Stream Compilers

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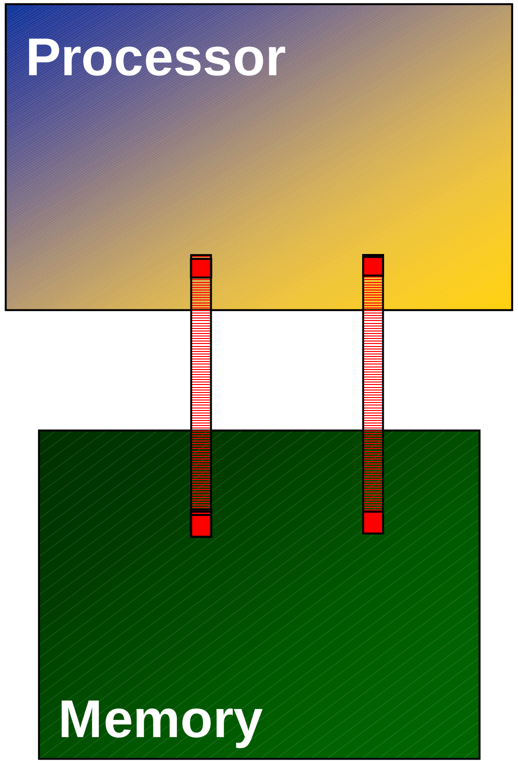
Schedule

1:30-1:40	Overview (Saman)
1:40-2:20	Stream Architectures (Saman)
2:20-3:00	Stream Languages (Bill)
3:00-3:30	Break
3:30-3:55	Stream Compilers (Saman)
3:55-4:35	Scheduling Algorithms (Bill)
4:35-5:00	Domain-specific Optimizations (Saman)

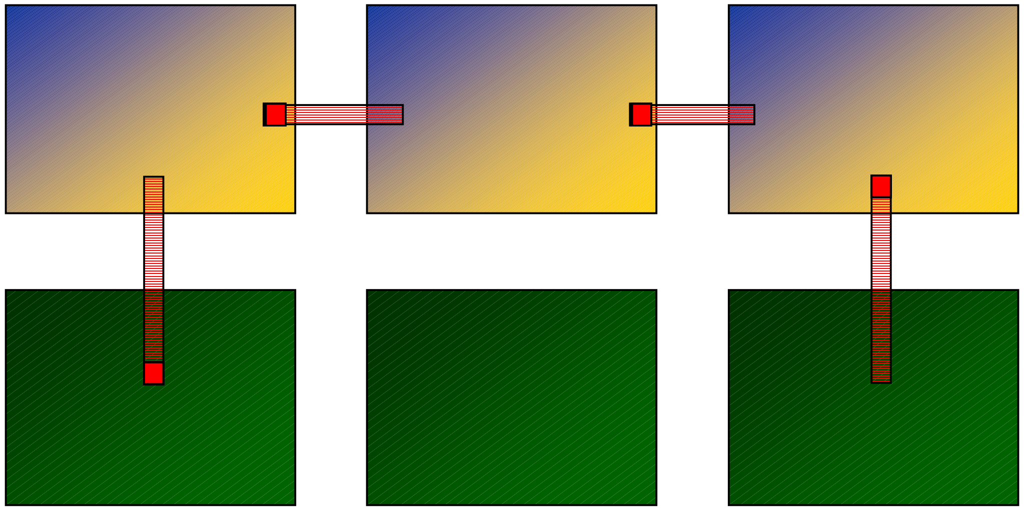
How to execute a Stream Graph? Method 1: Time Multiplexing

- Run one filter at a time
- Pros:
  - Perfectly load balanced
  - Allows SIMD control
  - Synchronization from Memory
- Cons:
  - If a filter run is too short
    - Filter load overhead is high
  - If a filter run is too long
    - Data spills down the cache hierarchy
    - Long latency
  - Lots of memory traffic
    - Bad cache effects
    - Could require storage to offset (SRF)
  - Does not scale with spatially-aware architectures



How to execute a Stream Graph?
Method 2: Space Multiplexing

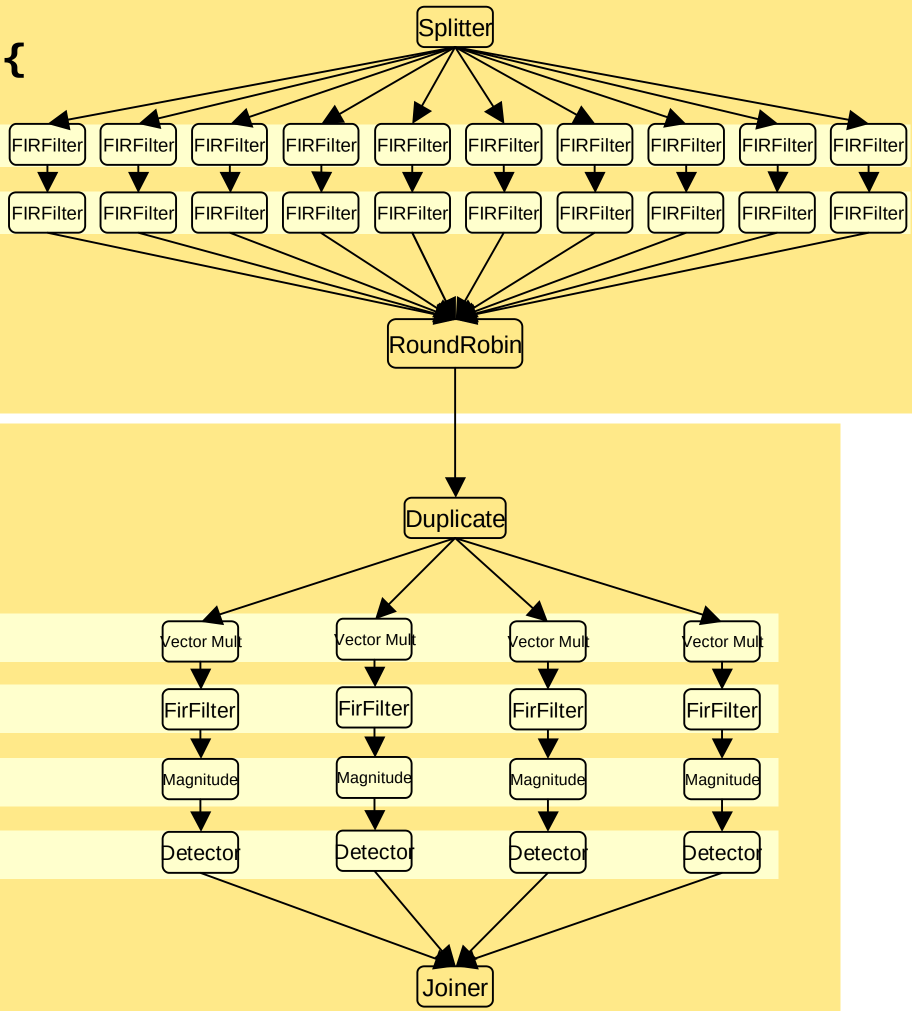
- Map filter per tile and run forever
- Pros:
  - No filter swapping overhead
  - Exploits spatially-aware architectures
    - Scales well
  - Reduced memory traffic
  - Localized communication
  - Tighter latencies
  - Smaller live data set



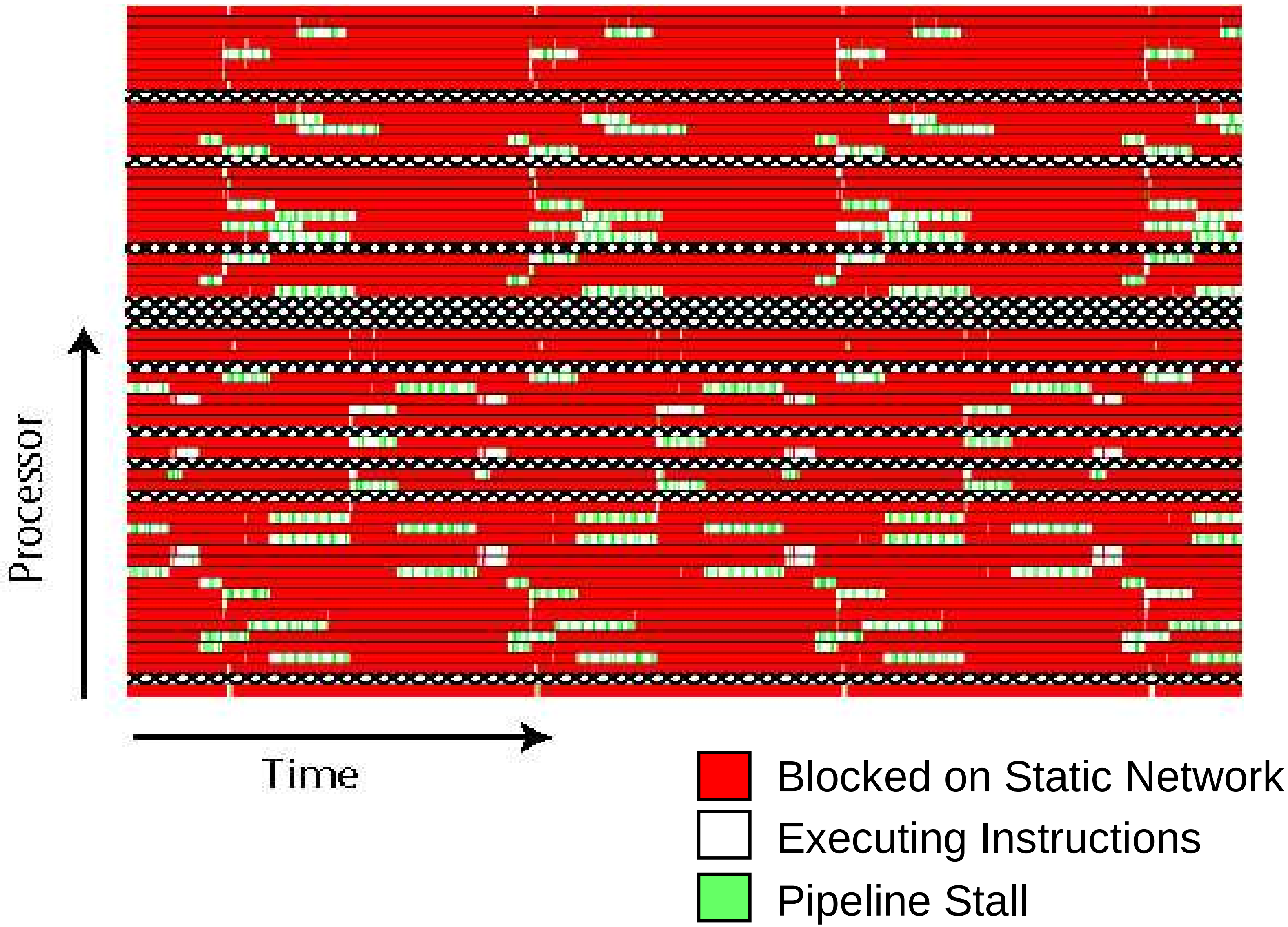
- Cons:
  - Load balancing is critical
  - Not good for dynamic behavior
  - Requires # filters ≤ # processing elements

Example: Radar Array Front End

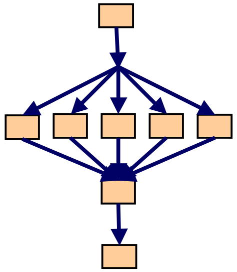
```
complex->void pipeline BeamFormer(int numChannels, int
    numBeams) {
  add splitjoin {
      split duplicate;
      for (int i=0; i<numChannels; i++) {
         add pipeline {
            add FIR1(N1);

            add FIR2(N2);
         };
      };
      join roundrobin;
  };
  add splitjoin {
      split duplicate;
      for (int i=0; i<numBeams; i++) {
         add pipeline {
            add VectorMult();
            add FIR3(N3);
            add Magnitude();
            add Detect();
         };
      };
      join roundrobin(0);
  };
}
```

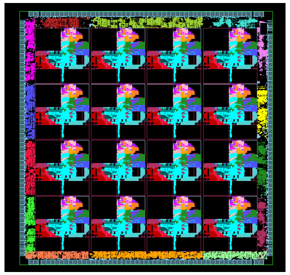


Radar Array Front End on Raw



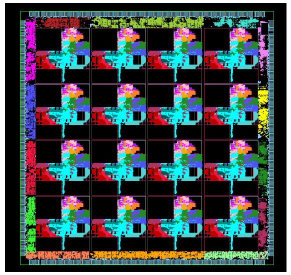
Bridging the Abstraction layers





- StreamIt language exposes the data movement
  - Graph structure is architecture independent
- Each architecture is different in granularity and topology
  - Communication is exposed to the compiler
- The compiler needs to efficiently bridge the abstraction
  - Map the computation and communication pattern of the program to the PE’s, memory and the communication substrate

