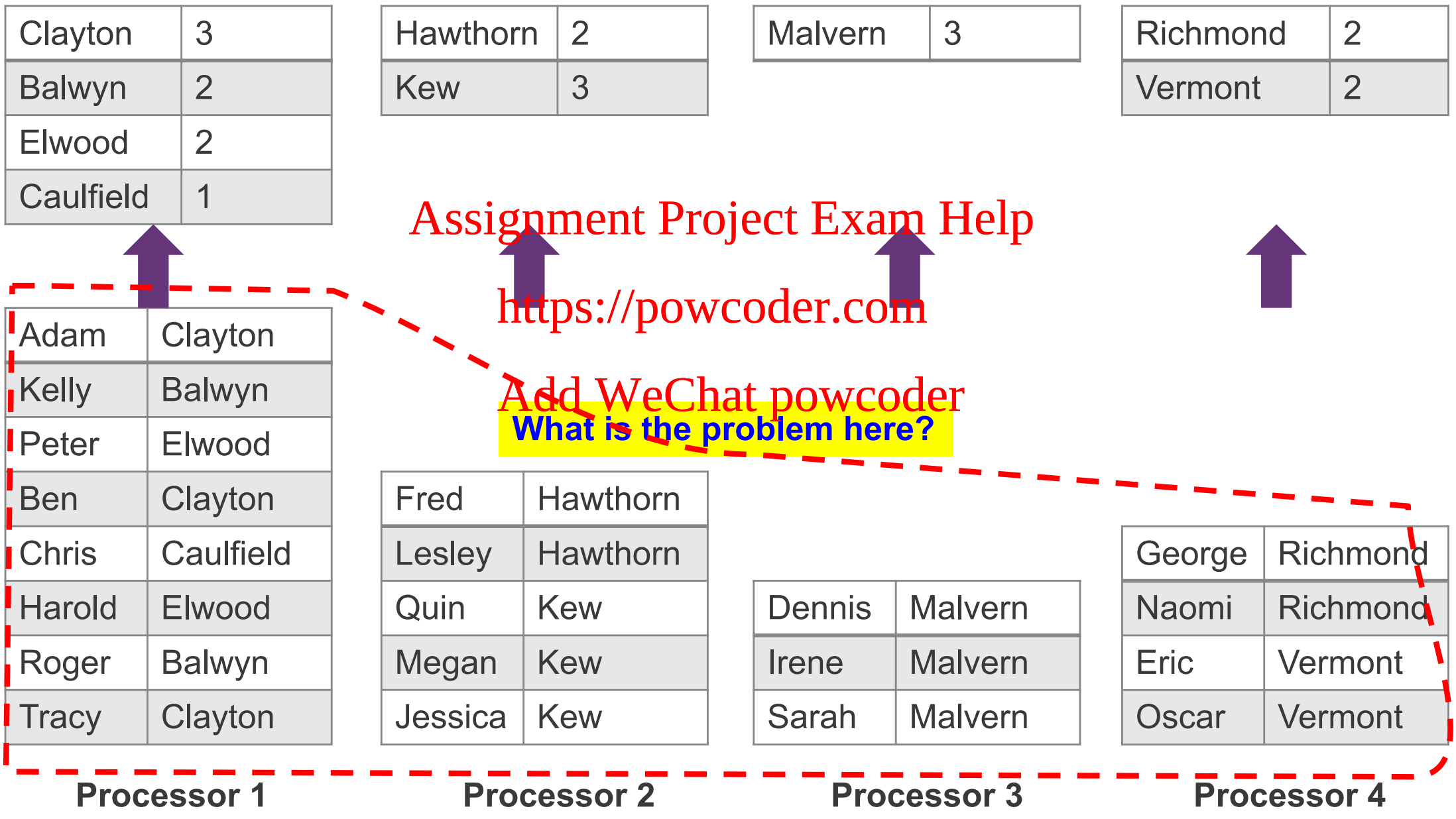
Dennis	Malvern
Irene	Malvern
Sarah	Malvern

