# Radically Simplified GPU Programming in F# and .NET

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F# User Meeting
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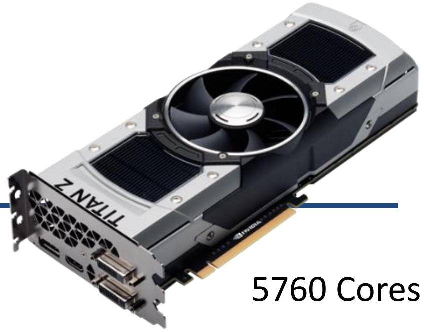
# GPU Programming Today



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

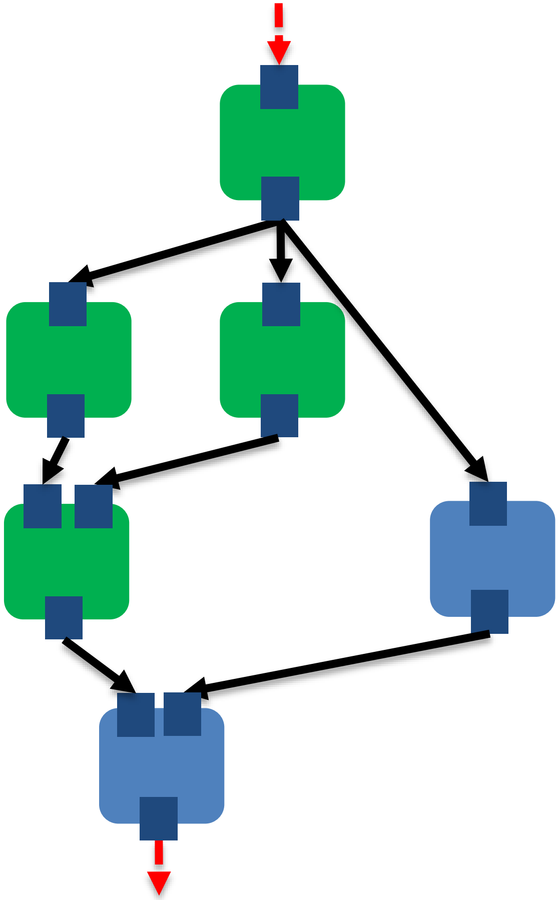
# Our Goal

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

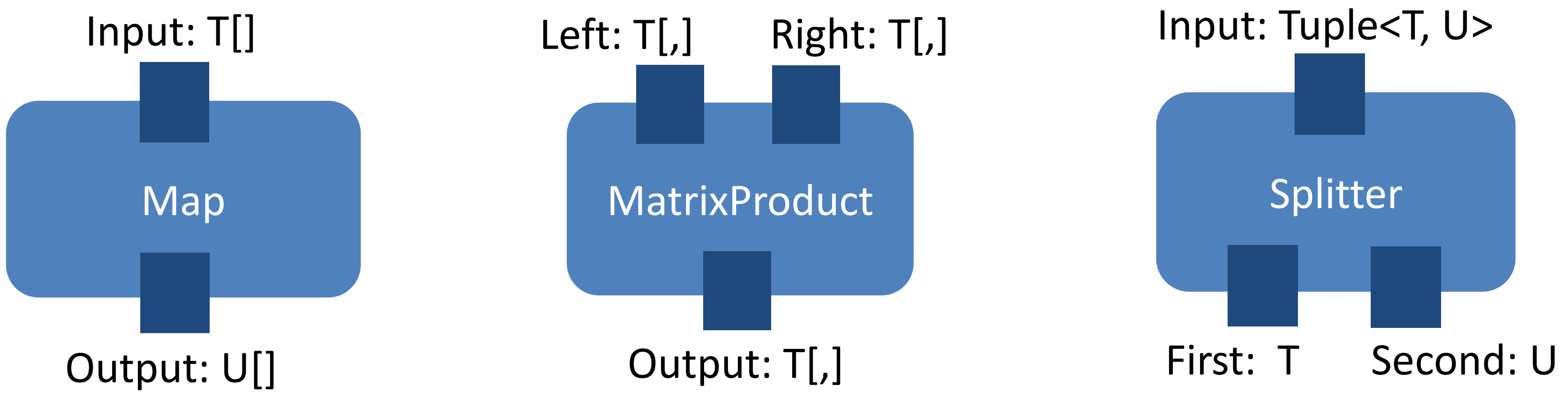


# The Descriptive Power

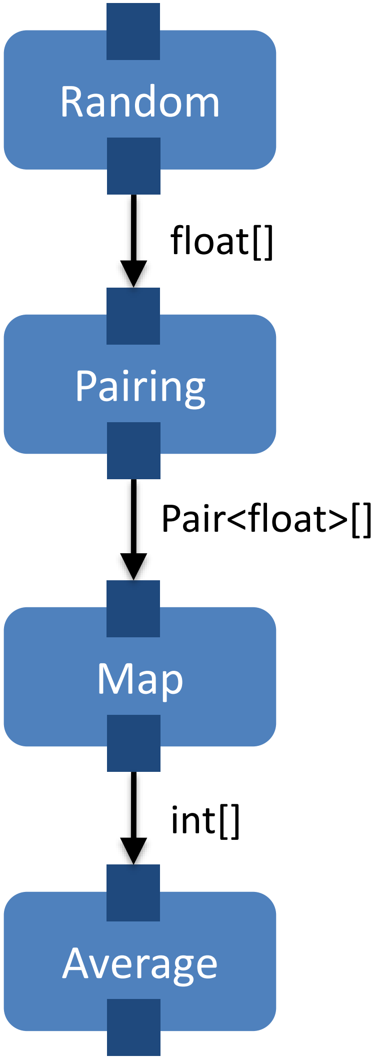
- Program is purely descriptive
  - What, not how
- Efficient execution behind the scenes
  - Vector-parallel operations
  - Stream operations on GPU
