Naiad: Iterative and Incremental Data-Parallel Computation

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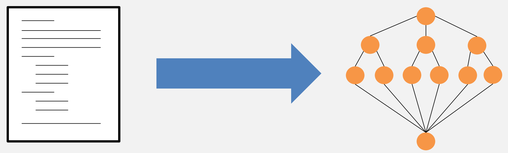
Background

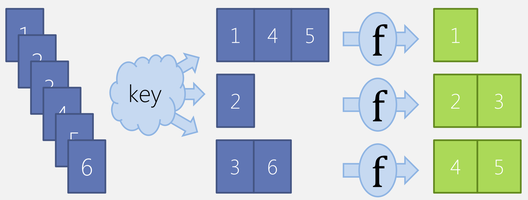
Data-parallel computation frameworks
- Process lots of data on many computers
- Hide low-level details from the programmer, like data distribution, scheduling and fault tolerance

The three basic techniques of data-parallel computation:

1. Express the program as a dataflow graph



2. Partition the data into many parts, across processors.
3. Each processor applies operators to its part of the data.



Typically, the dataflow graph is **acyclic** and the input data are **immutable** and **finite**.

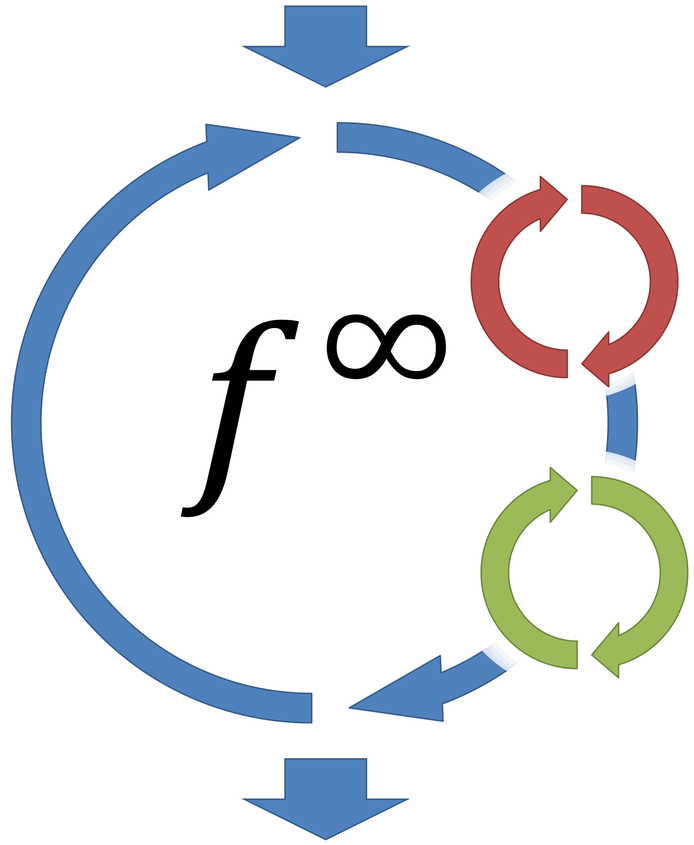
But: Many important algorithms contain loops
Many interesting problems are streaming

Leads to redundant computation and data movement (and often hard to write the programs too)

Hypothesis: Incremental computation allows efficient iteration and recomputation when the input changes.

Naiad recasts parallel dataflow as computation over **increments**

Payload	Time	Weight
"Brouwer"	1966	-1
"Erdős"	1913	+1
"Brouwer"	1881	+1



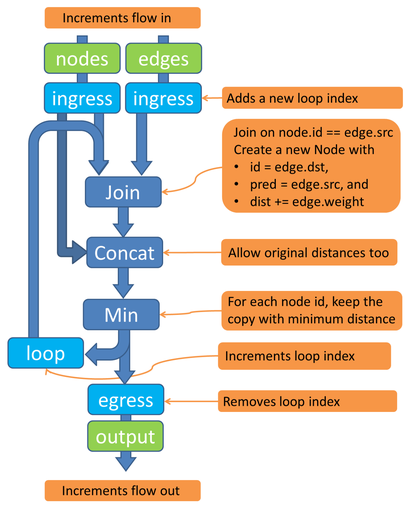
For example
- Declarative iteration using a **fixed-point operator**
- Each iteration produces a collection of increments
- Reaches fixed-point iff no increments produced

Worked Example: Shortest Paths

1. Programmer writes declarative program with loops

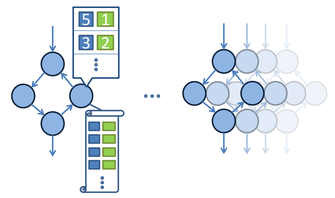
```
struct Node { int id; int predecessor; int dist; }
struct Edge { int src; int dst; int weight; }

Collection<Node> ShortestPath(this Collection<Node> nodes,
                              Collection<Edge> edges)
{
  return nodes.FixedPoint(
      x => x.Join(edges, n => n.id, e => e.src,
                  (n, e) => new Node(e.dst, e.src, n.dist + e.weight))
            .Concat(nodes)
            .Min(n => n.id, n => n.dist)
  );
}
```

2. C# Program is rendered to a cyclic dataflow graph:



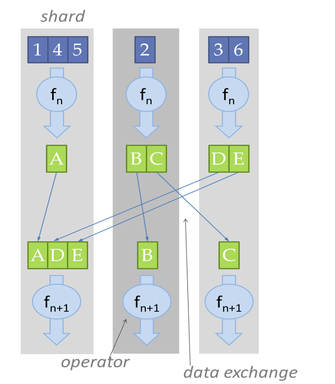
Dataflow graph operates on collections of increments, which represent either the introduction or removal of records, with loop indices indicating when they occur.

3. The dataflow graph is replicated for each independent { thread, process, computer }.



Each *shard* of each operator keeps its inputs in memory, indexed by key. From them, it can respond to arbitrary input increments, producing output increments

4. Computation proceeds with the shards exchanging increments on dataflow edges.



5. When no unprocessed increments remain, the computation quiesces and returns.

Future Research Directions

Scale up distributed implementation

Use dataflow graph to inform memory management

Explore trade-off between eager and lazy processing
- Optimistic: may do unnecessary work; may scale.
- Conservative: synchronizes to optimize work done.