Lecture 14: Mapping to parallel hardware

Embedded Software
Michael O'Boyle

Overview

- Mapping tasks to parallel hardware
  - crux issue but no agreed approach
- Developing (Discovering) parallel tasks
  - v difficult but infrequent
- Mapping
  - can be (semi-) automated
  - repeated for every platform
- Look at an explicit parallel task language StreamIT
  - consider different mapping approaches

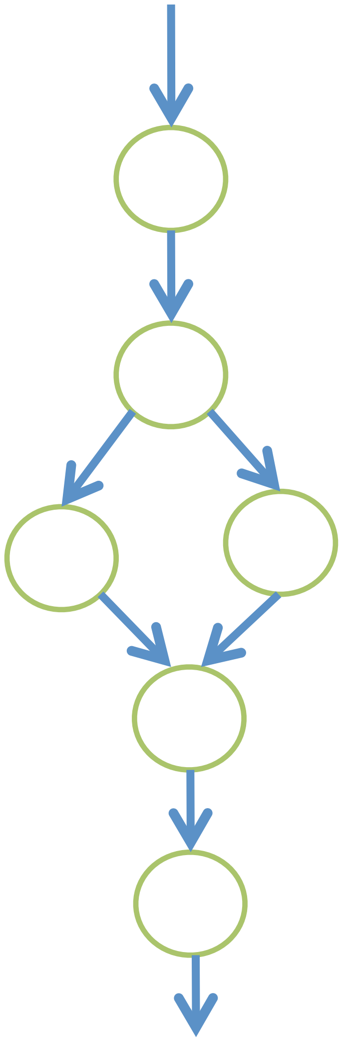
Mapping problem

- Sequential program
- Parallel program
  – machine unaware
- Partition into parallel tasks
- Allocate parallel tasks to processors
  – machine aware
- Schedule tasks
- If assume one task per processor
  – then partitioning is mapping

The Streaming Domain

- Widely applicable and increasingly prevalent
  - Embedded systems
    - Cell phones, handheld computers, DSP's
  - Desktop applications
    - Streaming media
    - Software radio
    - Real-time encryption
    - Graphics packages
  - High-performance servers
    - Software routers (Example: Click)
    - Cell phone base stations
    - HDTV editing consoles
- Based on audio, video, or data stream
- StreamIT from MIT
  - a language that supports this domain

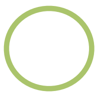
StreamIT Programs



- Operate on a large sequence of data items (data stream) in pipeline fashion.

- Each data item is processed for a limited time before being discarded.

- Each program has a stream graph
- Explicit parallel tasks

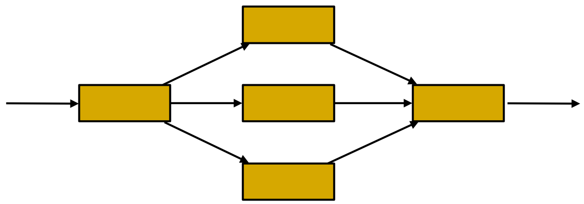
 Processing unit (or functions)

 Data flow

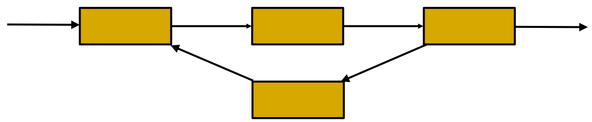
Structured Streams

- Hierarchical structures:
  - Pipeline

  - SplitJoin



  - Feedback Loop



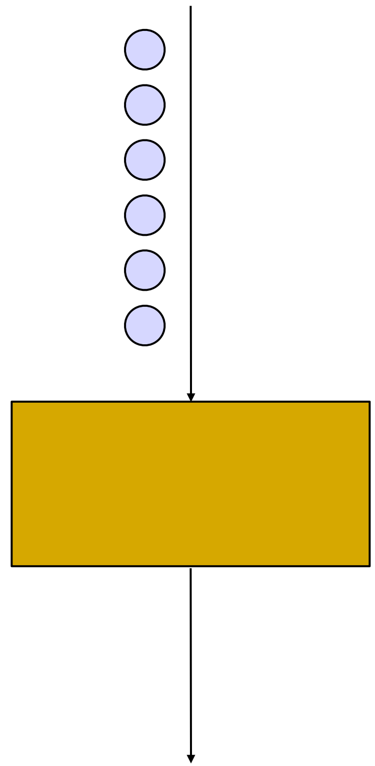
- Basic programmable unit: Filter

StreamIT Filter Example:

```
float->float filter LowPassFilter(int N) {
    float[N] weights;

    init {
        for (int i=0; i<N; i++)
            weights[i] = calcWeights(i);
    }

    work push 1 pop 1 peek N {
        float result = 0;
        for (int i=0; i<N; i++)
            result += weights[i] * peek(i);
        push(result);
        pop();
    }
}
```



Filter Example: LowPassFilter

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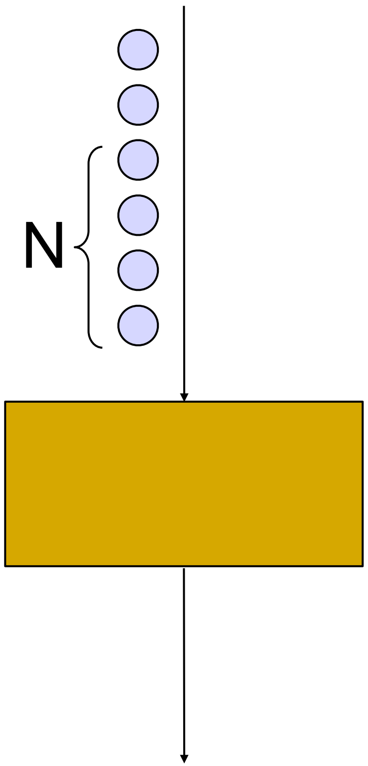

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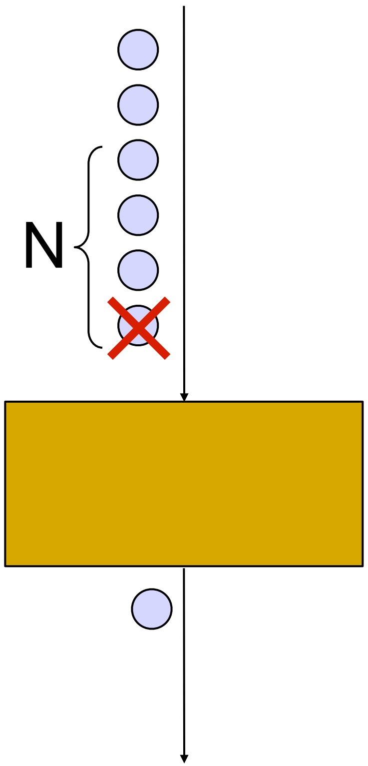

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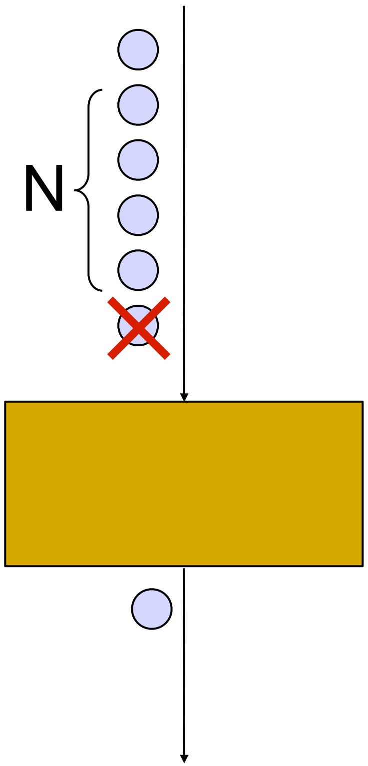

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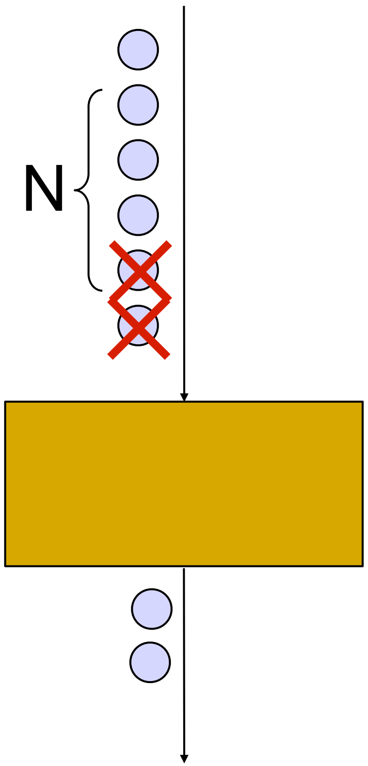
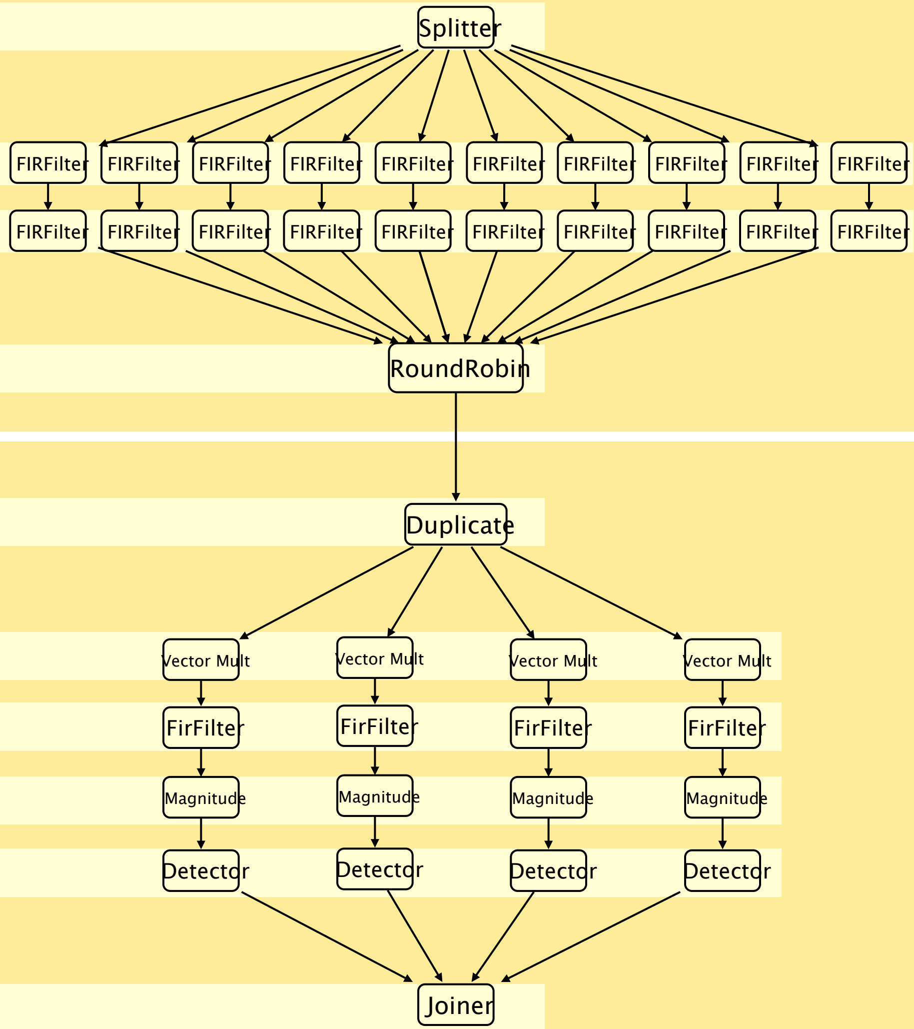