Bridging the Abstraction layers



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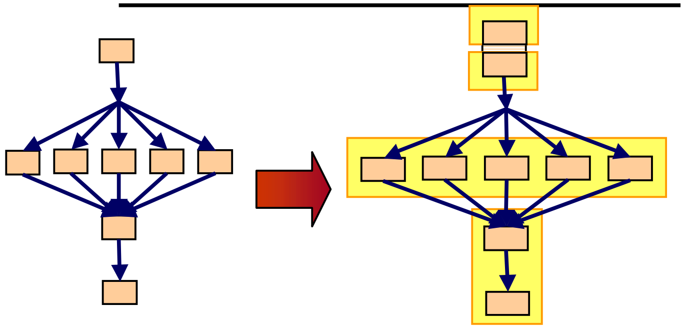
- The StreamIt Compiler
  - Partitioning
  - Placement
  - Scheduling
  - Code generation

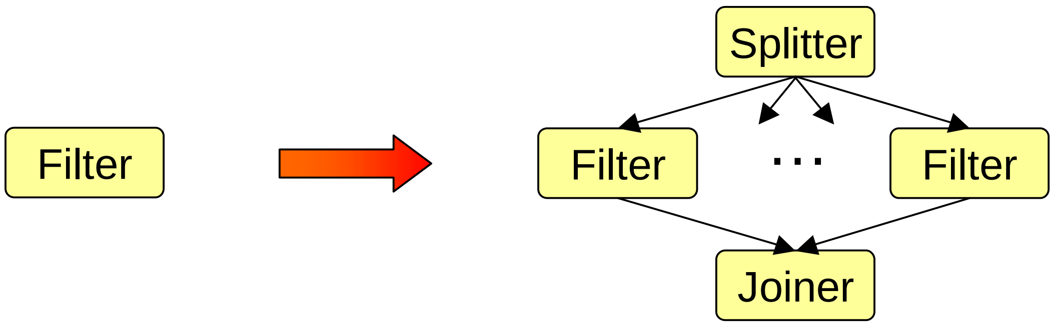
Partitioning: Choosing the Granularity



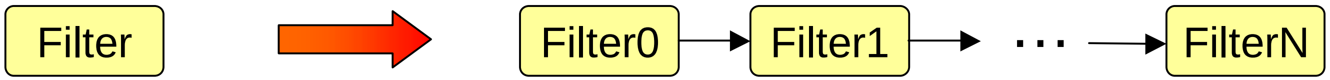
- Mapping filters to tiles
  - # filters should equal (or a few less than) # of tiles
  - Each filter should have similar amount of work
    - Throughput determined by the filter with most work
- Compiler Algorithm
  - Two primary transformations
    - Filter fission
    - Filter fusion
  - Uses a greedy heuristic

Partitioning - Fission

- Fission - splitting streams
  - Duplicate a filter, placing the duplicates in a SplitJoin to expose parallelism.

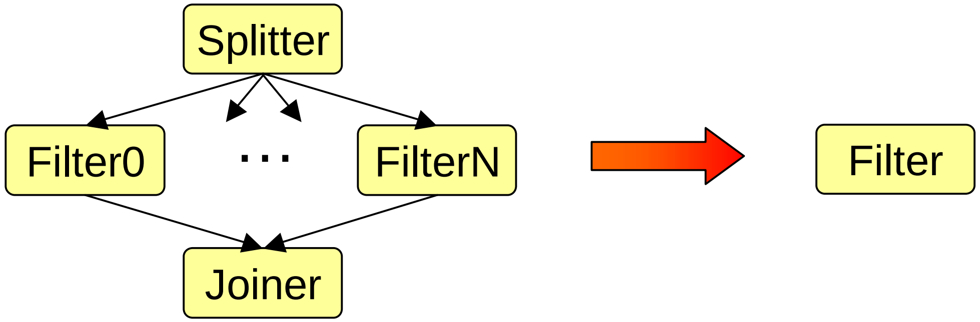


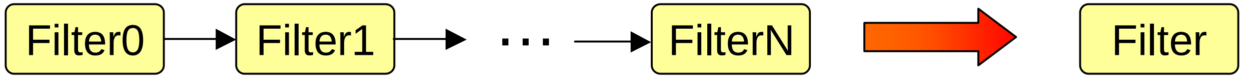
-Split a filter into a pipeline for load balancing



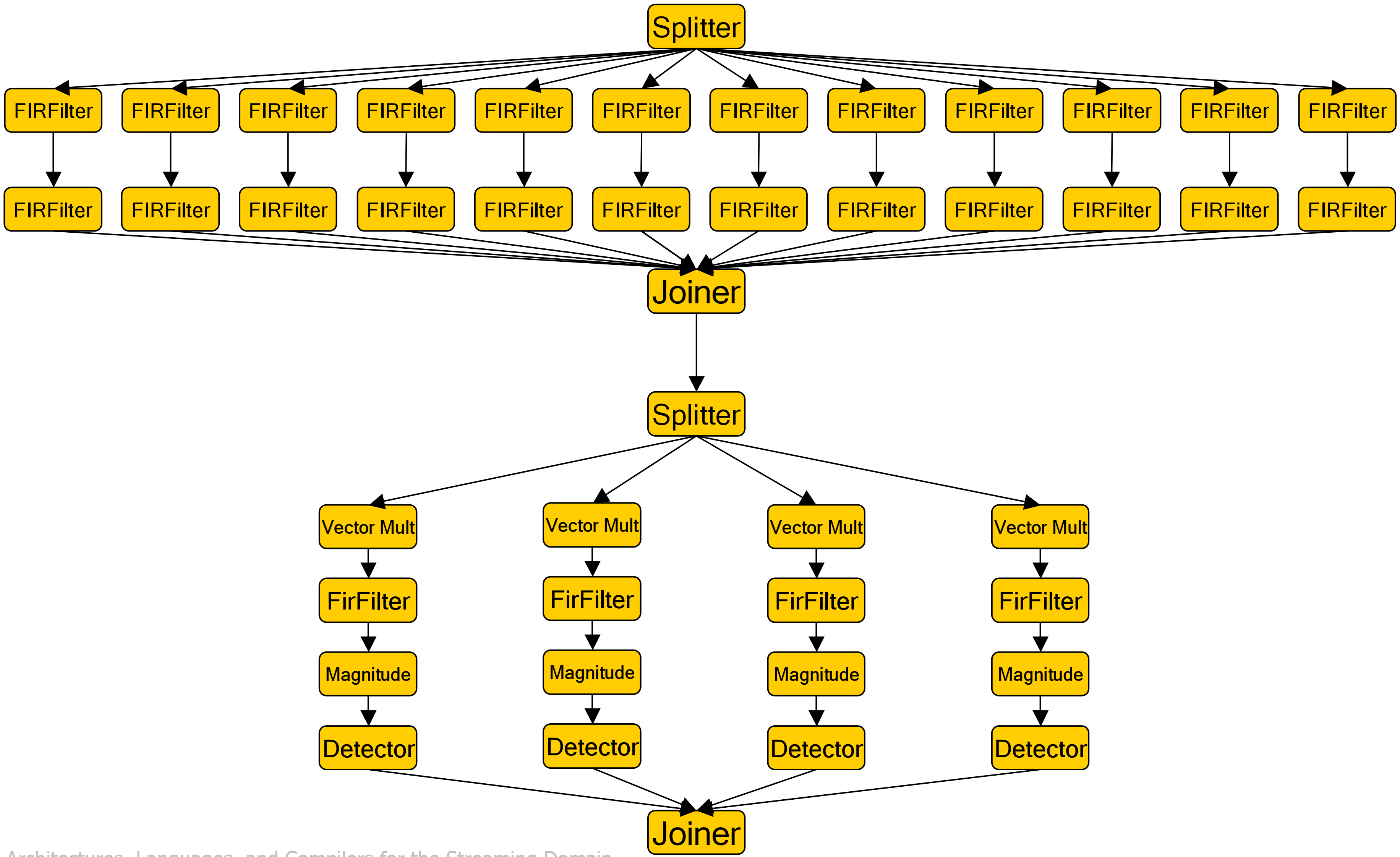
Partitioning - Fusion

- Fusion - merging streams
  - Merge filters into one filter for load balancing and synchronization removal





Example: Radar Array Front End (Original)



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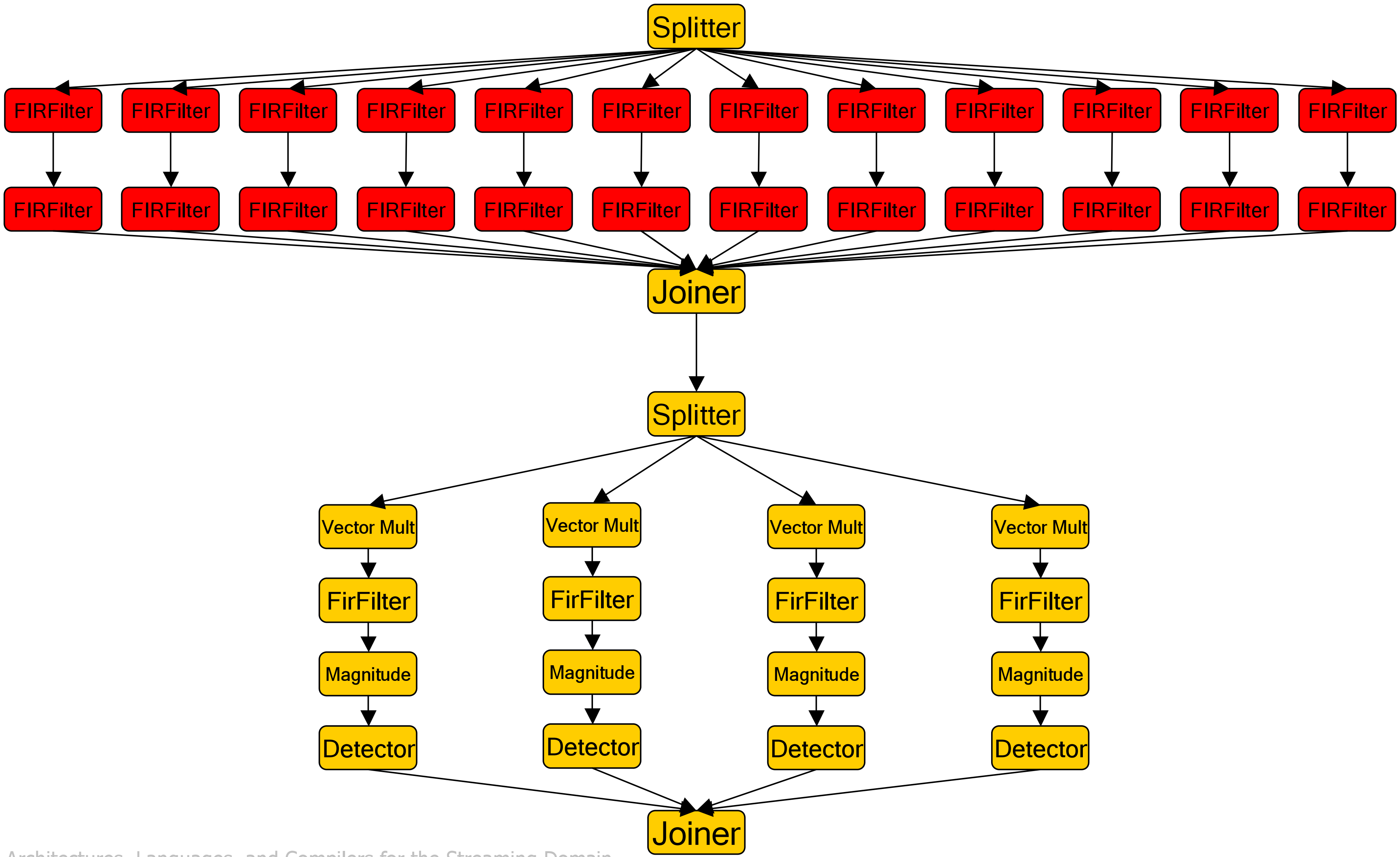

