DryadLINQ

Distributed Computation

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Outline

Outline

Dryad-LINQ

- Current programming models for large scale distributed programming
  - Map-Reduce
  - MPI
  - Microsoft Dryad
- A DryadLINQ program contains LINQ expressions that:
  - Use LINQ expressions to specify side effect free transformations to data
  - The Dryad system parallelizes portions of the program, and runs the program on thousands of machines
- A sort of a terabyte level data set takes 319 seconds, on a 240 node system.

Basic Idea

LINQ Constructs

- LINQ (Language INtegrated Query) is a set of .NET constructs
- It provides support for imperative and declarative programming
- Programming languages supported: C#, F#, VB

- Imperative programming: variables, loops, iterators, conditionals
- Declarative programming: functors, type inferencing

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Related Work

Parallel Databases

- Implement only declarative variants of SQL Queries
- The query oriented nature of SQL makes it hard to specify typical programming constructs

Map Reduce

- Not very flexible.
- Hard to perform operations such as sorting or database joins
- Lack of type support

Related Work - II

- Domain specific languages on top of MapReduce – Sawzall, Pig (Yahoo), Hive (Facebook)
- They are a combination of declarative constructs, and iterative constructs
- However, they are not very flexible since their pattern is inherently based on SQL
- How is DryadLINQ different ?
  - The computation is not dependent on the nature of underlying resources.
  - Uses virtual execution plans
  - Underlying computational resources can change dynamically (faults, outages, . . .)

Overview of DryadLINQ

Structure of a Dryad job

- It is a directed acyclic graph (DAG)
- Each vertex is a program
- Each edge is a data channel that transmits a finite sequence of records at runtime

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Dryad System Architecture

Dryad System Architecture

It contains a centralized job manager whose role is:

- Instantiating a job's dataflow graph.
- Scheduling processes
- Fault tolerance
- Job monitoring and management
- Transforming the job graph at runtime according to the user's instructions

DryadLINQ Execution Overview

1. The user runs a .NET application. It creates a DryadLINQ expression object that has deferred evaluation.
2. The application calls the method *ToDryadTable*. This method hands over the expression object to DryadLINQ.
3. DryadLINQ compiles the expression, and makes an execution plan
    1. Decomposition into sub-expressions
    2. Generation of code and data for Dryad nodes
    3. Generation of serialization and synchronization code.
4. Dryad invokes a custom job manager .

DryadLINQ Execution Overview - II

1. The job manager creates a job graph. It schedules and spawns the jobs.
2. Each node in the graph executes the program assigned to it.
3. When the program is done, it writes the data to the output table.
4. After the job manager terminates, DryadLINQ collates all the outputs and creates the DryadTable object.
5. Control returns to the user application.
    1. Dryad passes an iterator object to the table object.
    2. This can be passed to subsequent statements.

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LINQ

- The base type is an interface IEnumerable<T> – An iterator for a set of objects with type *T*
  - The programmer is not aware of the data type associated with an instance of IEnumerable
- IQueryable<T> is a subtype of IEnumerable<T>
  - This is an unevaluated expression
  - It undergoes deferred evaluation
  - DryadLINQ creates a concrete class to implement the IQueryable expression at runtime

LINQ SQL Syntax Example

```
// Join two tables: scoreTriples and staticRank
var adjustedScoreTripes =
  from d in scoreTriples
  join r in staticRank on d.docID equals r.key
  select new QueryScoreDocIDTriple(d, r);
var rankedQueries =
  from s in adjustedScoreTriples
  group s by s.query into g
  select TakeTopQueryResults(g);
```

LINQ OOP Syntax Example

```
var adjustedScoreTriples =
  scoreTriples.Join(staticRank,
   d => d.docID, r => r.key,
    (d, r) => new QueryScoreDocIDTriple(d, r));
var groupedQueries =
  adjustedScoreTriples.GroupBy(s => s.query);
var rankedQueries = groupedQueries.Select(
  g => TakeTopQueryResults(g));
```

DryadLINQ Constructs

- A DryadLINQ collection (defined by IEnumerable) is a distributed dataset. Partitioning strategies.
  - Hash Partitioning
  - Range Partitioning
  - Round-robin Partitioning
- The results of a DryadLINQ computation are represented by the object – DryadTable<T>
  - Subtypes determine the actual storage interface.
  - Can include additional details such as metadata and schemas.