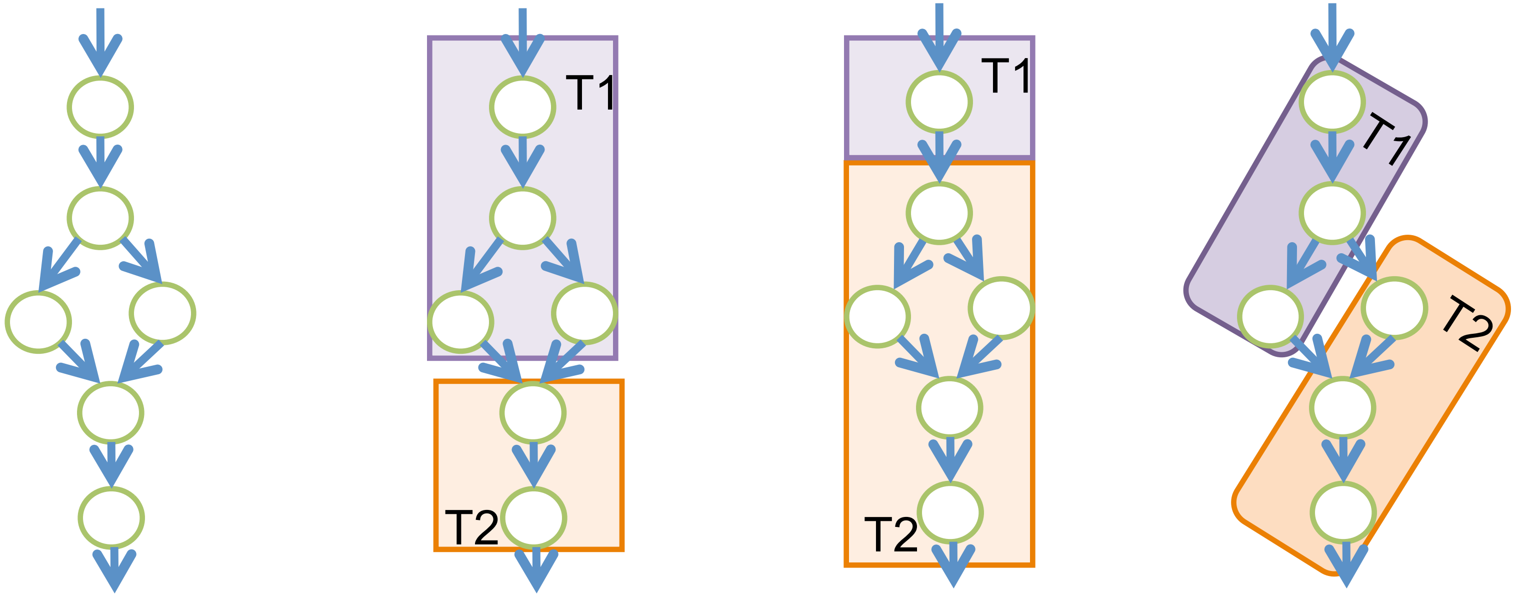
Example: Radar Array Front End

```
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();
            };
```



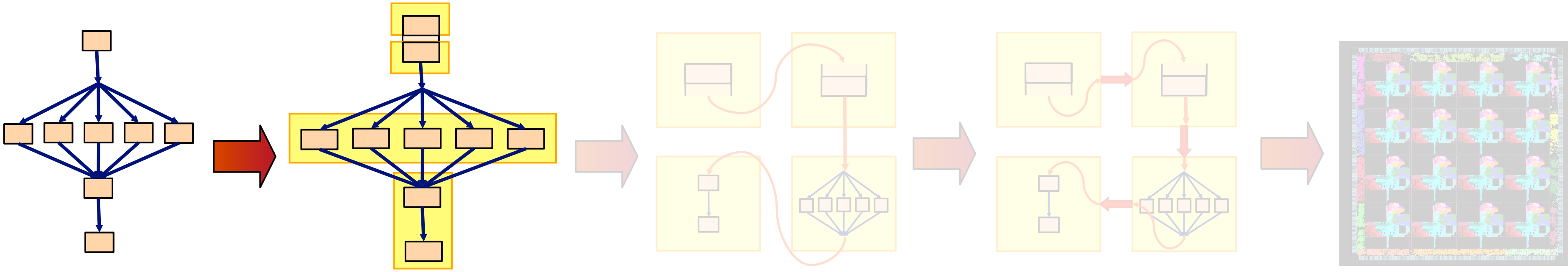
Partitioning the Program

- Map the input program graph to threads
- Need to find a good one from many possible partitions



3 possible partitions on a 2-core machine

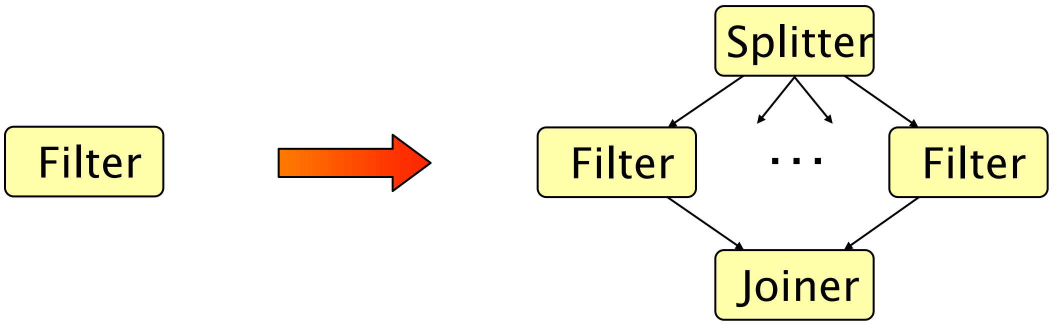
Partitioning



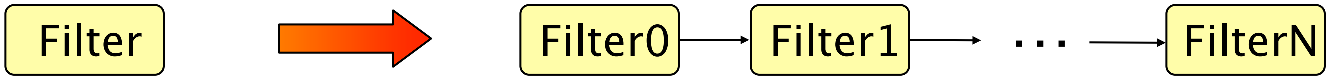
- Mapping filters
  - Each filter should have similar amount of work
    - Throughput determined by the filter with most work
- Original StreamIT Compiler Algorithm
  - Two primary transformations
    - Filter fission
    - Filter fusion
  - Uses a greedy heuristic

Partitioning - Fission

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

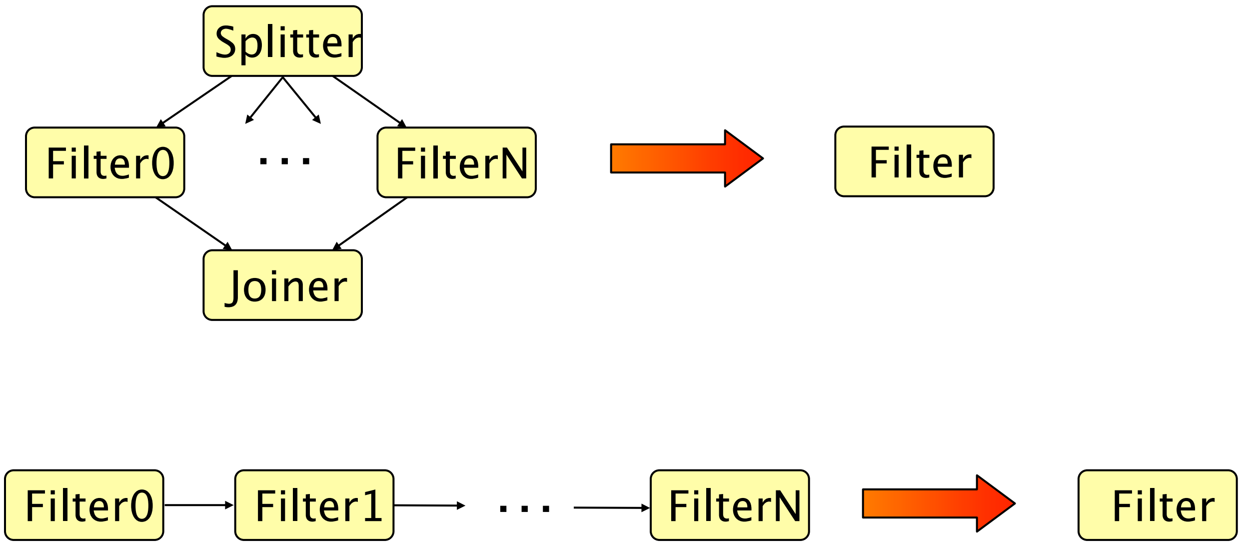


  - Split a filter into a pipeline for load balancing

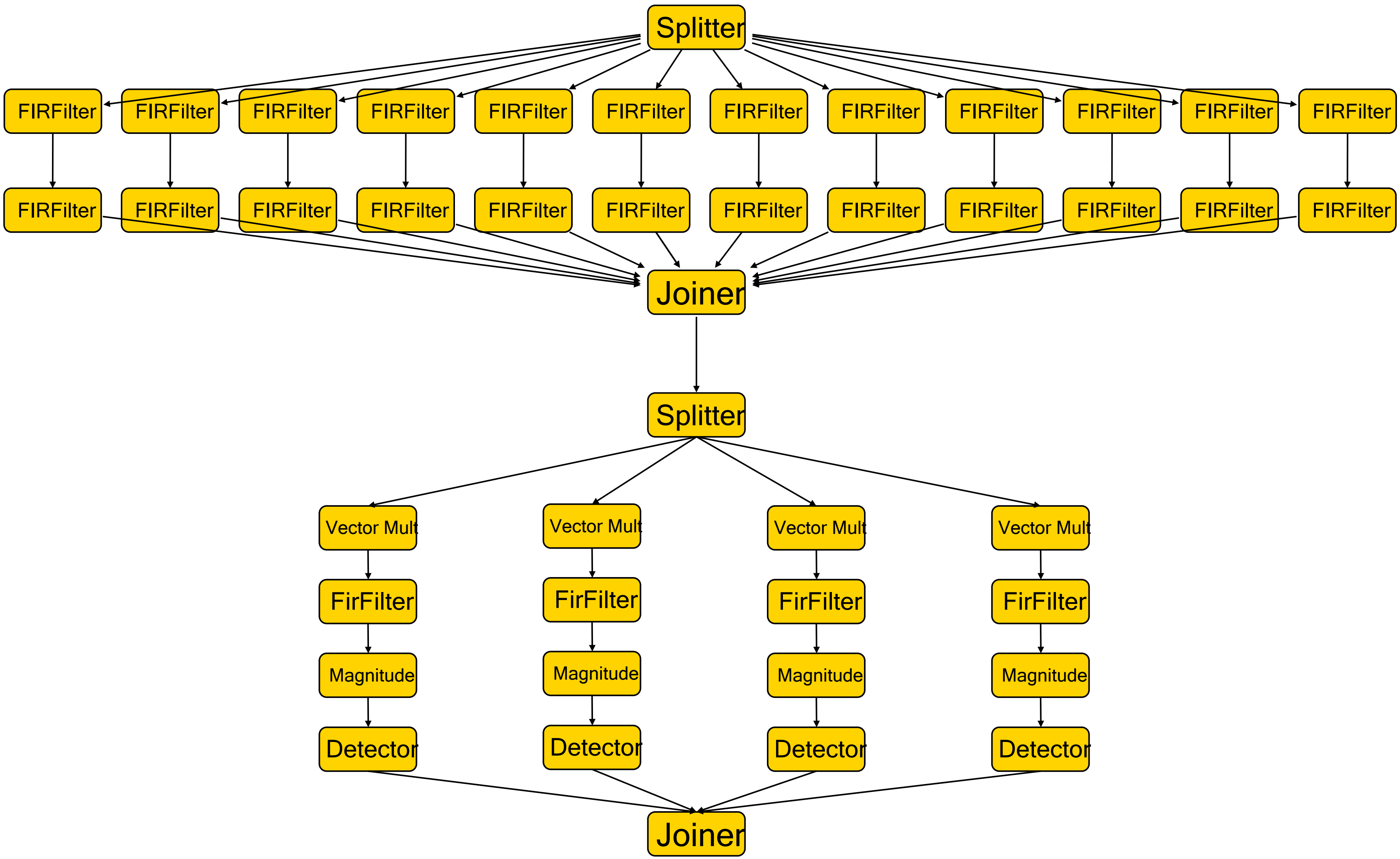


Partitioning - Fusion

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



Example: Radar Array Front End (Original)