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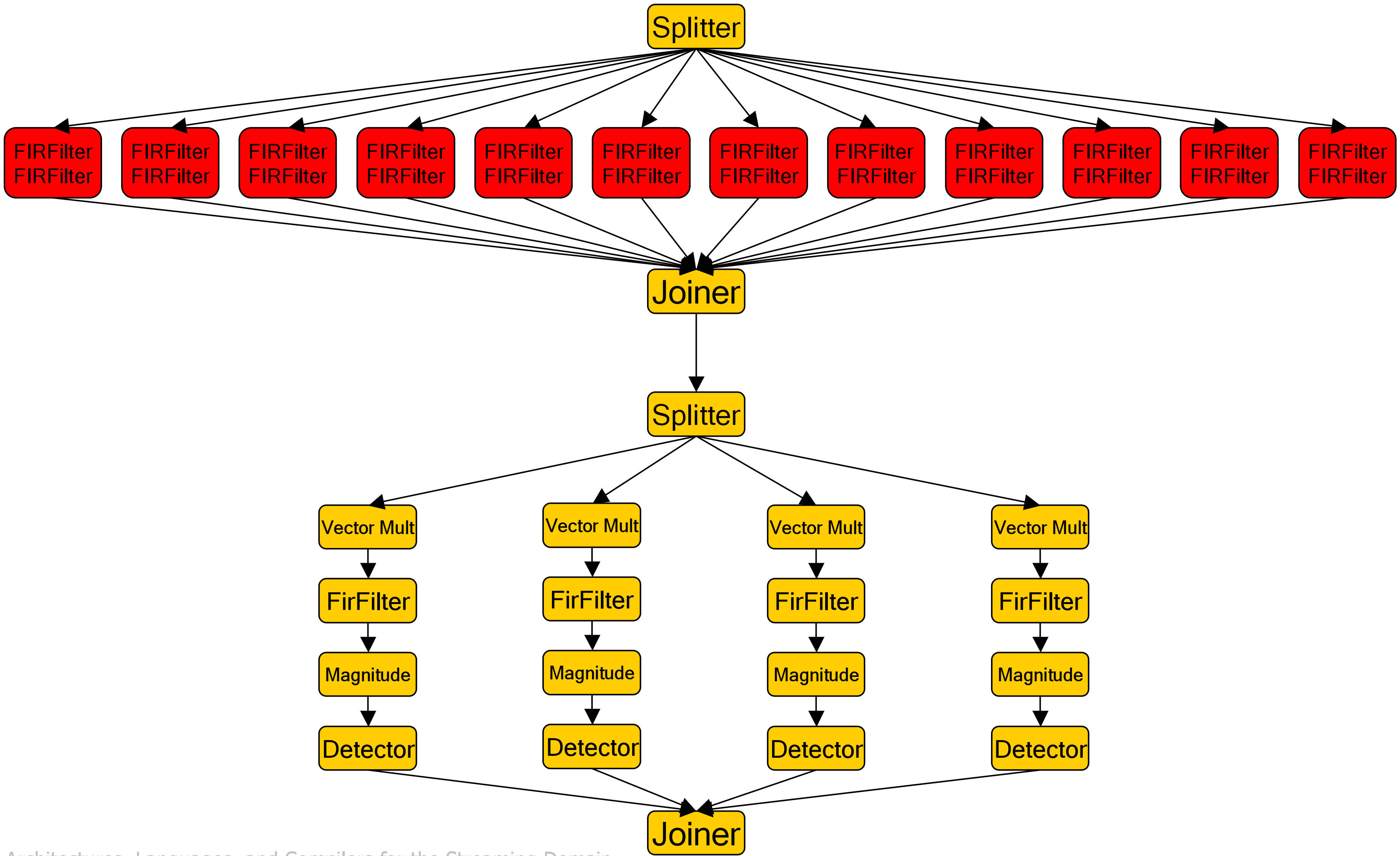

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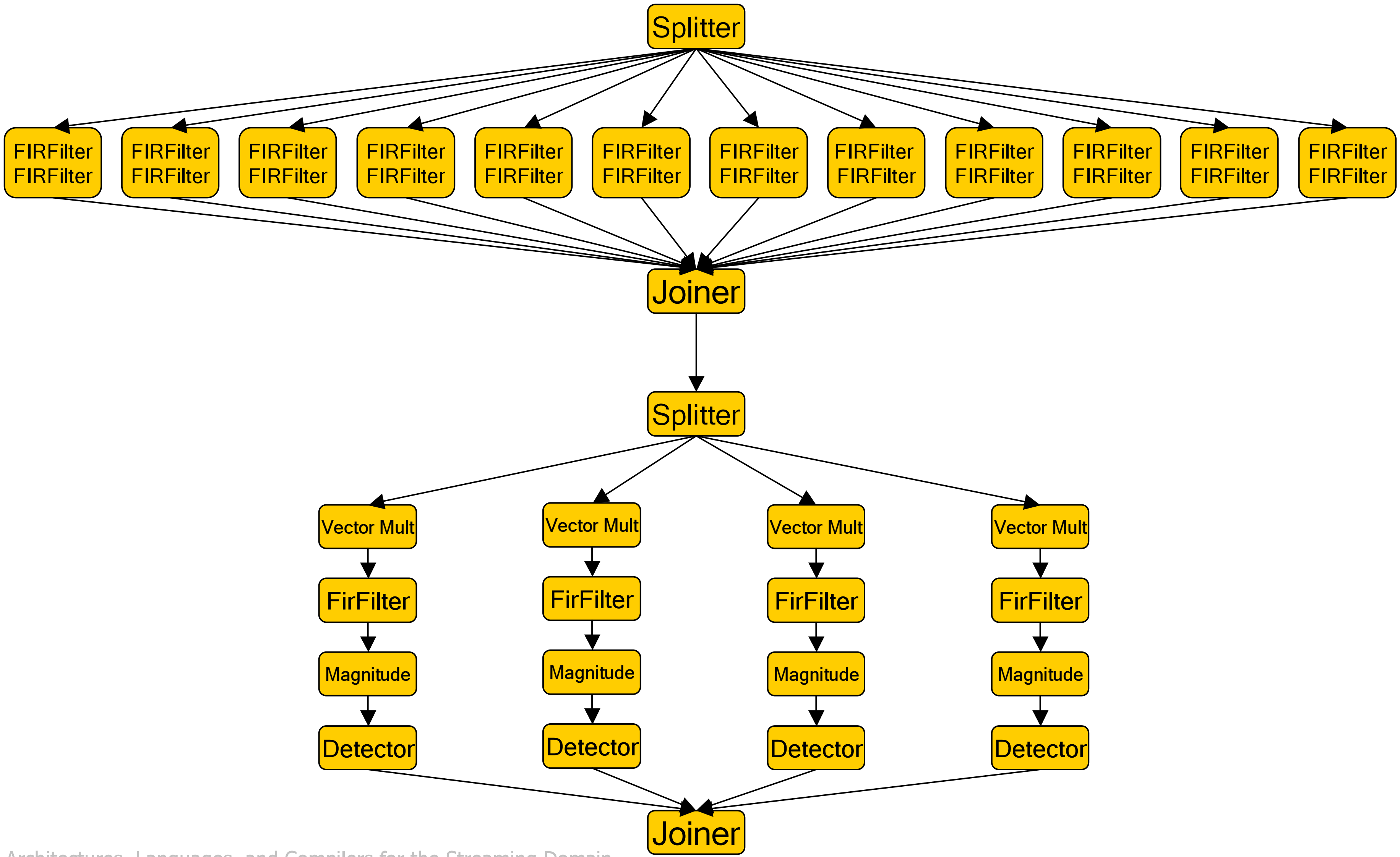

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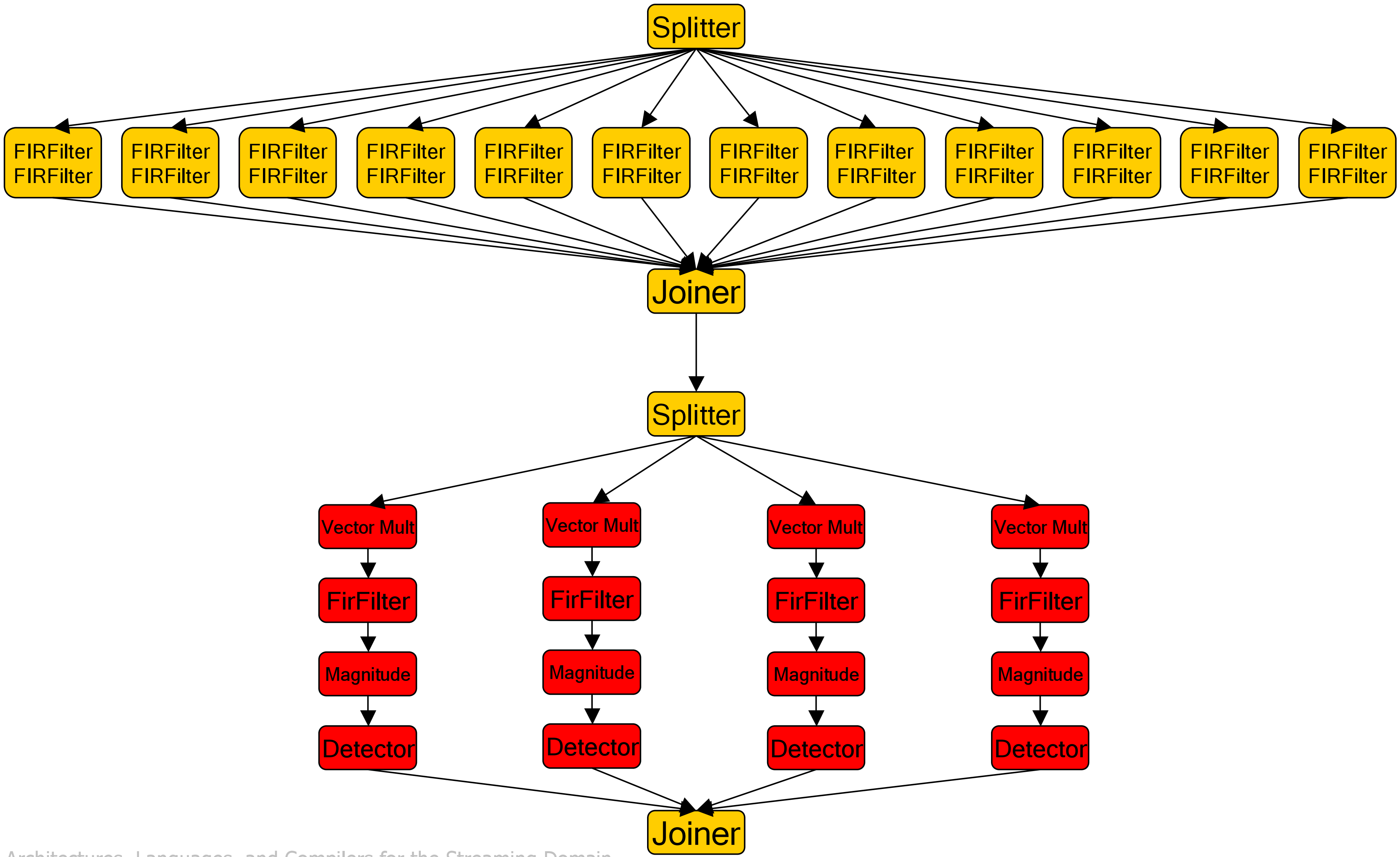

