Steps in Query Processing

1. Translation
   - check SQL syntax
   - check existence of relations and attributes
   - replace views by their definitions
   - generate internal query representation
2. Optimization
   - consider alternative **plans** for processing the query
   - select an efficient plan
3. Processing
   - execute the plan
4. Data Delivery

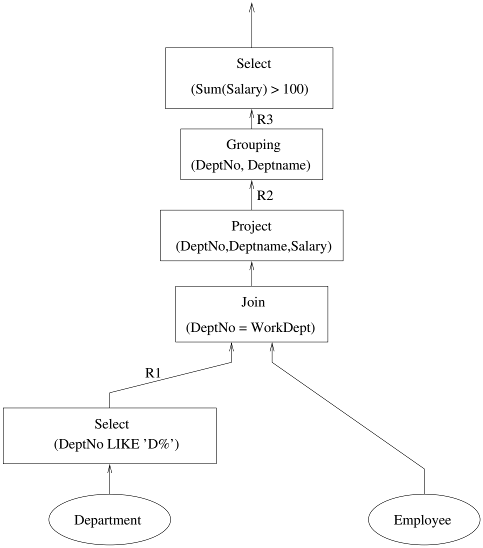
Example

```
Select DeptNo, Deptname, Count*, SumSalary
From Employee, Department
Where WorkDept = DeptNo And DeptNo Like ’D%’
GroupBy DeptNo, Deptname
Having SumSalary > 1000000
```

An Execution Plan

1. Scan the Employee table, select all tuples for which WorkDept starts with ‘D’, call the result R_1.
2. Join R_1 and Department, eliminate attributes other than DeptNo, Deptname, and Salary. Call the result R_2. This may involve:
   - sorting R_1 on WorkDept
   - sorting Department on Deptno
   - joining the two sorted relations to produce R_2
3. Group the tuples of R_2. Call the result R_3. This may involve:
   - sorting R_2 on DeptNo and Deptname
   - group tuples with identical values of DeptNo and Deptname
   - count tuples in each group, and add their Salaries
4. Scan R_3, select all tuples with **sum**(Salary) > 1000000

Pictorial Access Plan



Pipelined Plans and Iterators

- In a pipelined plan, each tuples stream from one operator to another.
- Pipelining allows for parallel execution of operators, and avoids unnecessary *materialization* of intermediate results. (Sometimes materialization may be necessary...)
- Iterators are a common model for plan operators:
  - every operator is an iterator
  - an iterator provides the following interface: *Open*, *GetNext*, and *Close*
  - each iterator implements its interface, using calls to the interface functions of its child (or children)

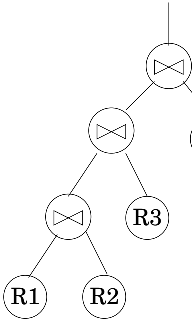
DB2 Access Plan

```
                FILTER  (having)
                  |
                GRPBY (deptno,deptname)
                  |
                MSJOIN
               /      \
          TBSCAN       FILTER
             |           |
(deptno)   SORT          TBSCAN
             |           |
(like D%) TBSCAN         SORT (workdept)
             |           |
        DEPARTMENT     TBSCAN  (like D%)
                         |
                       EMPLOYEE
```

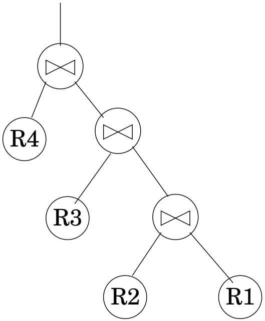
DB2 Access Plan with Index

```
       FILTER
          |
        GRPBY
          |
        TBSCAN
          |
        SORT
          |
        NLJOIN
     /          \
 TBSCAN          FETCH
    |          /     \
EMPLOYEE  IXSCAN     DEPARTMENT
            |
        DEPTNOIND
```

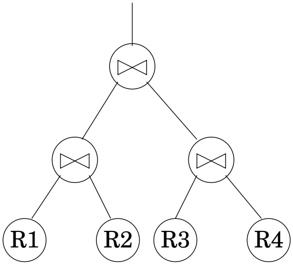
Plan Structures



Left–Deep



Right–Deep



Bushy

Some Basic Query Processing Operations

- Data Access and Filtering
    - Index scans
    - Table scans
- Projection
- Joining
    - nested loop join
    - hash join
    - sort-merge join
    - and others . . .
- Sorting
- Grouping and Duplicate Elimination
    - by sorting
    - by hashing