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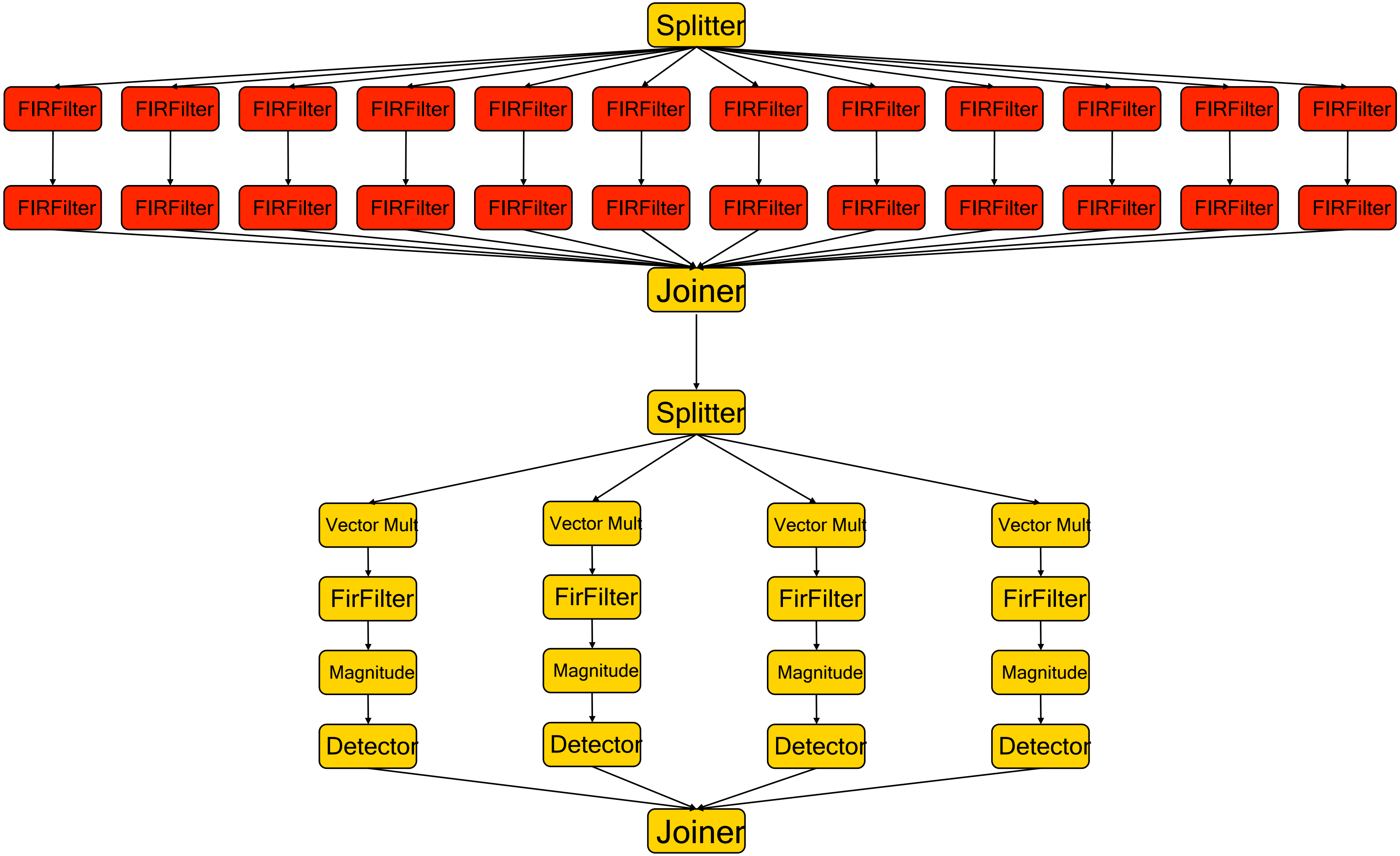

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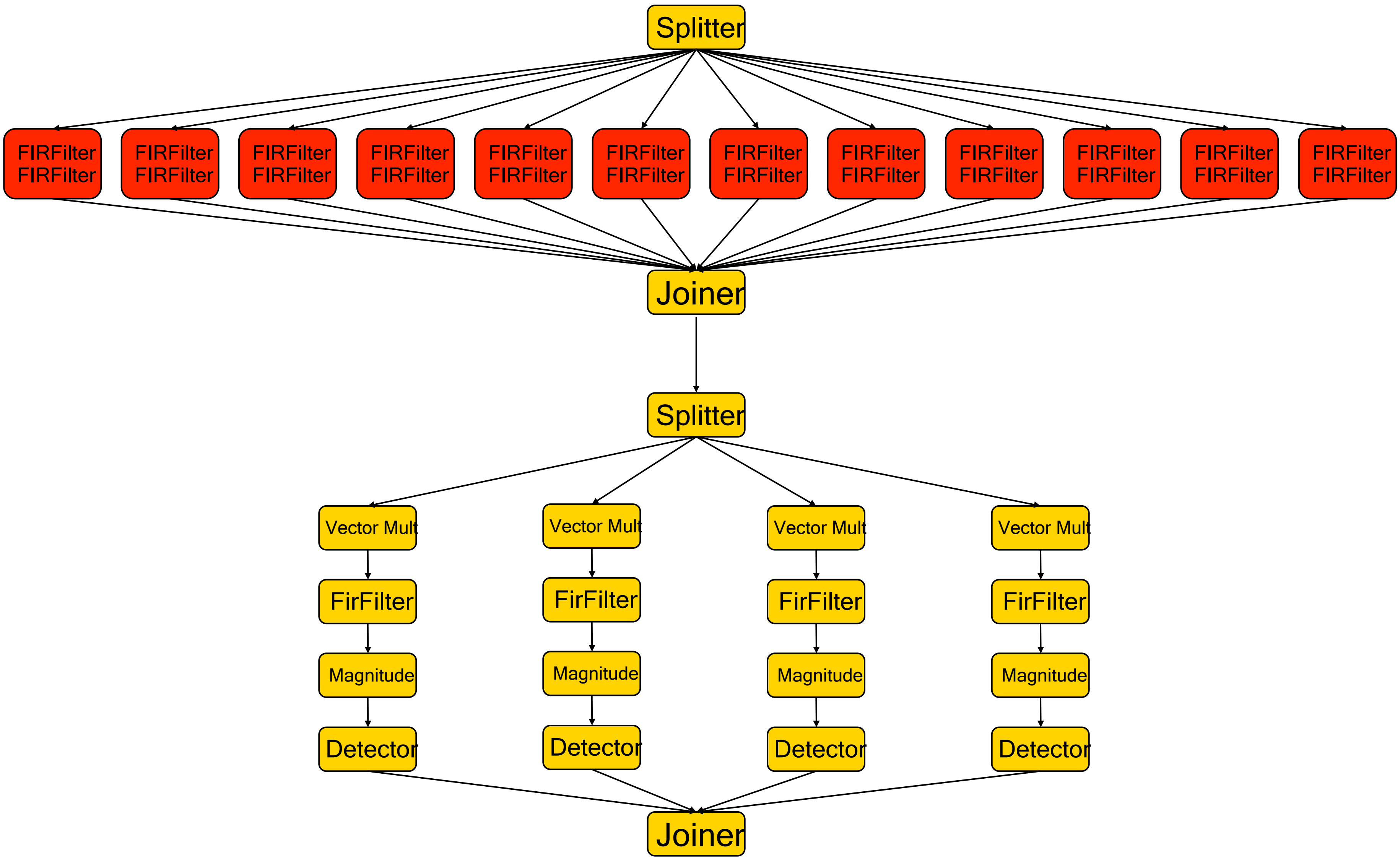

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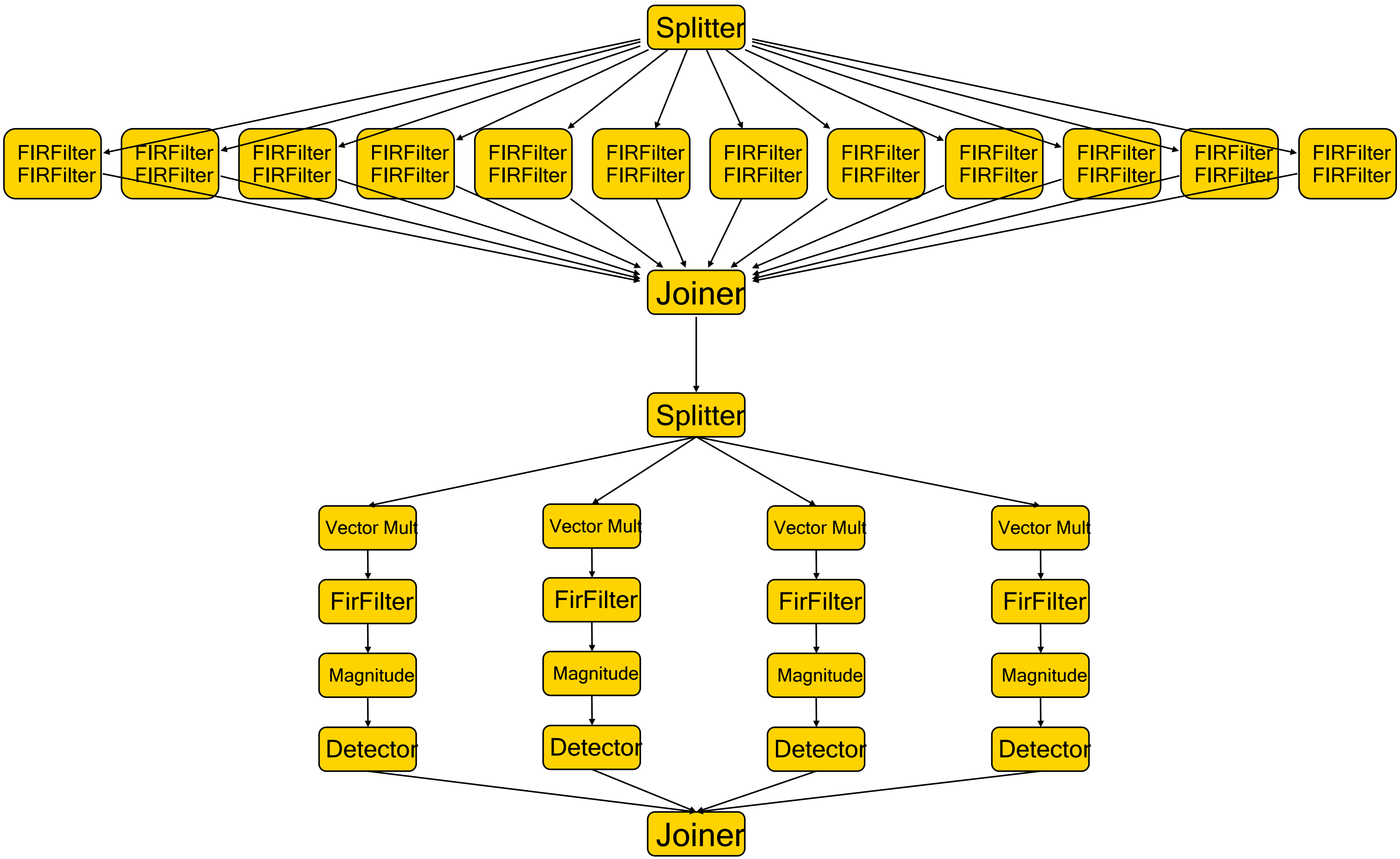