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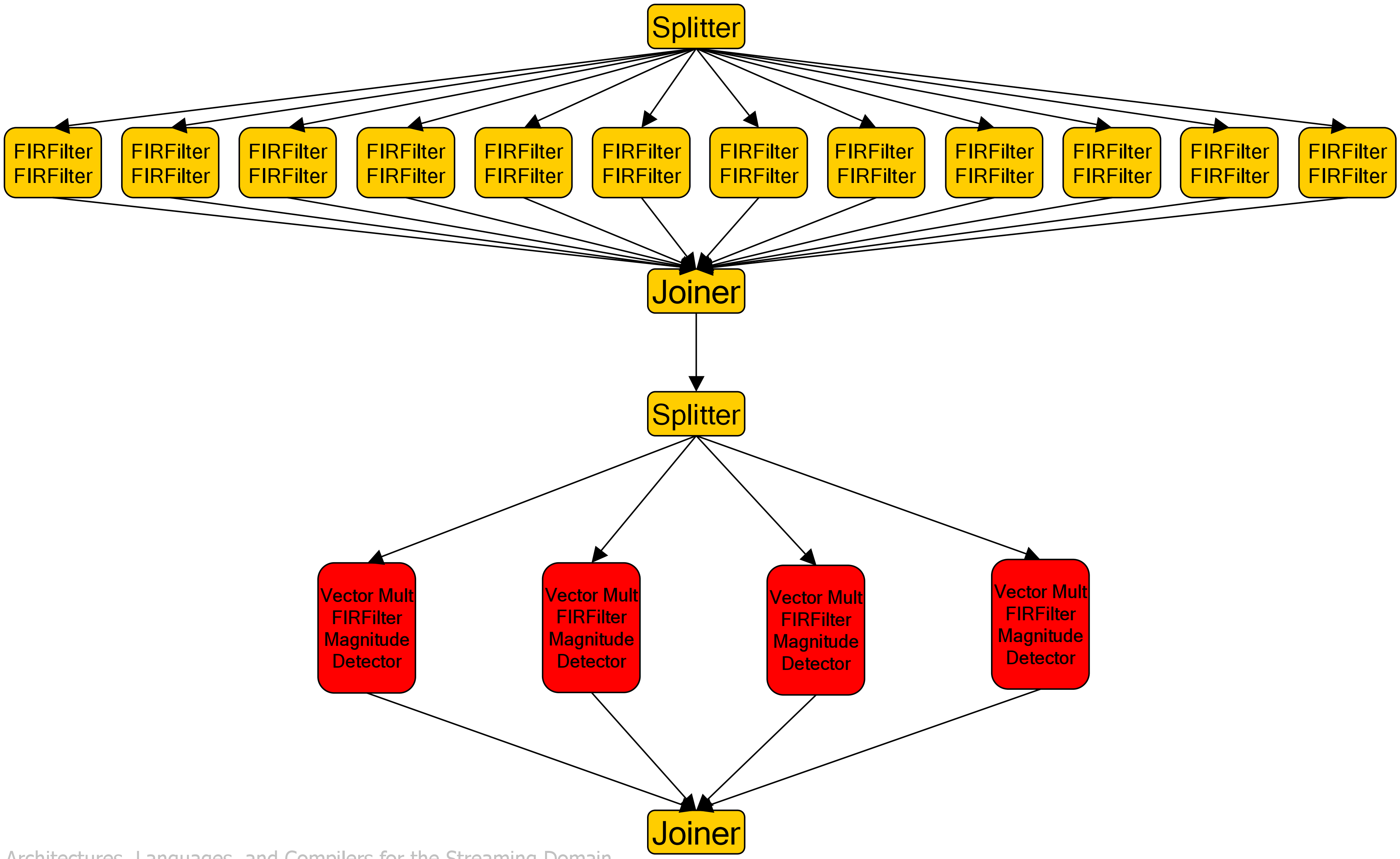

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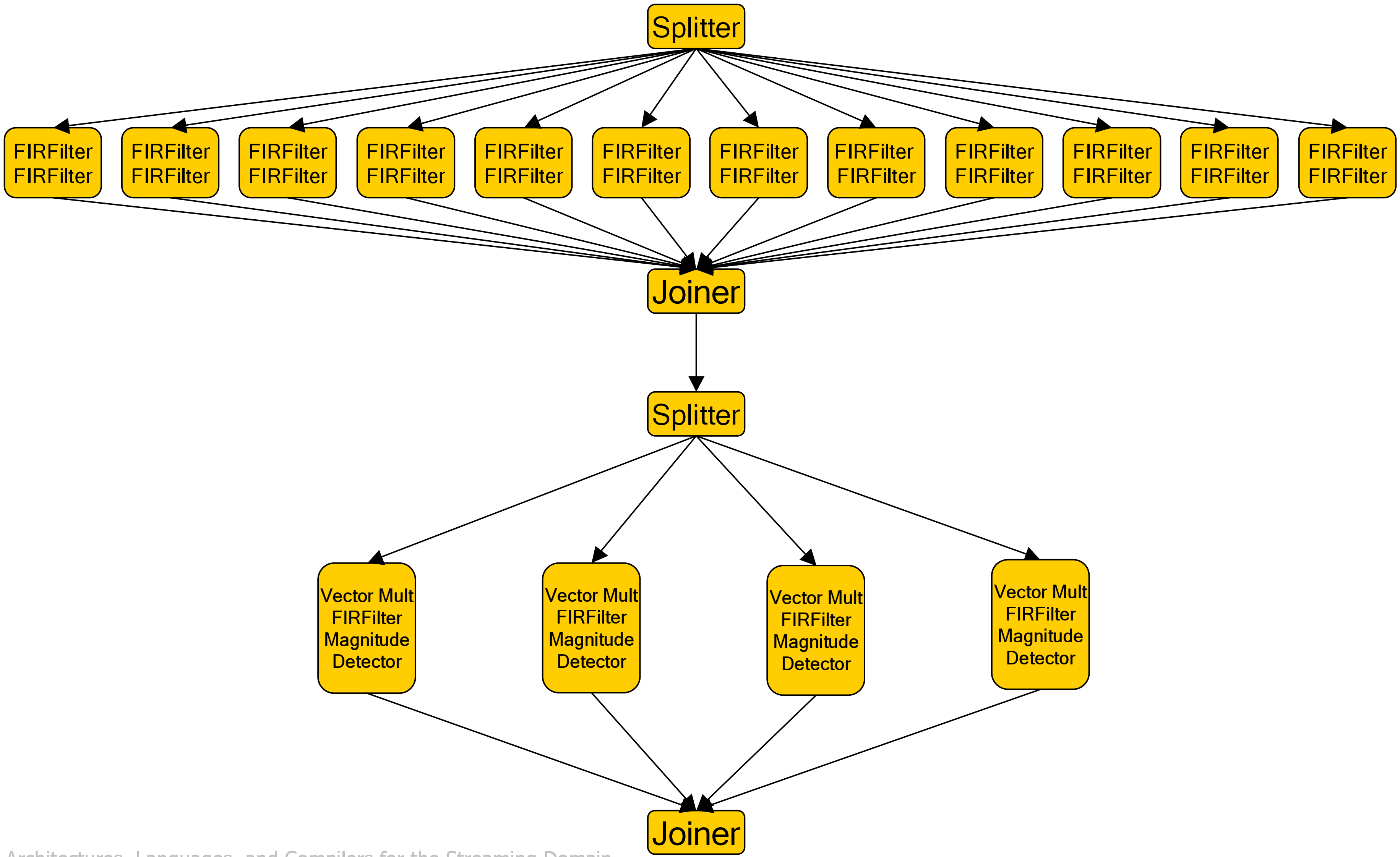

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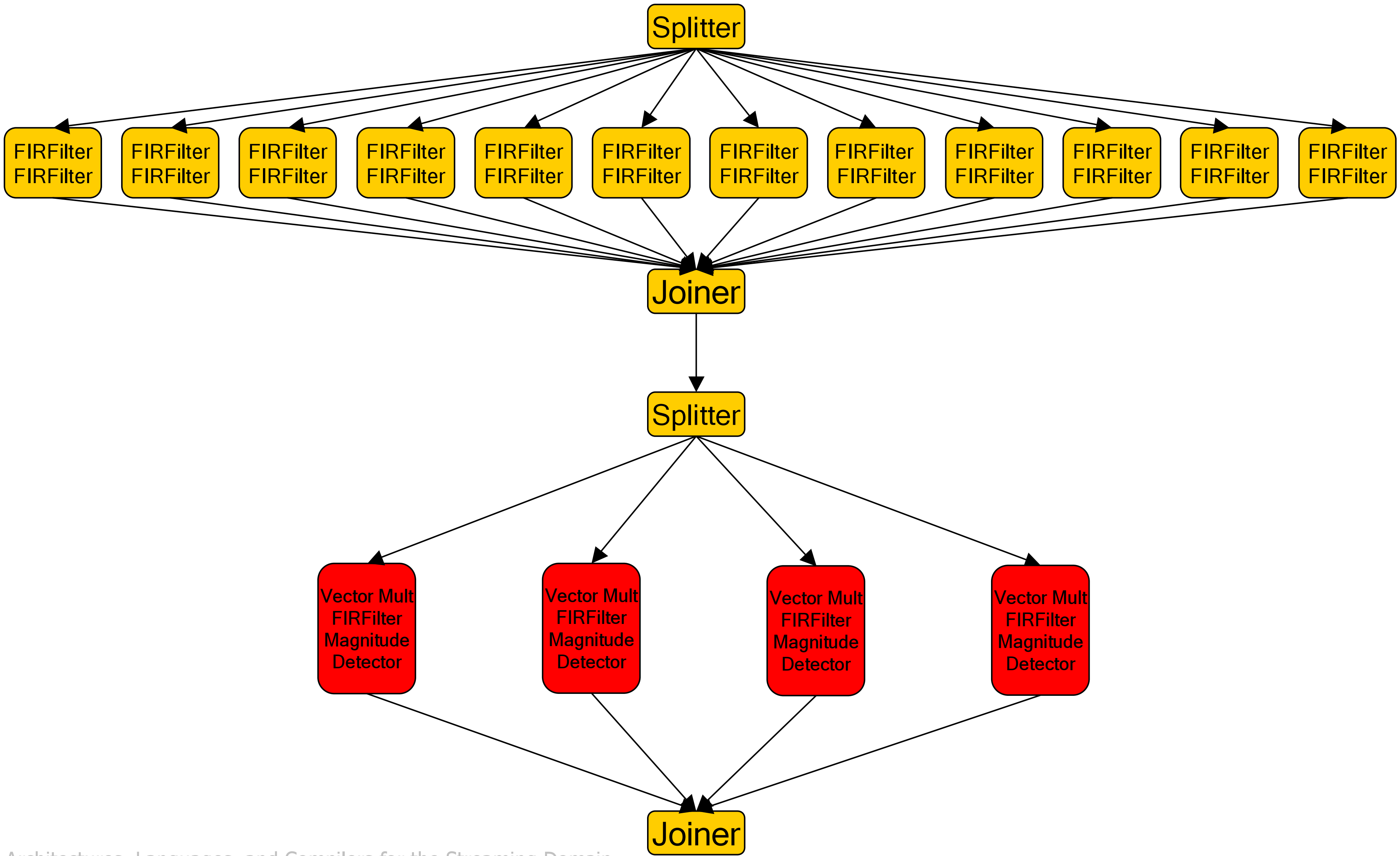

