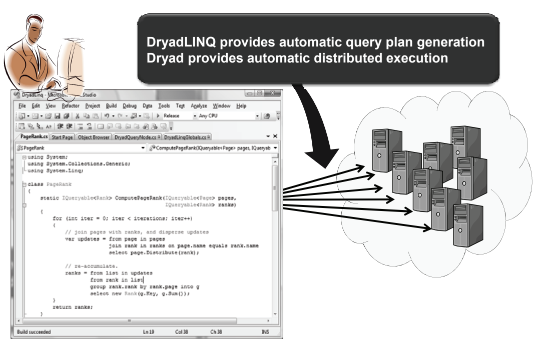
Distributed Data-Parallel Computing Using a High-Level Programming Language

Slides adapted from those of Michal Isard and Yuan Yu

Distributed Data-Parallel Computing

- Research problem: How to write distributed data-parallel programs for a compute cluster?
- DryadLINQ programming model
  - Sequential, single machine programming abstraction
  - Same program runs on single-core, multi-core, or cluster
  - Familiar programming languages
  - Familiar development environment
- Dryad
  - Provides a general, flexible execution layer
  - Automatic handling
    - Scheduling
    - Distribution
    - Fault-tolerance

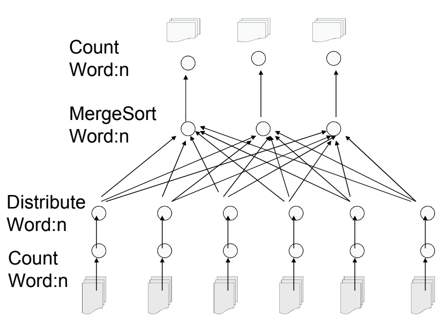
Dryad and DryadLINQ



Dryad

- Similar goals as MapReduce
  - focus on throughput, not latency
    - Why is throughput important and not latency?
  - Automatic management of scheduling, distribution, fault tolerance
- Computations expressed as a graph
  - Vertices are computations
  - Edges are communication channels
  - Each vertex has several input and output edges

WordCount in Dryad

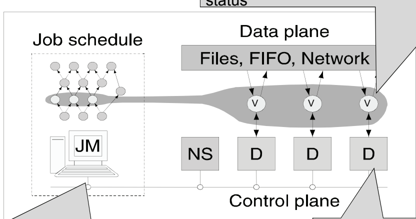


Why using a dataflow graph?

- Many programs can be represented as a distributed dataflow graph
  - The programmer may not have to know this
    - “SQL-like” queries: LINQ
- Dryad will run them for you

Runtime

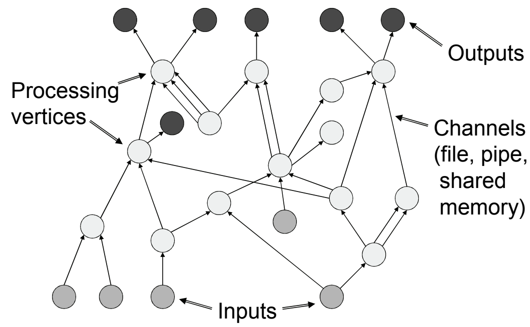
- Vertices (V) run arbitrary app code
- Vertices exchange data through files, TCP pipes etc.
- Vertices communicate with JM to report status



- Job Manager (JM) consults name server(NS) to discover available machines.
- JM maintains job graph and schedules vertices

- Daemon process (D) executes vertices

Job = Directed Acyclic Graph



Scheduling at JM

- General scheduling rules:
  - Vertex can run anywhere once all its inputs are ready
    - Prefer executing a vertex near its inputs
  - Fault tolerance
    - If A fails, run it again
    - If A's inputs are gone, run upstream vertices again (recursively)
    - If A is slow, run another copy elsewhere and use output from whichever finishes first

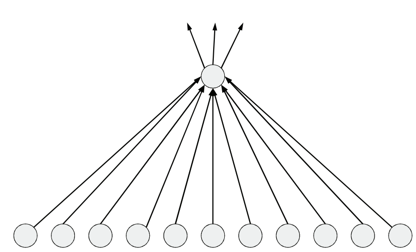
Advantages of DAG over MapReduce

- Big jobs more efficient with Dryad
  - MapReduce: big job runs >=1 MR stages
    - reducers of each stage write to replicated storage
    - Output of reduce: 2 network copies, 3 disks
  - Dryad: each job is represented with a DAG
    - intermediate vertices write to local file