Joining Relations

select `DeptName, LastName`
from `Department, Employee`
where `DeptNo = WorkDept`

Conceptually, a nested-loop join works like this:

```
foreach tuple d in Department do
   foreach tuple e in Employee do
      if d.DeptNo = e.WorkDept then
         output d,e
   end
end
```

Block Nested Loop Join

select `DeptName, LastName`
from `Department, Employee`
where `DeptNo = WorkDept`

Process outer relation a chunk at a time

```
foreach chunk C of Department
   foreach tuple e in Employee do
      foreach tuple d in C
         if d.DeptNo = e.WorkDept then
             output d,e
      end
   end
end
```

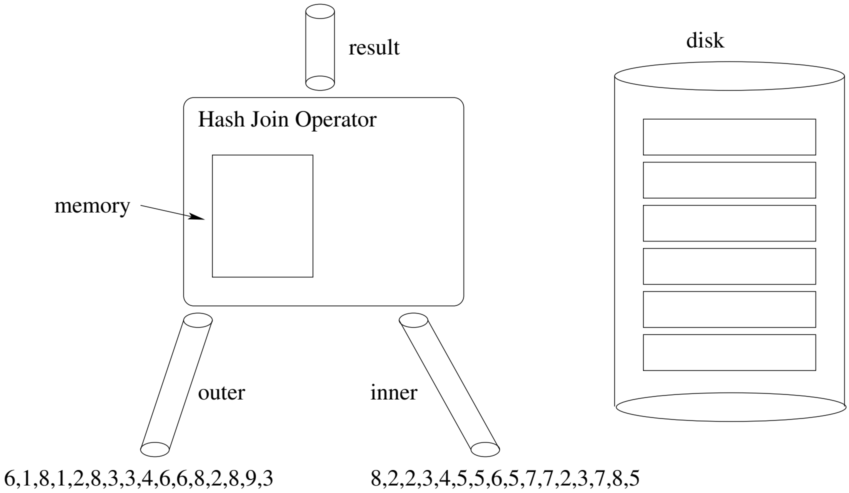
Other Techniques for Join

- If there is an index on the WorkDept attribute of the Employee relation, an **index join** can be used:

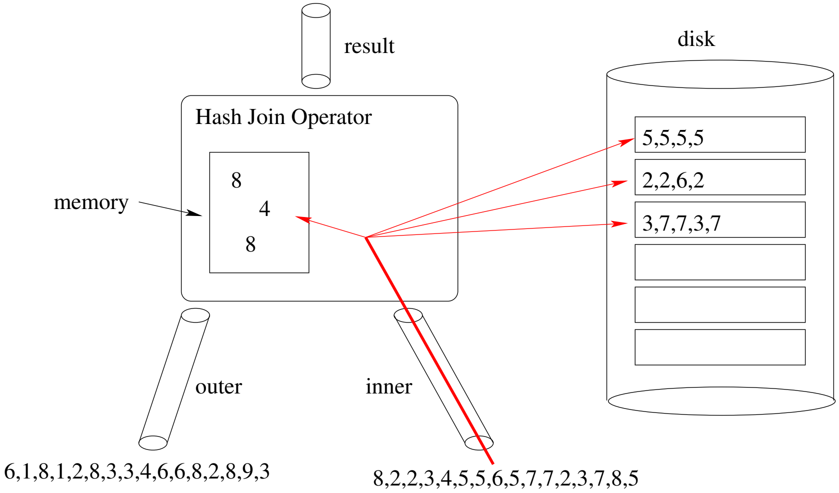
```
foreach tuple d in Department do
   use the index to find Employee tuples where d
   for each such tuple e
      output d,e
end
```

- Examples of other join techniques:
  - **Sort-Merge Join**: sort the tuples of Employee on WorkDept and the tuples of Department of DeptNo, then merge the sorted relations.
  - **Hash Join**: assign each tuple of Employee and of Department to a "bucket" by applying a hash function to its WorkDept (DeptNo) value. Within each bucket, look for Employee/Department tuple pairs for which WorkDept = DeptNo.

