# StreamIt: High-Level Stream Programming on Raw

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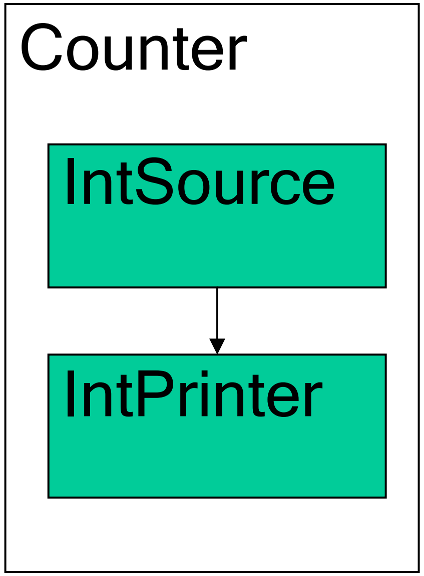
# The StreamIt Language

- Why use the StreamIt compiler?
  - Automatic partitioning and load balancing
  - Automatic layout
  - Automatic switch code generation
  - Automatic buffer management
  - Aggressive domain-specific optimizations
- All with a simple, high-level syntax!
  - Language is architecture-independent

# A Simple Counter

```
void->void pipeline Counter() {
    add IntSource();
    add IntPrinter();
}
void->int filter IntSource() {
    int x;
    init { x = 0; }
    work push 1 { push (x++); }
}
int->void filter IntPrinter() {
    work pop 1 { print(pop()); }
}
```



# Demo

- Compile and run the program

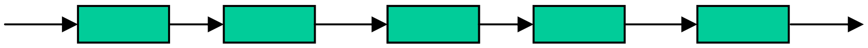
```
counter % knit --raw 4 Counter.str
counter % make -f Makefile.streamit run
```

- Inspect graphs of program

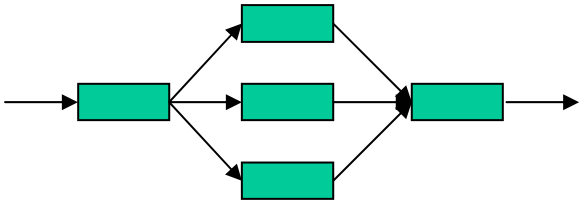
```
counter % dotty schedule.dot
counter % dotty layout.dot
```

# Representing Streams

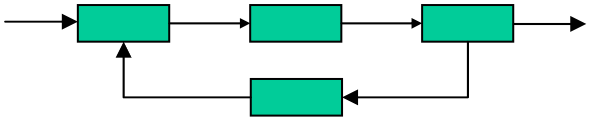
- Hierarchical structures:
  - Pipeline



  - SplitJoin



  - Feedback Loop



- Basic programmable unit:  Filter

# Representing Filters

- Autonomous unit of computation

  - No access to global resources
  - Communicates through FIFO channels
    - pop()   - peek(index)   - push(value)
  - Peek / pop / push rates must be constant
- Looks like a Java class, with
  - An initialization function
  - A steady-state “work” function

# Filter Example:  LowPassFilter

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

   init {
      weights = calcWeights(N);
   }

   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();
   }
}
```

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  init {
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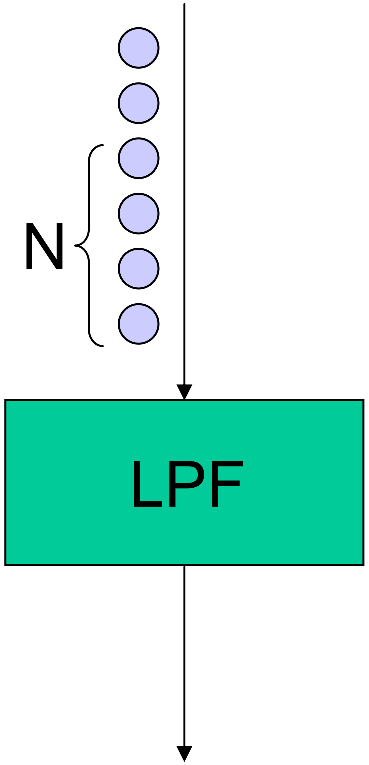
      result += weights[i] * peek(i);
    }
    push(result);
    pop();
  }
}
```



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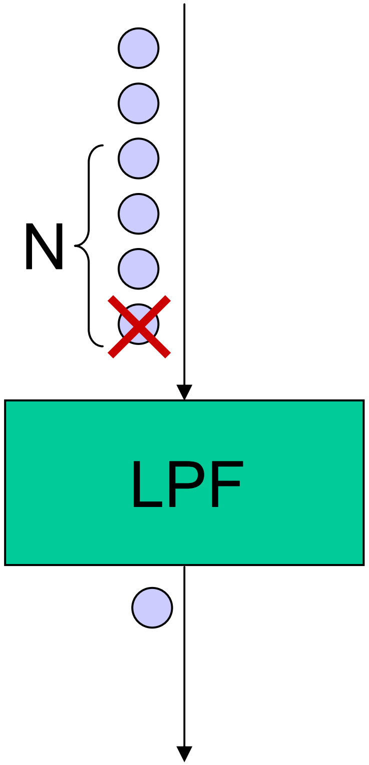
      }
      push(result);
      pop();
   }
}
```



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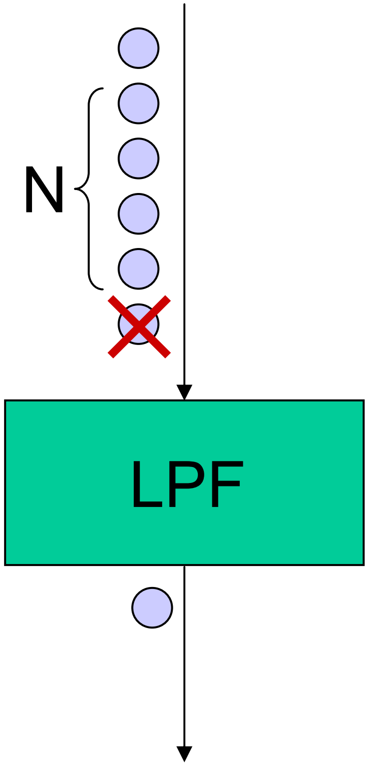
    }
    push(result);
    pop();
  }
}
```



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    float result = 0;
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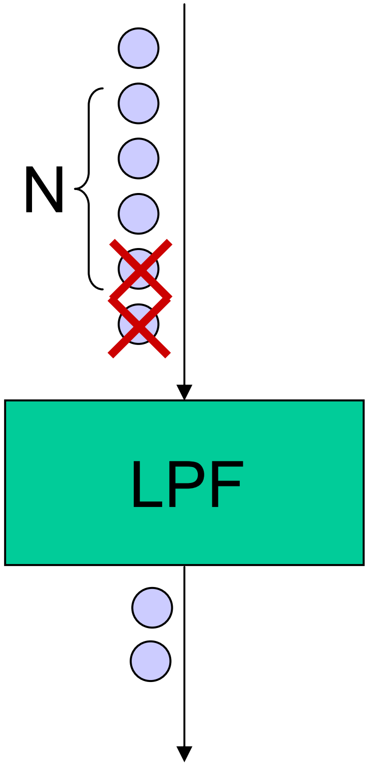
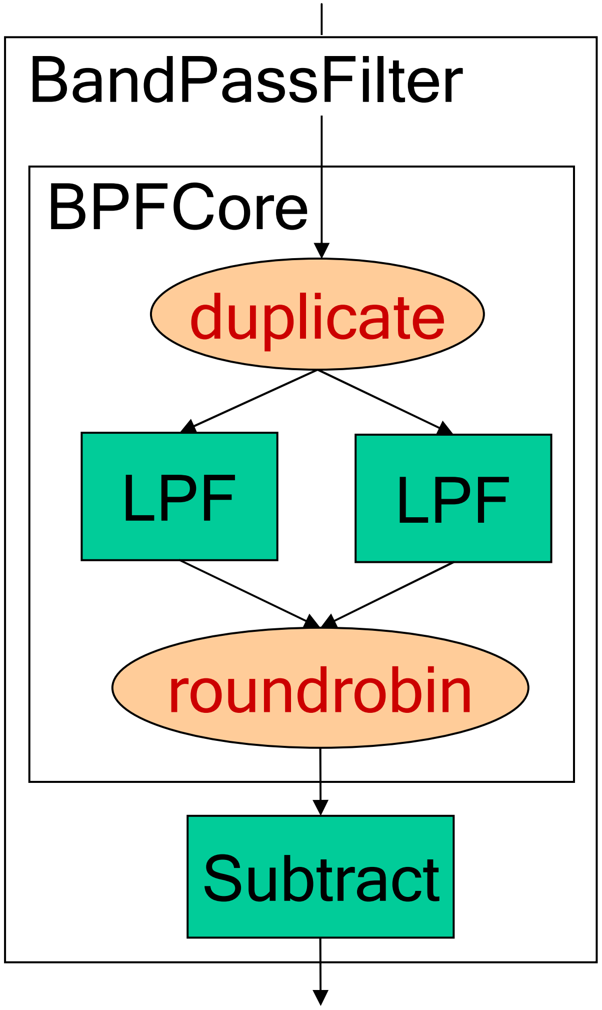
      result += weights[i] * peek(i);
    }
    push(result);
    pop();
  }
}
```



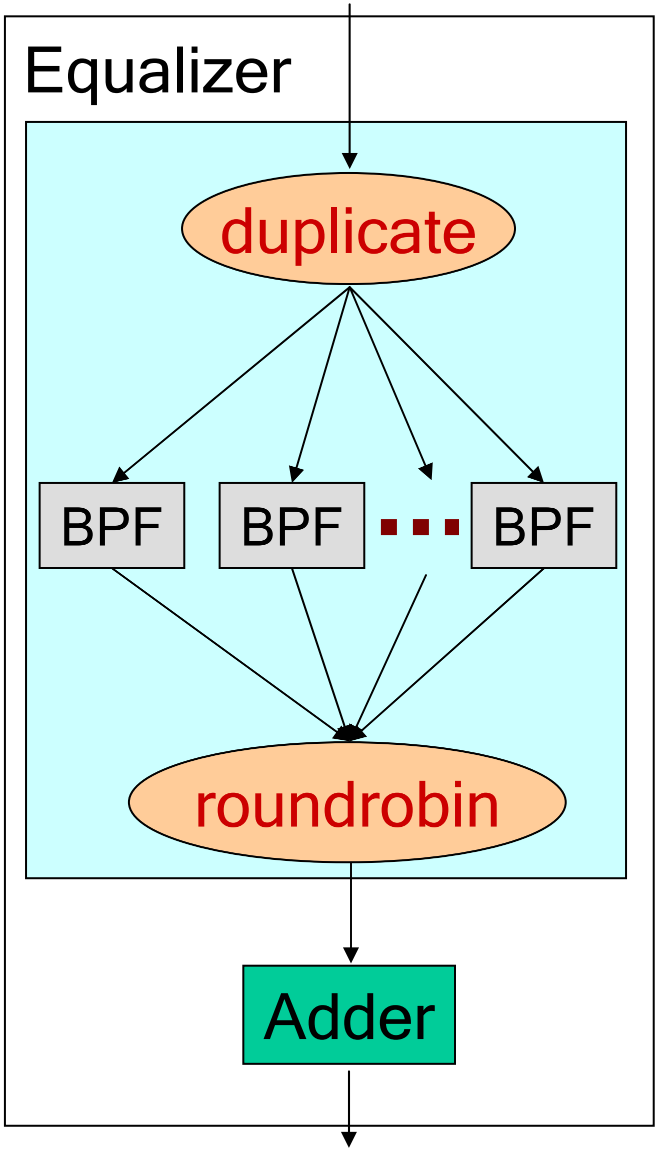
# SplitJoin Example:  BandPass Filter