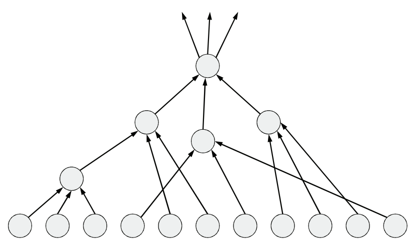
Advantages of DAG over MapReduce

- Dryad provides explicit join
  - MapReduce: mapper (or reducer) needs to read from shared table(s) as a substitute for join
  - Dryad: explicit join combines inputs of different types
- Dryad "Split" produces outputs of different types
  - Parse a document, output text and references

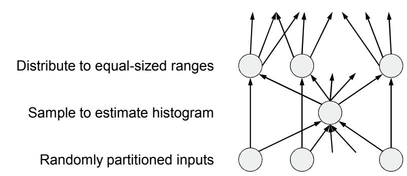
DAG optimizations: merge tree



DAG optimizations: merge tree



Dryad Optimizations: data-dependent re-partitioning



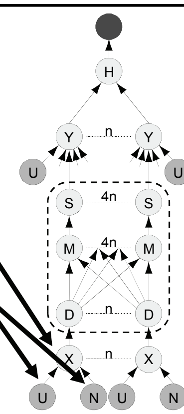
Dryad example 1: SkyServer Query

- 3-way join to find gravitational lens effect
- Table U: (objId, color) 11.8GB
- Table N: (objId, neighborId) 41.8GB
- Find neighboring stars with similar colors:
  - Join U+N to find
    T = N.neighborID where U.objID = N.objID, U.color
  - Join U+T to find
    U.objID where U.objID = T.neighborID
    and U.color ≈ T.color

SkyServer query

```
select
  u.color,n.neighborobjid
from u join n
where
  u.objid = n.objid
```

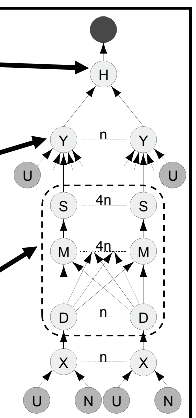
```
u: objid, color
n: objid, neighborobjid
[partition by objid]
```




```
[distinct]
[merge outputs]
```

```
(u.color,n.neighborobjid)
[re-partition by
n.neighborobjid]
[order by n.neighborobjid]
```

```
select
  u.objid
from u join <temp>
where
  u.objid =
<temp>.neighborobjid and
  |u.color - <temp>.color| < d
```



Immutable Input

- Assumes that inputs are immutable
  - High performance: Scales out to shared-nothing clusters made up of thousands of machines
  - Significantly simplifies the design/implementation
    - Simple fault-tolerant story
    - No need to handle complex transaction and synchronization
  - Good for processing largely static datasets
  - Not suitable for fine-grain, frequent updates

DryadLINQ

LINQ

- Microsoft's Language INtegrated Query
  - Available in .NET3.5 and Visual Studio 2008
- A set of operators to manipulate datasets in .NET
  - Support traditional relational operators
    - Select, Join, GroupBy, Aggregate, etc.
  - Integrated into .NET programming languages
    - Programs can invoke operators
    - Operators can invoke arbitrary .NET functions
- Data model
  - Data elements are strongly typed .NET objects
  - Much more expressive than relational tables
    - For example, nested data structures

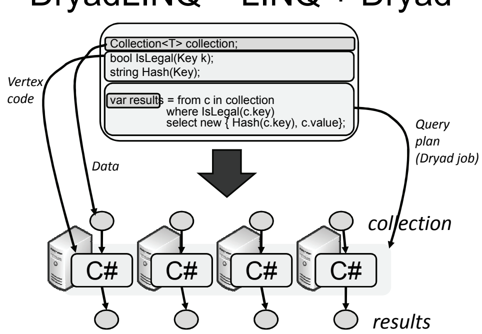
DryadLINQ

- More general than distributed SQL
  - Inherits flexible C# type system and libraries
  - Data-clustering, inference, …
- Uniform data-parallel programming model
  - From SMP to clusters

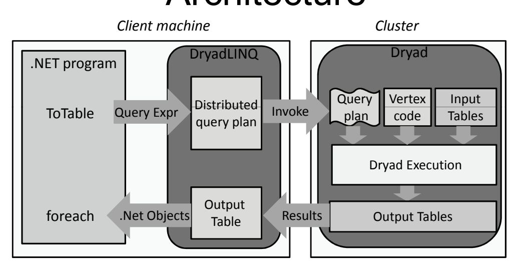
LINQ

```
Collection<T> collection;
bool IsLegal(Key);
string Hash(Key);

var results = from c in collection
              where IsLegal(c.key)
              select new { Hash(c.key), c.value};
```

