Parallel and Distributed Storage

Introduction

- Parallel machines have become quite common and affordable
  - prices of microprocessors, memory and disks have dropped sharply
- Data storage needs are growing increasingly large
  - user data at web-scale
    - 100’s of millions of users, petabytes of data
  - transaction data are collected and stored for analysis.
  - multimedia objects like images/videos
- Parallel storage system requirements
  - storing large volumes of data
  - processing time-consuming decision-support queries
  - providing high throughput for transaction processing
  - Very high demands on **scalability** and **availability**

Parallel/Distributed Data Storage History

- 1980/1990s
  - Distributed database systems with tens of nodes
- 2000s:
  - Distributed file systems with 1000s of nodes
    - Millions of Large objects (100's of megabytes)
    - Web logs, images, videos, …
    - Typically create/append only
  - Distributed data storage systems with 1000s of nodes
    - Billions to trillions of smaller (kilobyte to megabyte) objects
    - Social media posts, email, online purchases, …
    - Inserts, updates, deletes
  - **Key-value stores**
- 2010s: Distributed database systems with 1000s of nodes

I/O Parallelism

- Reduce the time required to retrieve relations from disk by partitioning the relations on *multiple disks*, on *multiple* ***nodes*** (computers)
  - Our description focuses on parallelism across nodes
  - Same techniques can be used across disks on a node

- **Horizontal partitioning** – tuples of a relation are divided among many nodes such that some subset of tuple resides on each node.
  - Contrast with **vertical partitioning**, e.g. $r(A,B,C,D)$ with primary key A into r1(A,B) and r2(A,C,D)
  - By default, the word partitioning refers to horizontal partitioning

I/O Parallelism

- Partitioning techniques (number of nodes = *n*):

  Round-robin:

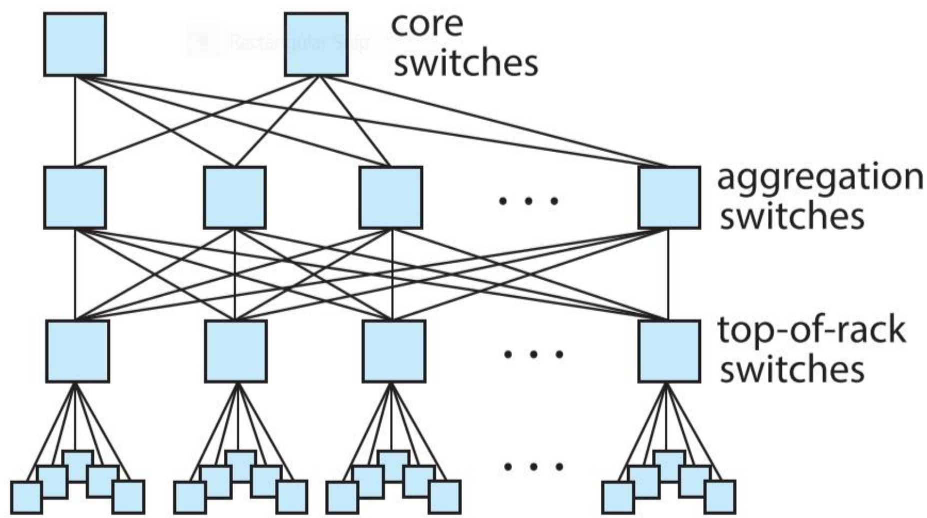
  Send the i^{th} tuple inserted in the relation to node *i* mod *n*.

In a data center,
Nodes N0…N19 in Rack 1

Nodes N20…N39 in Rack 2
Total nodes N = 40

NID-Person relation has tuples
T0, T1, T2, T3 ………T39999

Question 4-1: Explain how tuples will be distributed into the nodes using round-robin technique.