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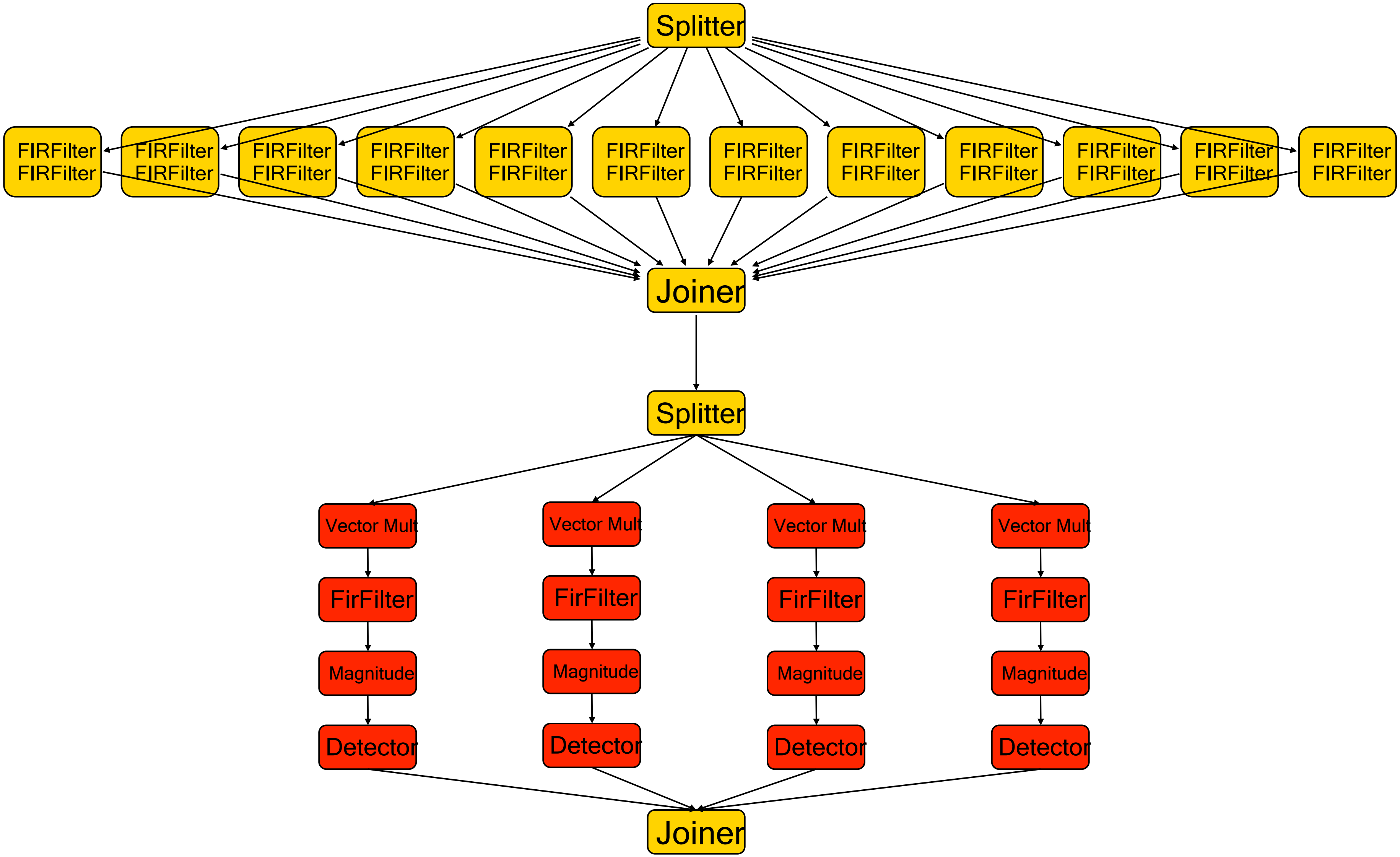

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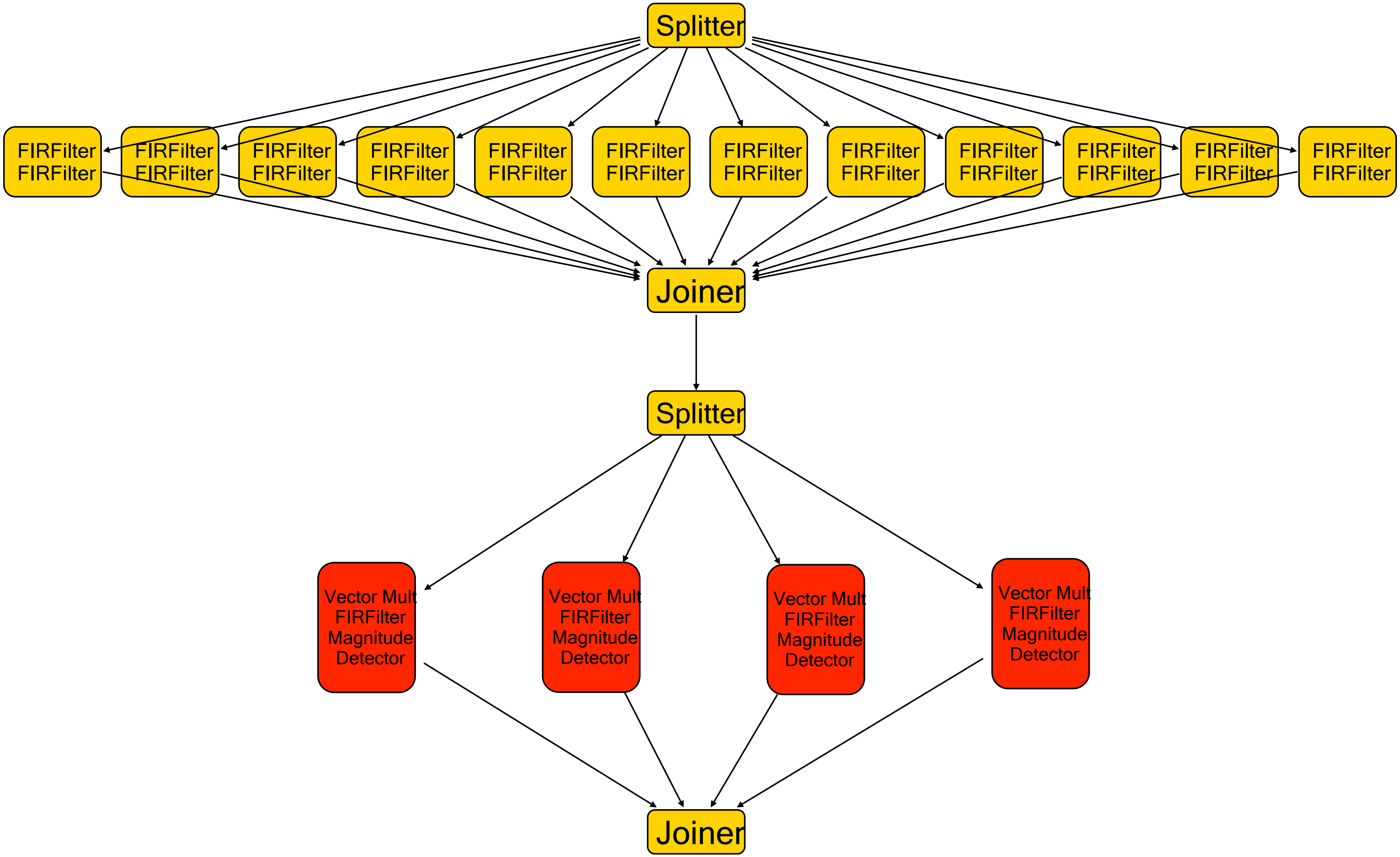