  - Minimize memory copying
  - Hybrid multi-platform scheduling
  - Tune degree of parallelization
  - …

# Operation

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



# Graph

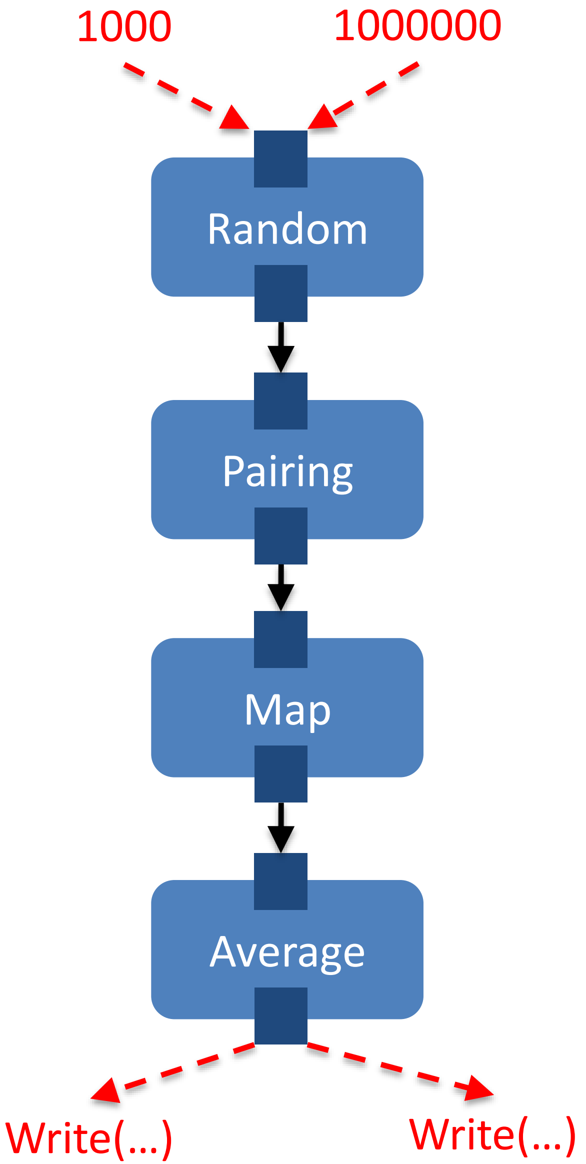


```
let randoms = Random<single>(0.f, 1.f)
let coordinates = Pairing<single>()
let inUnitCircle = Map<Pair<single>, single>
   (fun p -> if p.Left * p.Left +
                p.Right * p.Right <= 1.f
             then 1.f else 0.f)
let average = new Average<single>()

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

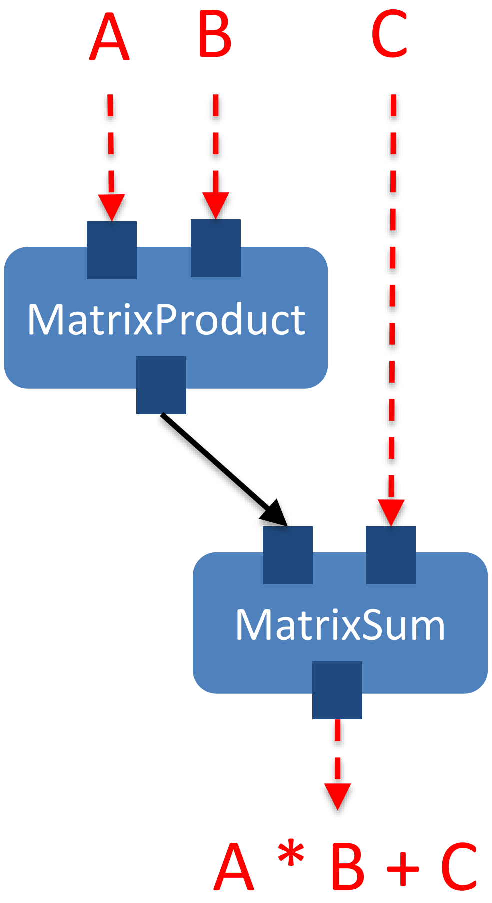
```
average.Output.OnReceive(fun x ->
          Console.WriteLine(4.f * x))