```
float->float pipeline BandPassFilter(float low, float high) {
  add BPFCore(low, high);
  add Subtract();
}
float->float splitjoin BPFCore(float low, float high) {
  split duplicate;
  add LowPassFilter(high);
  add LowPassFilter(low);
  join roundrobin;
}
float->float filter Subtract {
  work pop 2 push 1 {
    float val1 = pop();
    float val2 = pop();
    push(val1 – val2);
  }
}
```



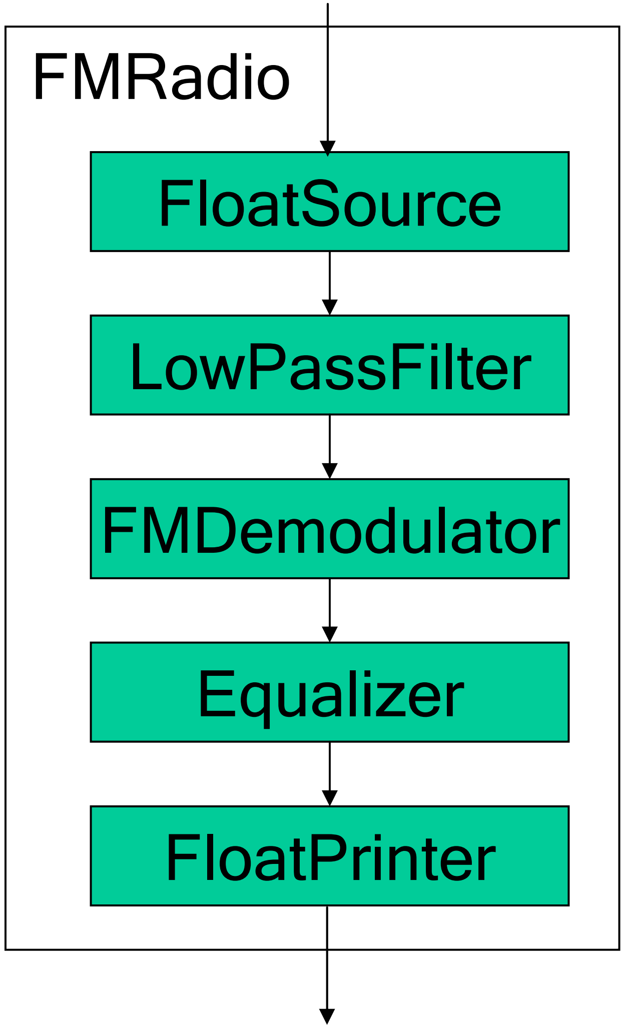
# Parameterization:  Equalizer

```
float->float pipeline Equalizer (int N) {
  add splitjoin {
    split duplicate;
    float freq = 10000;
    for (int i = 0; i < N; i ++, freq*=2) {
      add BandPassFilter(freq, 2*freq);
    }
    join roundrobin;
  }
  add Adder(N);
}
```



# FM Radio

```
float->float pipeline FMRadio {
    add FloatSource();
    add LowPassFilter();
    add FMDemodulator();
    add Equalizer(8);
    add FloatPrinter();
}
```



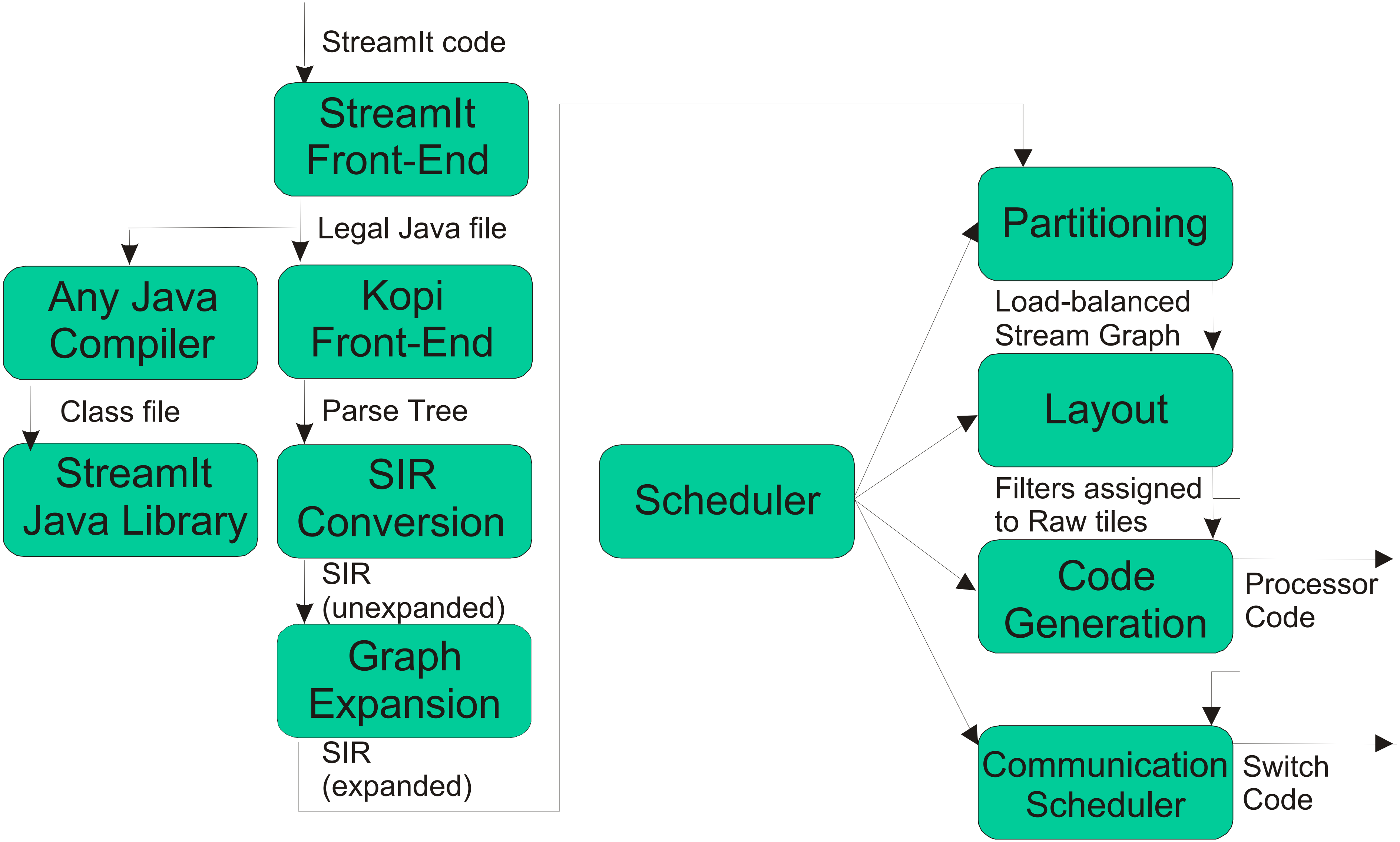
# Demo:  Compile and Run