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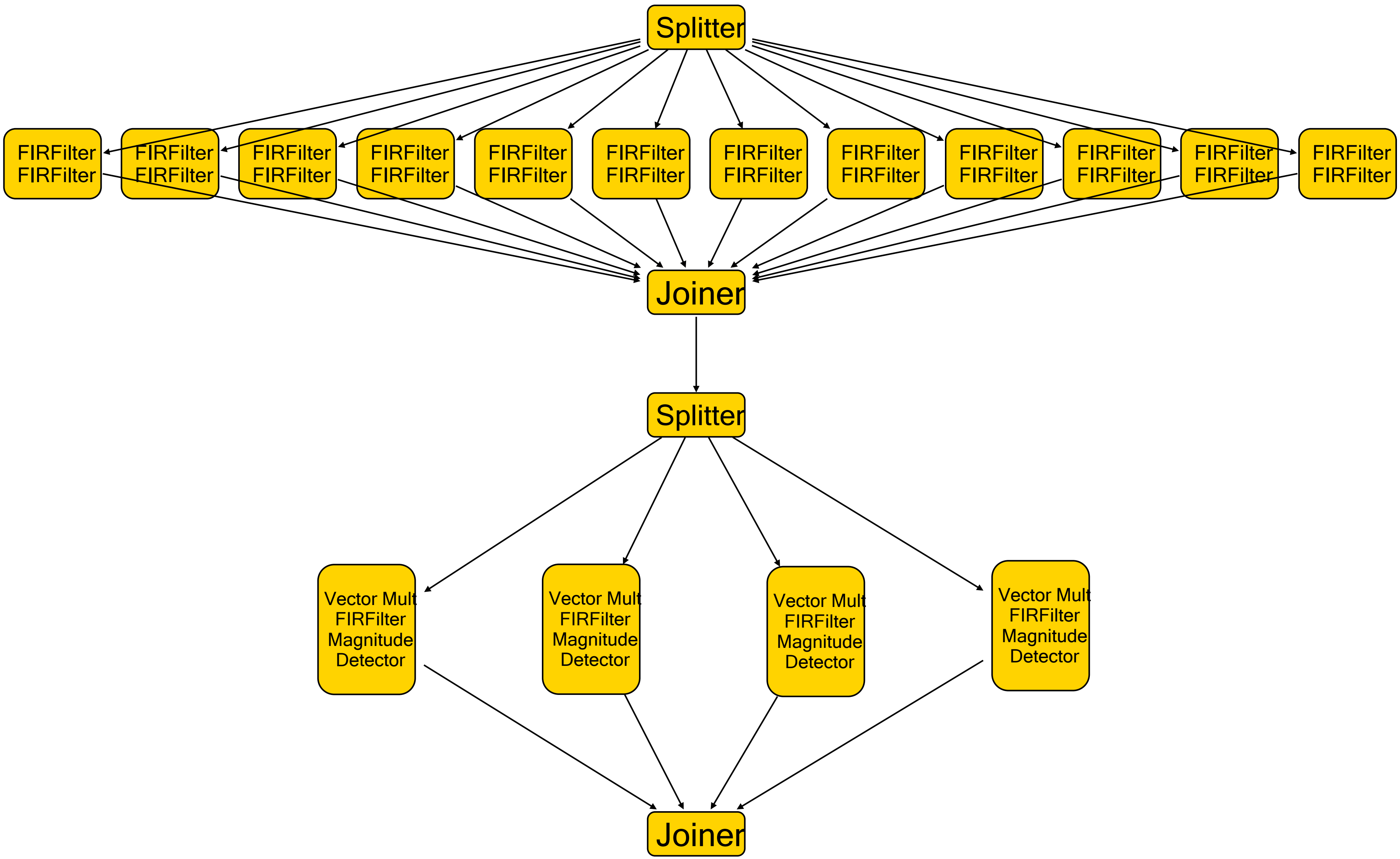

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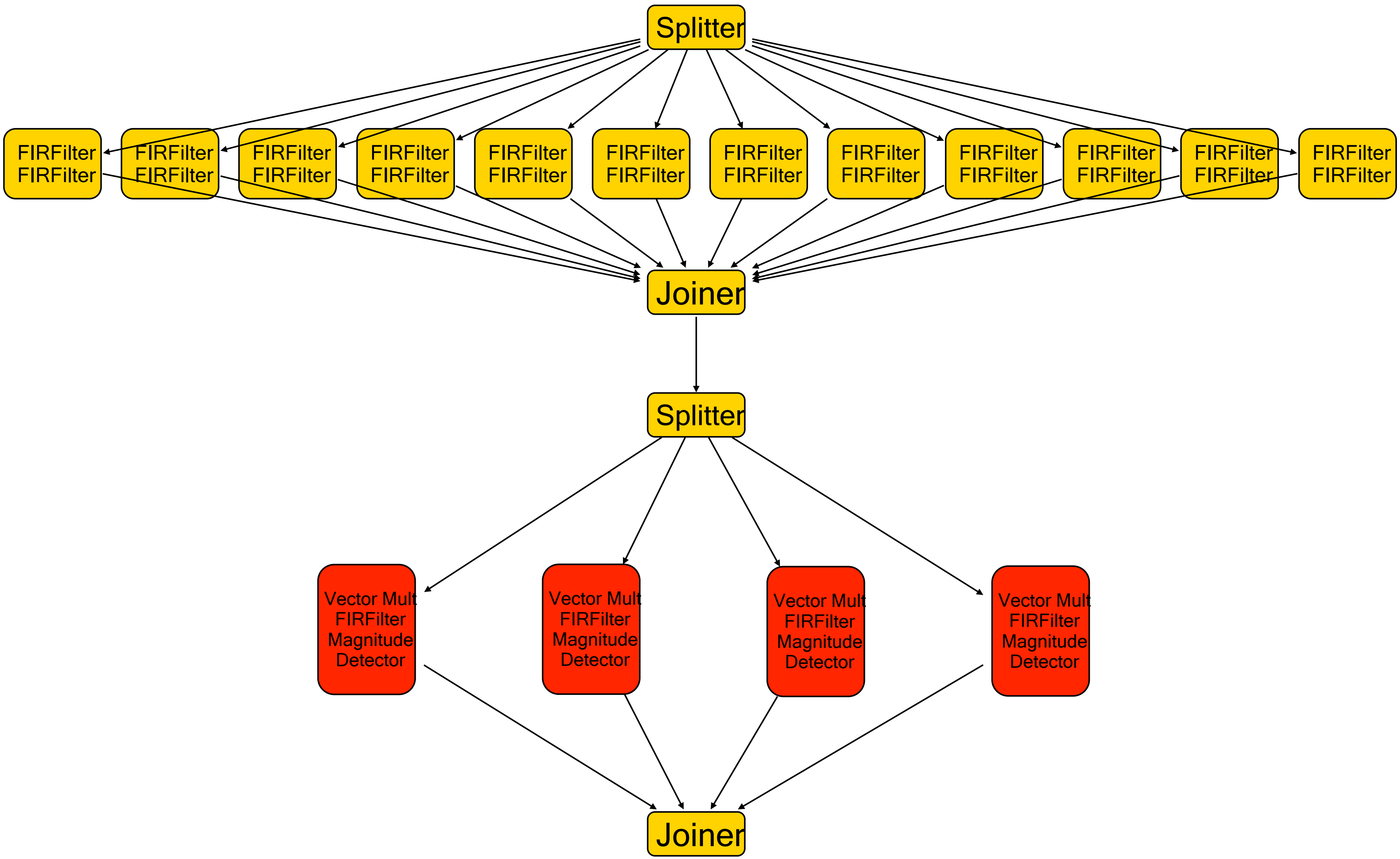

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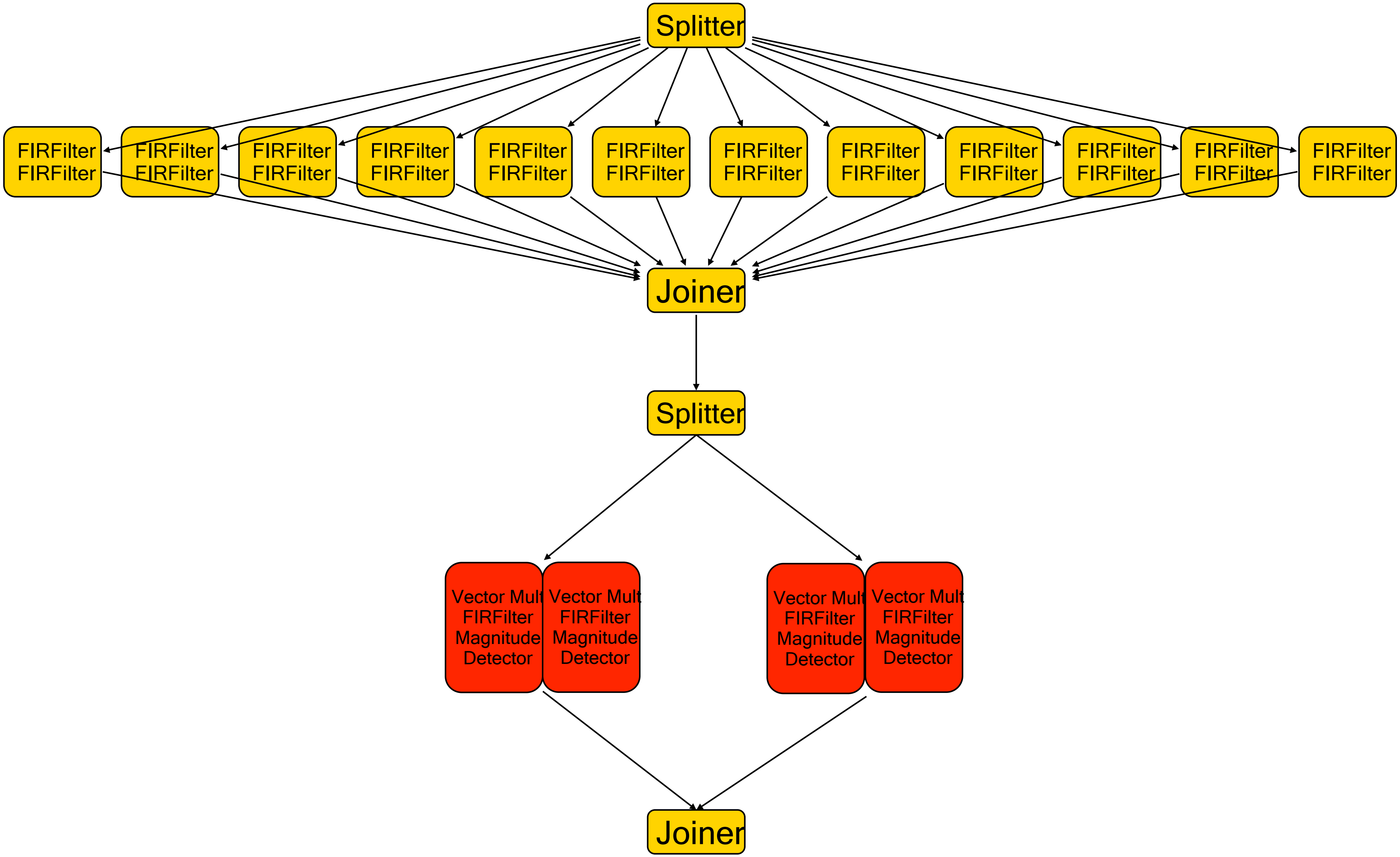
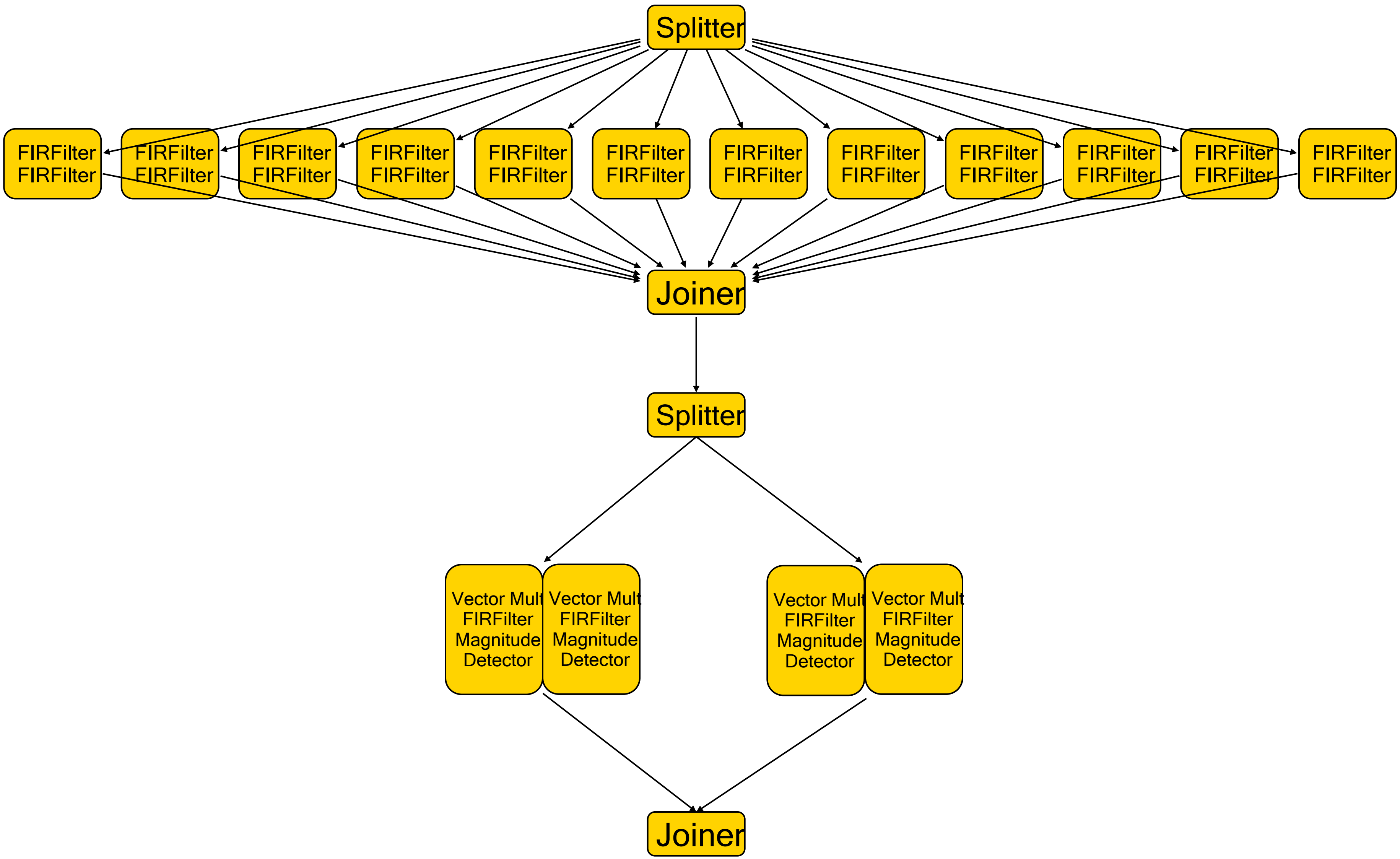
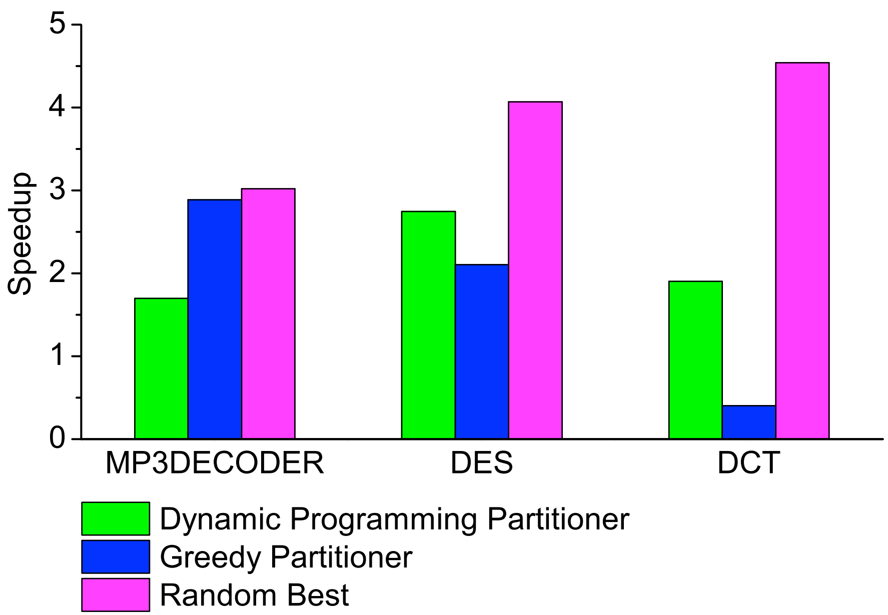