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



# Short Fluent Notation

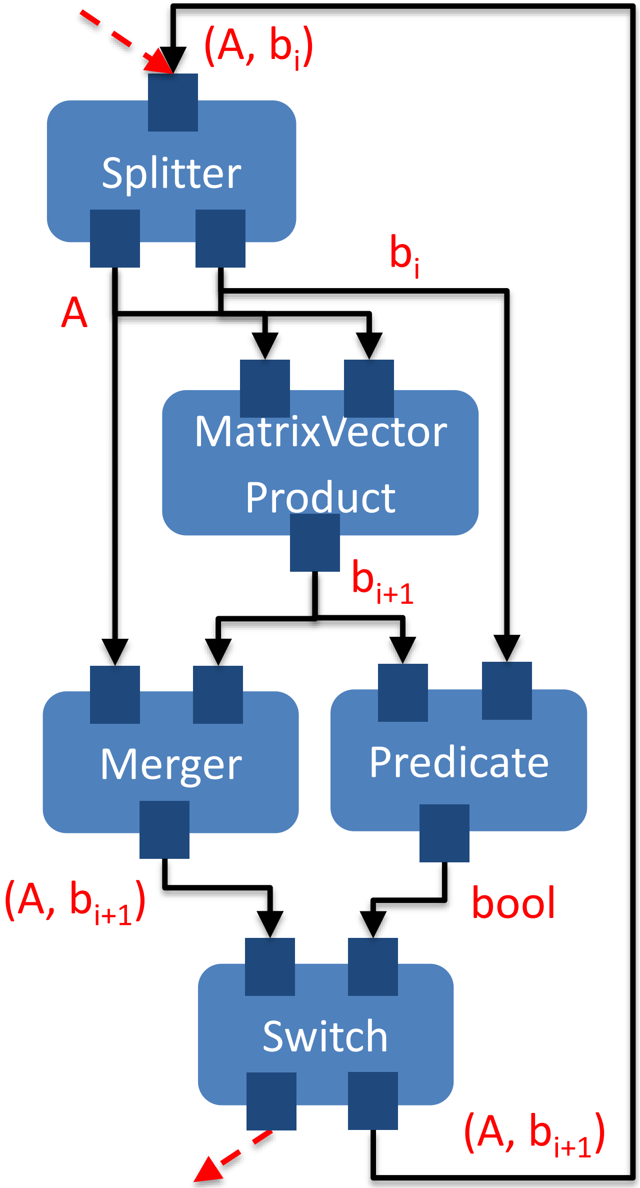
```
let randoms = new Random<single>(0.f, 1.f)
randoms
  .Pairing()
  .Map(fun p -> if p.Left * p.Left + p.Right * p.Right <= 1.f
                then 1.f else 0.f)
  .Average()
  .OnReceive(fun x -> Console.WriteLine(4.f * x))

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

# Algebraic Computation



