Flexible Cluster Computing: Dryad and DryadLINQ

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Computing on Clusters

How to crunch lots of data?
▶ Explicit distribution
  ▶ Write it by hand
  ▶ Hard! failure, resource allocation, scheduling, . . .

▶ Implicit distribution
  ▶ MapReduce, DryadLINQ
  ▶ Easy! As long as your computation is expressible. . .

▶ Virtualized distribution
  ▶ Dryad
  ▶ In between. Programmer specifies data flow, system handles details
Dryad Overview — Jobs

Dryad Job is a Directed Acyclic Graph

- Vertices are subcomputations
- Edges are data channels
- Graph is *virtual* — may be more or fewer vertices than cluster nodes.
Centralized *Job Manager* distributes virtual graph to actual cluster.
Writing Vertex Programs

- A Vertex Program is a class that extends the base VP class
  - Base class provides typed I/O channels
  - Specialized abstract subclasses available
    - Map, Reduce, Distribute, ...

- Special support for legacy executables
  - grep, perl, legacyApp, ...

- Asynchronous I/O API available for vertices that require it
  - Runtime distinguishes asynch vertices, executes them efficiently on thread pool
Composing Vertex Programs

Vertex programs are joined into graphs
  ▶ edges are local files by default
  ▶ can also be TCP pipes or in-memory FIFOs
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Predefined operators for common composition patterns:
- Clone \( G^n \)

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- Clone \((G^n)\)

- Merge \((G_1 || G_2)\)

- Pointwise composition \((G_1 \geq G_2)\)
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Predefined operators for common composition patterns:
- Clone \((G^n)\)
- Merge \((G1 \mid \mid G2)\)
- Pointwise composition \((G1 \geq G2)\)
- Bipartite composition \((G1 \gg G2)\)
Example Job

\[
(((U > X) \lor (N > X)) > D) \land^n \lor (((M > S)^4 \lor Y) \land U > Y) \land^n H > out
\]
Running a Job

Vertices are instantiated on nodes
- May be multiple *execution records* due to failure
- Node placement handled by Job Manager
  - Applications can specify locality “hints” or “requirements”
  - Edge requirements may force vertices to co-locate

Job manager is notified of node transitions
- May rerun failed vertices
- Can rewrite the graph
- May run duplicate process to route around slow nodes
Callback Example: Dynamic Optimization

Client may not know size or distribution of data at load time
- Can dynamically rewrite the graph
MapReduce in Dryad
So Far...

- Dryad provides a mid-level execution platform
- Good performance possible
- Flexibility
- But
  - Data parallelization done by hand
  - Optimization done by hand
  - Unfamiliar programming style
DryadLINQ

LINQ (Language INtegrated Query)
- Standard .NET extension
- Embeds SQL-like operators into programming languages
- Developers can mix declarative, functional, and imperative statements

DryadLINQ
- Compiles LINQ statements to run on Dryad
- Provides simple, flexible, efficient access to cluster computing
var adjustedScoreTriples =
  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 Example

```csharp
var adjustedScoreTriples =
    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);

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

Types:
- `IEnumerable<T>`
- `IQueryable<T>`
- `DryadTable<T>`
  - NTFS
  - GFS
  - SQL Table

Data Partitioning Operators:
- `HashPartition<T,K>`
- `RangePartition<T,K>`

Escape Hatches:
- `Apply (f)`
- `Fork (f)`
Execution Overview

Client machine

ToDryadTable

.NET

foreach

DryadLINQ

Compile

Invoke

Data center

Input tables

Dryad Execution

Output Tables

Output

Vertex code

Exec plan

 Publié

.JM

Results

LINQ

Expr

.NET

Objects
Execution Details

1. LINQ expression is compiled to an Execution Plan Graph
   - EPG is a skeleton of a job
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2. EPG is optimized using term rewriting
   ▶ Pipelining added
   ▶ Redundancy redundancy removed
   ▶ Aggregation made eager
   ▶ TCP/FIFO annotations added where possible
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3. Code Generated
   ▶ Partially evaluated LINQ subexpressions
   ▶ Serialization code
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   - Partially evaluated LINQ subexpressions
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4. Dynamically, EPG is executed by DryadLINQ job manager
   - Vertices replicated to match data
   - Dynamic optimizations automated
   - Vertices use local LINQ execution engines (e.g., PLINQ)
public static MapReduce(source, mapper, keySelector, reducer) {
    var mapped = source.selectMany(mapper);
    var groups = mapped.groupBy(keySelector);
    return groups.selectMany(reducer);
}
Scalability Evaluation — TeraSort

Execution Time

Machines: 0 50 100 150 200 240

Data: 0Gb 208Gb 416Gb 624Gb 832Gb 1000Gb

319s
Conclusions and Discussion

Dryad meets its goals:
  ▶ efficient
  ▶ flexible
  ▶ programmable

DryadLINQ builds on Dryad:
  ▶ almost as efficient
  ▶ concise
  ▶ familiar