Example: Radar Array Front End (Balanced)

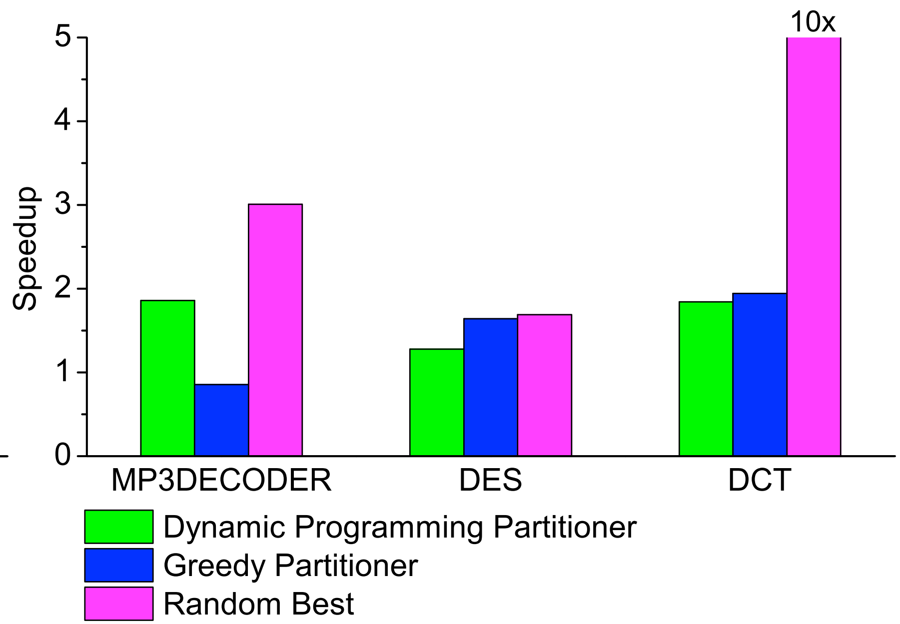


Performance?

- The best partitioning strategy varies across programs and platforms



(a) Intel Xeon 4-core (2x dual-cores)



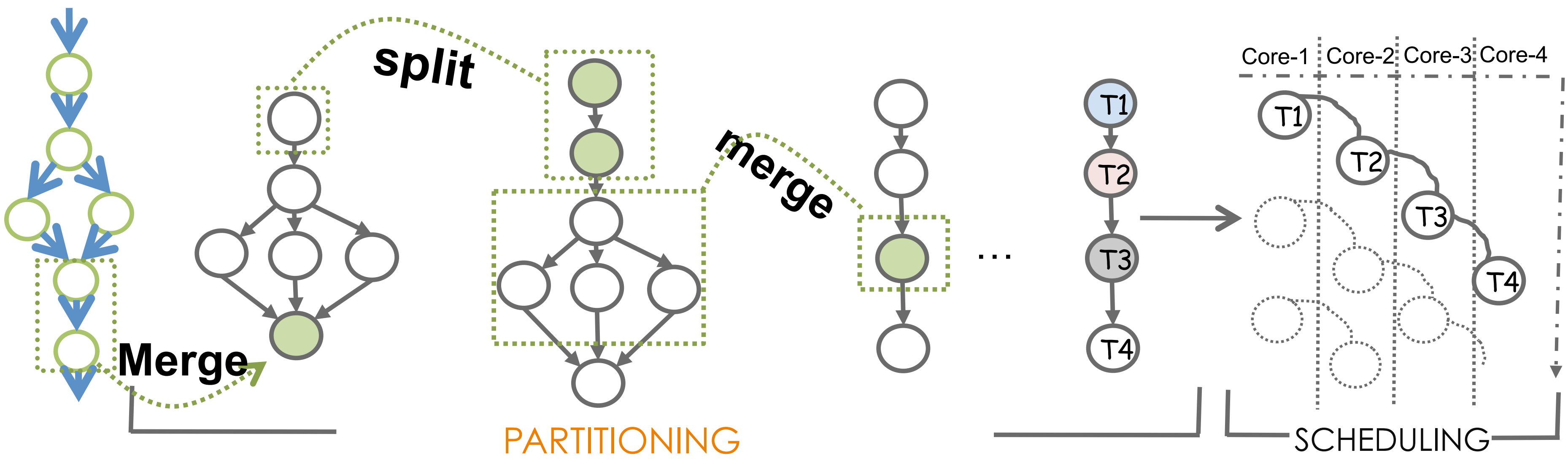
(b) Intel Xeon 8-core (2x quad-cores)

Using Machine Learning

- Problem
  - Tuning heuristics is hard
  - Architectures and system software keep changing
- Goal
  - Replace an heuristic with a machine learning one
- Machine learning (ML) performs very well (Zheng Wang 2010)

How to model partitioning for ML

- Use a sequence of merging and splitting operations to generate a partition



Compact graph representation.

A Two Step Approach

1. Predict characteristics of the ideal partition
2. Search for a partition with those characteristics

Do NOT run any of the generated partition for searching

Characterise the Ideal Partition

- Use static compiler information to characterise the ideal partitioning structure

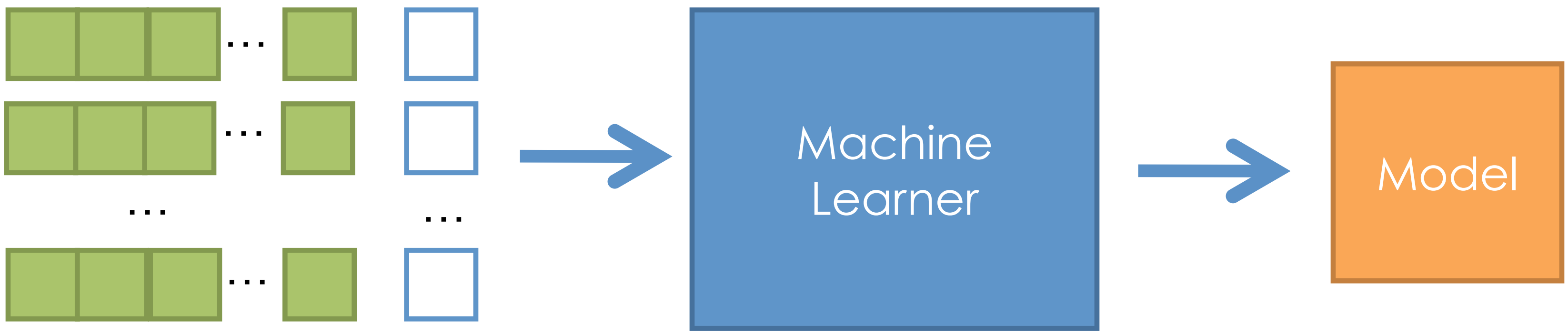
Information from compiler	
#Processing units	#communication channels
Pipeline depth	Data parallel section width
Load balance	Computation-communication ratio
…	…