DryadLINQ Methods

- All the methods need to be side effect free
- Shared objects can be distributed in any way
- The functions to access a DryadTable are serializable
  - GetTable<T>
  - ToDryadTable<T>
- Custom partitioning operators
  - HashPartition<T,K>
  - RangePartition<T,K>
- Functional Operators
  - apply(f,dataset) Applies function f to all the elements in a dataset
  - fork(f,dataset) Similar to Apply , but can produce multiple output datasets.
- Dryad annotations – parallelization, storage policies

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System Implementation

Execution Plan Graph (EPG)

- DryadLINQ converts the raw LINQ expressions to the nodes of the EPG
- The EPG is a DAG
- A part of the EPG can also be generated at runtime based on the values of iterative and conditional expressions
- DryadLINQ also needs to respect the metadata (node requirements, and parallelization directives) while generating the EPG
- Needs to support the deferred evaluation of functions

Static Optimizations

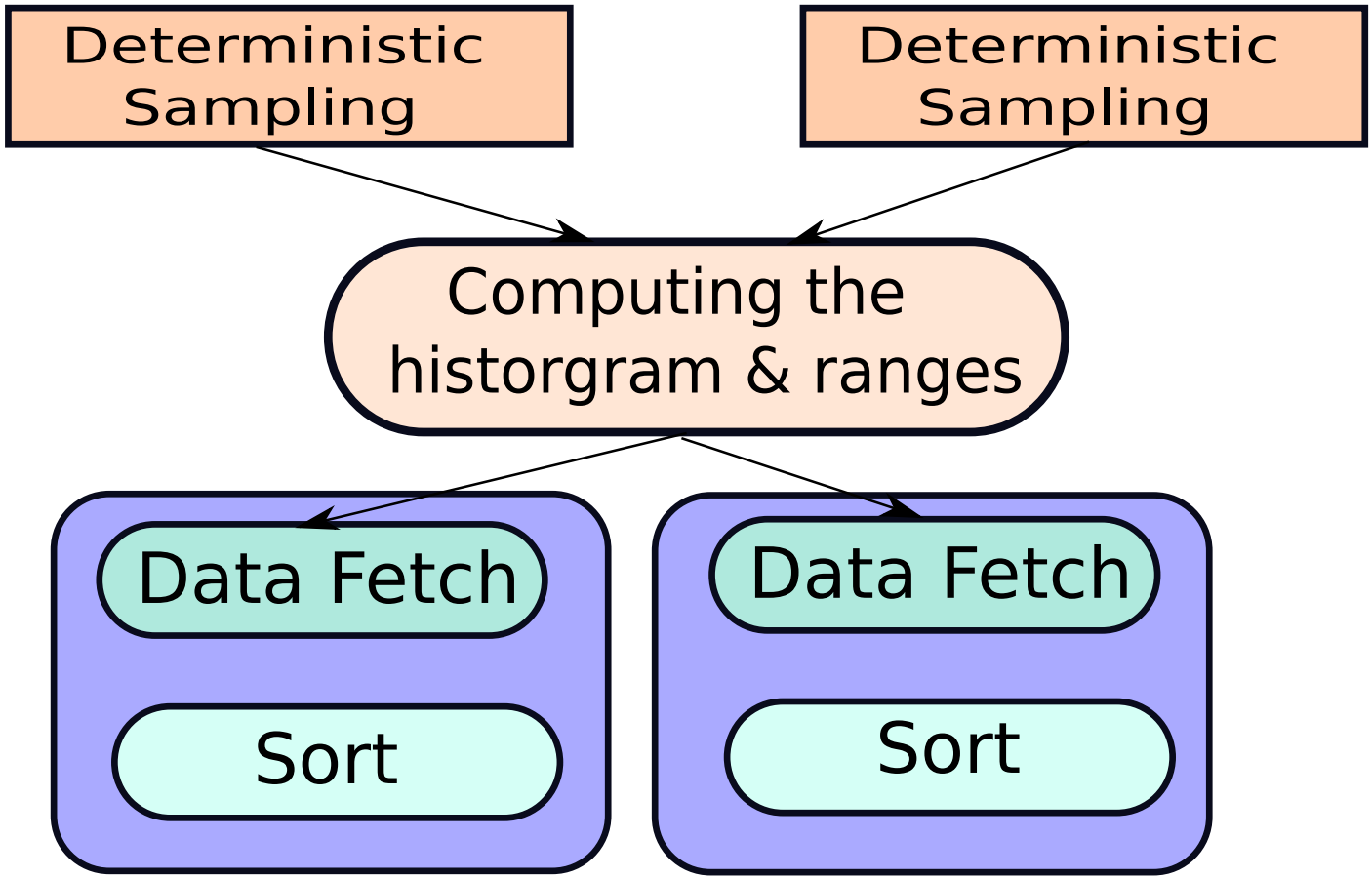
- Pipelining : One process executes multiple operations in a pipelined fashion
- Redundancy Removal : Remove dead code, and unnecessary partitioning
- Eager Aggregation : Intelligently reduce data movement by optimizing aggregation and repartitioning
- I/O Reduction : Use TCP pipes, and in-memory channels to reduce persistence to files

