Alea Reactive Dataflow
GPU Parallelization Made Simple

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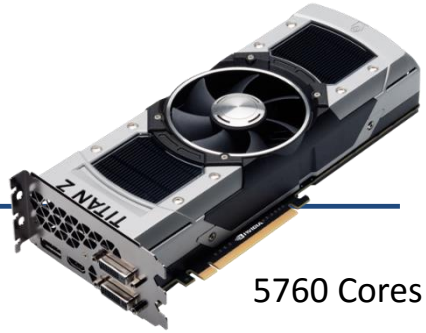
GPU Programming Today



5760 Cores

- Massive parallel power
  - Very specific pattern: vector-parallelism
- High obstacles
  - Particular algorithms needed
  - Machine-centric programming models
  - Poor language and runtime integration
- Good excuses against it - unfortunately
  - Too difficult, costly, error-prone, marginal benefit

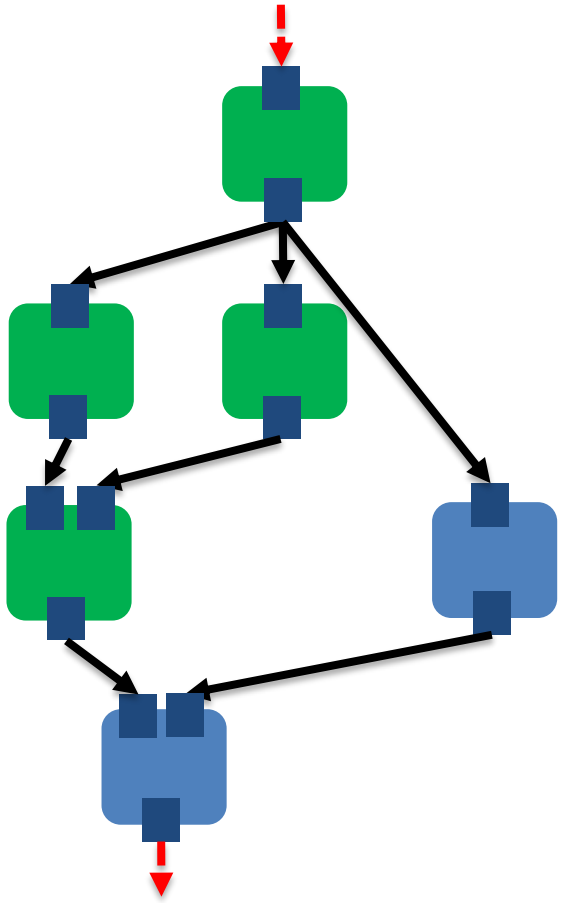
Our Goal

GPU parallel programming for (almost) everyone

- Radical simplification
  - No GPU experience required
  - Fast development
  - High performance comes automatically
  - Guaranteed memory safety
- Broad community
  - .NET in general: C#, F#, VB etc.
  - Based on Alea cuBase F# runtime

Alea Dataflow Programming Model

- Dataflow
  - Graph of operations
  - Data propagated through graph
- Reactive
  - Feed input in arbitrary intervals
  - Listen for asynchronous output

