Flexible Cluster Computing: Dryad and DryadLINQ

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Computing on Clusters

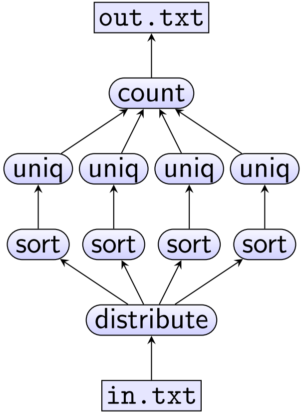
How to crunch lots of data?

- 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

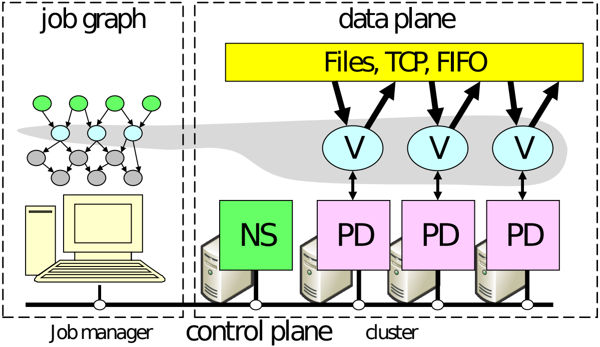
Dryad Job is a Directed Acyclic Graph

- Vertices are subcomputations
- Edges are data channels
- Graph is *virtual* — may be more or fewer vertices than cluster nodes.



Dryad Overview — Execution

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

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- can also be TCP pipes or in-memory FIFOs

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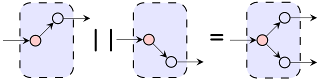

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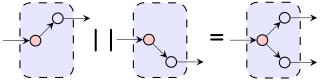
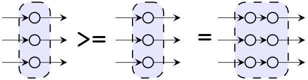


- Pointwise composition (`G1>=G2`)



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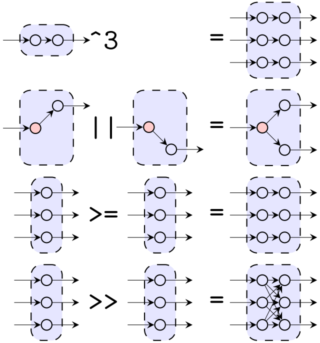
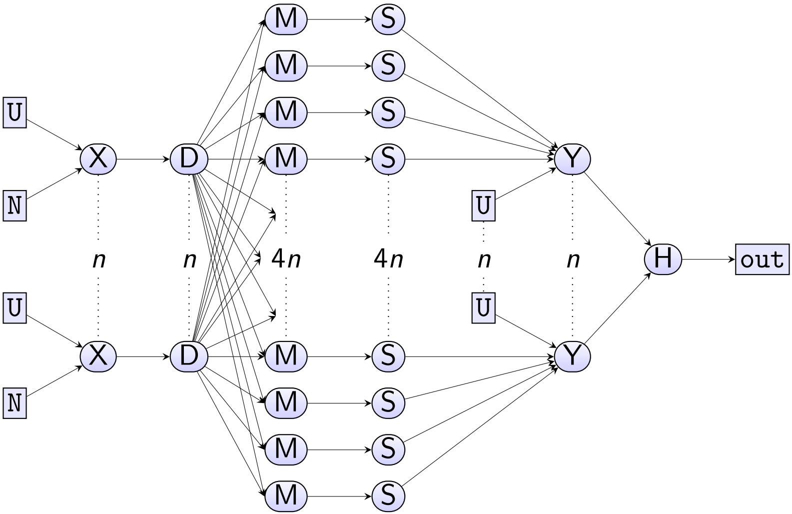
Predefined operators for common composition patterns:

- Clone (`G^n`)
- Merge (`G1||G2`)
- Pointwise composition (`G1>=G2`)
- Bipartite composition (`G1>>G2`)