```
fm % knit --raw 4 --partition --numbers 10 FMRadio.str
fm % make -f Makefile.streamit run
```

Options used:

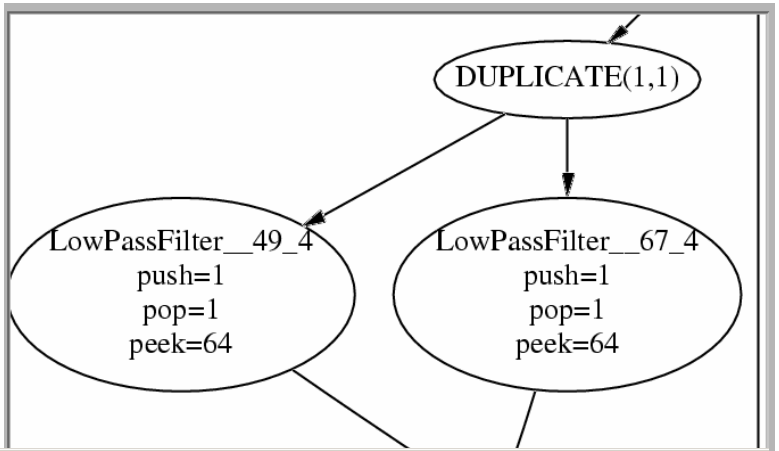
| | |
|---|---|
| --raw 4 | target 4x4 raw machine |
| --partition | use automatic greedy partitioning |
| --numbers 10 | gather numbers for 10 iterations, and store in results.out |

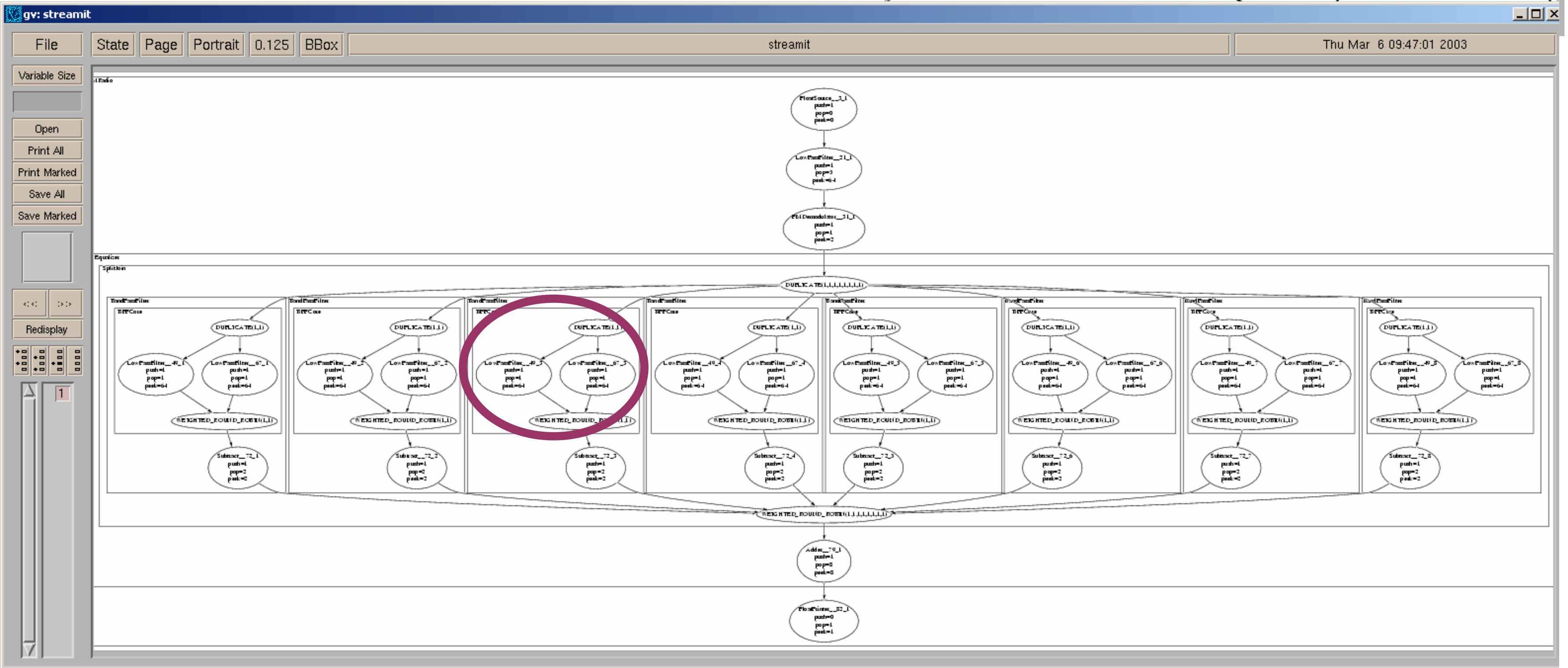
# Compiler Flow Summary



# Stream Graph Before Partitioning