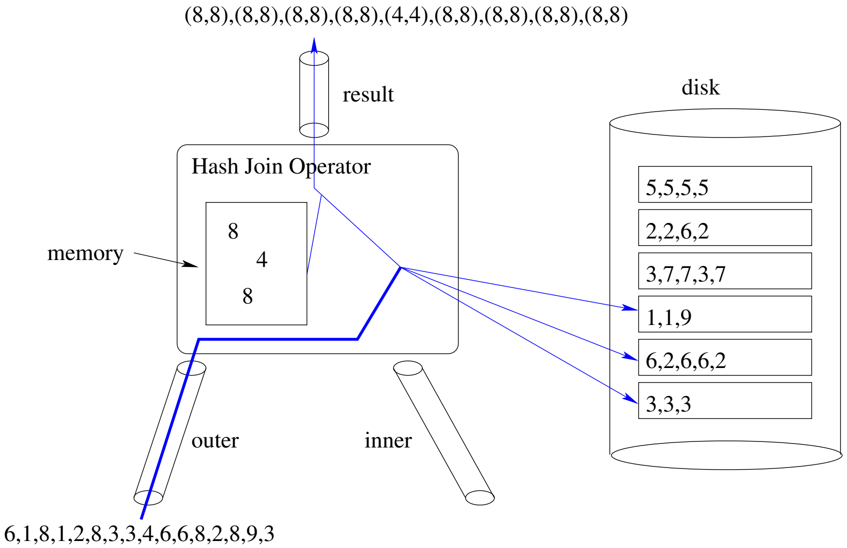
Hash Join Example



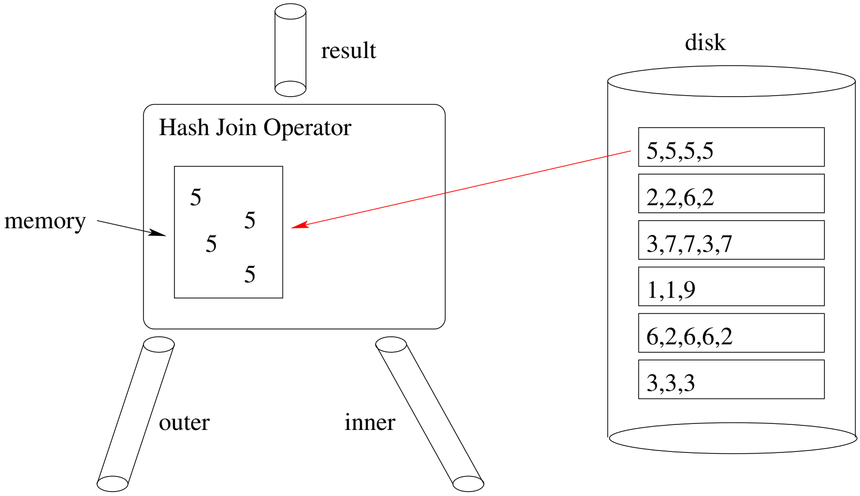
Hash Join Example (cont'd)



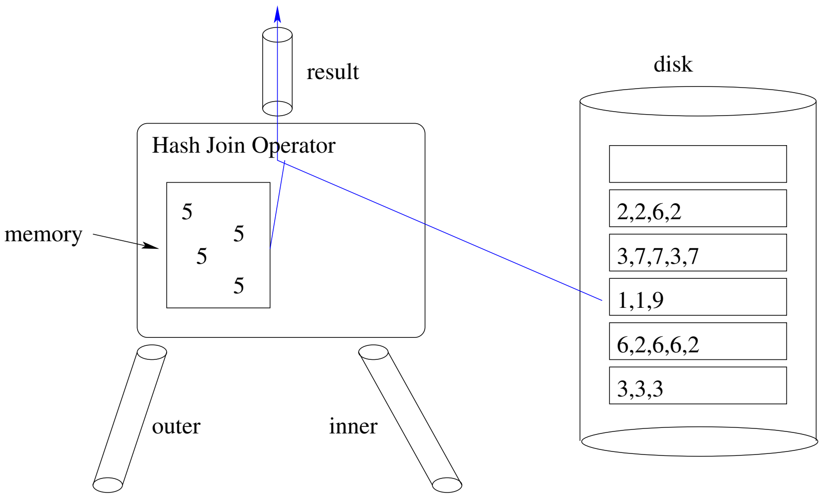
Hash Join Example (cont'd)