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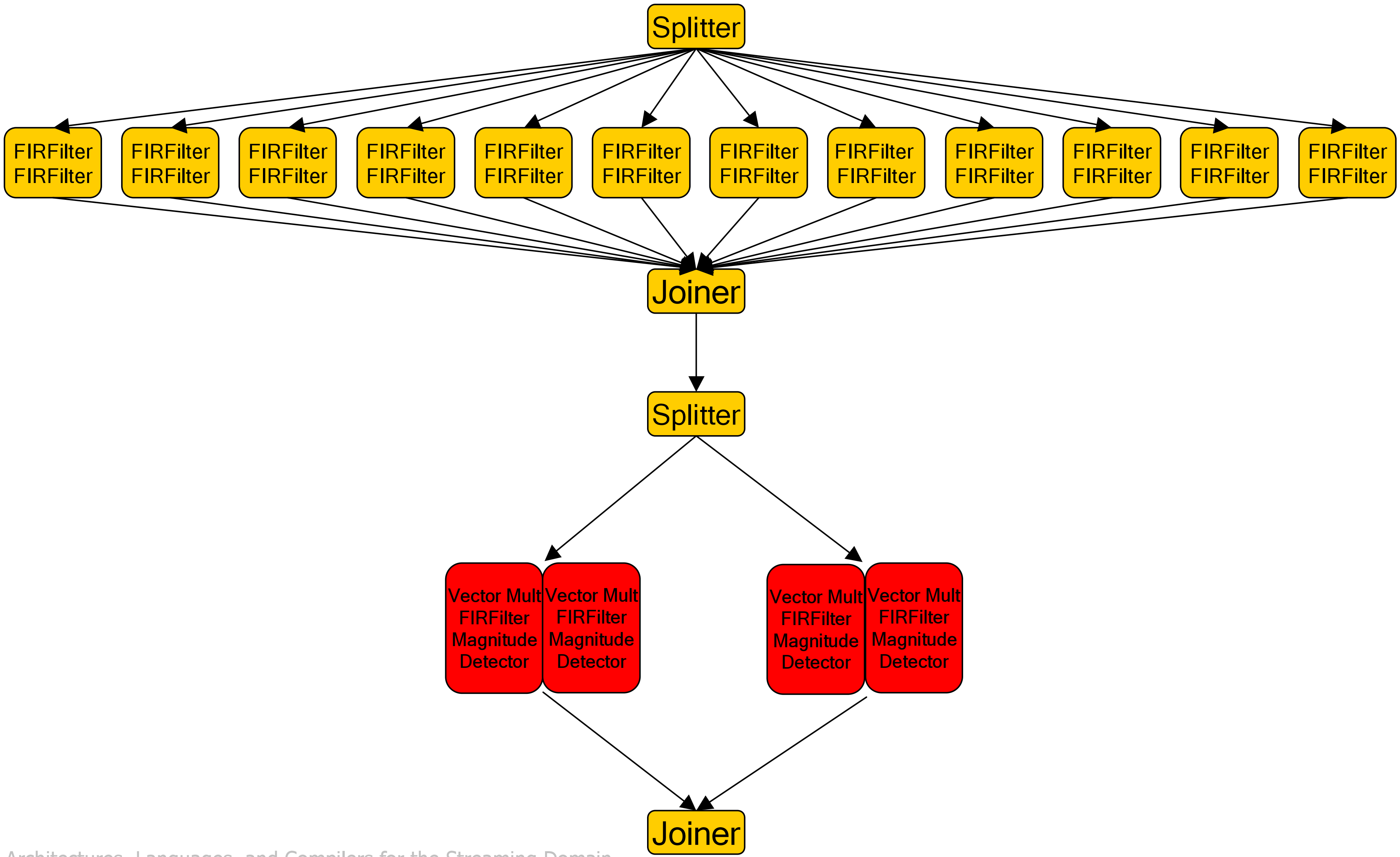
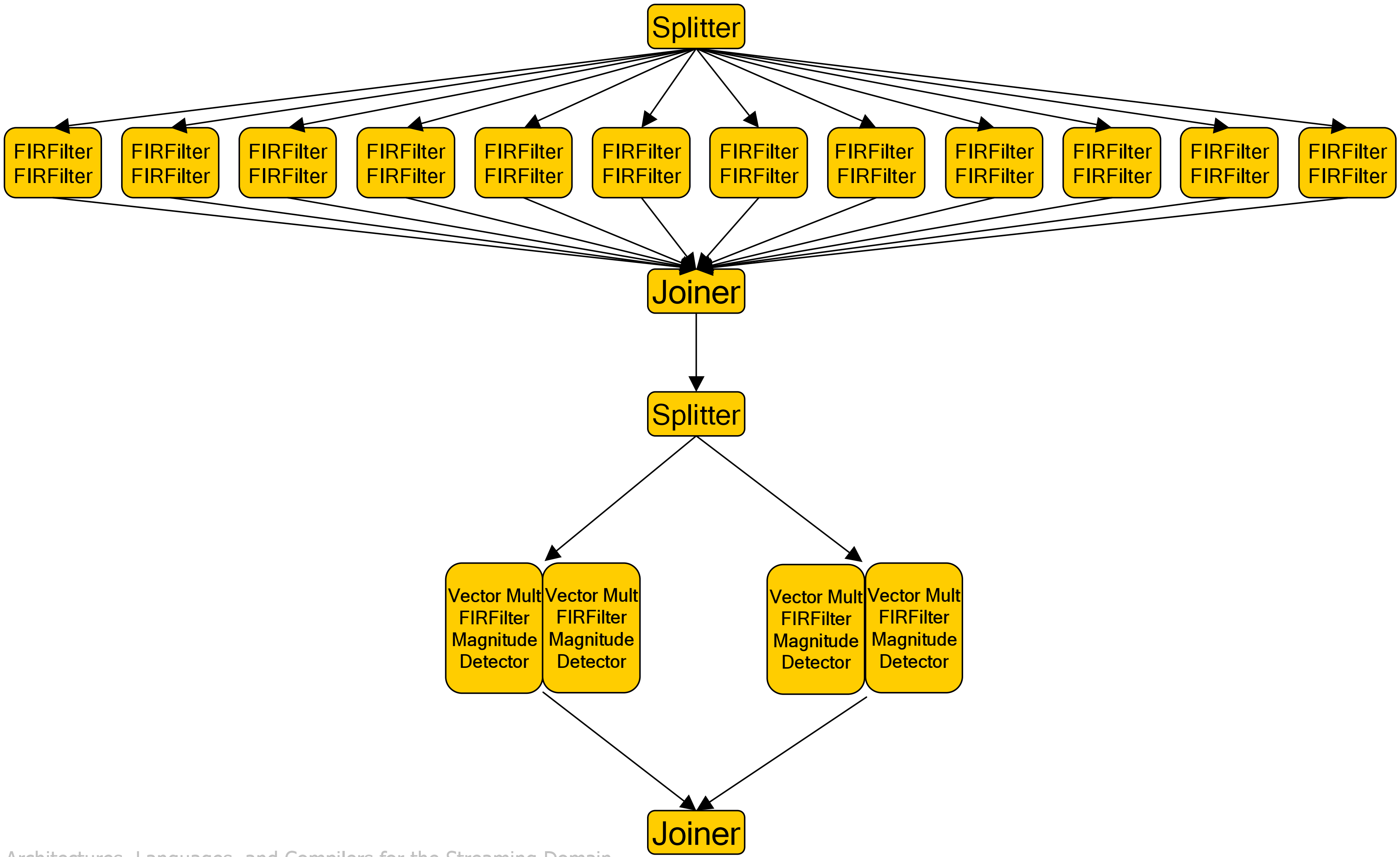
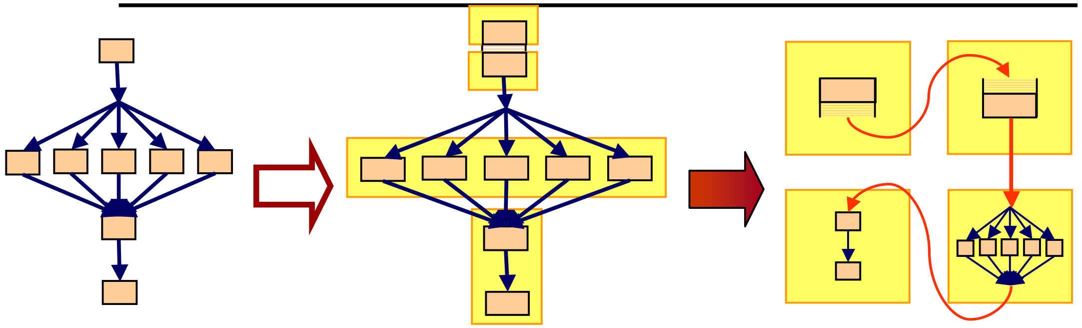


Example: Radar Array Front End (Balanced)

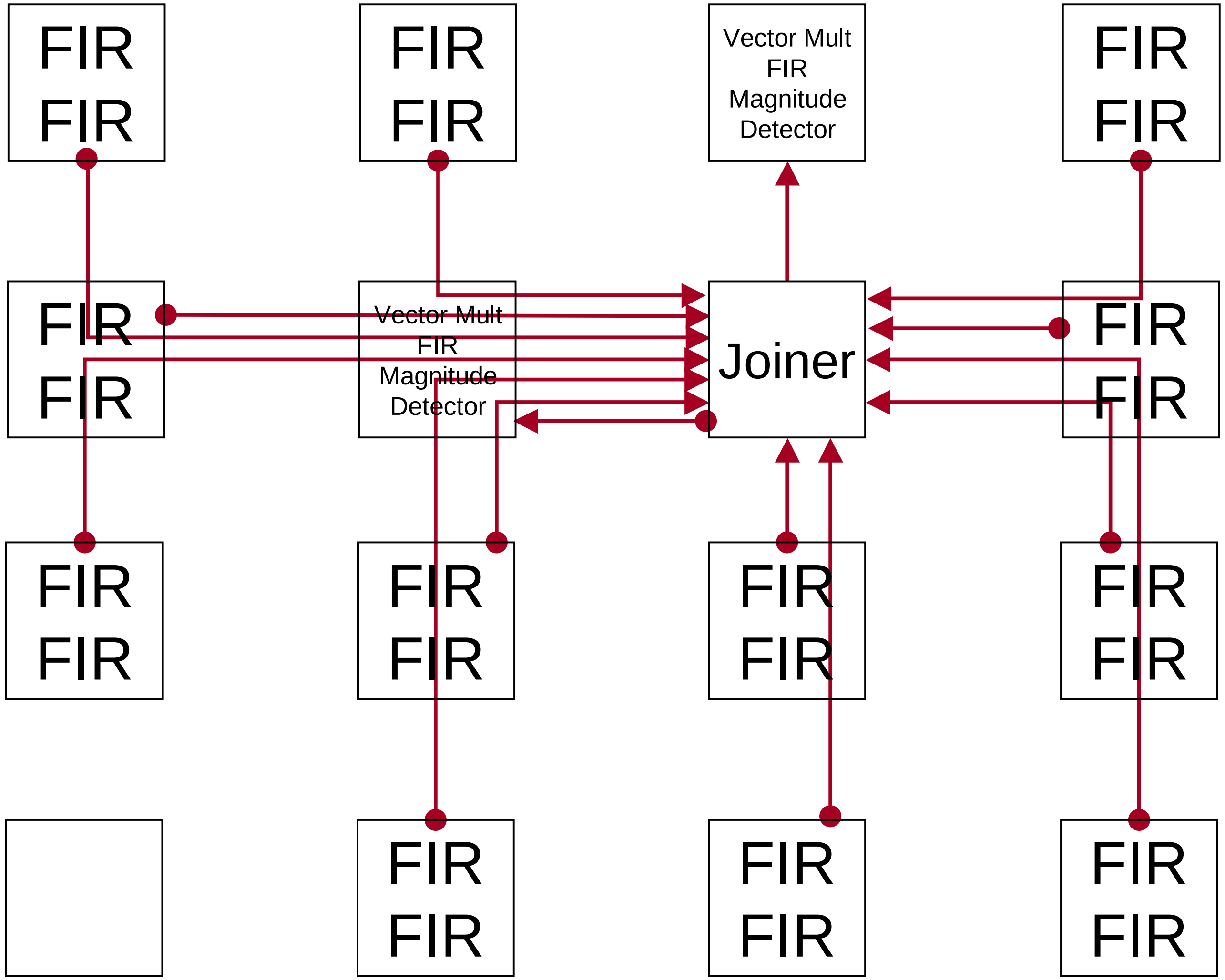


Placement: Minimizing Communication

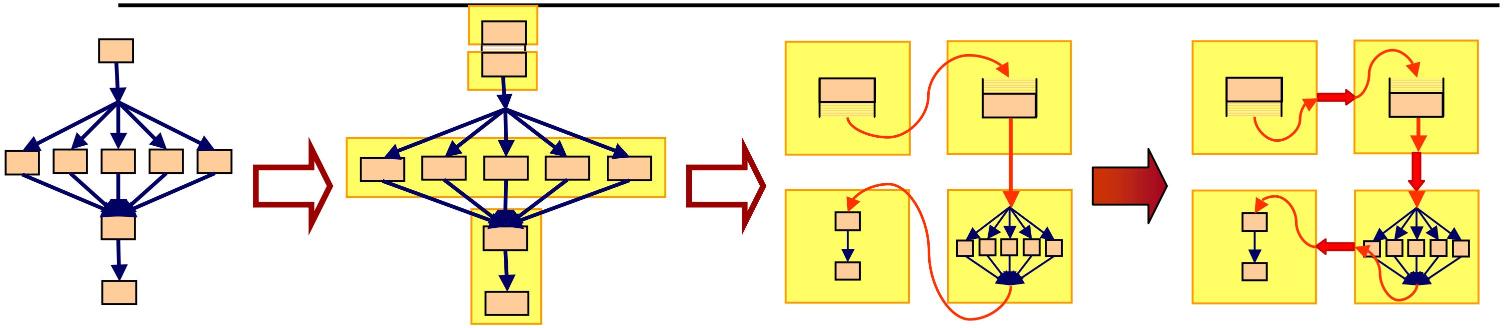


- Assign filters to tiles
  - Communicating filters → try to make them adjacent
  - Reduce overlapping communication paths
  - Reduce/eliminate cyclic communication if possible
- Compiler algorithm
  - Uses Simulated Annealing