Predictive Modelling

- Use a machine learning model to predict characteristics of the ideal structure

Build a Machine Learning

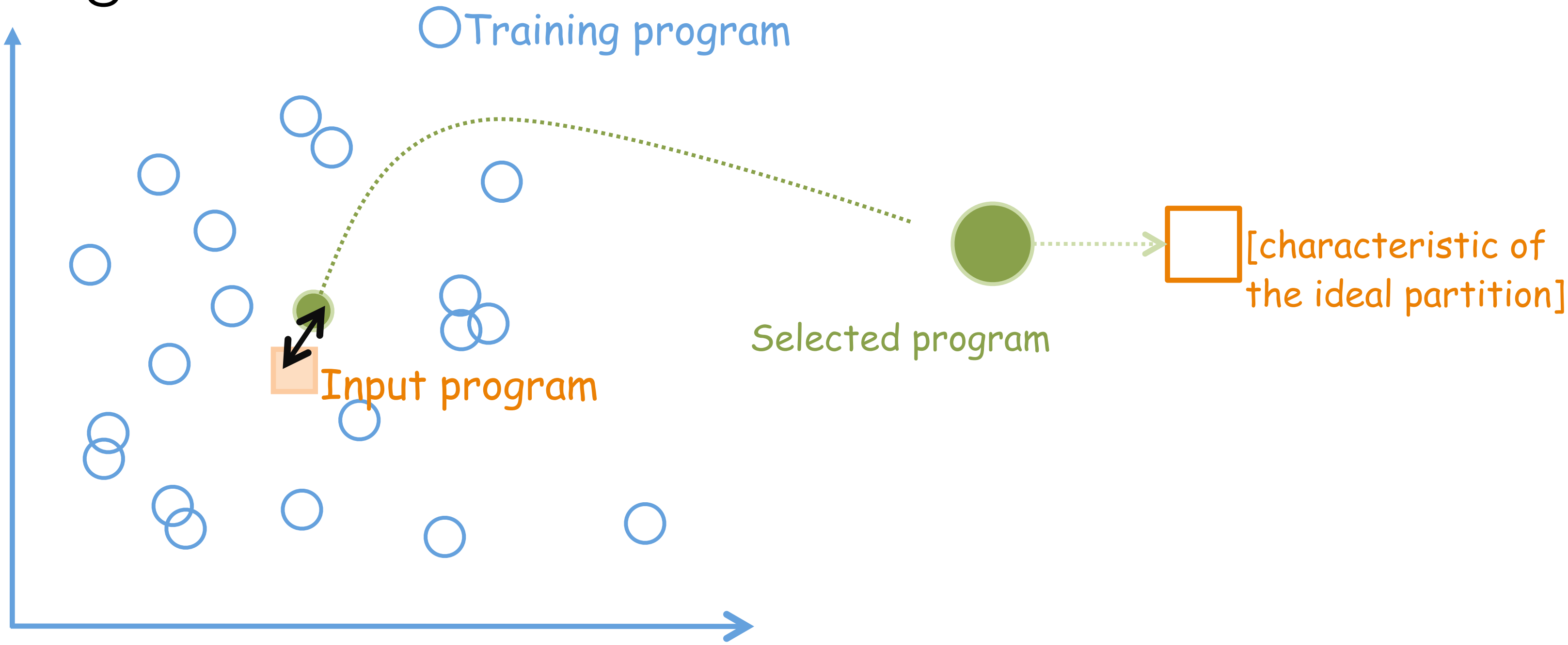
1. Determining the feature values of many training programs
2. Try different partitions and find the best for each
3. Give the training examples to a machine learner to learn a model



Training Examples

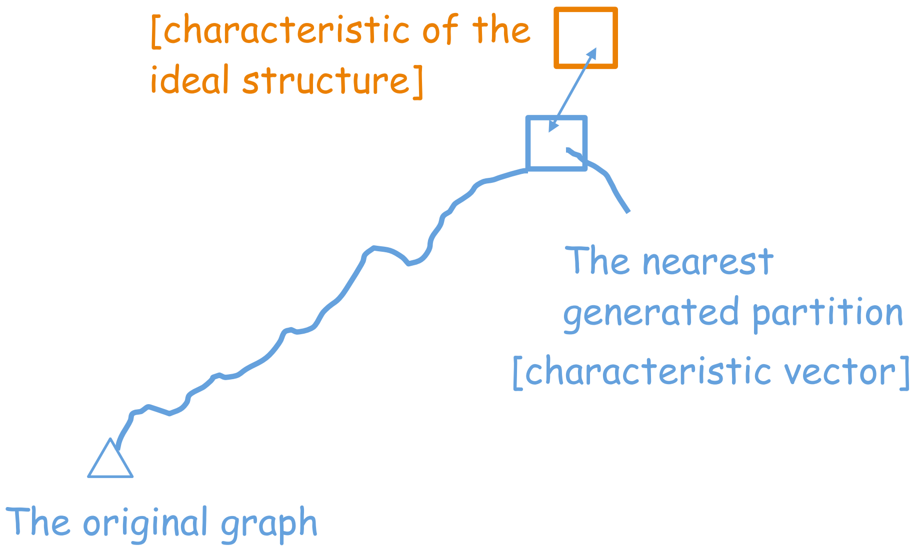
Use the Model: Step 1

- Nearest neighbour algorithm chooses a training program that is the most similar to the input program

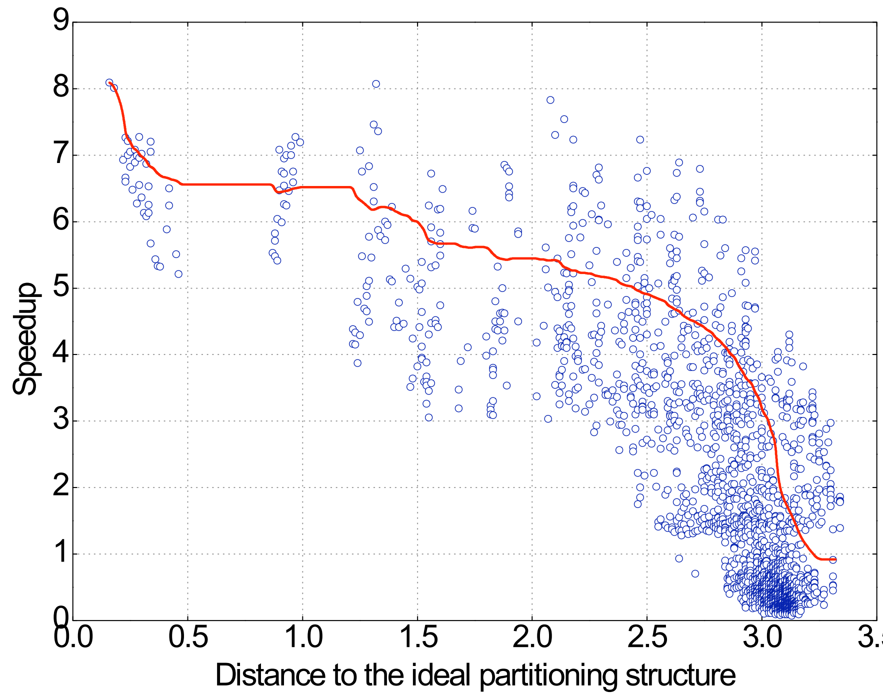


Use the Model: Step 2

- Select a randomly generated partition whose structure is the most close to the predicted one



* We do not run the program!



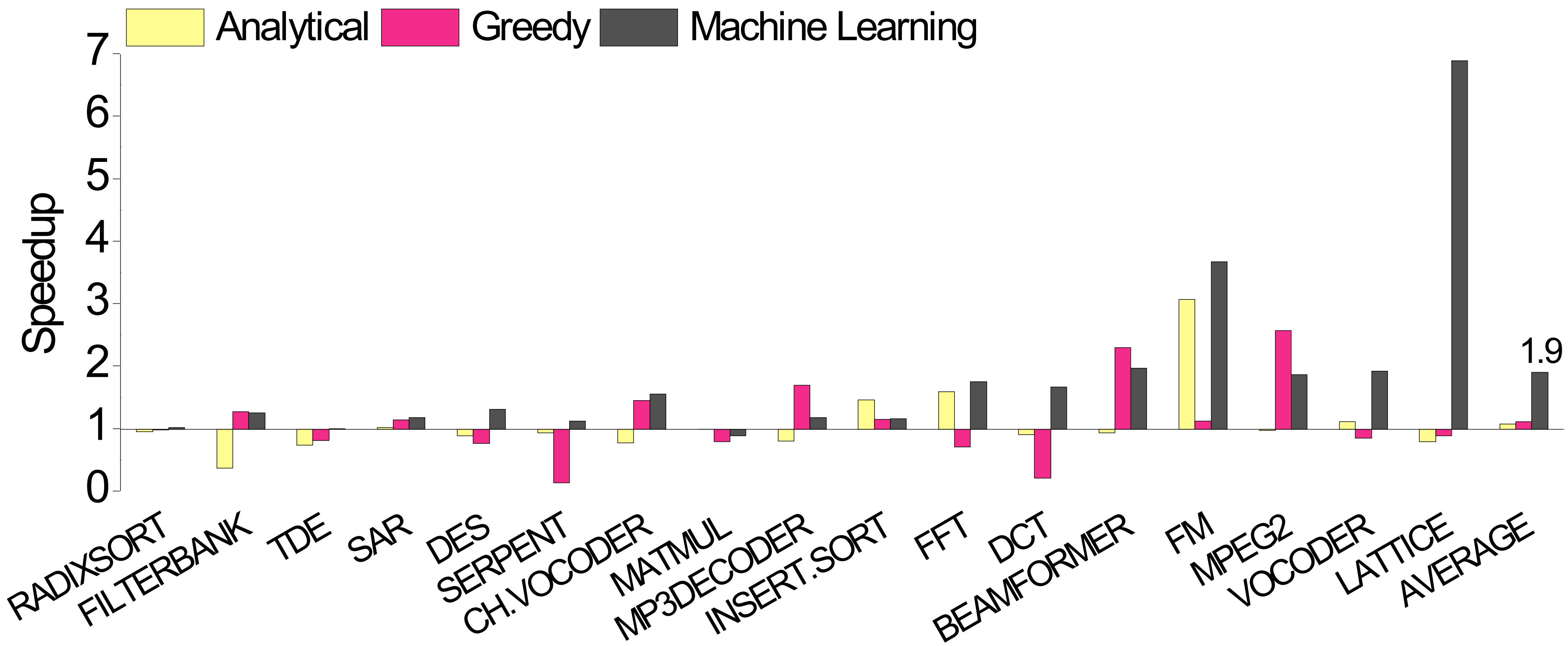
Distance is measured by calculating the Euclidean distance of 2 characteristic vectors

Experimental Setup

- Platforms
  - 2 x Dual Intel Xeon 5160 processors
    (4 cores in total)
  - 2 x Quad Intel Xeon 5450 processors
    (8 cores in total)
- Compilers:
  - StreamIt version 2.1.1
- Benchmarks:
  - 17 StreamIt applications