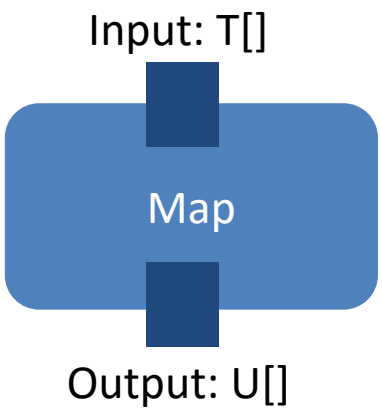


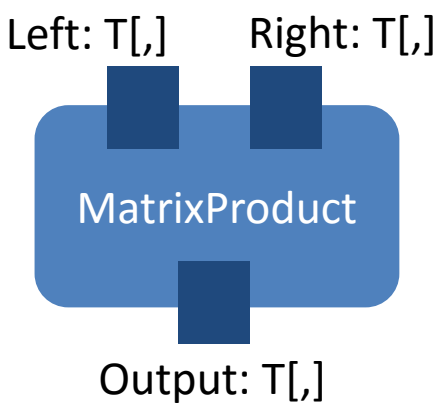
The Descriptive Power

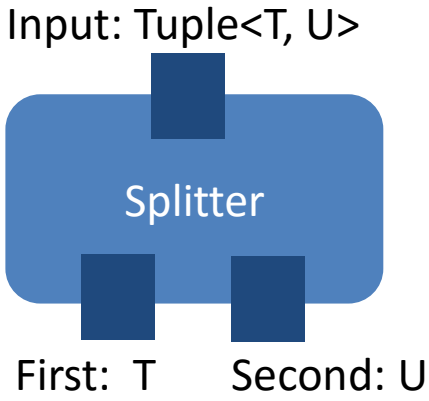
- Program is purely descriptive
  - What, not how
- Efficient execution behind the scenes
  - Vector-parallel operations
  - Stream operations on GPU
  - Minimize memory copying
  - Hybrid multi-platform scheduling
  - Tune degree of parallelization
  - …

Operation

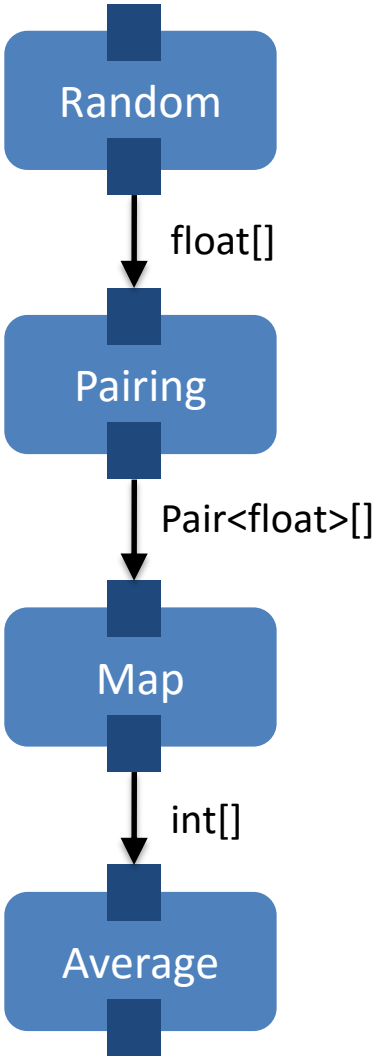
- Unit of calculation (typically vector-parallel)
- Input and output ports
- Port = stream of typed data
- Consumes input, produces output