George	Richmond
Naomi	Richmond
Eric	Vermont
Oscar	Vermont

Processor 1 **Processor 2** **Processor 3** **Processor 4**

4.4. Parallel GroupBy (cont'd)

- **Redistribution Method**



4.4. Parallel GroupBy (cont'd)

- **Redistribution Method (Task Stealing)**

Adam	Clayton
Kelly	Balwyn
Ben	Clayton
Chris	Caulfield
Roger	Balwyn
Tracy	Clayton

Peter	Elwood
Harold	Elwood

Create 5 buckets, instead of 4

Fred	Hawthorn
Lesley	Hawthorn
Quin	Kew
Megan	Kew
Jessica	Kew

Dennis	Malvern
Irene	Malvern
Sarah	Malvern

George	Richmond
Naomi	Richmond
Eric	Vermont
Oscar	Vermont

Processor 1

Adam	Clayton
Ben	Clayton
Chris	Caulfield
Dennis	Malvern
Eric	Vermont

Processor 2

Fred	Hawthorn
George	Richmond
Harold	Elwood
Irene	Malvern
Jessica	Kew

Processor 3

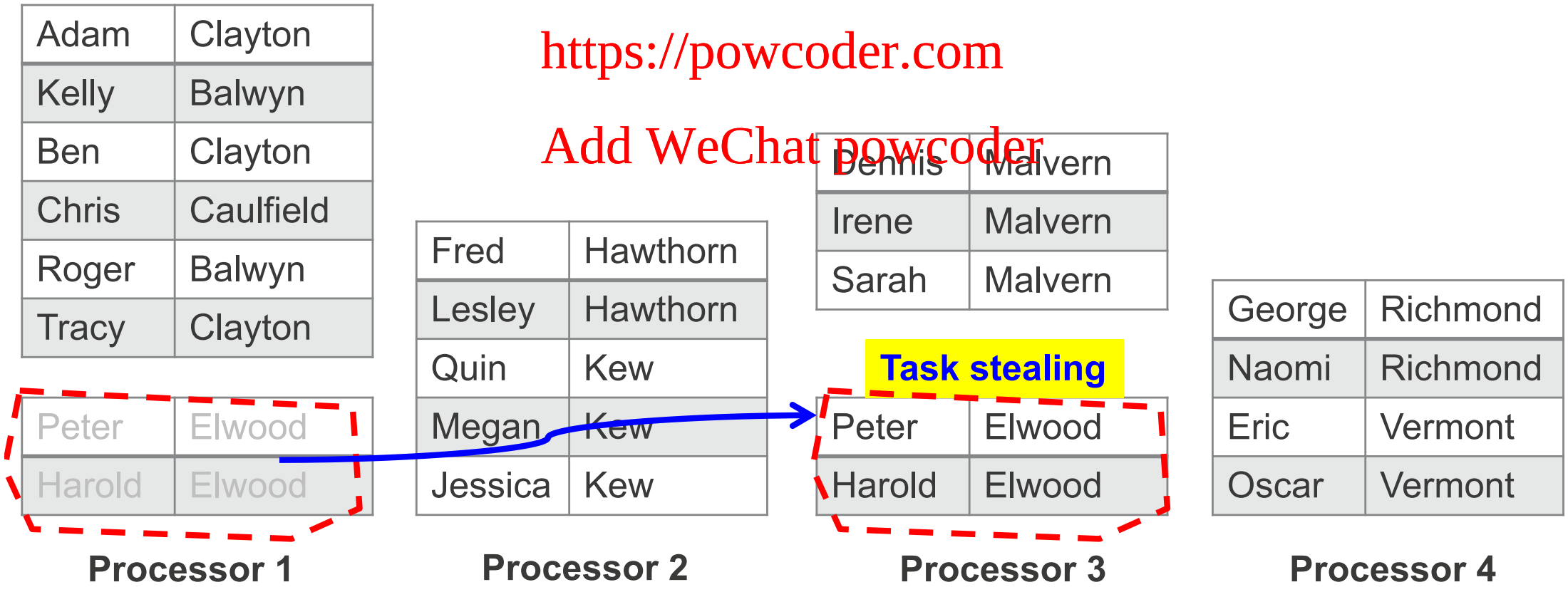
Kelly	Balwyn
Lesley	Hawthorn
Megan	Kew
Naomi	Richmond
Oscar	Vermont