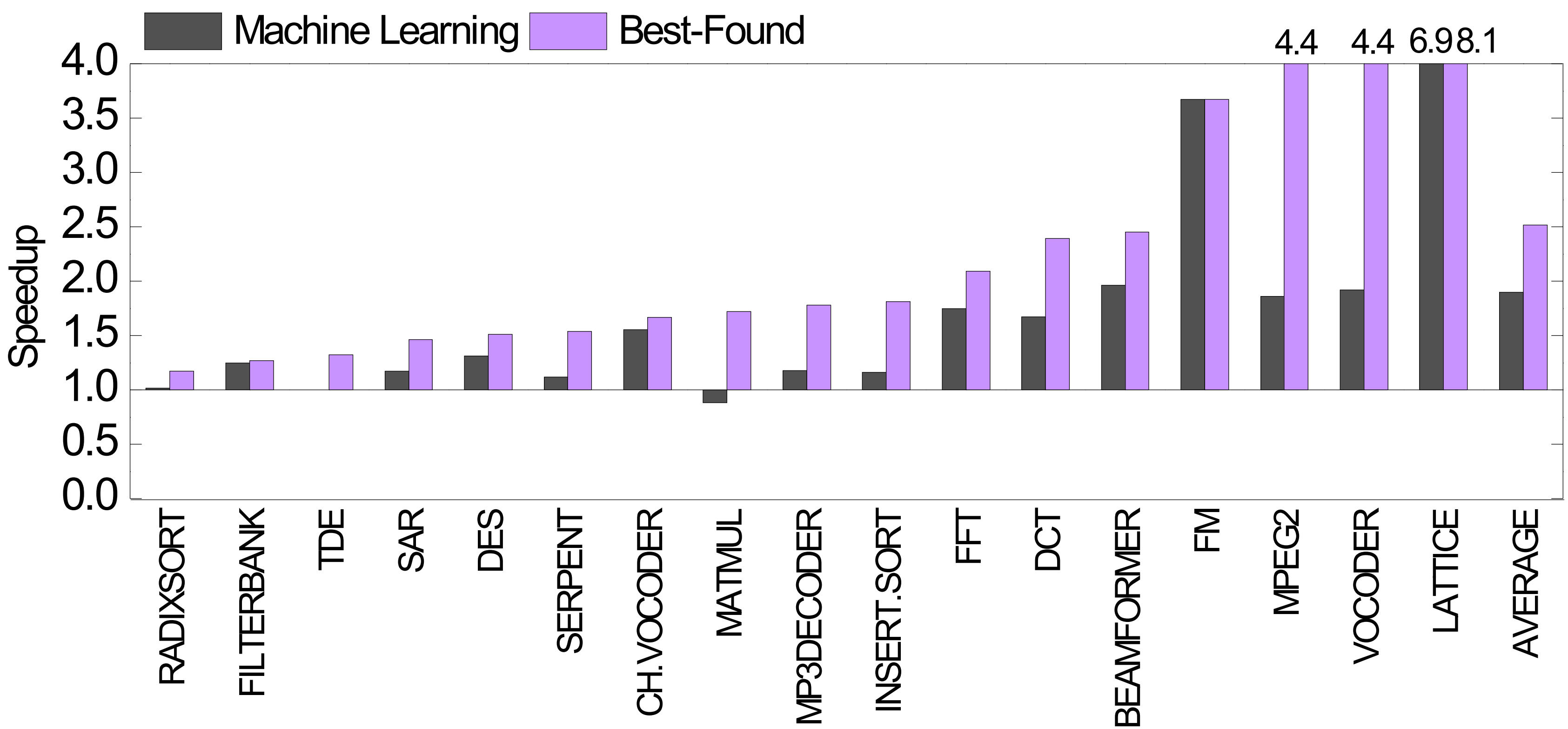
- Comparison:
  - 2 StreamIt compiler built-in partitioners
  - An analytical-based model (*Navarro et al., PACT 2009*)
  - Baseline: StreamIt dynamic programming-based partitioner

1.9x Improvement over State-of-Art (4-core)



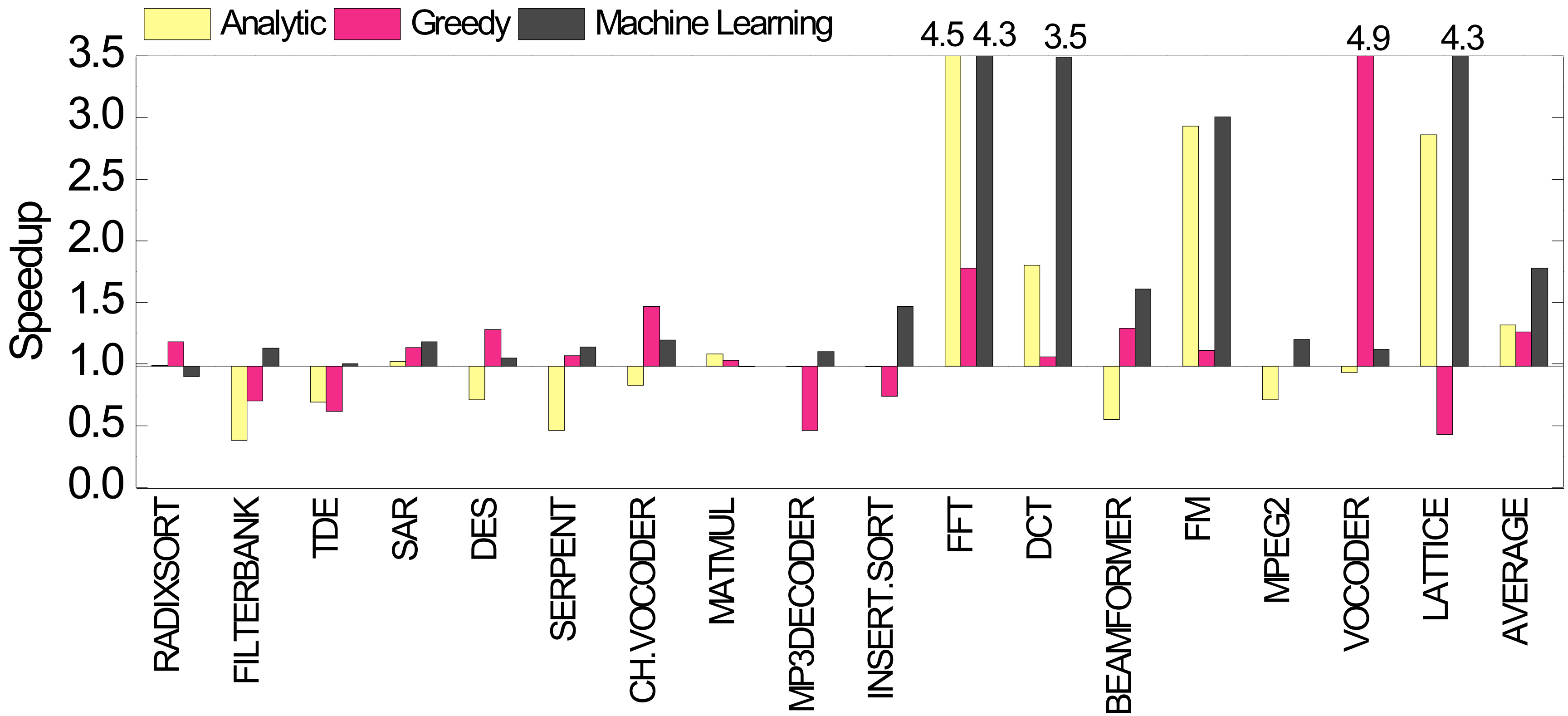
StreamIt

Compare with the Best-found Performance (4-Core)



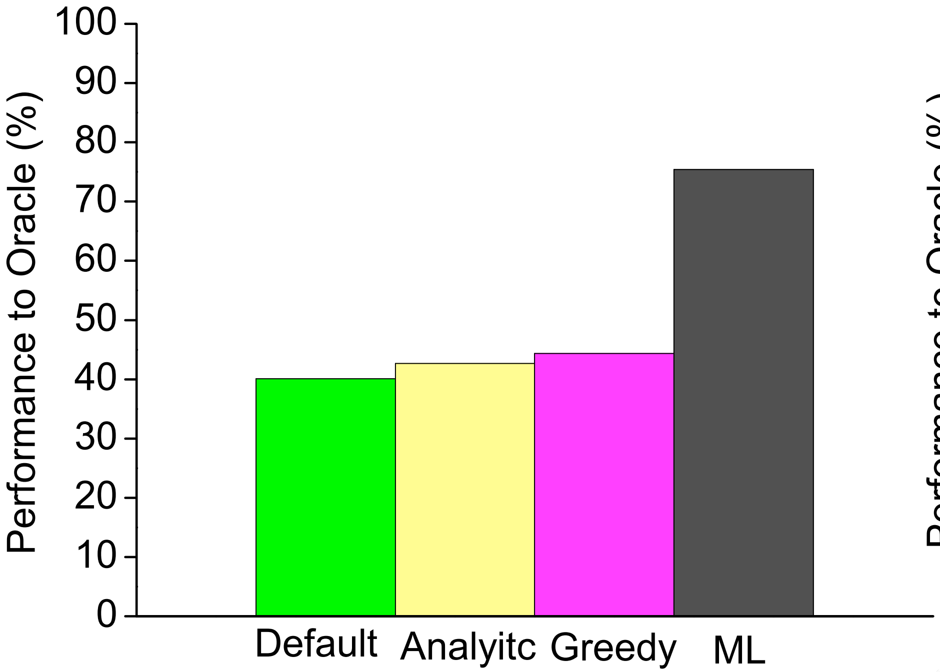
1.8x Improvement over State-of-Art (8-Core)

*Baseline: StreamIt compiler default strategy

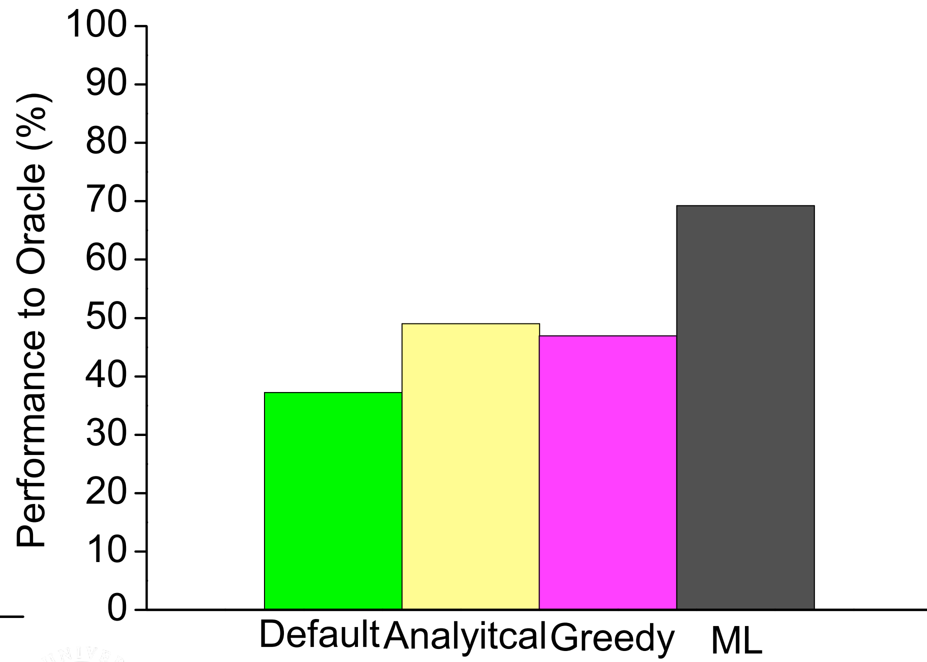


Comparison to 'Oracle' (Best) Performance

- Similar performance on the two platforms
- ML significantly outperforms others



(4-Core)



(8-Core)

Conclusion

- Mapping is a crux issue
- Depends on how parallelism and tasks represented
- Looked at StreamIT
- Smart heuristics vulnerable to change
  - ml can help
- Wide open research area
- Large research interest at ICSA Edinburgh