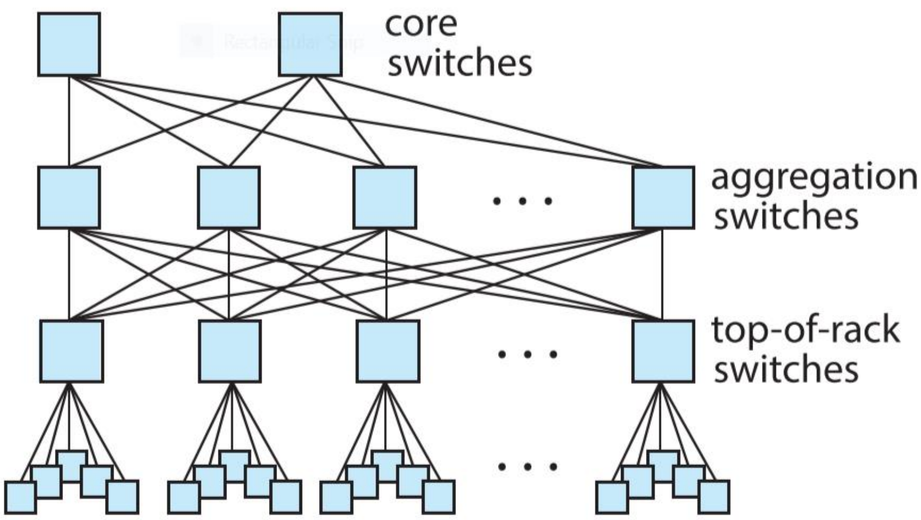
(e) tree-like topology

- Partitioning techniques (number of nodes = *n*):

  Hash partitioning:

  - Choose one or more attributes as the partitioning attributes.
  - Choose hash function *h* with range 0…*n* - 1
  - Let *i* denote result of hash function *h* applied to the partitioning attribute value of a tuple. Send tuple to node *i*.

In a data center,
Nodes N0…N19 in Rack 1
Nodes N20…N39 in Rack 2
Total nodes N = 40
NID-Person(NID, name, DOB, street, city, district)
The tuples are:
T0, T1, T2, T3 ………T39999



(e) tree-like topology

Question 4-2: Explain how tuples will be distributed into the nodes using hash partitioning technique using

a. NID
b. Street, city, district.

Range Partitioning

Data Partitioning among Nodes

Range partitioning technique:

- Choose an attribute as the partitioning attribute.
- A partitioning vector [v_o, v_1, ..., v_{n-2}] is chosen.
- Let v be the partitioning attribute value of a tuple.
- Tuples such that $v_i \leq v < v_{i+1}$ go to node i+ 1.
- Tuples with $v < v_0$ go to node 0 and tuples with $v \geq v_{n-2}$ go to node n-1.
  - E.g., with a partitioning vector [5,11]
  - a tuple with partitioning attribute value of 2 will go to node 0,
  - a tuple with value 8 will go to node 1, while
  - a tuple with value 20 will go to node2.

In a data center,
Nodes N0…N9 in Rack 1
Nodes N20…N19 in Rack 2
Total nodes N = 20
Student(Id, name, DOB, street, city, district)
The tuples are:
T0, T1, T2, T3 ………T399
Id ranges from 202105001 to 202105400

Question 4-3

a. Design a partition vector on Id for storage of student relation
b. Find partitions P0, P1, P19

Range Partitioning

Data Partitioning among Nodes

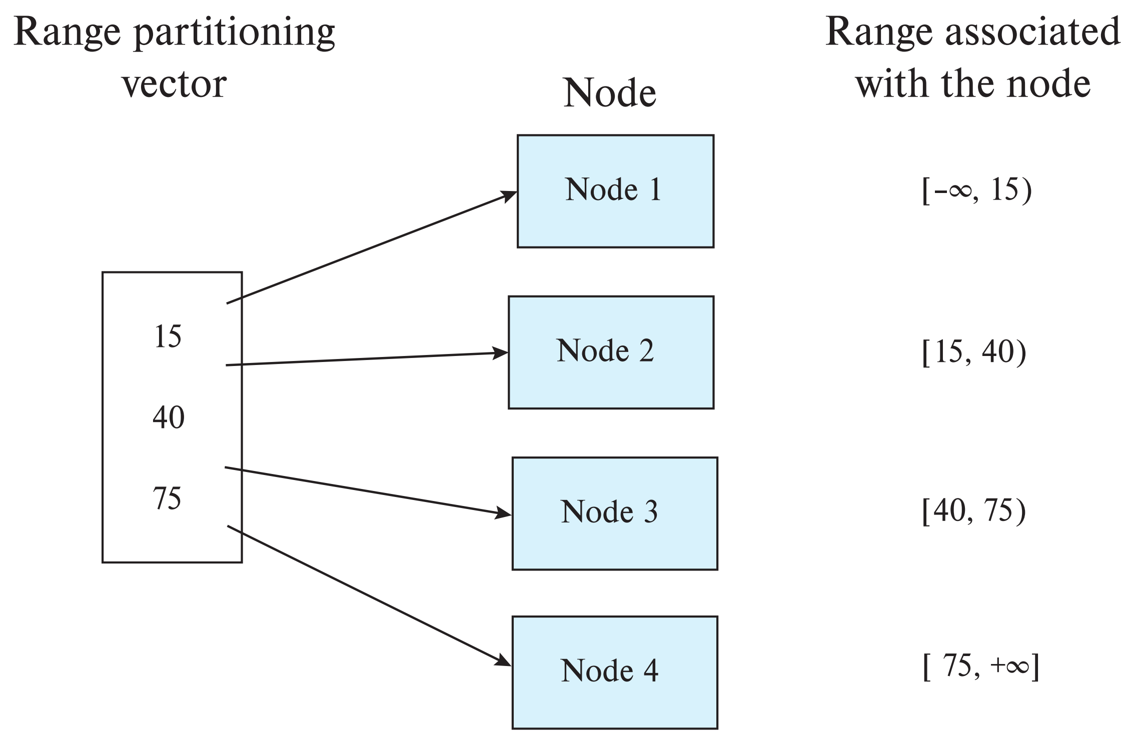
Example: There are 4 nodes: N1, N2, N3 and N4 in a parallel database system. The schema of the relation person is as follows:

Person(NID, Name, Thana, District, Age)

Partition vector

P[f-age] = [30, 50, 75]

Perform range partitioning of person relation into 4 nodes.



Partitions:
Partition 1, age <30 in Node N1
Partition 2, 30<=age <50 in Node N2
Partition 3, 50<=age <75 in Node N3
Partition 4, age >=75 in Node N4

Range Partitioning

Data Partitioning among Nodes

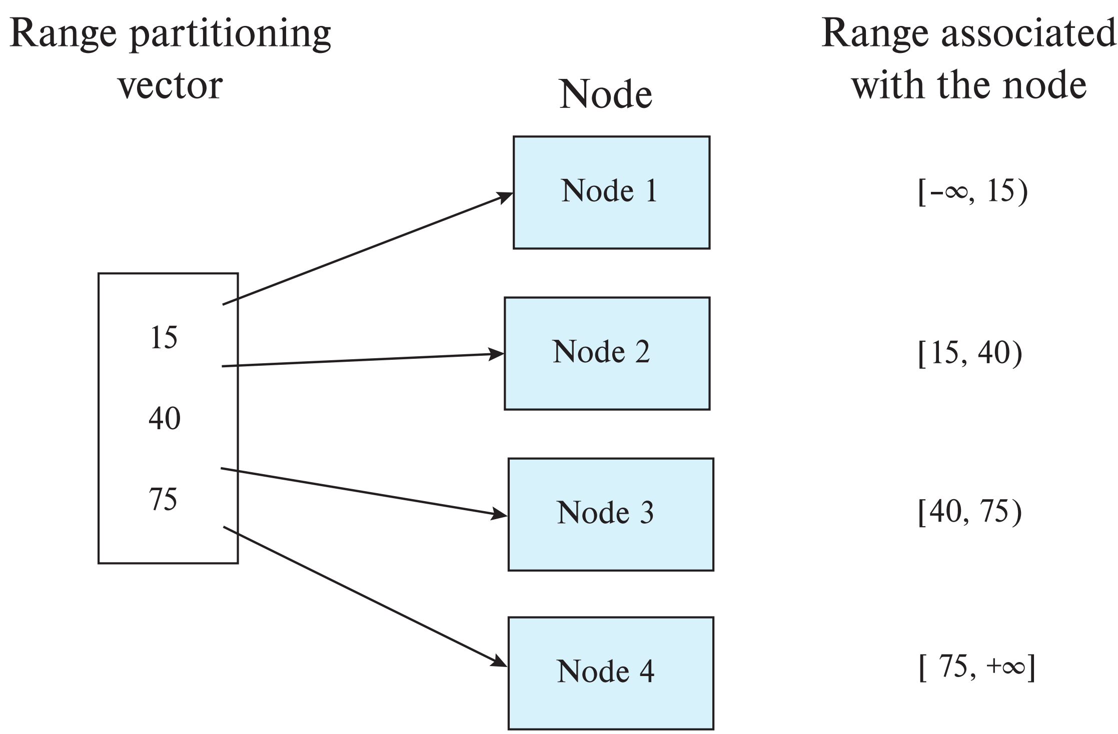
Example: There are 4 nodes: N1, N2, N3 and N4 in a parallel database system. The schema of the relation parents is as follows:

parents(m-NID, f-NID, c-NID, f-age)

Partition vector

P[f-age] = [30, 50, 75]

Perform range partitioning of parents relation into 4 nodes.