DryadLINQ = LINQ + Dryad



DryadLINQ System Architecture



DryadLINQ example: PageRank

- PageRank scores web pages using the hyperlink graph

To compute the pagerank of (i+1)-th iteration:

$$P_{i+1}(u) = \sum_{v \in In(u)} \frac{P_i(v)}{|Out(v)|}$$

A page u's score is contributed by all neighboring pages v that link to it

The contribution of v is its pagerank normalized by the number of outgoing links

DryadLINQ example: PageRank

- DryadLINQ express each iteration as a SQL query

1. Join **pages** with **ranks**
2. Distribute **ranks** on outgoing **edges**
3. GroupBy edge destination
4. Aggregate into **ranks**
5. Repeat

One PageRank Step in DryadLINQ

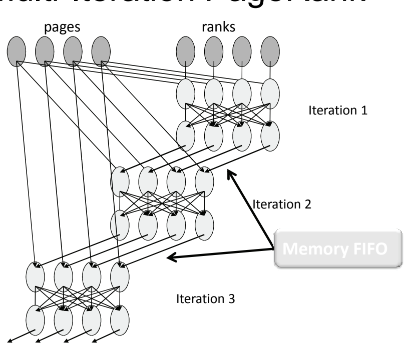
```
// one step of pagerank: dispersing and re-accumulating rank
public static IQueryable<Rank> PRStep(IQueryable<Page> pages,
                                      IQueryable<Rank> ranks)
{
   // join pages with ranks, and disperse updates
   var updates = from page in pages
                 join rank in ranks on page.name equals rank.name
                 select page.Disperse(rank);

   // re-accumulate.
   return from list in updates
          from rank in list
          group rank.rank by rank.name into g
          select new Rank(g.Key, g.Sum());
}
```

The Complete PageRank Program

```
public static IQueryable<Rank> PRStep(IQueryable<Page> pages,
                                      IQueryable<Rank> ranks) {
   // join pages with ranks, and disperse updates
   var updates = from page in pages
                 join rank in ranks on page.name equals rank.name
                 select page.Disperse(rank);

   // re-accumulate.
   return from list in updates
          from rank in list
          group rank.rank by rank.name into g
          select new Rank(g.Key, g.Sum());
}

var pages = PartitionedTable.Get<Page>("dfs://pages.txt");
var ranks = pages.Select(page => new Rank(page.name,
   1.0));

// repeat the iterative computation several times
for (int iter = 0; iter < n; iter++) {
   ranks = PRStep(pages, ranks);
}

ranks.ToPartitionedTable<Rank>("dfs://outputranks.txt");
```

```
public struct Page {
   public UInt64 name;
   public Int64 degree;
   public UInt64[] links;

   public Page(UInt64 n, Int64 d, UInt64[] l) {
      name = n; degree = d; links = l; }

   public Rank[] Disperse(Rank rank) {
      Rank[] ranks = new Rank[links.Length];
      double score = rank.rank / this.degree;
      for (int i = 0; i < ranks.Length; i++) {
         ranks[i] = new Rank(this.links[i], score);
      }
      return ranks;
   }
}

public struct Rank {
   public UInt64 name;
   public double rank;

   public Rank(UInt64 n, double r) {
      name = n; rank = r; }
}
```

Multi-Iteration PageRank



Lessons of Dryad/DryadLINQ

- Acyclic dataflow graph is a powerful computation model
  - Trees
    - SQL
  - Cyclic graphs
    - ML
- Language integration increases programmer productivity
- Decoupling of Dryad and DryadLINQ
  - Dryad: execution engine (given DAG, do scheduling and fault tolerance)
  - DryadLINQ: programming model (given query, generate DAG)

Questions on Dryad/DryadLINQ

- What do you think about DryadLINQ?
  - Sweet spot between imperative and declarative?
  - Supports complex objects
    - What about access methods?
- Hard problems
  - Loops
    - No data dependent termination
  - Query optimization
    - Not dynamic

Questions on Dryad/DryadLINQ

- Comparison
  - Two language approach
    - PigLatin
    - SCOPE
  - Map Reduce Online (Eurosys'10)
- Centralized scheduler
  - Quincy (SOSP'09)