Placement for Partitioned Radar Array Front End



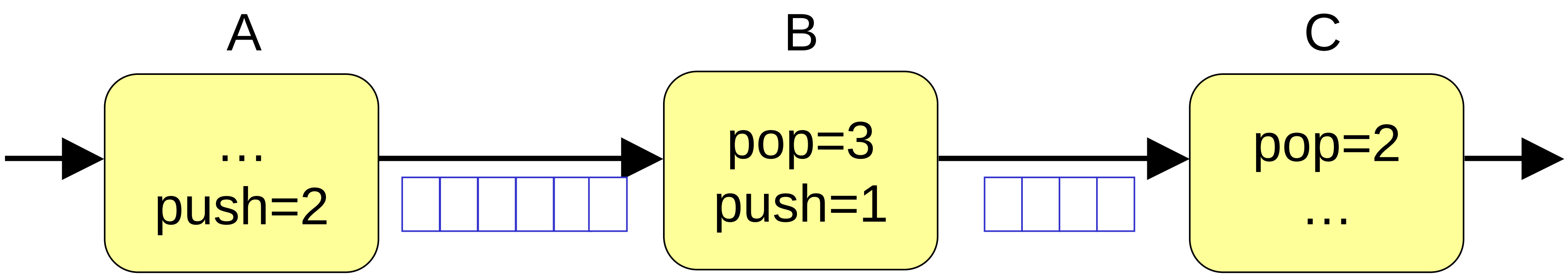
Scheduling: Communication Orchestration



- Create a communication schedule
- Compiler Algorithm
  - Calculate an initialization and steady-state schedule
  - Simulate the execution of an entire cyclic schedule
  - Place static route instructions at the appropriate time

Steady-State Schedule

- All data pop/push rates are constant
- Can find a Steady-State Schedule
  - # of items in the buffers are the same before and the after executing the schedule
  - There exist a unique minimum steady state schedule
  - *More details later, in section on scheduling*
- Schedule = { }



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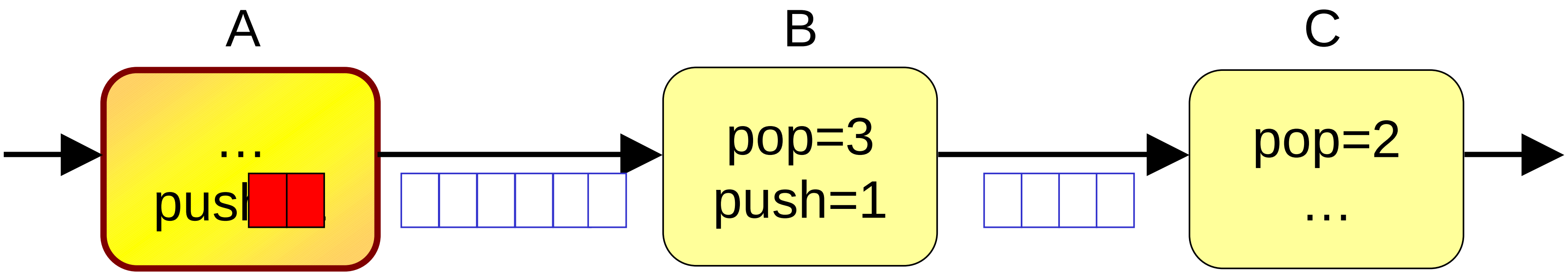
- Schedule = { A }



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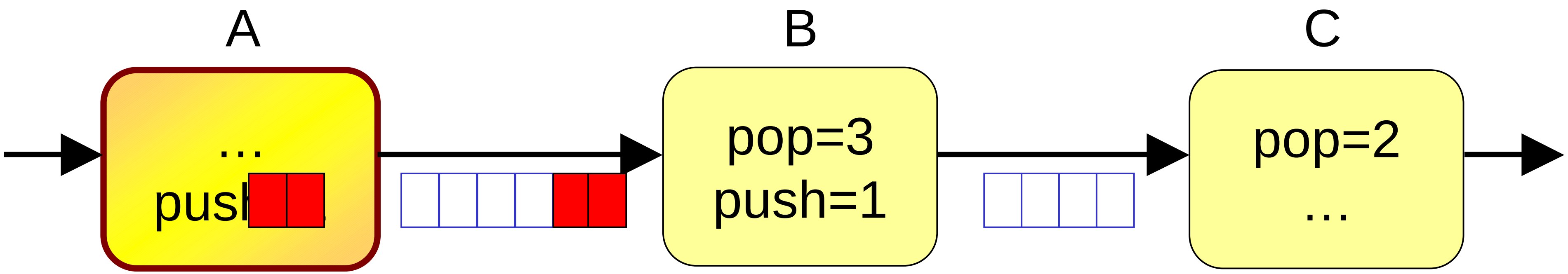

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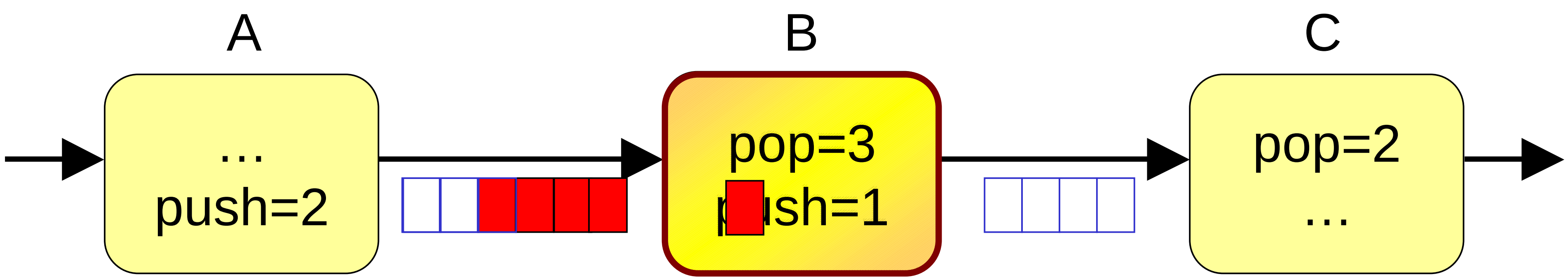
- Schedule = { A, A, B }



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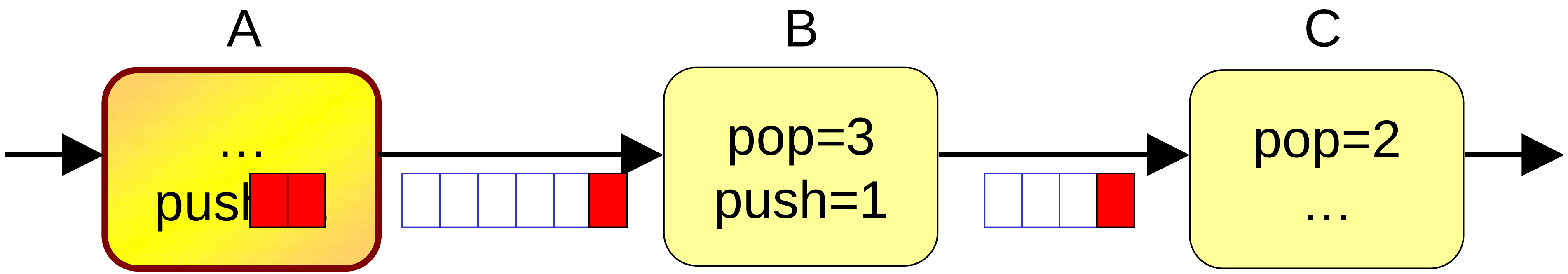

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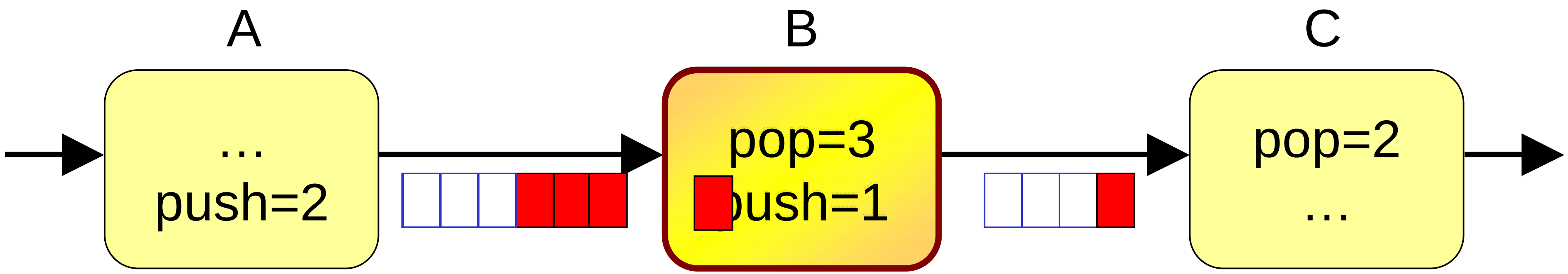

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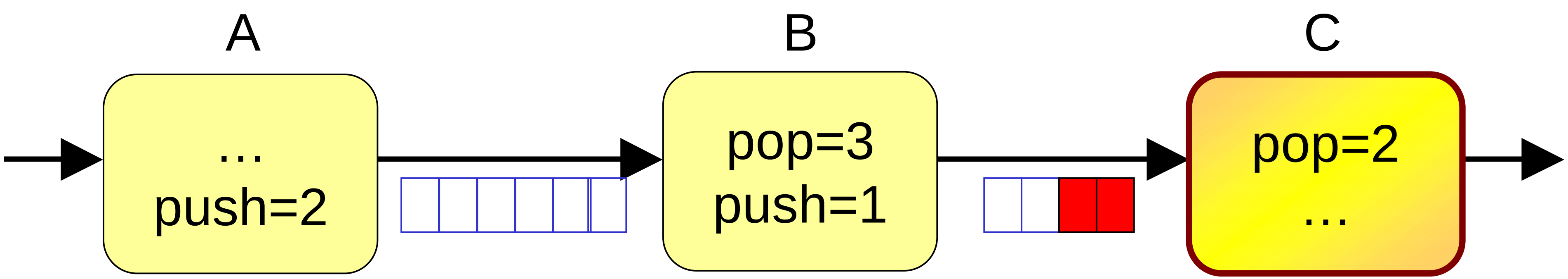
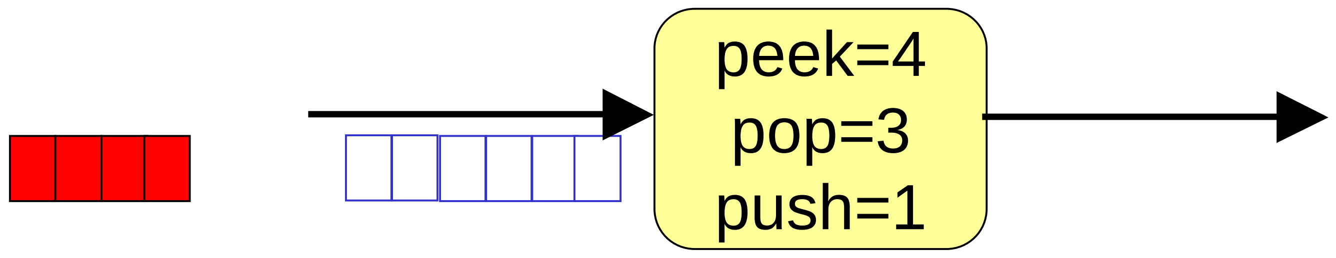
- Schedule = { A, A, B, A, B, C }



Initialization Schedule

- When peek > pop, buffer cannot be empty after firing a filter
- Buffers are not empty at the beginning/end of the steady state schedule
- Need to fill the buffers before starting the steady state execution
- *More details later, in section on scheduling*