Partitions:

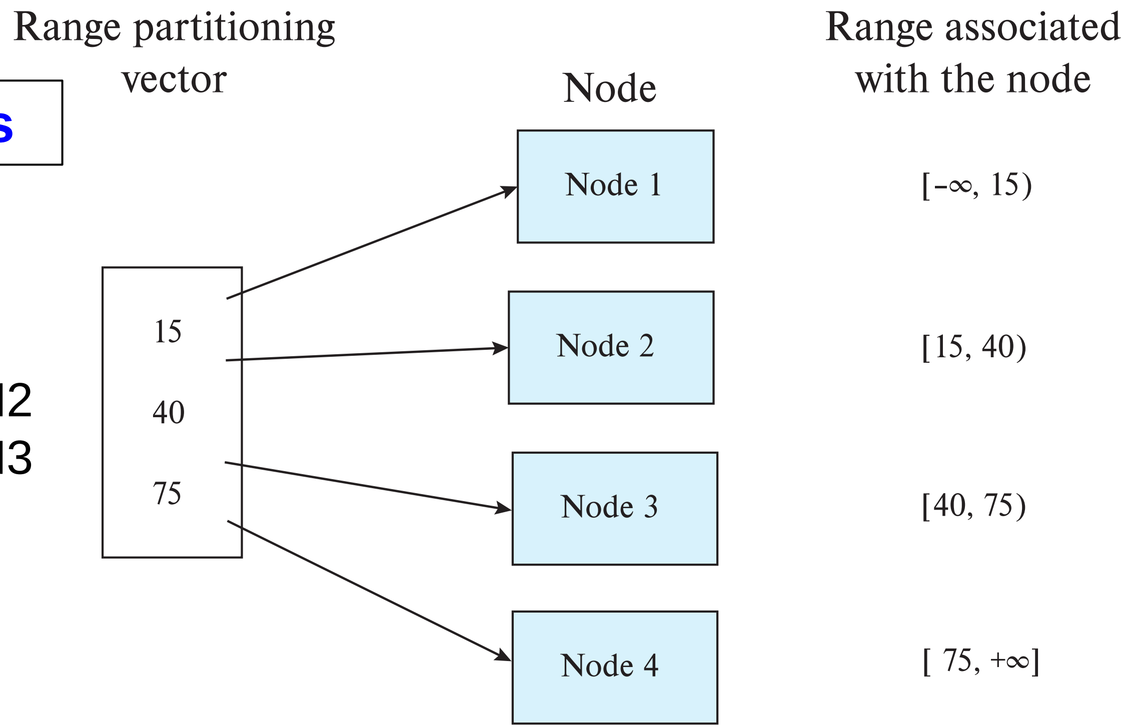
Partition 1, f-age <30 in Node N1

Partition 2, 30<=f-age <50 in Node N2

Partition 3, 50<=f-age <75 in Node N3

Partition 4, f-age >=75 in Node N4

Data Partitioning among Nodes



Partitions:
Person relation
Partition 1, age <30 in Node N1
Partition 2, 30<=age <50 in Node N2
Partition 3, 50<=age <75 in Node N3
Partition 4, age >=75 in Node N4

Partitions:
Parents relation
Partition 1, f-age <30 in Node N1
Partition 2, 30<=f-age <50 in Node N2
Partition 3, 50<=f-age <75 in Node N3
Partition 4, f-age >=75 in Node N4

Person(NID, Name, Thana, District, Age), parents(m-NID, f-NID, c-NID, f-age)
process the query1: SELECT * FROM person r, parents s WHERE r.age = s.f-age
Question 4-4:
a. Explain how query 1 will be executed using 4 nodes?
b. Comments on speed-up and scale-up for the system.

Comparison of Partitioning Techniques

- Evaluate how well partitioning techniques support the following types of data access:

  1. Scanning the entire relation.
  2. Locating a tuple associatively – **point queries**.
     - E.g., $r.A = 25$.
  3. Locating all tuples such that the value of a given attribute lies within a specified range – **range queries**.
     - E.g., $10 \leq r.A < 25$.