```
fm % dotty before.dot
```





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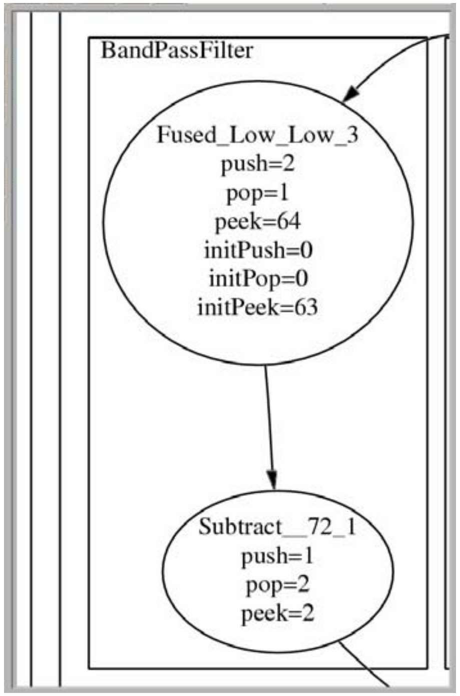
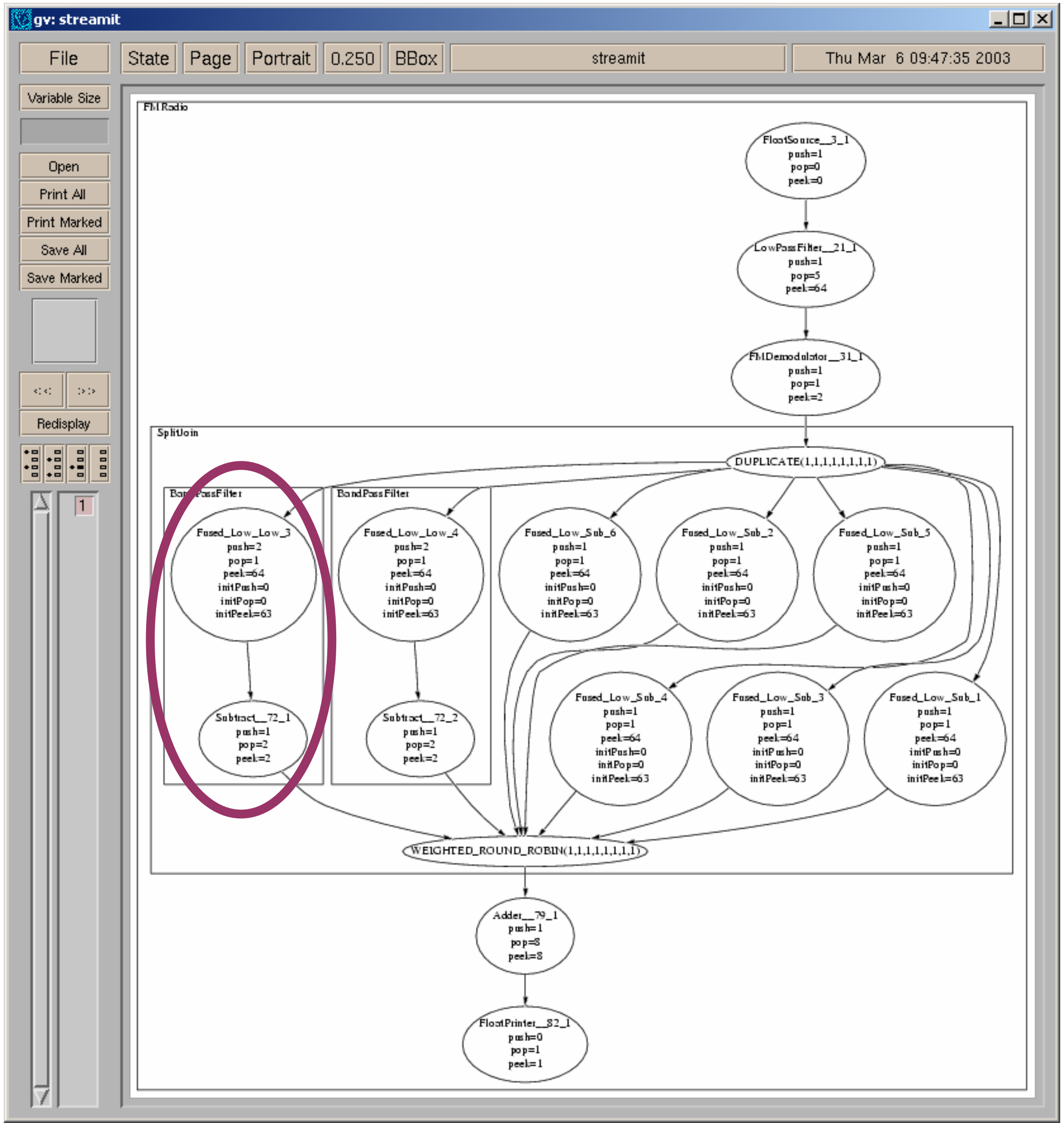
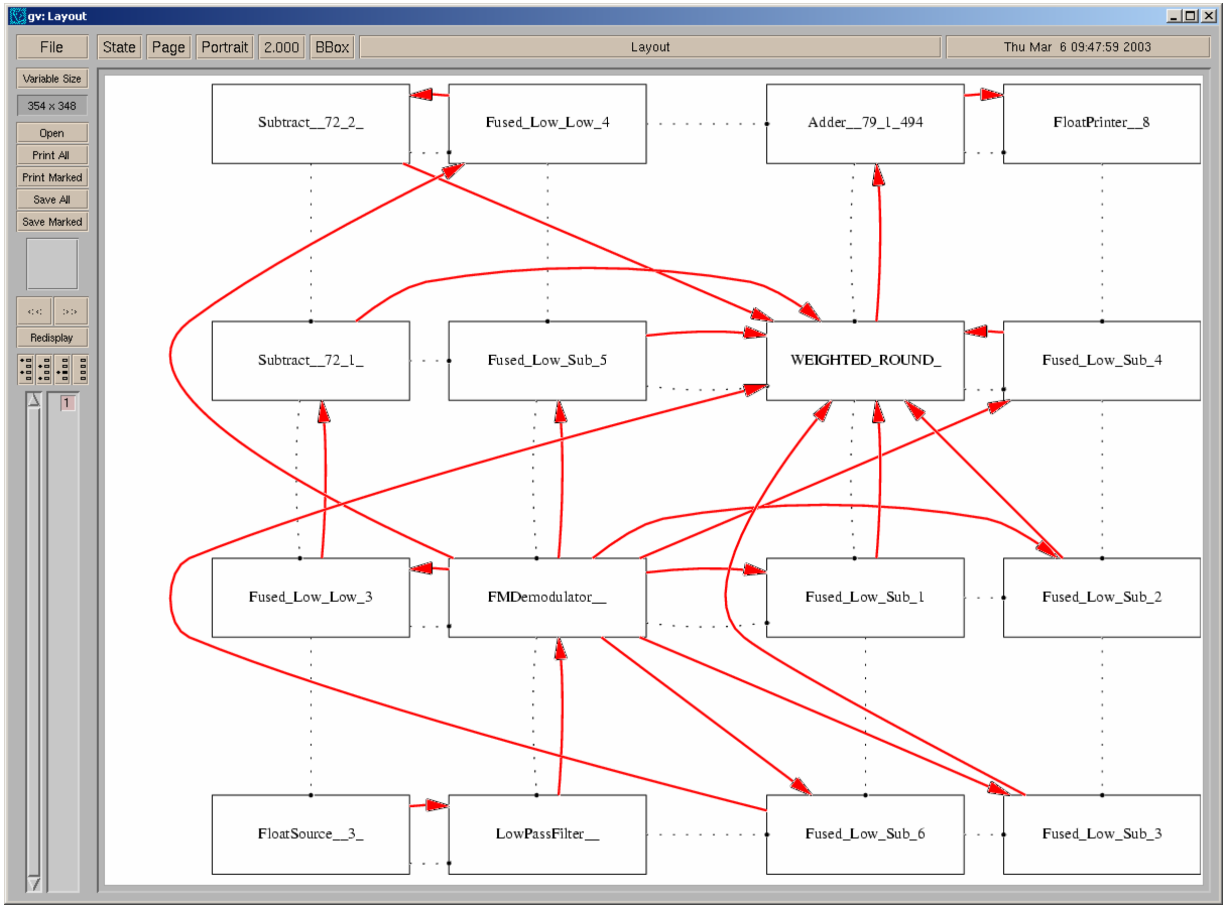




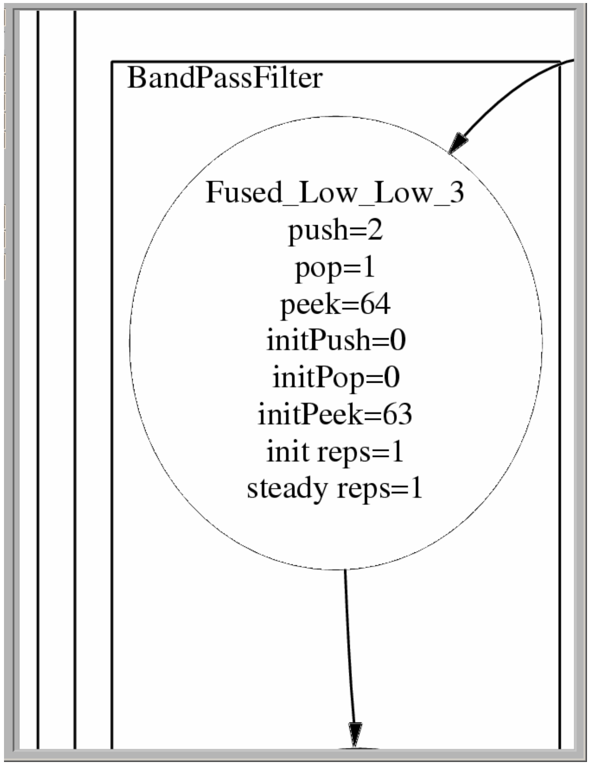
# Layout on Raw

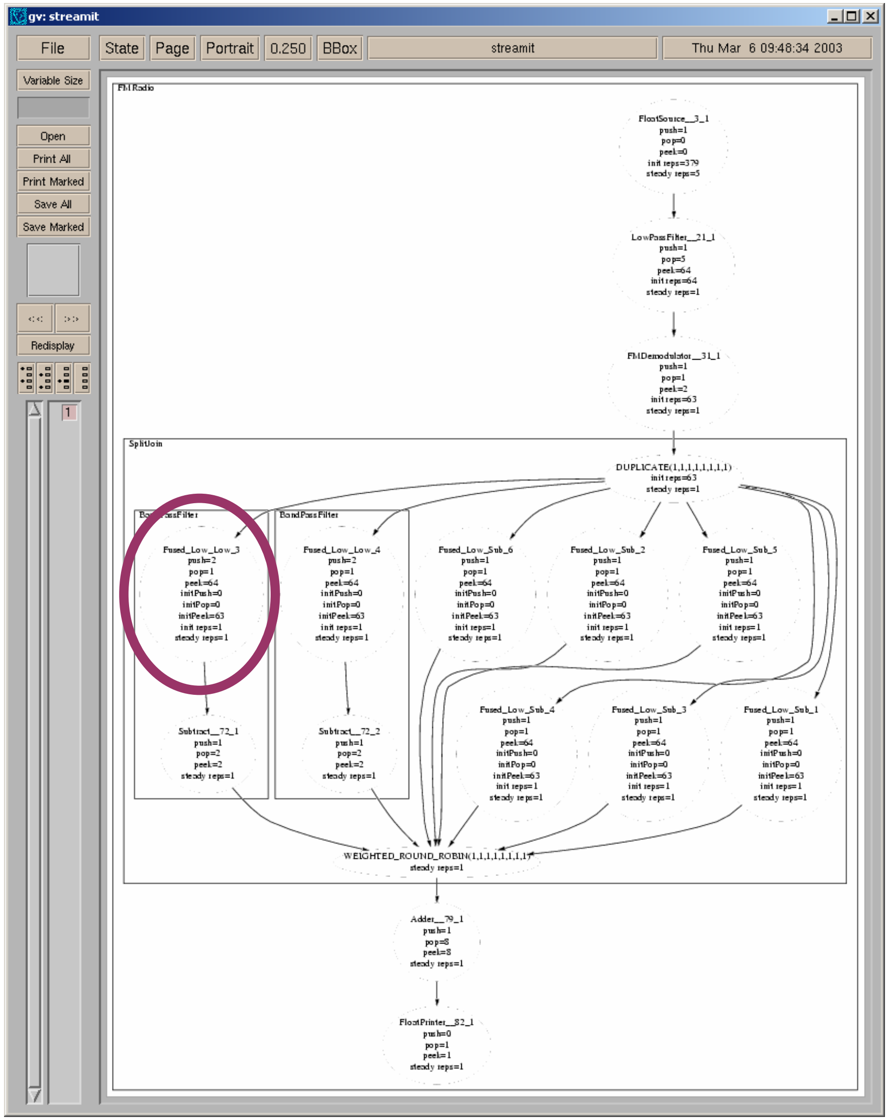
```
fm % dotty layout.dot
```



# Initial and Steady-State Schedule

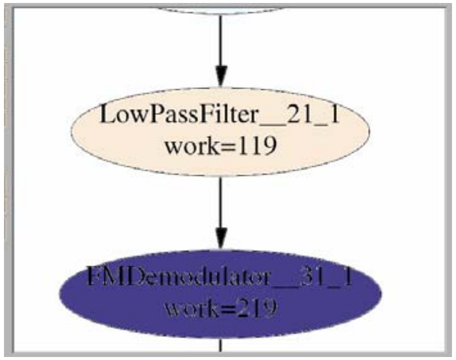
```
fm % dotty schedule.dot
```

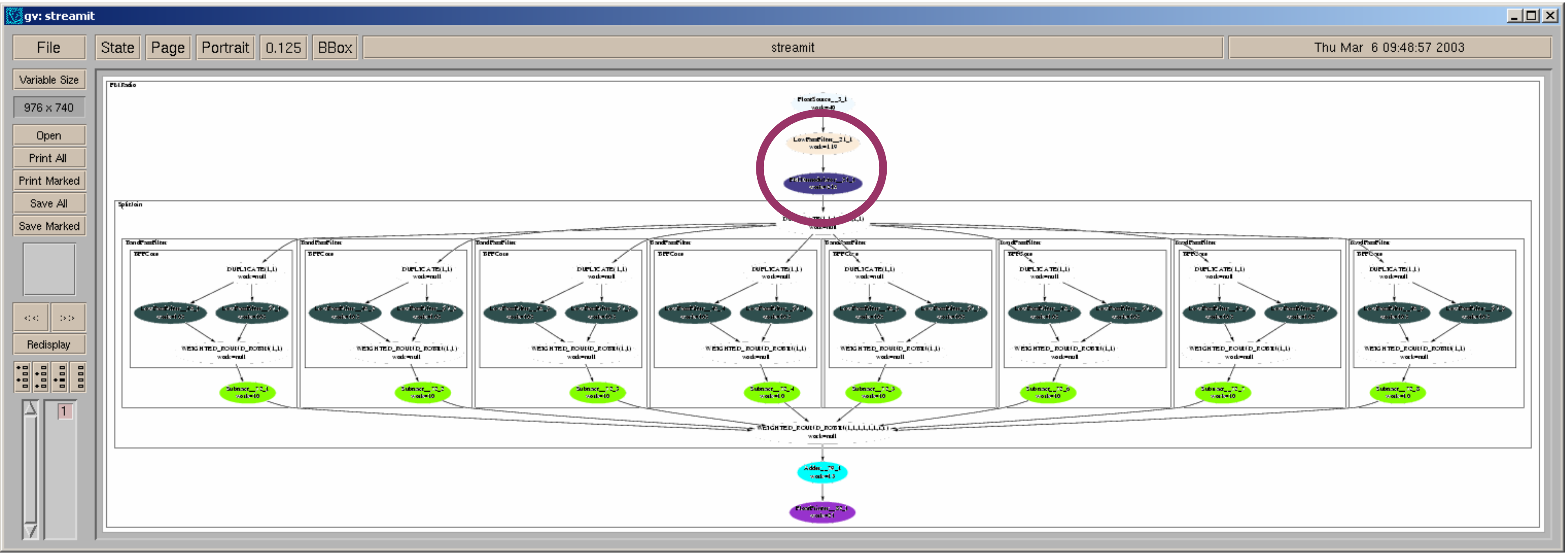




# Work Estimates (Graph)

```
fm % dotty work-before.dot
```





# Work Estimates (Table)