Graph

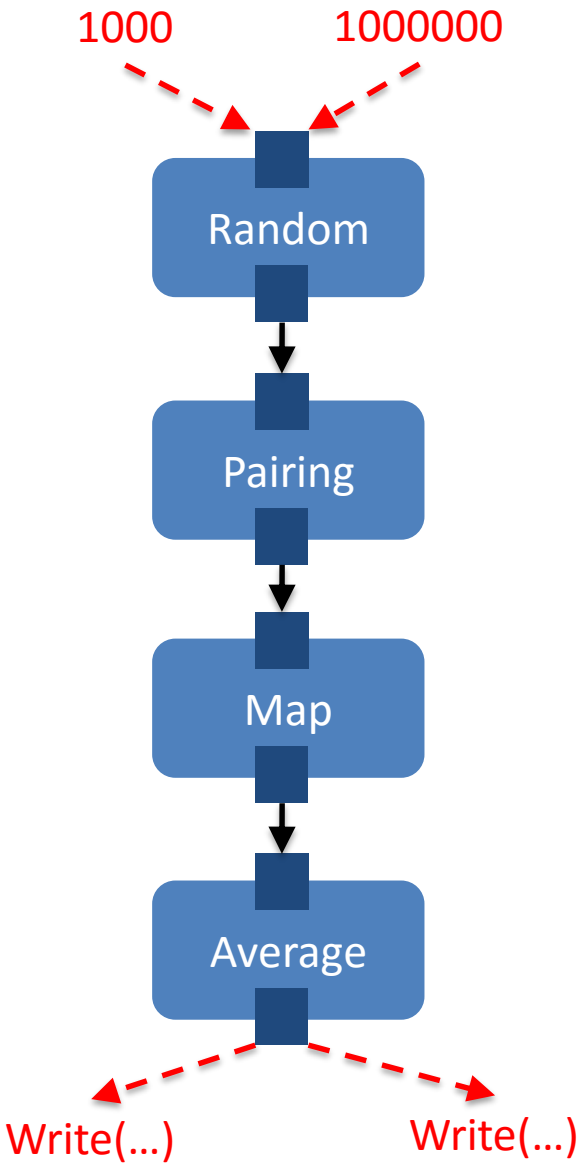



```
var randoms = new Random<float>(0, 1);
var coordinates = new Pairing<float>();
var inUnitCircle = new Map<Pair<float>, float>(
 p => p.Left * p.Left + p.Right * p.Right <= 1
      ? 1f : 0f
);
var average = new Average<float>();

randoms.Output.ConnectTo(coordinates.Input);
coordinates.Output.ConnectTo(inUnitCircle.Input);
inUnitCircle.Output.ConnectTo(average.Input);
```

Dataflow

- Send data to input port
- Receive from output port
- All asynchronous

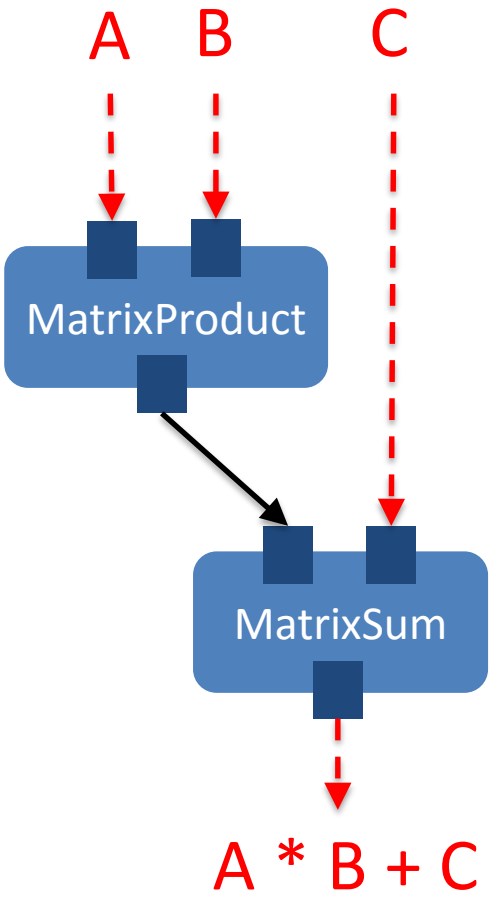
```
average.Output.OnReceive(x =>
       Console.WriteLine(4 * x));


random.Input.Send(1000);
random.Input.Send(1000000);
```