```
let product = MatrixProduct<float>()
let sum = 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

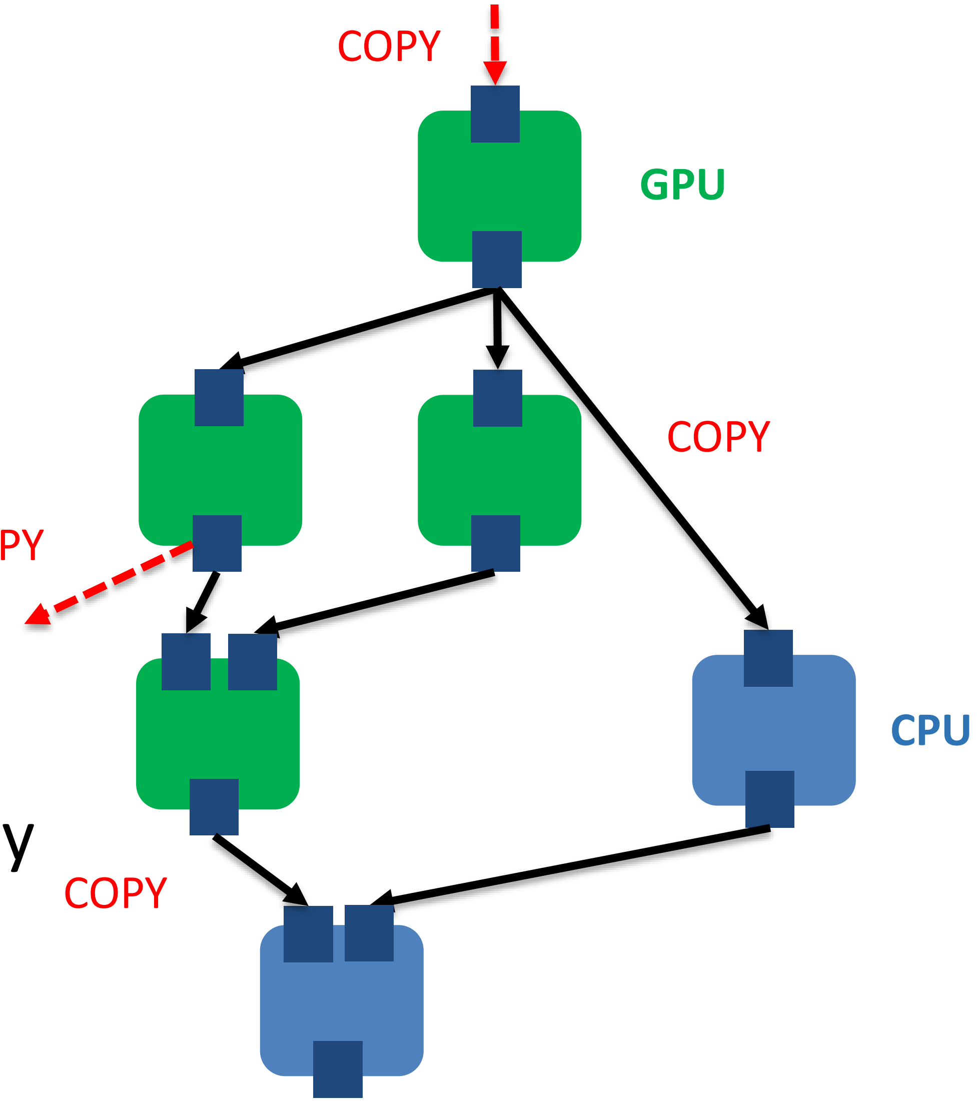


$$b_{i+1} = A \cdot b_i \text{ (until } b_{i+1} = b_i\text{)}$$

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

branch.True.OnReceive(Console.WriteLine)
source.Send((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, Predicate
  - Map, Reduce, 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 (margin 10-20%)

# 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

# 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