```
fm % cat work-before.txt
Filter               Reps  Measured Work  Estimated Work  (Measured-Estimated)/Measured  Total Measured Work
FMDemodulator__31       1            219             219                              0                  219
LowPassFilter__21       1            119             119                              0                  119
LowPassFilter__49       1            103             103                              0                  103
LowPassFilter__49       1            103             103                              0                  103
LowPassFilter__67       1            103             103                              0                  103
LowPassFilter__49       1            103             103                              0                  103
LowPassFilter__49       1            103             103                              0                  103
LowPassFilter__49       1            103             103                              0                  103
LowPassFilter__49       1            103             103                              0                  103
LowPassFilter__67       1            103             103                              0                  103
LowPassFilter__67       1            103             103                              0                  103
LowPassFilter__67       1            103             103                              0                  103
LowPassFilter__49       1            103             103                              0                  103
LowPassFilter__67       1            103             103                              0                  103
LowPassFilter__49       1            103             103                              0                  103
LowPassFilter__67       1            103             103                              0                  103
LowPassFilter__67       1            103             103                              0                  103
LowPassFilter__67       1            103             103                              0                  103
FloatSource__3          5              8               8                              0                   40
```

# Collected Results

```
fm % cat results.out

 Performance Results

 Tiles in configuration: 16
 Tiles assigned (to filters or joiners): 16
 Run for 10 steady state cycles.
 With 0 items skipped for init.
 With 1 items printed per steady state.

 cycles MFLOPS work_count
 --------------------------
 2153 350 19227
 2220 347 19731
 2229 310 18963
 2229 291 18512
```

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 -------------------------
 2153 350 19227
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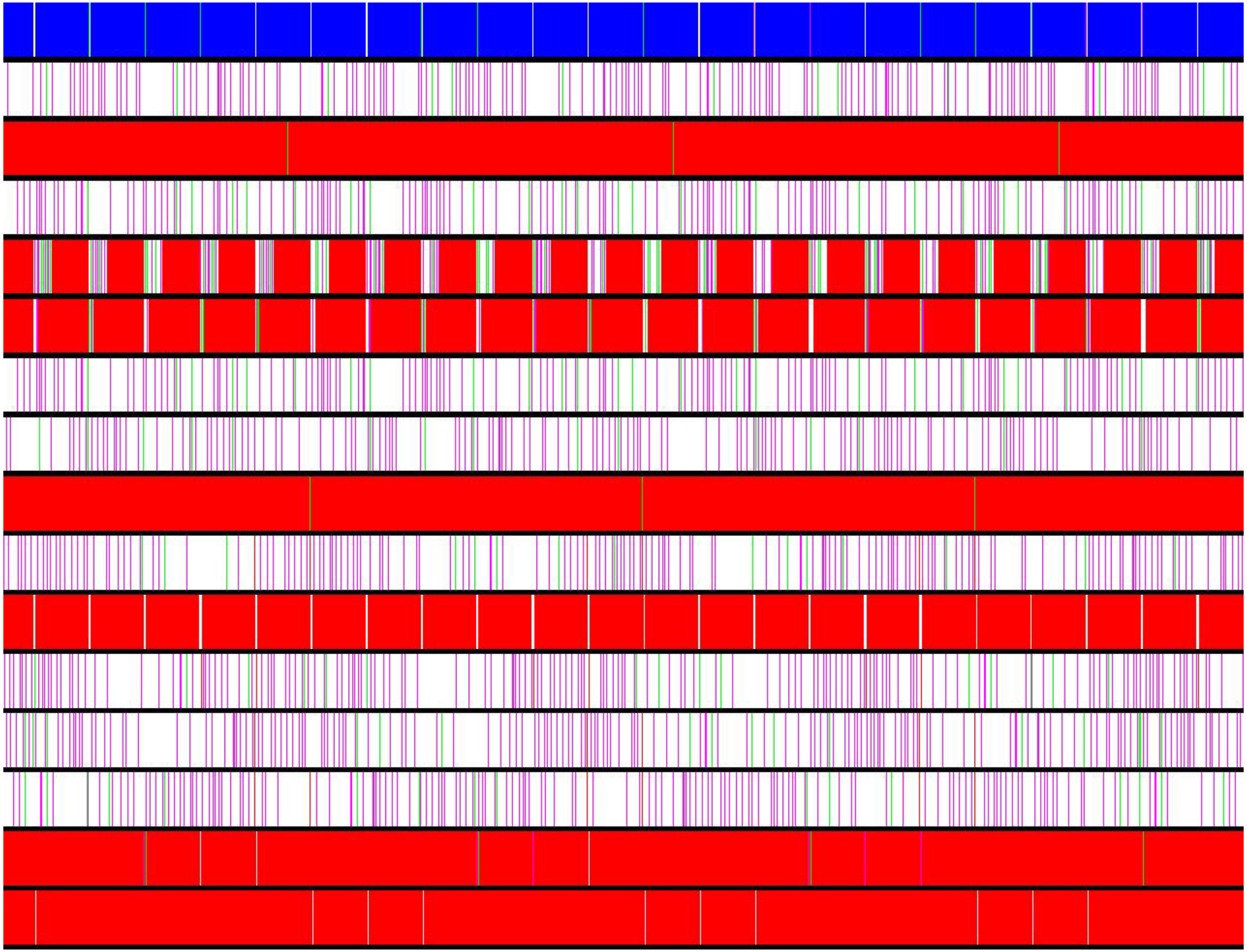
 2229 310 18963
 2229 291 18512
 2229 292 18537
 2229 293 18559
 2229 291 18513
 2229 292 18557
 2229 289 18510
 2229 291 18530

 Summmary:
 Steady State Executions: 10
 Total Cycles: 22205
 Avg Cycles per Steady-State: 2220
 Thruput per 10^5: 45
 Avg MFLOPS: 304
 workCount* = 187639 / 355280
```

# Understanding Performance



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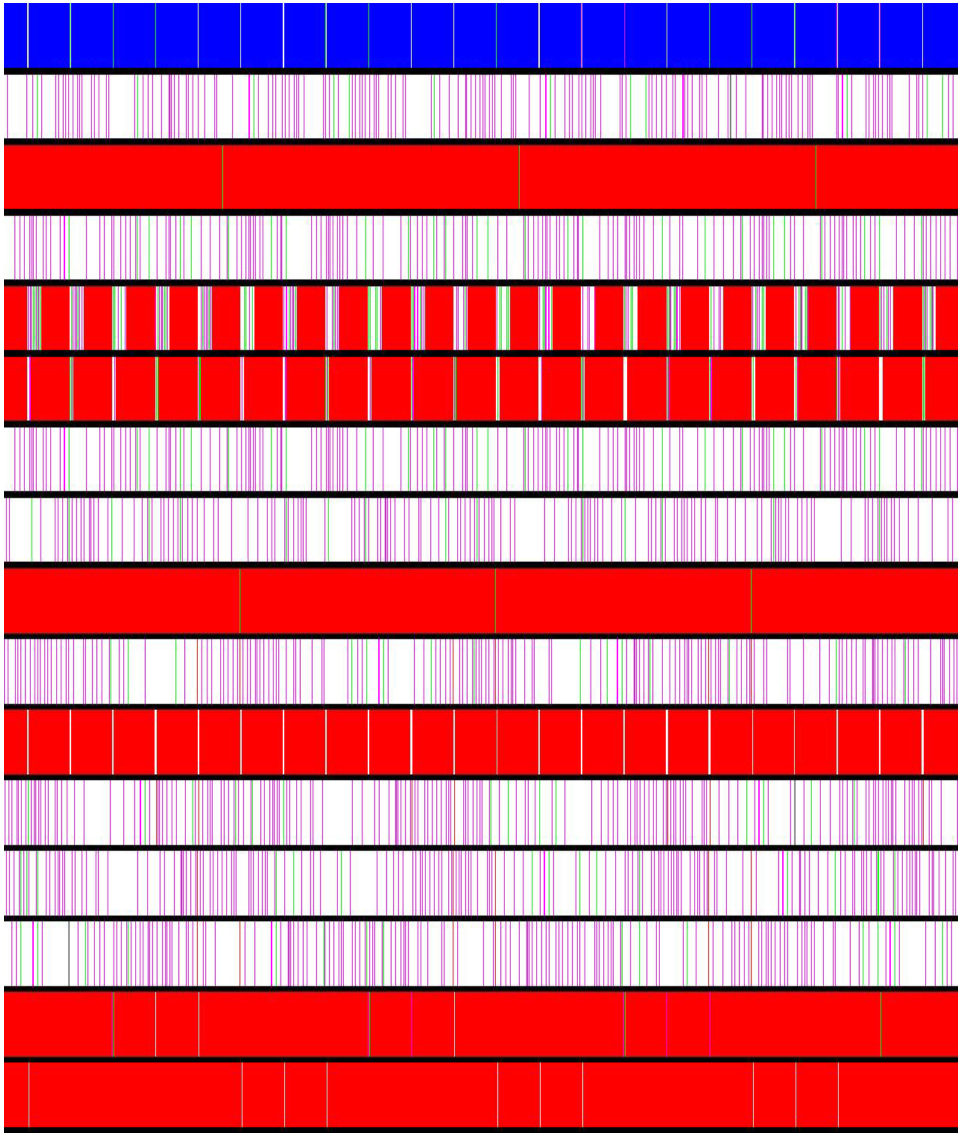
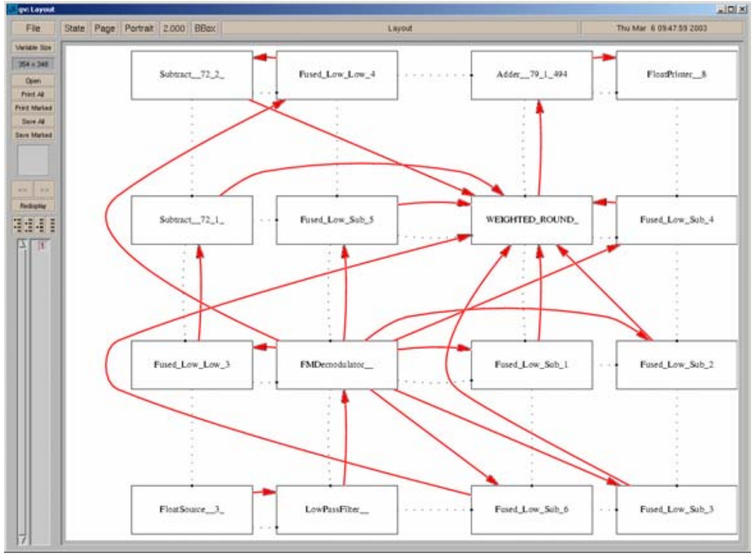
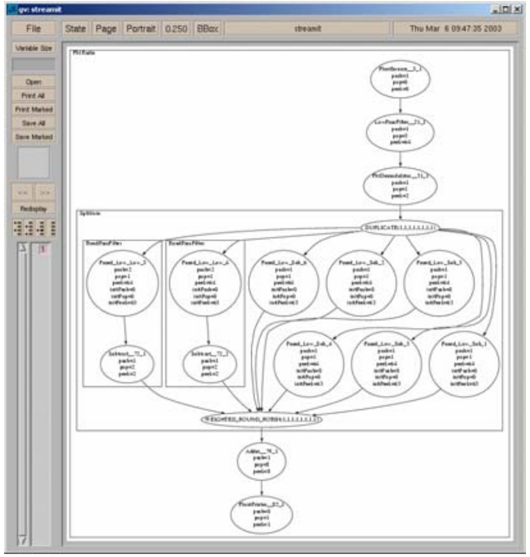