Select * from person

Select * from person where NID = 1234567890

Select * from person where NID > 1234567890

Question5-1: Explain the performance of Round robin partitioning technique for

a. Scanning the entire relation
b. Point query
c. Range query

Comparison of Partitioning Techniques (Cont.)

Round robin:

- Best suited for sequential scan of entire relation on each query.
  - All nodes have almost an equal number of tuples; retrieval work is thus well balanced between nodes.
- All queries must be processed at all nodes

Comparison of Partitioning Techniques

- Evaluate how well partitioning techniques support the following types of data access:

  1. Scanning the entire relation.
  2. Locating a tuple associatively – **point queries**.
     - E.g., $r.A = 25$.
  3. Locating all tuples such that the value of a given attribute lies within a specified range – **range queries**.
     - E.g., $10 \leq r.A < 25$.

Select * from person

Select * from person where NID = 1234567890

Select * from person where NID > 1234567890

Question5-2: Explain the performance of hash partitioning technique for

a. Scanning the entire relation
b. Point query
c. Range query

Comparison of Partitioning Techniques (Cont.)

Hash partitioning:

- Good for sequential access
  - Assuming hash function is good, and partitioning attributes form a key, tuples will be equally distributed between nodes
- Good for point queries on partitioning attribute
  - Can lookup single node, leaving others available for answering other queries.
- Range queries inefficient, must be processed at all nodes

Comparison of Partitioning Techniques

- Evaluate how well partitioning techniques support the following types of data access:

  1. Scanning the entire relation.

     Select * from person

  2. Locating a tuple associatively – **point queries**.

     Select * from person where NID = 1234567890

     - E.g., *r.A* = 25.

  3. Locating all tuples such that the value of a given attribute lies within a specified range – **range queries**.

     Select * from person where NID > 1234567890

     - E.g., $10 \leq r.A < 25$.

Question5-3: Explain the performance of range partitioning technique for

a. Scanning the entire relation
b. Point query
c. Range query

Comparison of Partitioning Techniques (Cont.)

Range partitioning:

- Provides data clustering by partitioning attribute value.
  - Good for sequential access
  - Good for point queries on partitioning attribute: only one node needs to be accessed.
- For range queries on partitioning attribute, one to a few nodes may need to be accessed
  - Remaining nodes are available for other queries.
  - Good if result tuples are from one to a few blocks.
  - But if many blocks are to be fetched, they are still fetched from one to a few nodes, and potential parallelism in disk access is wasted
    - Example of **execution skew**.

Handling Small Relations

- Partitioning not useful for small relations which fit into a single disk block or a small number of disk blocks
  - Instead, assign the relation to a single node, or
  - Replicate relation at all nodes

- For medium sized relations, choose how many nodes to partition across based on size of relation

- Large relations typically partitioned across all available nodes.

Types of Skew

- **Data-distribution skew:** some nodes have many tuples, while others may have fewer tuples. Could occur due to
  - **Attribute-value skew**.
    - Some partitioning-attribute values appear in many tuples
      - E.g., partitioning on age in ecommerce database

      Game related DB, P[age] = [10, 20, 30, 40, 50, 60, 70]

      Comments on the partition vector???

    - All the tuples with the same value for the partitioning attribute end up in the same partition.
    - Can occur with range-partitioning and hash-partitioning.

Types of Skew

- **Partition skew**.
  - Imbalance, even without attribute –value skew
  - Badly chosen range-partition vector may assign too many tuples to some partitions and too few to others.
  - Less likely with hash-partitioning

Types of Skew (Cont.)

- Note that **execution skew** can occur even without data distribution skew
  - E.g. relation range-partitioned on date, and most queries access tuples with recent dates
- Data-distribution skew can be avoided with range-partitioning by creating **balanced range-partitioning vectors**
- We assume for now that partitioning is **static**, that is partitioning vector is created once and not changed
  - Any change requires **repartitioning**
  - **Dynamic partitioning** once allows partition vector to be changed in a continuous manner
    - More on this later