Example Job




```
((((U >= X) || (N >= X)) >= D)^n >> (((M >= S)^4 >> Y) || U >= Y)^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

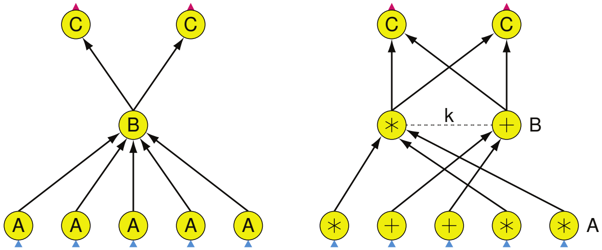
Job manager is notified of node transitions

- May rerun failed vertices
- Can rewrite the graph
- May run duplicate process to route around slow nodes

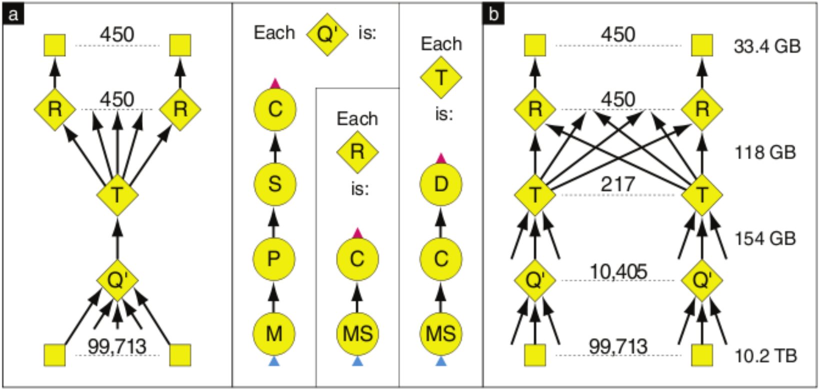
Callback Example: Dynamic Optimization

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 extenstion
- 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

LINQ Example

```
var adjustedScoreTriples =
  from d in scoreTriples
  join r in staticRank on d.docID equals r.key
  select new QueryScoreDecIDTriple(d,r);
var rankedQueries =
  from  s in adjustedScoreTriples
  group s by s.query into g
  select TakeTopQueryResults(g);
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```
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

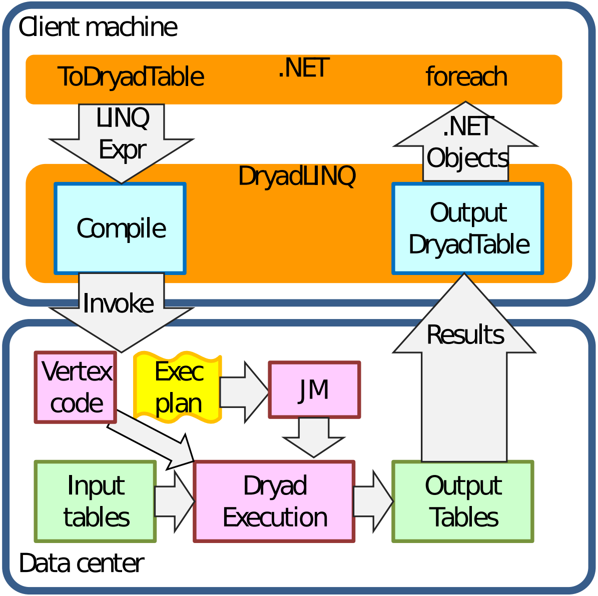
Data Partitioning Operators:

- HashPartition<T,K>
- RangePartition<T,K>

Escape Hatches:

- Apply (f)
- Fork (f)