# Demo:  Linear Optimization

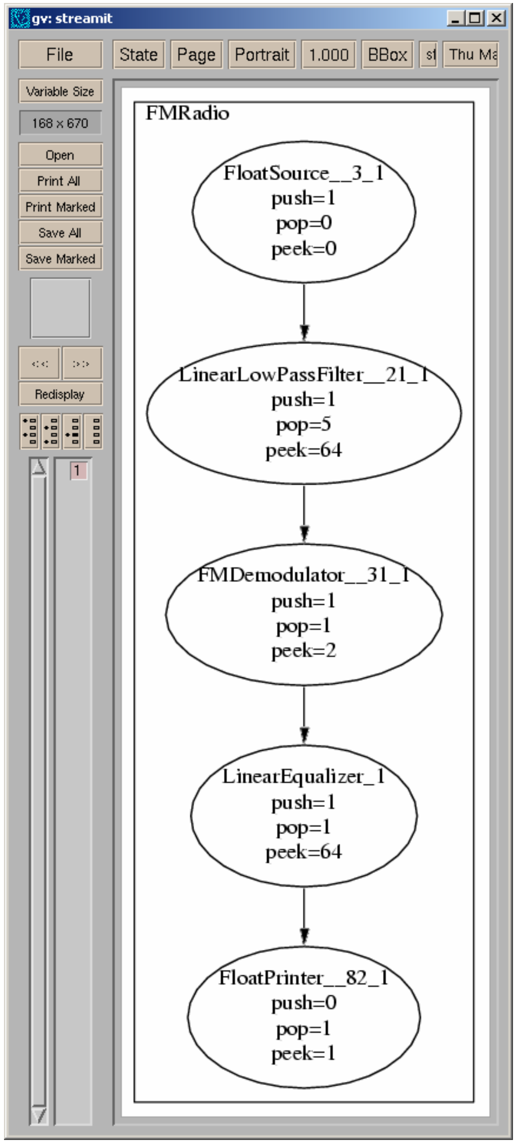
```
fm % knit --linearreplacement
          --raw 4 --numbers 10 FMRadio.str
fm % make -f Makefile.streamit run
```

New option:

--linearreplacement identifies filters which compute linear functions of their input, and replaces adjacent linear nodes with a single matrix-multiply

# Stream Graph Before Partitioning

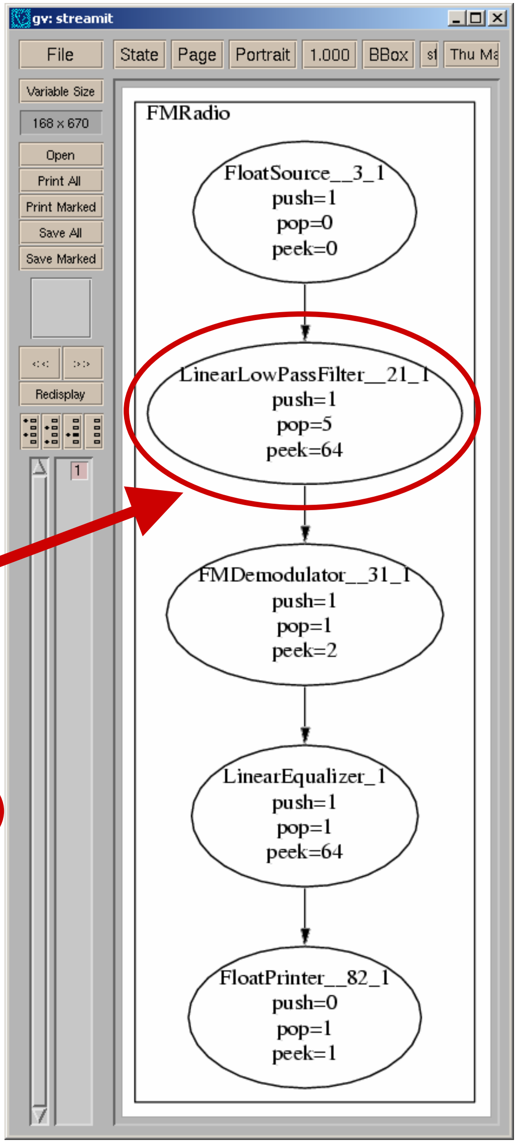
```
fm % dotty before.dot
```

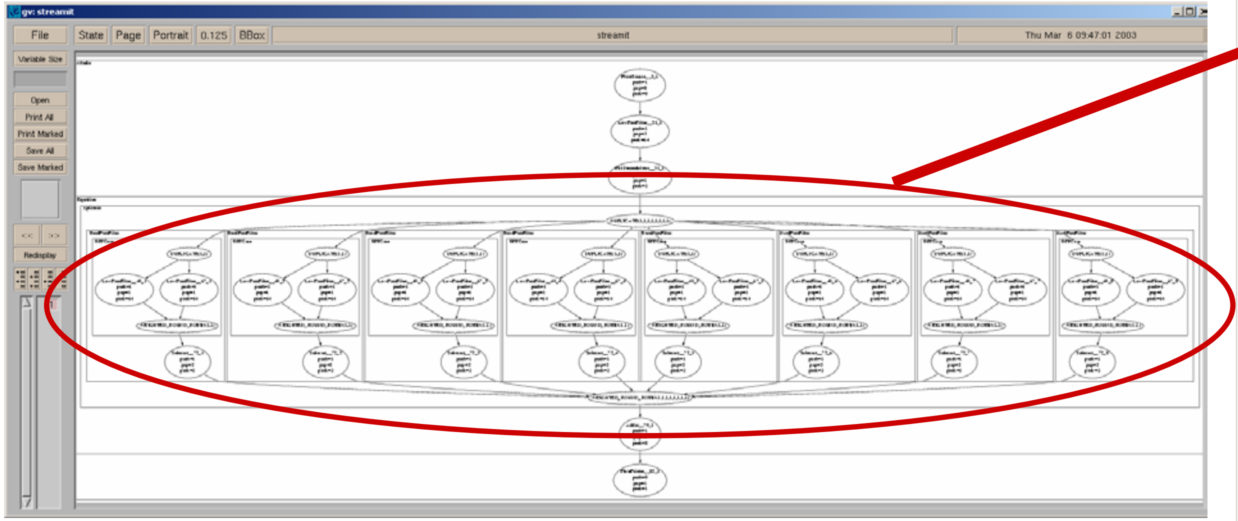


# Stream Graph Before Partitioning

```
fm % dotty before.dot
```

Entire Equalizer collapsed!





*without linear replacement*

# Results with Linear Optimization

```
fm % cat results.out
```

```
Summmary:
Steady State Executions: 10
Total Cycles: 7260
Avg Cycles per Steady-State: 726
Thruput per 10^5: 137
Avg MFLOPS: 128
workCount* = 15724 / 116160
```