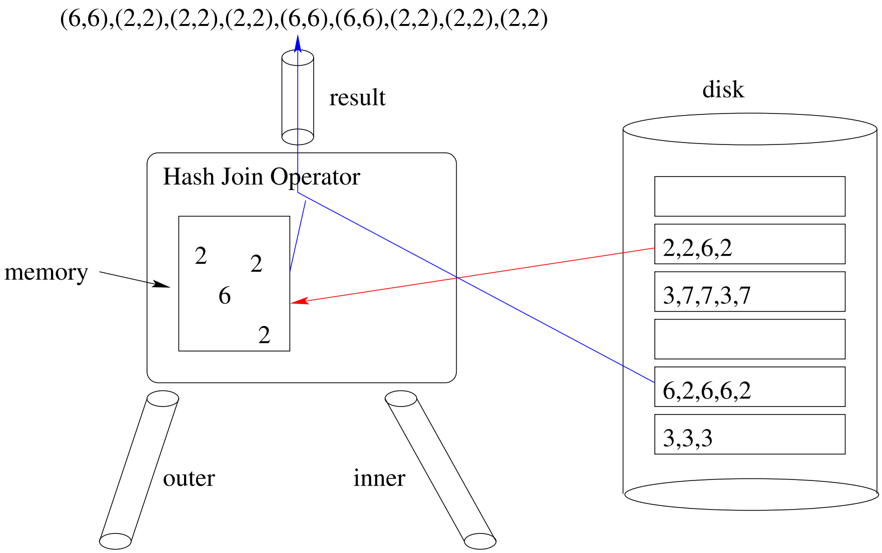
Hash Join Example (cont'd)



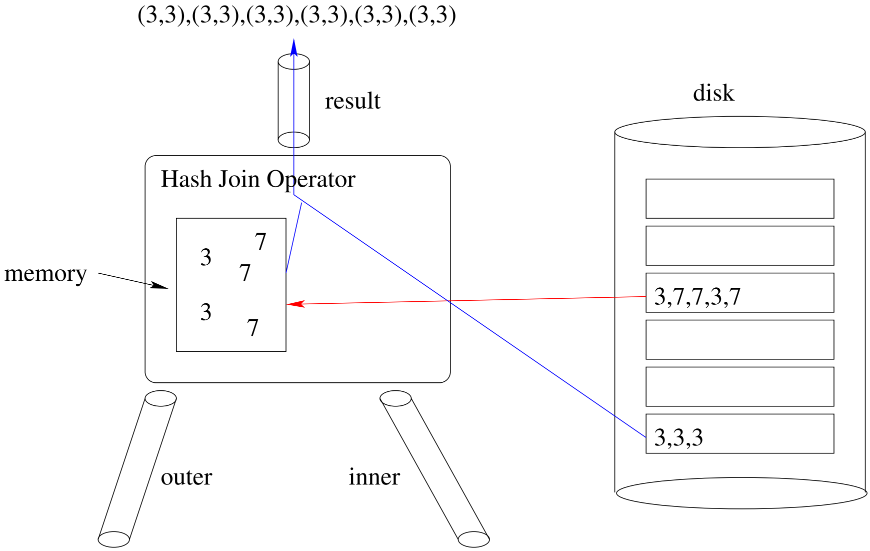
Hash Join Example (cont'd)



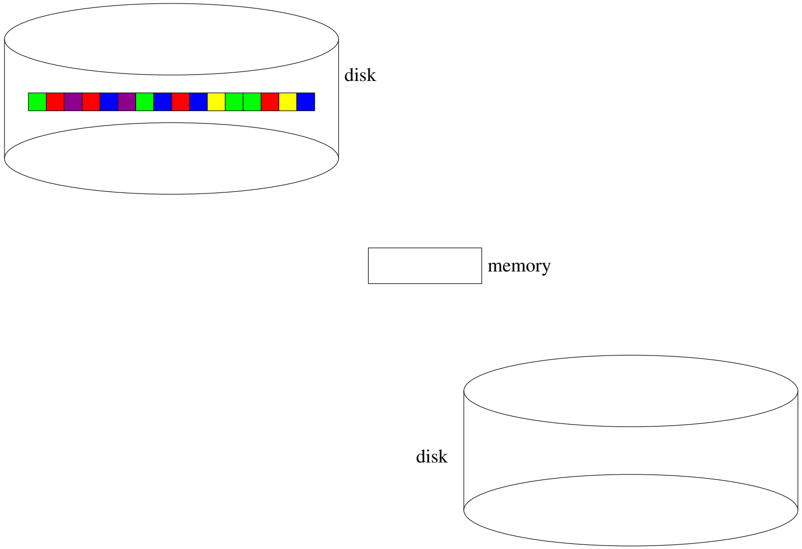
Hash Join Example (cont'd)