Question 6-1: Explain the various reasons and types of skews in

a. Hash partitioning
b. Range partitioning

Handling Skew in Range-Partitioning

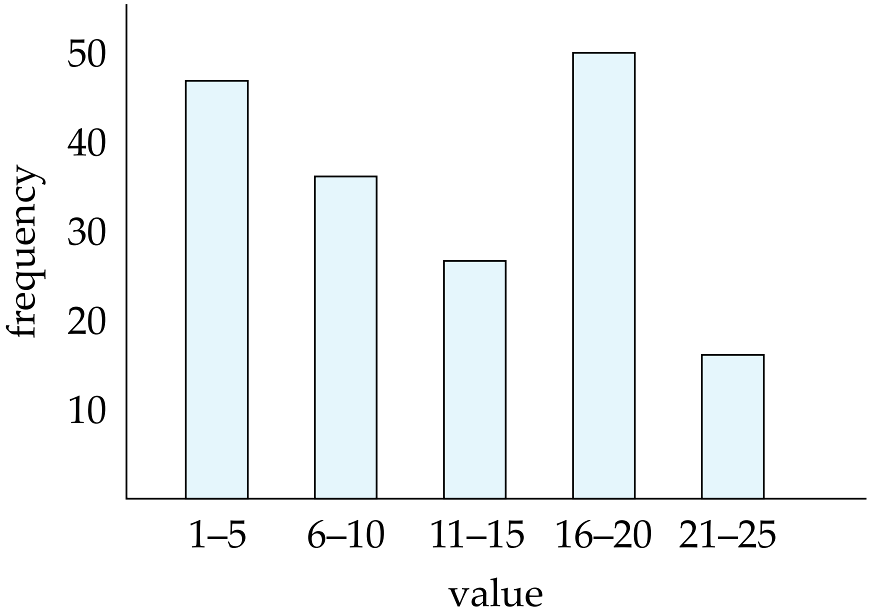
- To create a balanced partitioning vector
  - Sort the relation on the partitioning attribute.
  - Construct the partition vector by scanning the relation in sorted order as follows.
    - After every $1/n^{th}$ of the relation has been read, the value of the partitioning attribute of the next tuple is added to the partition vector.
  - *n* denotes the number of partitions to be constructed.
  - Imbalances can result if duplicates are present in partitioning attributes.

Handling Skew in Range-Partitioning

- To reduce cost
  - Partitioning vector can be created using a random sample of tuples
  - Alternatively histograms can be used to create the partitioning vector

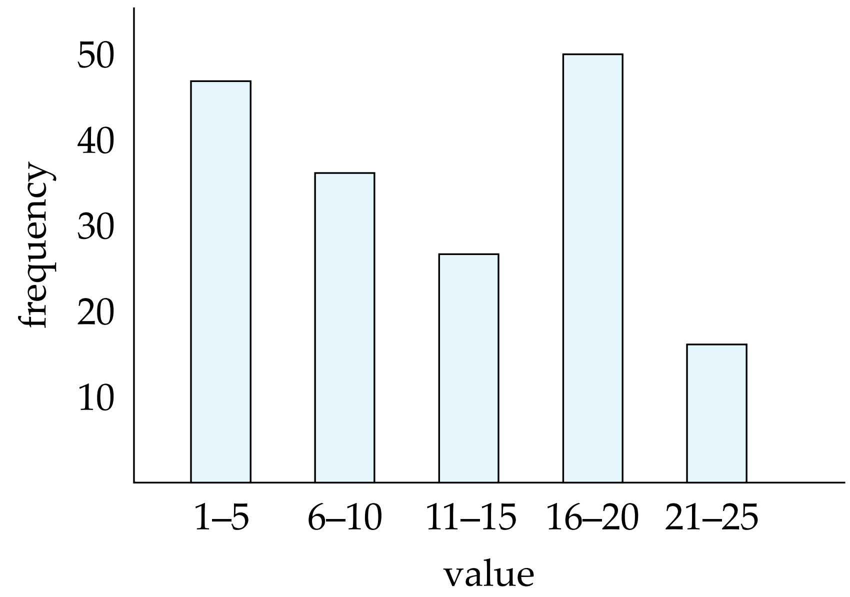
Histograms

- Histogram on attribute *age* of relation *person*



- **Equi-width** histograms
- **Equi-depth** histograms
  - break up range such that each range has (approximately) the same number of tuples
  - E.g. (4, 8, 14, 19)
- Assume uniform distribution within each range of the histogram
- Create partitioning vector for required number of partitions based on histogram

Histograms



Question 6-2:

a. What is the type of the given histogram?
b. Define an approximate partition vector using the histogram for a parallel system with nodes N0, N1, N2 and N3.
c. Draw the approximate histogram of your partition vector.