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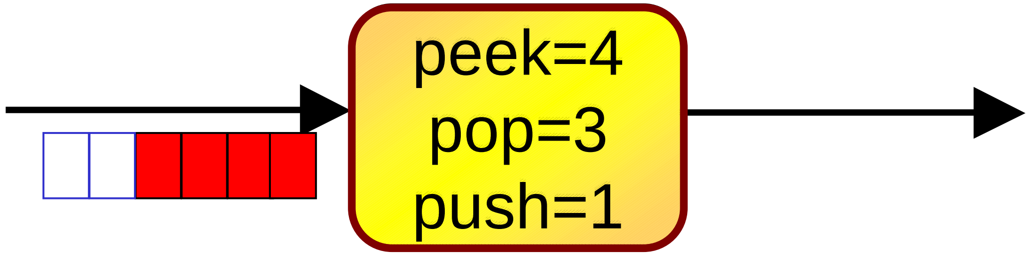
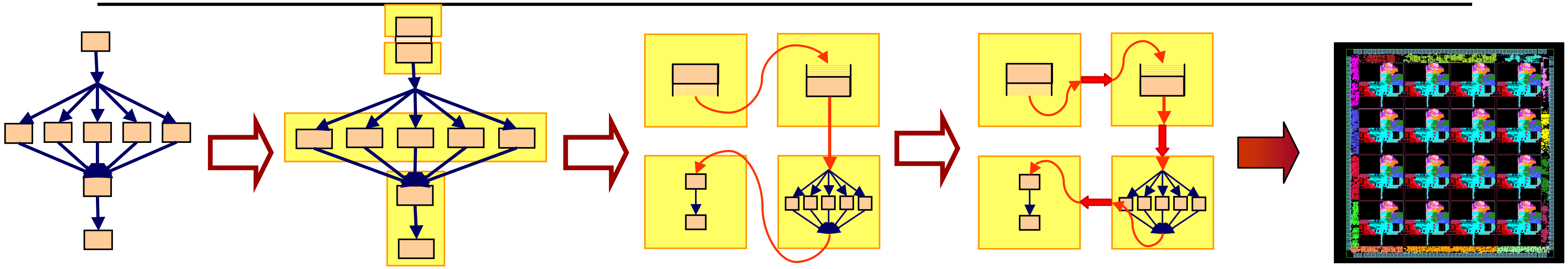
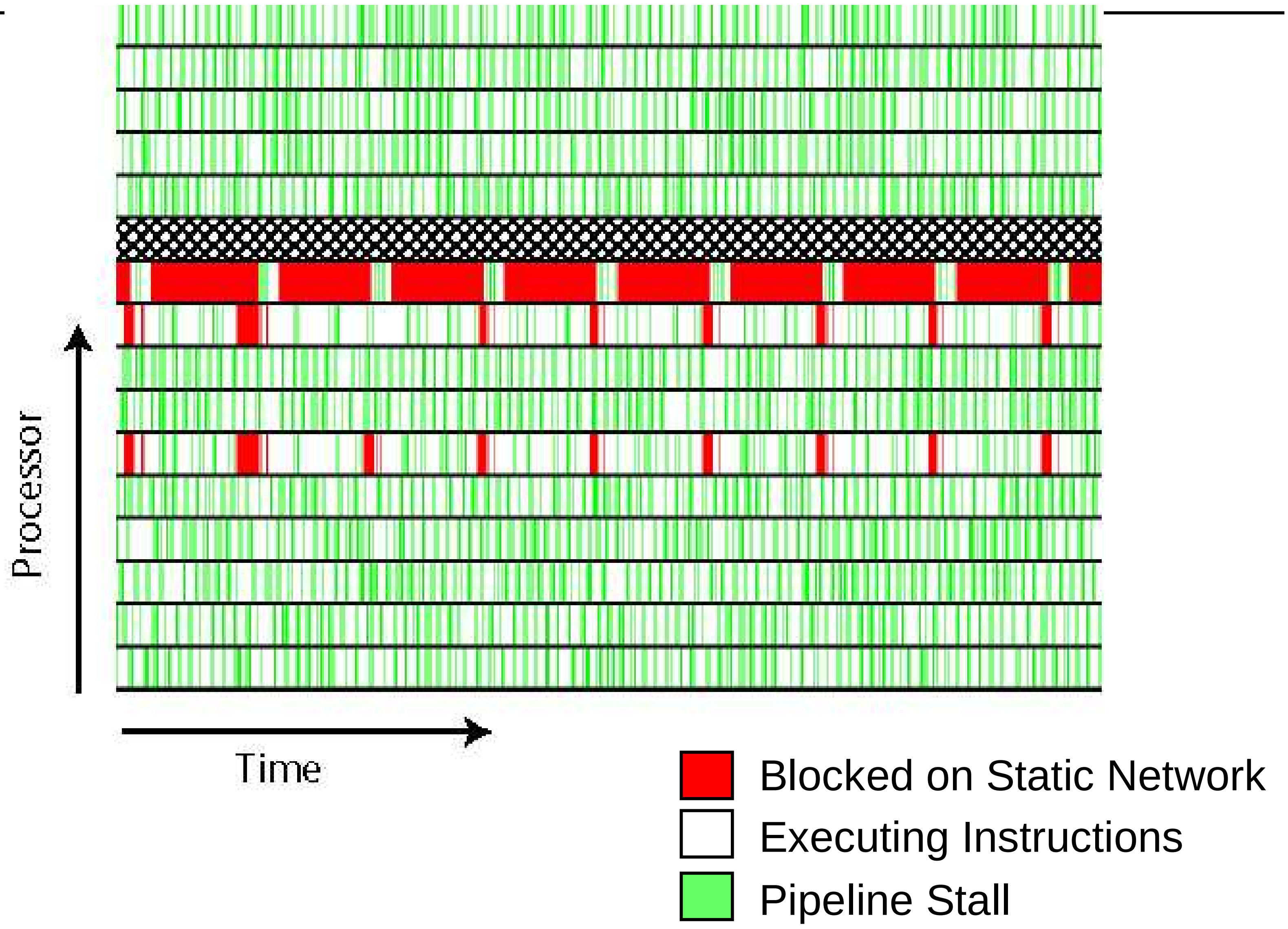


Code Generation: Optimizing tile performance

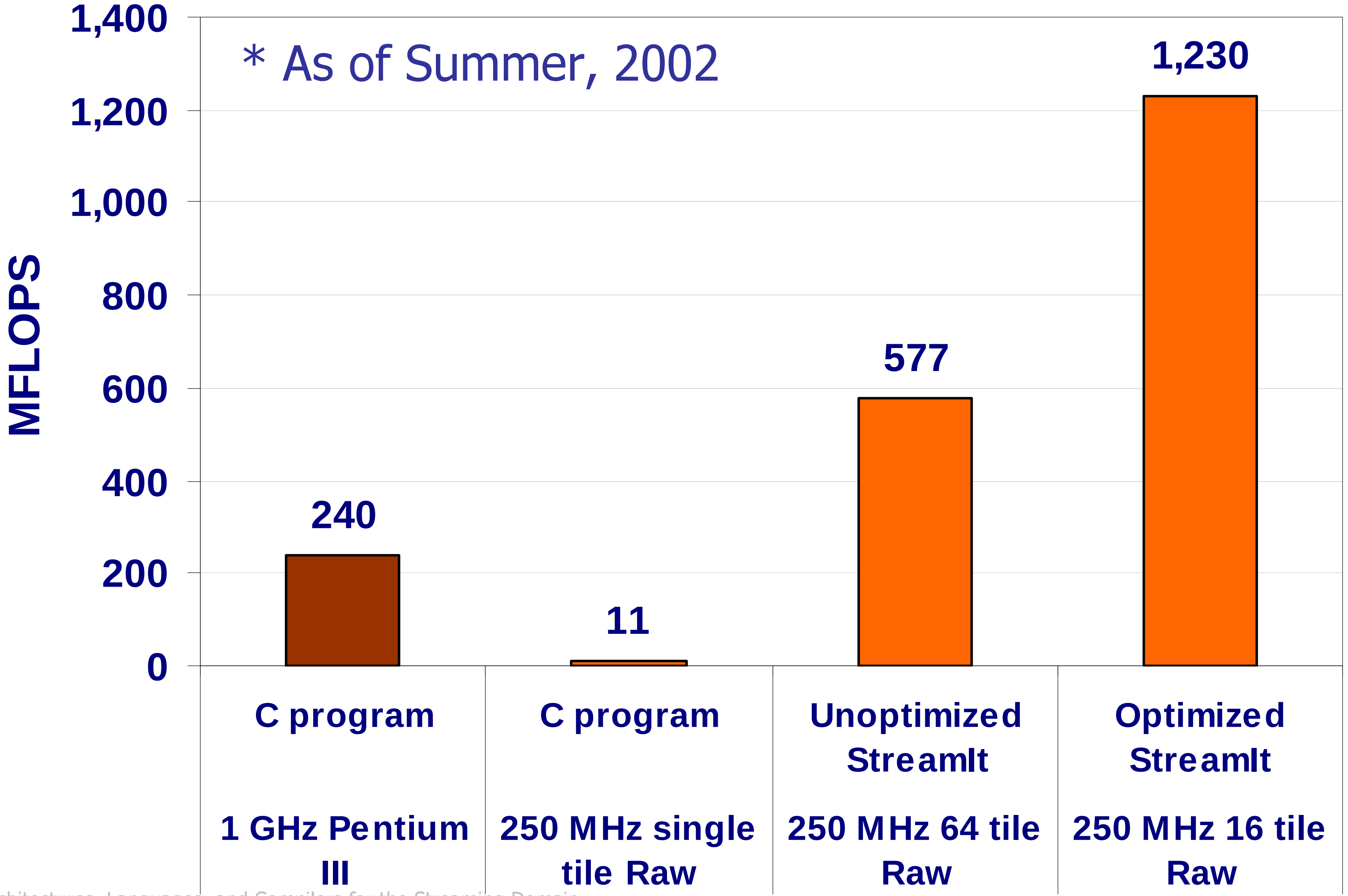


- Creates code to run on each tile
  - Optimized by the existing node compiler
- Generates the switch code for the communication

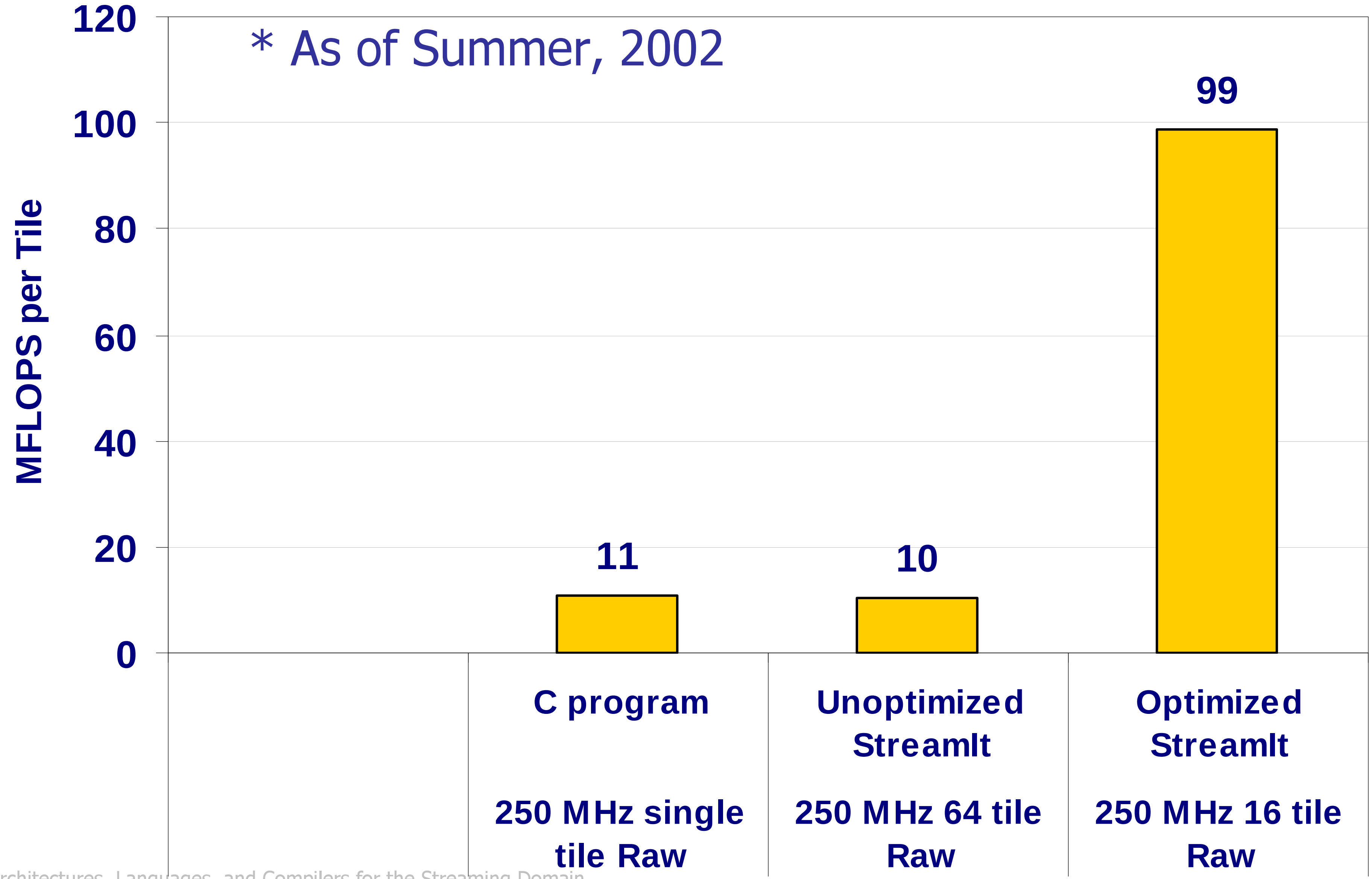
Performance Results for Radar Array Front End