Short Fluent Notation

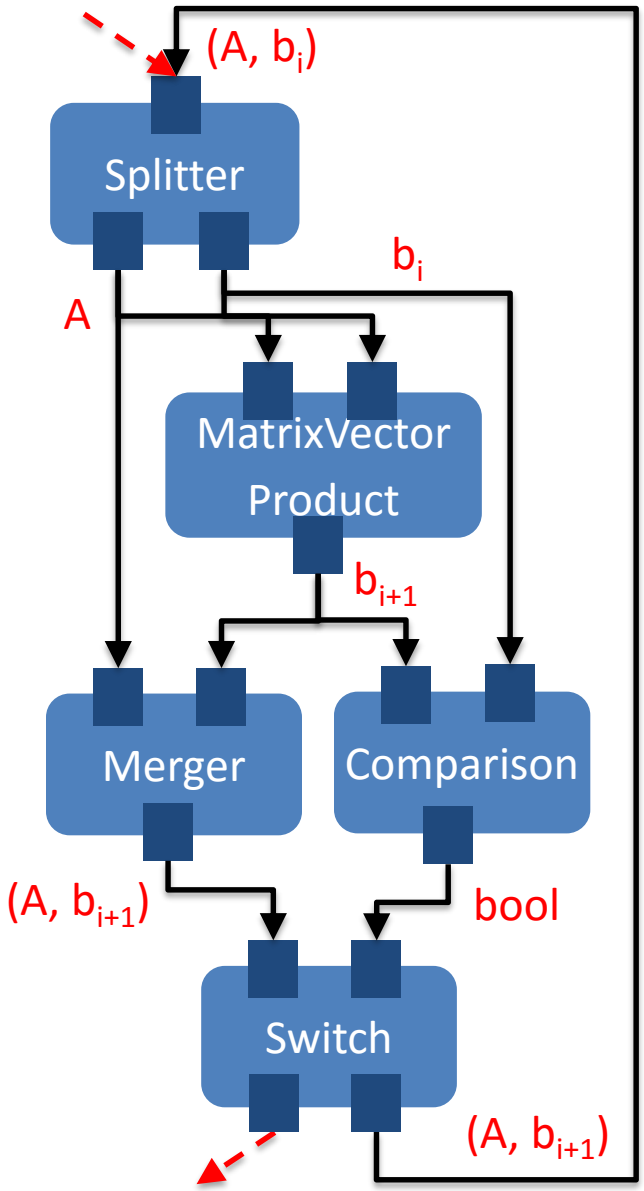
```
var randoms = new Random<float>(0, 1);
randoms
  .Pairing()
  .Map(p => p.Left * p.Left + p.Right * p.Right <= 1 ? 1f : 0f)
  .Average()
  .OnReceive(x => Console.WriteLine(4 * x));

randoms.Send(100);
randoms.Send(100000);
```

Algebraic Computation




```
var product = new MatrixProduct<float>();
var sum = new MatrixSum<float>();

product.Output.ConnectTo(sum.Left);

sum.Output.OnReceive(Console.WriteLine);

product.Left.Send(A);
product.Right.Send(B);
sum.Right.Send(C);
```