Dynamic Optimizations

Optimally Implementing **OrderBy**

- Deterministically sample the values.
- Plot a histogram, and compute the appropriate keys for range partitioning
- A set of vertices now perform the range partitioning.
- A node now fetches the inputs, and then sorts them. These two actions can be pipelined.

Execution Plan of OrderBy



Code Generation

- The EPG is a virtual execution plan
- DryadLINQ dynamically generates code for each EPG node
  - DryadLINQ generates a .NET assembly snippet that corresponds to each LINQ subexpression.
  - It contains the serialization and I/O code for ferrying data.
  - The EPG node code is generated at the computer of the client (job submitter), because it may depend on the local context. Values in the local context are embedded in the function/expression. The expression undergoes partial evaluation later.
  - Uses .NET reflection to find the transitive closure of all .NET libraries. The EPG code, and all the associated libraries are shipped to the cluster computer for remote execution.

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Interacting with other Frameworks

PLINQ

- Runs a subexpression in a cluster node in parallel using multicore processors.
- Uses user supplied annotations (mostly transparent to the user).
- Uses parallel iterators (similar to OpenMP)

SQL

- DryadLINQ nodes can directly access SQL databases.
- They can save internal datasets in SQL tables.
- Can ship some subexpressions to run directly as SQL procedures.

Debugging

Debugging massively parallel applications is very difficult

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Debugging

- Visual Studio .NET interface to debug the DryadLINQ program on a single computer
- DryadLINQ has a deterministic replay model
  - It is possibly to replay the entire execution – event by event
  - Secondly, it is possible to replay any subexpression on a local machine and view the outputs
  - Performance Debugging
    - Collect detailed profiling information.

Setup

- 240 computer cluster
- Each node contains two AMD Opteron nodes
- 16GB of main memory
- Experiments

Terasort

- Sort a terabyte size dataset.
- 3.87 GB saved per node.

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Results: Terasort

- The number of nodes was varied from 1 to 240
- Each node stored 3.87 GB of data.
- The execution time was 120s for 1 machine, and quickly jumped to 250 s.
- Then it grew very slowly (sub-linearly) to 320s.

Source [1]

Outline

SkyServer benchmark

- Three-way join for two tables containing astronomical data. Size: 11.8 GB and 41.8 GB
- The number of machines was varied from 1 to 40
- The speedup increased from 1 to 19 sub-linearly for DryadLINQ
- The speedup increased from 1 to 24 sub-linearly for Dryad Two-pass

Source [1]

DryadLINQ: A System for General-Purpose Distributed Data-Parallel Computing Using a High-Level Language by Yuan Yu, Michael Isard, Dennis Fetterly, Mihai Budiu, Ulfar Erlingsson, Pradeep Kumar Gunda, and Jon Currey, OSDI 2008