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Speedup by factor of 3

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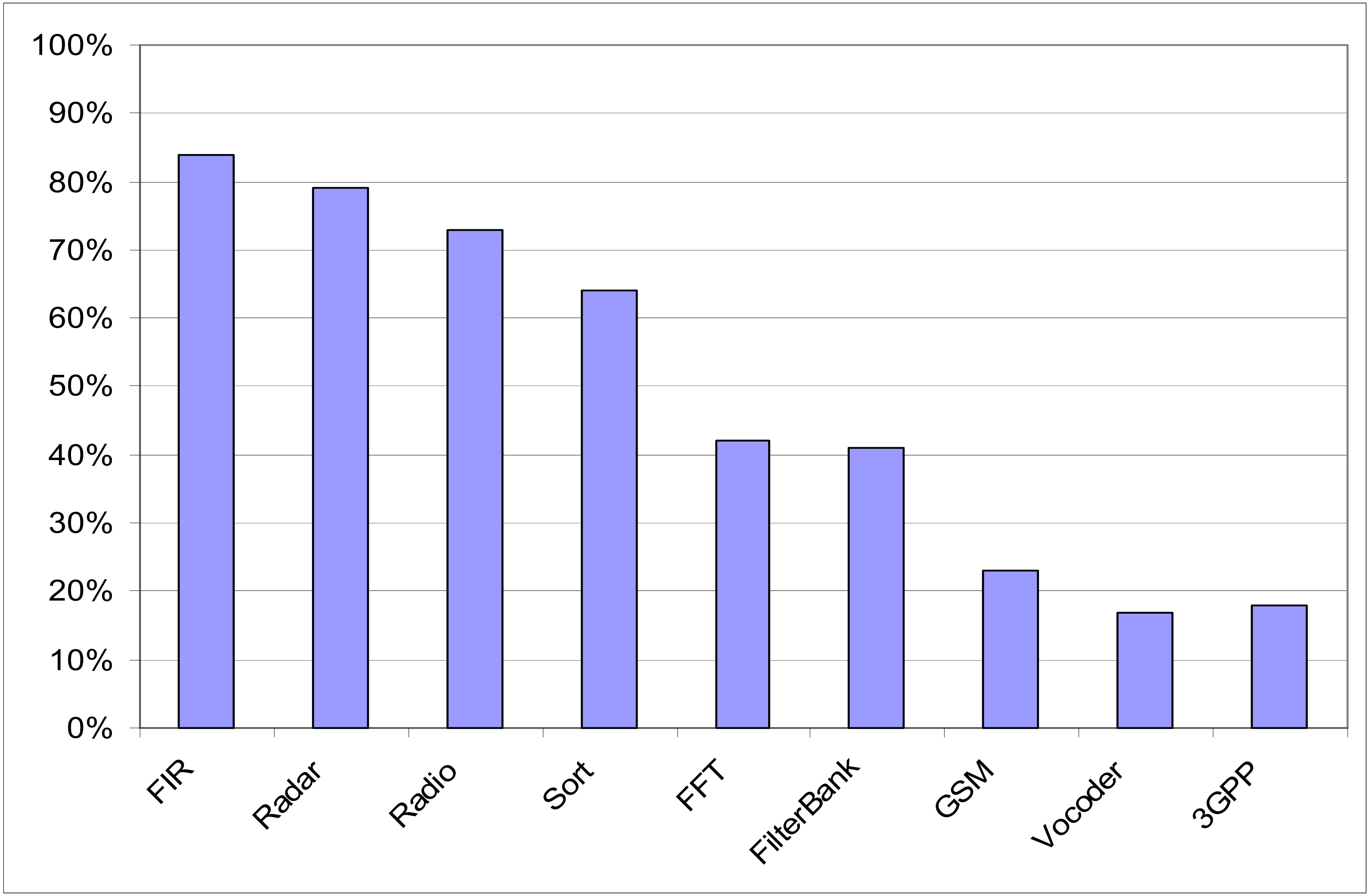
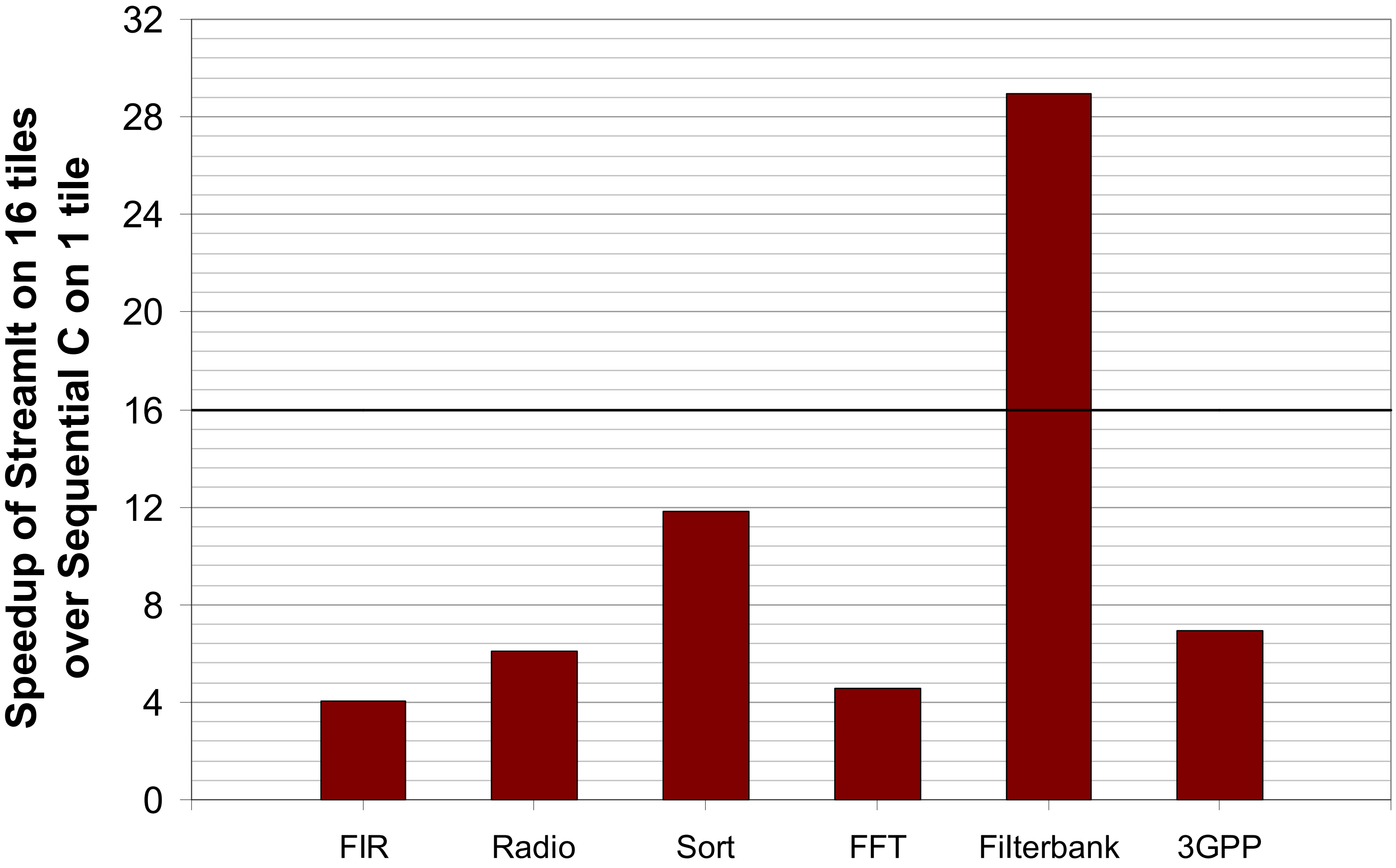
Speedup by factor of 3

Allows programmer to write simple, modular filters which compiler combines automatically

# Other Results: Processor Utilization



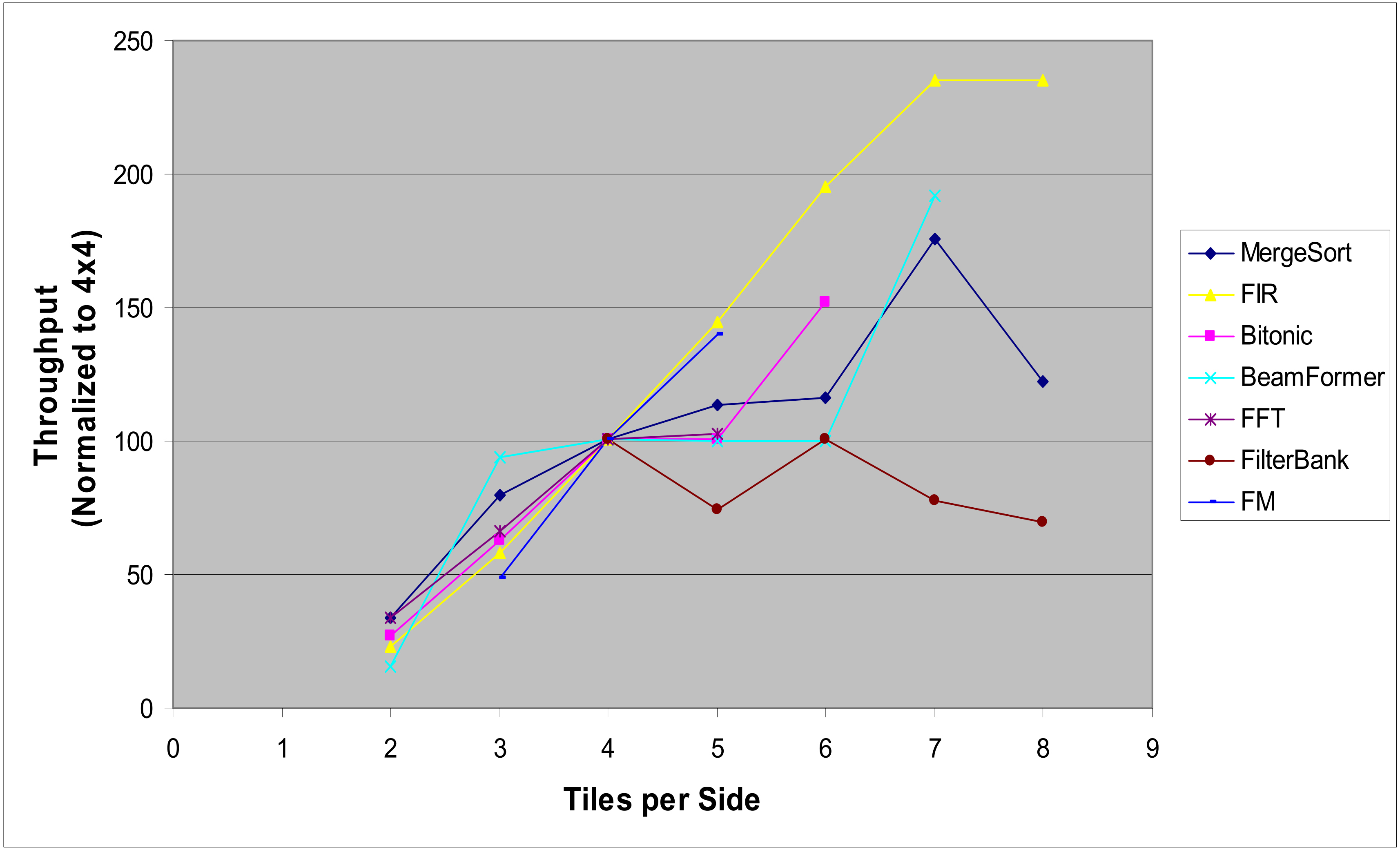
# Speedup Over Single Tile



-For Radio we obtained the C implementation from a 3rd party

-For FIR, Sort, FFT, Filterbank, and 3GPP we wrote the C implementation following a reference algorithm.