Iterative Computation

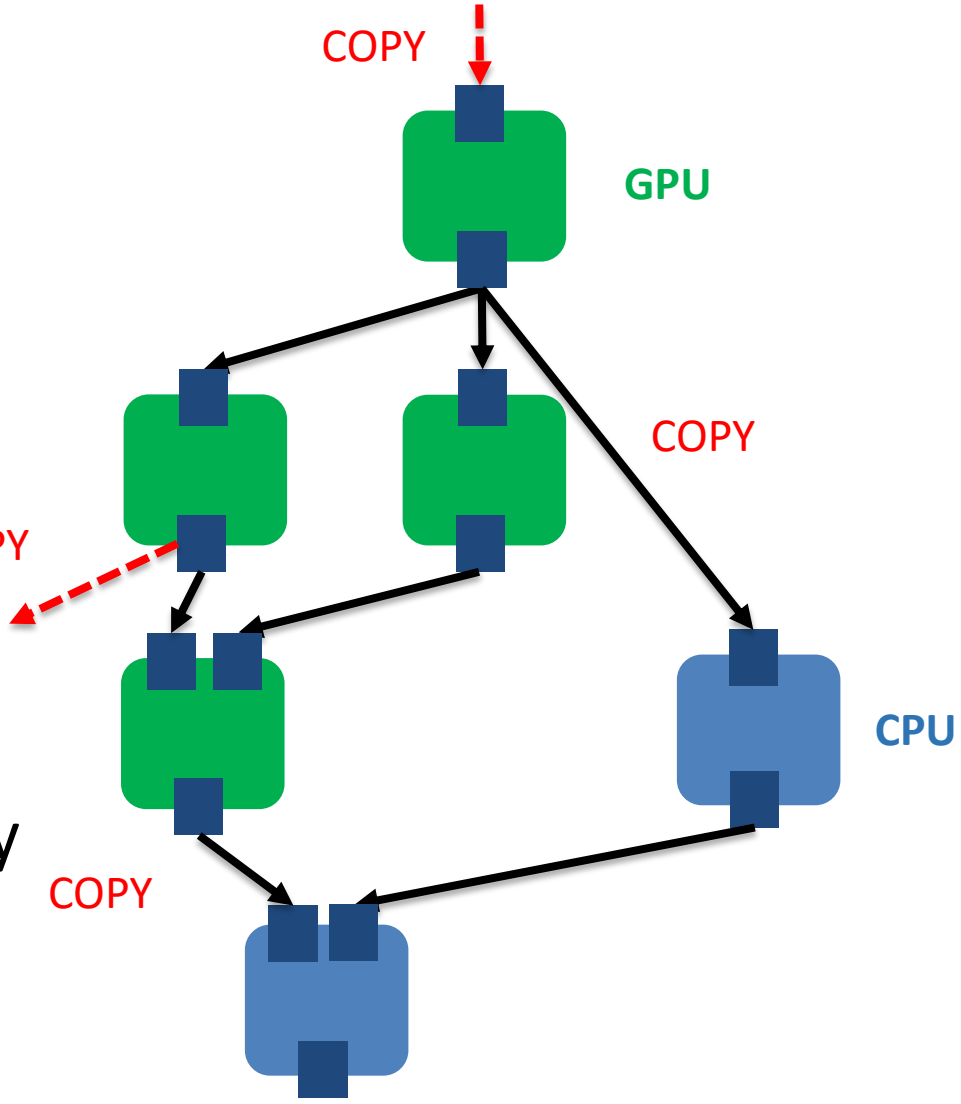


$$b_{i+1} = A \cdot b_i \text{ (until } b_{i+1} = b_i)$$

```
var source = new Splitter<double[,], double[]>();
var product =
  source.First.Multiply(source.Second);
var steady =
  product.Compare(source.Second, fun x y ->
                        Math.Abs(x - y) < 1E-6);
var next = source.First.Merge(product);
var branch = steady.Switch(next);
branch.False.ConnectTo(source.Input);

branch.True.OnReceive(Console.WriteLine)
source.Send(new Tuple<double[,], double>(A, b0));
```

Current Scheduler

- Operation implement GPU and/or CPU
- GPU operations combined to stream
- Memory copy only when needed
- Host scheduling with .NET TPL
- Automatic free memory management



Operation Catalogue

- Prefabricated generic operations
  - Switch, Merger, Splitter, Comparison
  - Map, Reduction, Average, Pairing
  - Random, MatrixProduct, MatrixSum, MatrixVectorProduct, VectorSum, ScalarProduct
  - More to come…
- Custom operations can be added
- Good performance
  - Nearly as fast as native C CUDA: overhead about 10%
    - Performance depends on operation implementation
    - Small overhead (cross-compilation, managed to unmanaged interop, scheduler)

Related Works

- Rx.NET / TPL Dataflow
  - Single input and output port
  - Not for GPU
- Xcelerit
  - Not reactive: single flow per graph
  - No generic operations with functors
- MSR PTasks / Dandelion
  - Synchronous receive, on C++, no generic operations
  - .NET LINQ integration (pull instead of push)
- Fastflow
  - Not reactive (sync run of the graph)
  - More low-level C++ tasks, no functors
- Nikola
  - Implicit dataflow described by functions
  - Limited set of operations

Conclusions

- Simple but powerful GPU parallelization in .NET
  - No low-level GPU artefacts
  - Fast and condensed problem formulation
  - Efficient and safe execution by the scheduler
- The descriptive paradigm is the key
  - Reactive makes it very general: cycles, infinite etc.
  - Practical suitability depends on operations
- Future directions
  - Advanced schedulers: multi GPUs, cluster, optimizations
  - Larger operation catalogue, optimized operations