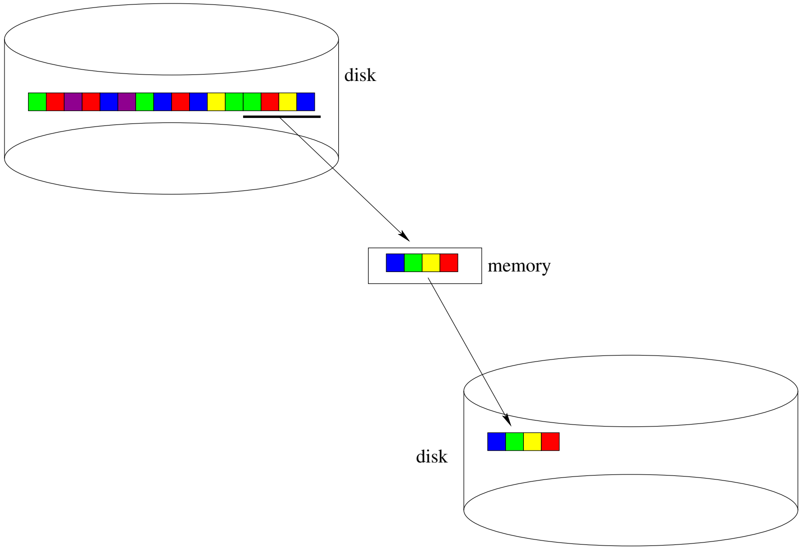
Hash Join Example (cont'd)



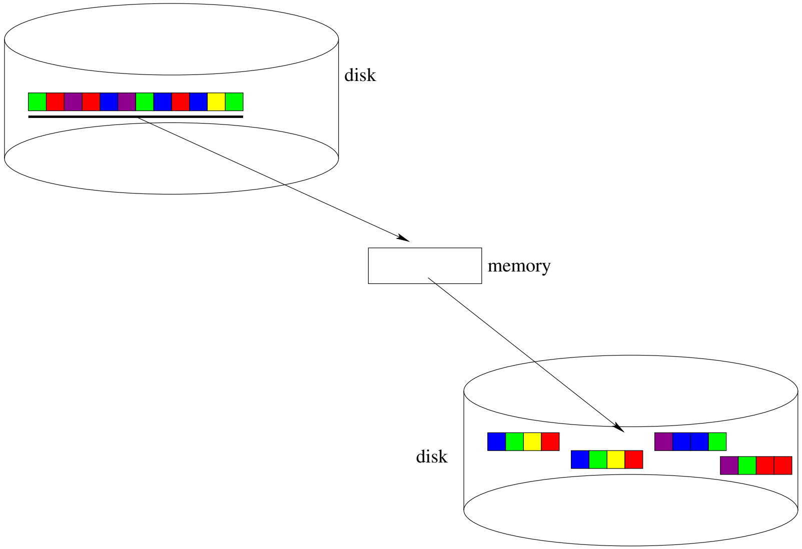
External Merge Sort: Run Formation



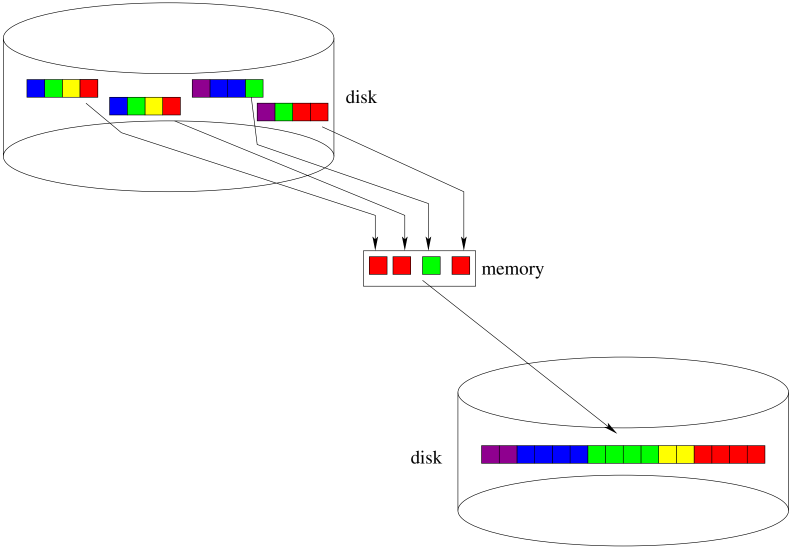
External Merge Sort: Run Formation (cont'd)



External Merge Sort: Run Formation (cont'd)



External Merge Sort: Merging Runs



Summary

- A plan describes how a query is executed, including:
    - the sequence of basic operations (select, project, join, sort, etc.) used to process the query
    - how each operation will be implemented, e.g., which join method will be used, which indices will be used to perform a selection.