Execution Overview



Execution Details

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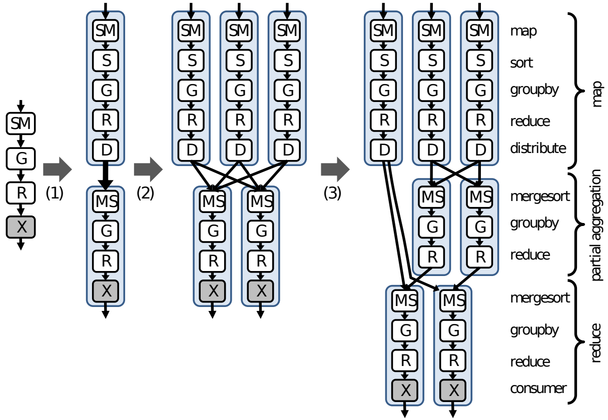
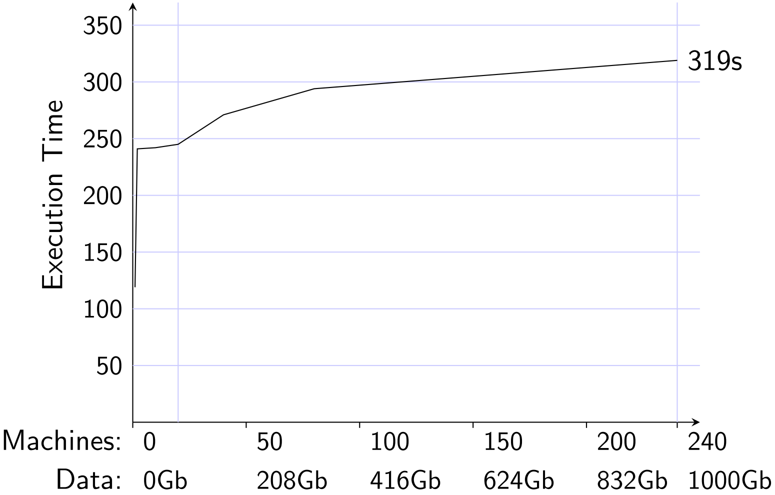
4. Dynamically, EPG is executed by DryadLINQ job manager
   - vertices replicated to match data
   - dynamic optimizations automated
   - vertices use local LINQ execution engines (e.g. PLINQ)

MapReduce on DryadLINQ

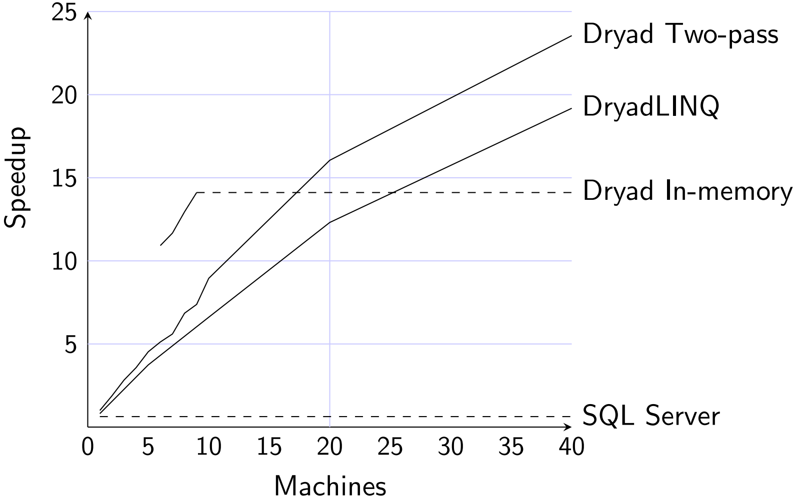
```
public static MapReduce(source, mapper, keySelector, reducer) {
  var mapped = source.selectMany(mapper);
  var groups = mapped.groupBy(keySelector);
  return groups.selectMany(reducer);
}
```



Scalability Evaluation — TeraSort



Overhead Evaluation — SkyServer



Conclusions and Discussion

Dryad meets its goals:

- efficient
- flexible
- programmable

DryadLINQ builds on Dryad:

- almost as efficient
- concise
- familiar