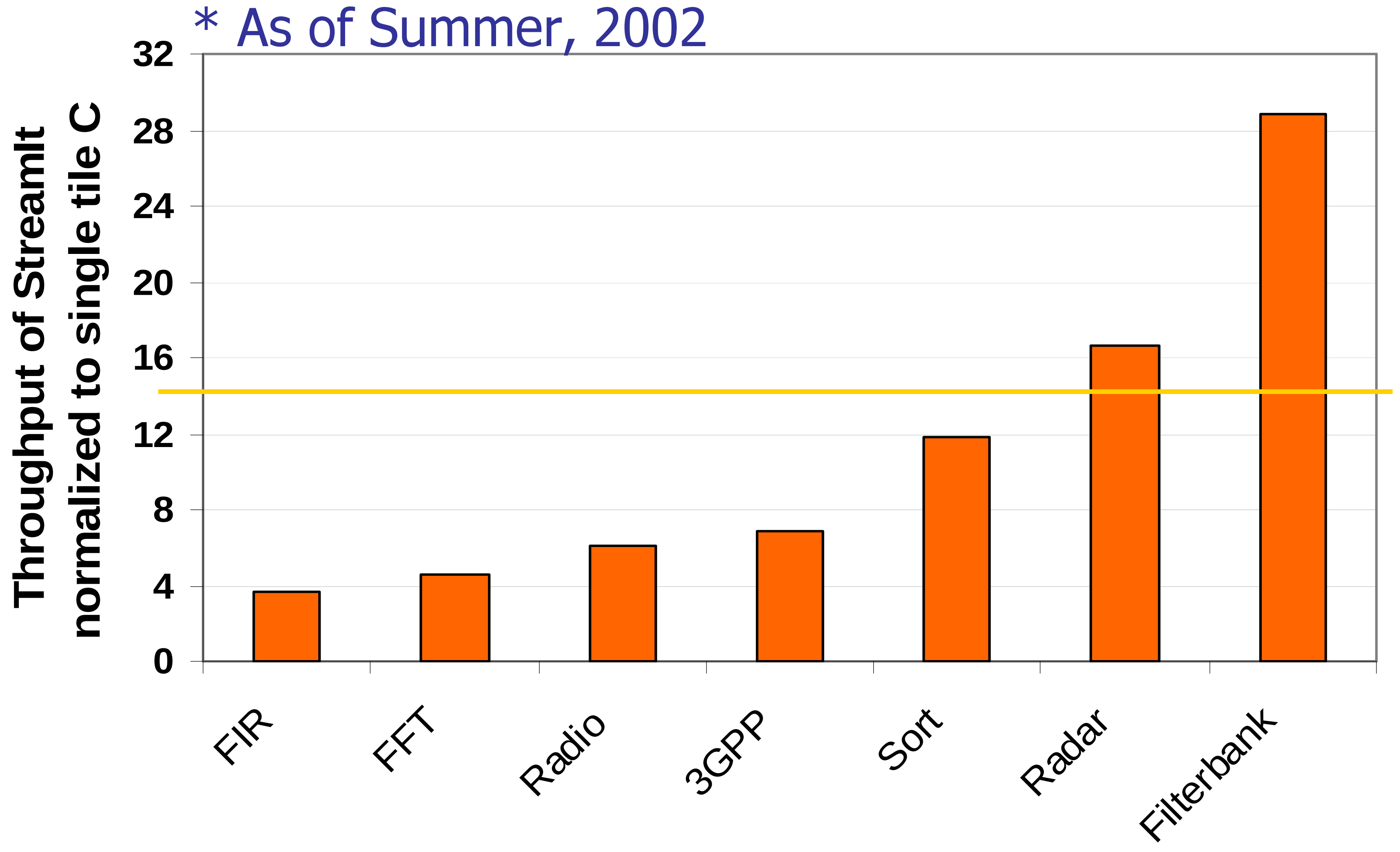
Performance of Radar Array Front End*



Utilization of Radar Array Front End*

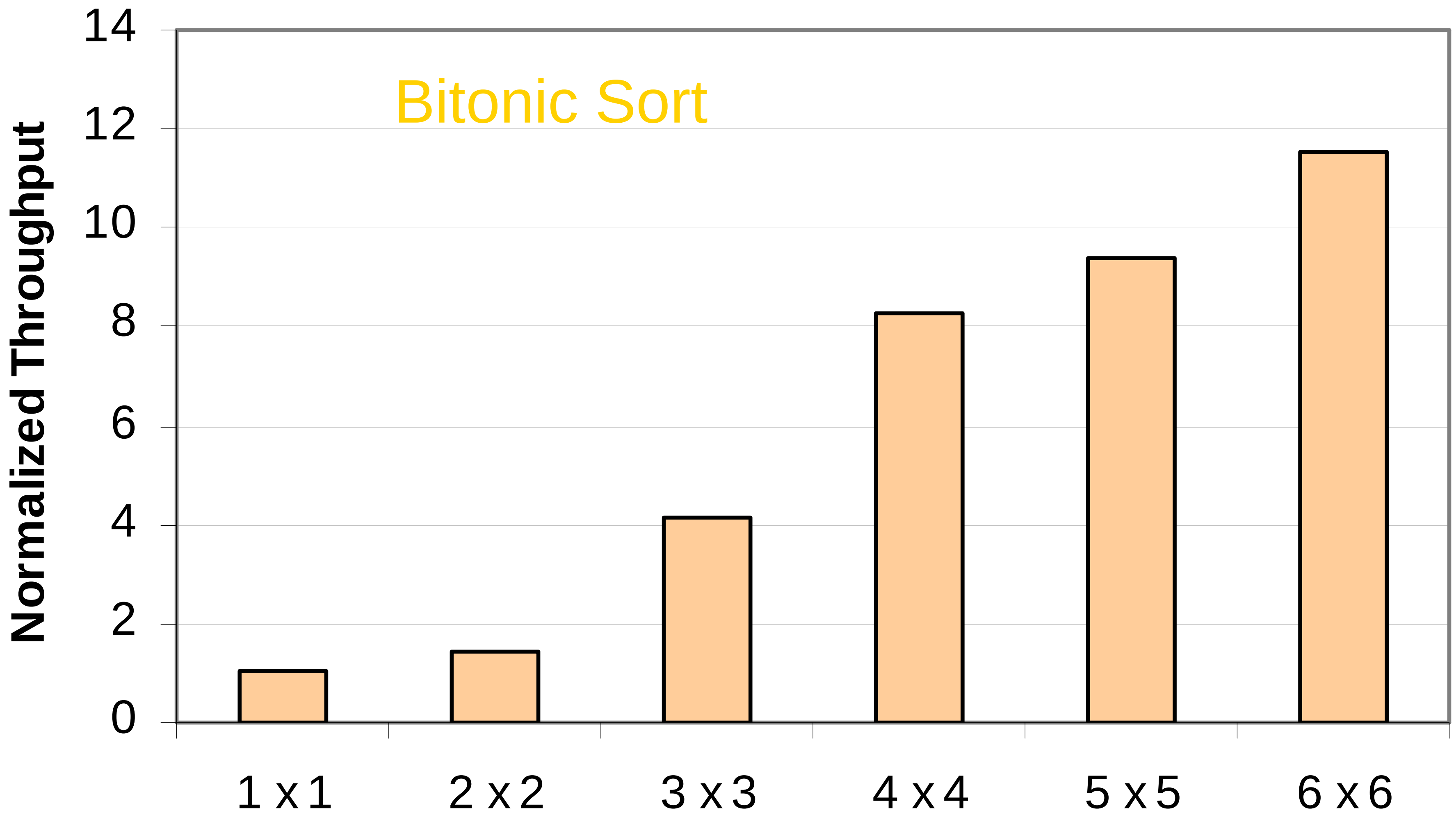


Application Performance*



Scalability of StreamIt*

* As of Summer, 2002



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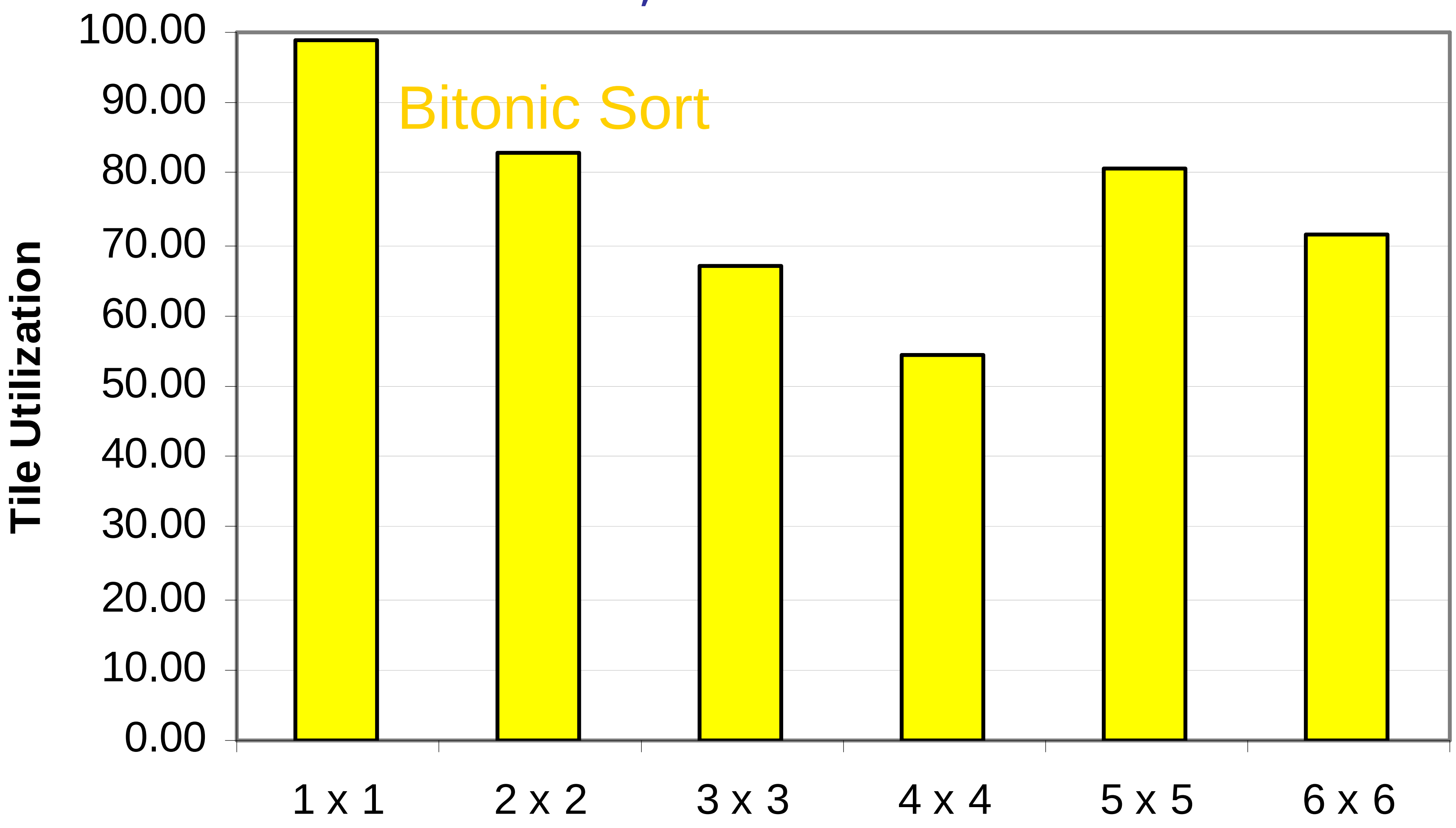

Related Work

- Stream-C / Kernel-C (Dally et. al)
  - Compiled to Imagine with time multiplexing
  - Extensions to C to deal with finite streams
  - Programmer explicitly calls stream "kernels"
  - Need program analysis to overlap streams / vary target granularity
- Brook (Buck et. al)
  - Architecture-independent counterpart of Stream-C / Kernel-C
  - Designed to be more parallelizable
- Ptolemy (Lee et. al)
  - Heterogeneous modeling environment for DSP
  - Many scheduling results shared with StreamIt
  - Don't focus on language development / optimized code generation
- Other languages
  - Occam, SISAL – not statically schedulable
  - LUSTRE, Lucid, Signal, Esterel – don't focus on parallel performance

Conclusion

- Streaming Programming Model
  - An important class of applications
  - Can break the von Neumann bottleneck
  - A natural fit for a large class of applications
  - Straightforward mapping to the architectural model
- StreamIt: A Machine Language for Communication Exposed Architectures
  - Expose the common properties
    - Multiple instruction streams
    - Software exposed communication
    - Fast local memory co-located with execution units
  - Hide the differences
    - Granularity of execution units
    - Type and topology of the communication network
    - Memory hierarchy
- A good compiler can eliminate the overhead of abstraction