Processor 4

Peter	Elwood
Quin	Kew
Roger	Balwyn
Sarah	Malvern
Tracy	Clayton

4.4. Parallel GroupBy (cont'd)

- Redistribution Method (Task Stealing)



4.4. Parallel GroupBy (cont'd)

- **Redistribution Method (Task Stealing)**

Clayton	3
Balwyn	2
Caulfield	1

Hawthorn	2
Kew	3

Malvern	3
Elwood	2

Richmond	2
Vermont	2

Adam	Clayton
Kelly	Balwyn
Ben	Clayton
Chris	Caulfield
Roger	Balwyn
Tracy	Clayton

Fred	Hawthorn
Lesley	Hawthorn
Quin	Kew
Megan	Kew
Jessica	Kew

Dennis	Malvern
Irene	Malvern
Sarah	Malvern

Peter	Elwood
Harold	Elwood

George	Richmond
Naomi	Richmond
Eric	Vermont
Oscar	Vermont

Processor 1 **Processor 2** **Processor 3** **Processor 4**

- **Exercise 7 (FLUX Quiz)**
  - The Redistribution Method has a load balancing option, through the Task Stealing method. The Two-Phase Method does not have a load balancing problem.

  - A. TRUE
  - B. FALSE

4.7. Summary

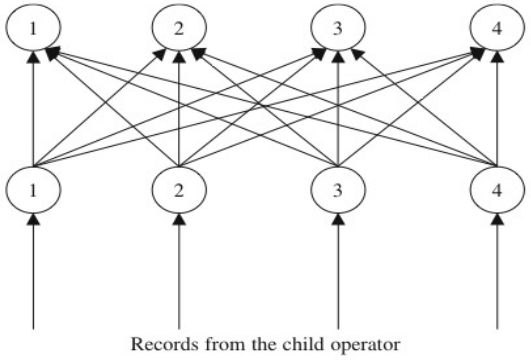
- Parallel groupby algorithms
  - Traditional methods (merge-all and hierarchical methods)
  - Two-phase method - – Local aggregation before data redistribution
  - Redistribution methods – global aggregation after data redistribution

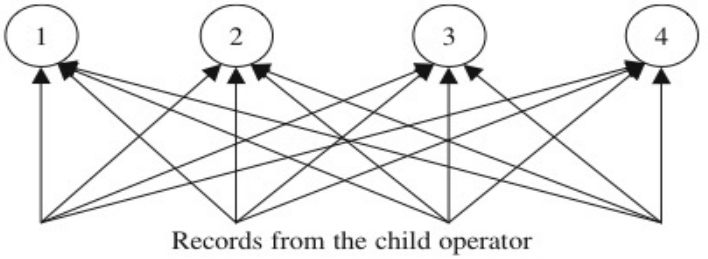
- **Two-phase** and **Redistribution** methods perform better than the traditional and hierarchical merging methods

- **Two-phase method** works well when the number of groups is small, whereas the **Redistribution method** works well when the number of groups is large

Ambuj and Naughton. "Adaptive parallel aggregation algorithms." (1995):

Why??





Homework Exercises

- 1. Show how Load Balancing through Task Stealing be achieved in the Two Phase Method (using the same sample data as above) – EASY
- 2. Why is the Two-Phase Method good when the number of groups is small, whereas the Redistribution Method good when the number of groups is large? – MORE CHALLENGING
- 3. In what scenario may super linear speed up be achieved? – MORE CHALLENGING
- (Hints: See slides #8-#13 ➔ the hash table cannot fit into main-memory)