# Scaling of Throughput



# Compiler Status

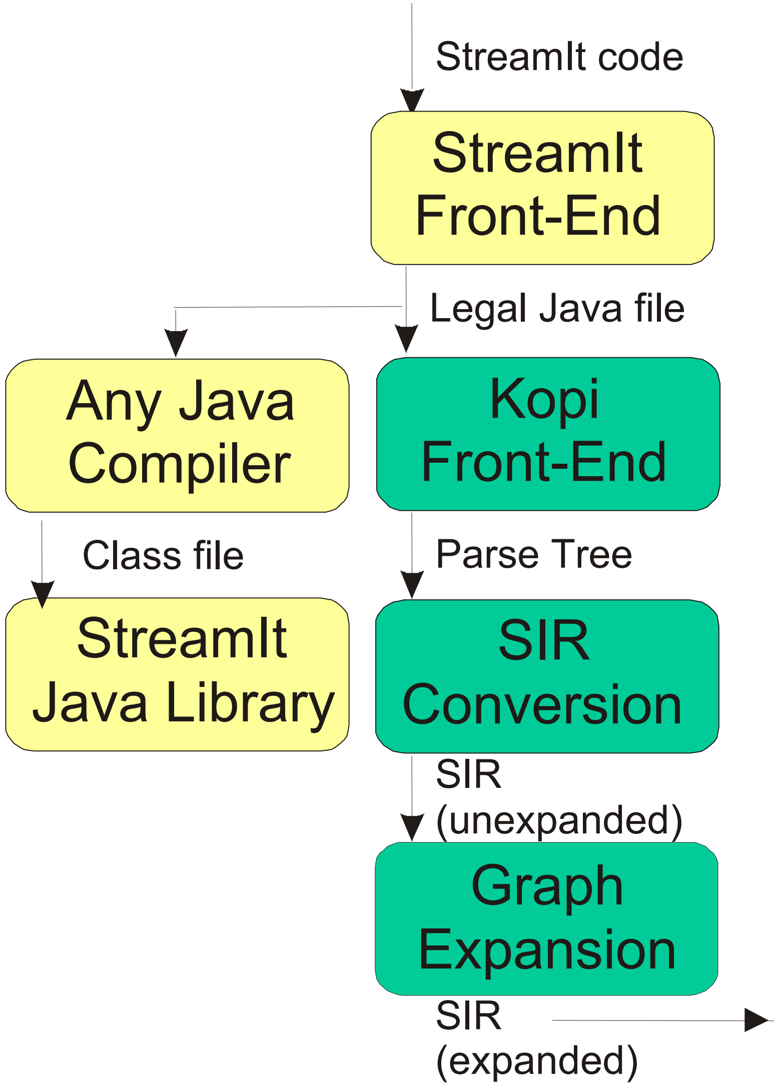
- Raw backend has been working for more than a year
  - Robust partitioning, layout, and scheduling
  - Still working on improvements:
    - Dynamic programming partitioner
    - Optimized scheduling, routing, code generation
- Frontend is relatively new
  - Semantic checker still in progress
  - Some malformed inputs cause Exceptions
- We are eager to gain user feedback!

# Library Support

Option: `--library`

Run with Java library, not the compiler. Greatly facilitates application development, debugging, and verification.

Given File.str, the frontend will produce File.java, which you can edit and instrument like a normal Java file.



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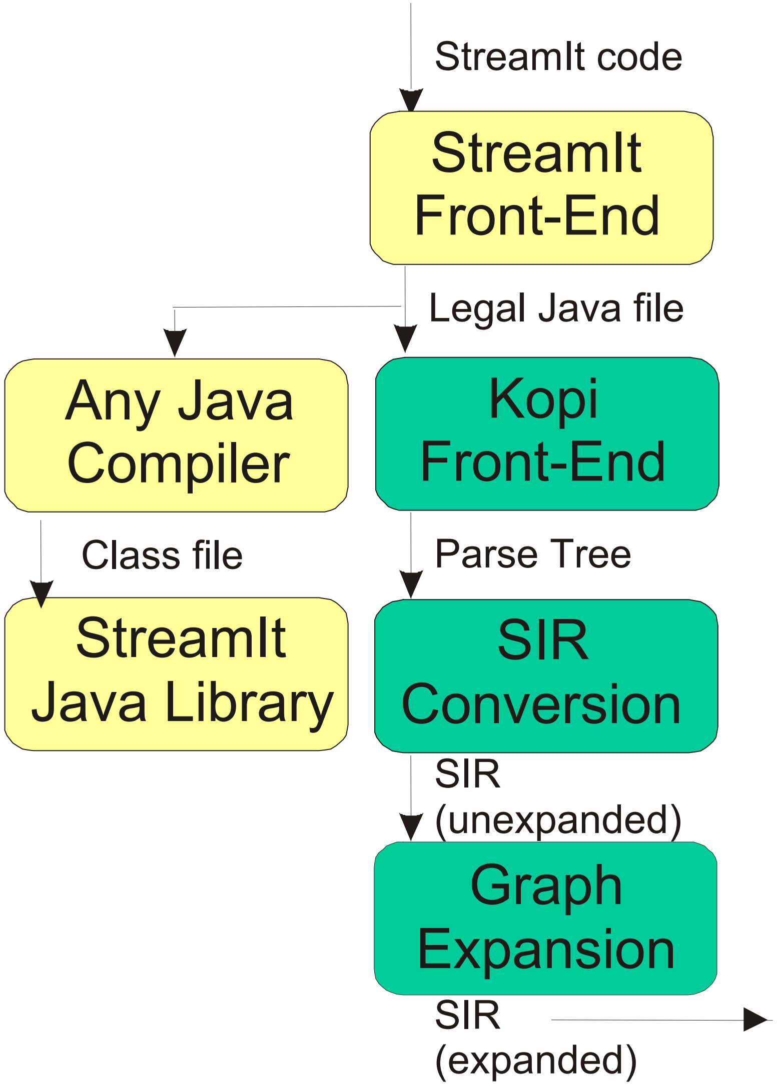
Many more options will be documented in the release.



# Summary

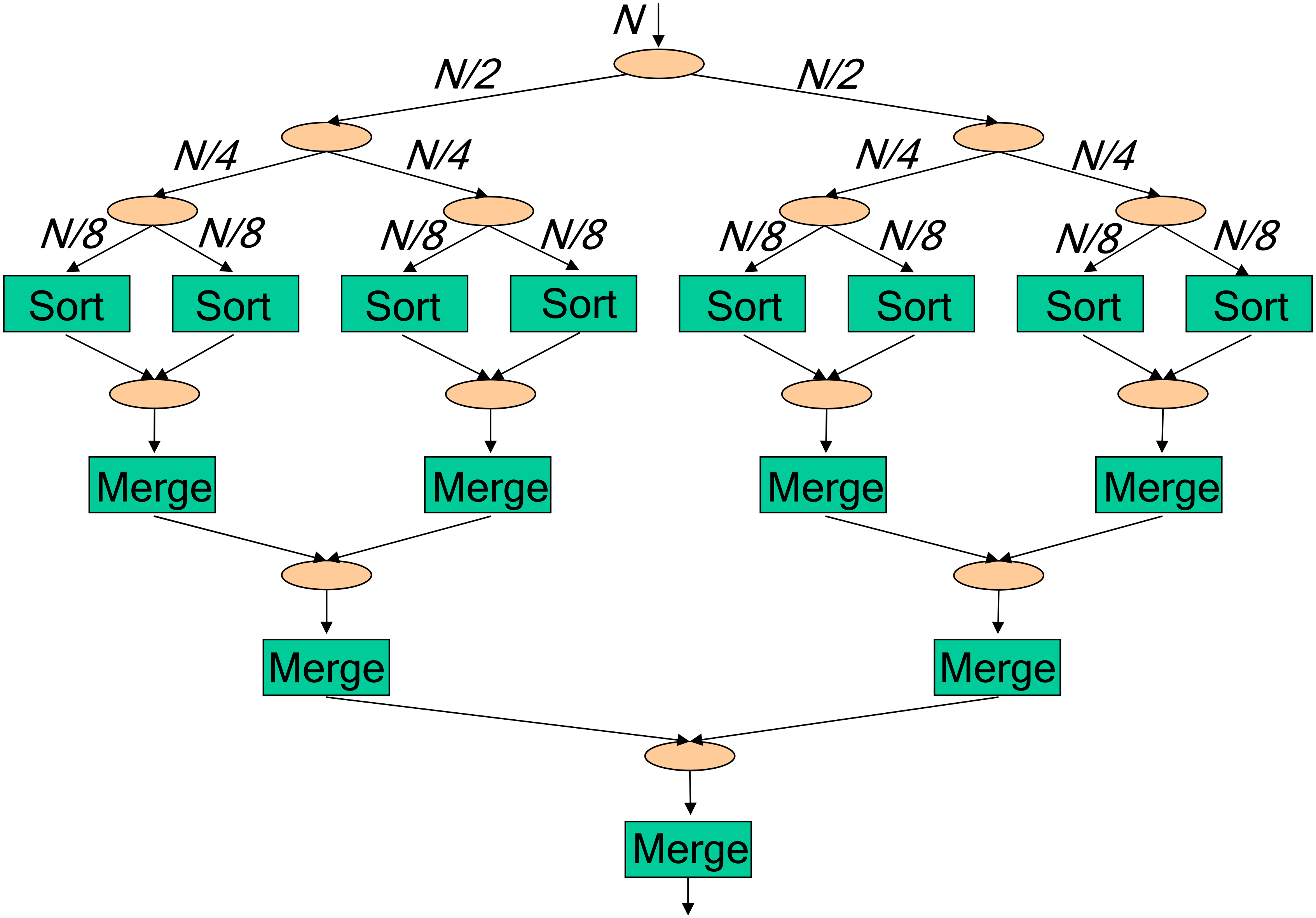
- Why use StreamIt?
  - High-level, architecture-independent syntax
  - Automatic partitioning, load balancing, layout, switch code generation, and buffer management
  - Aggressive domain-specific optimizations
  - Many graphical outputs for programmer
- Release by next Friday, 3/14/03

StreamIt Homepage

http://cag.lcs.mit.edu/streamit

# Backup Slides

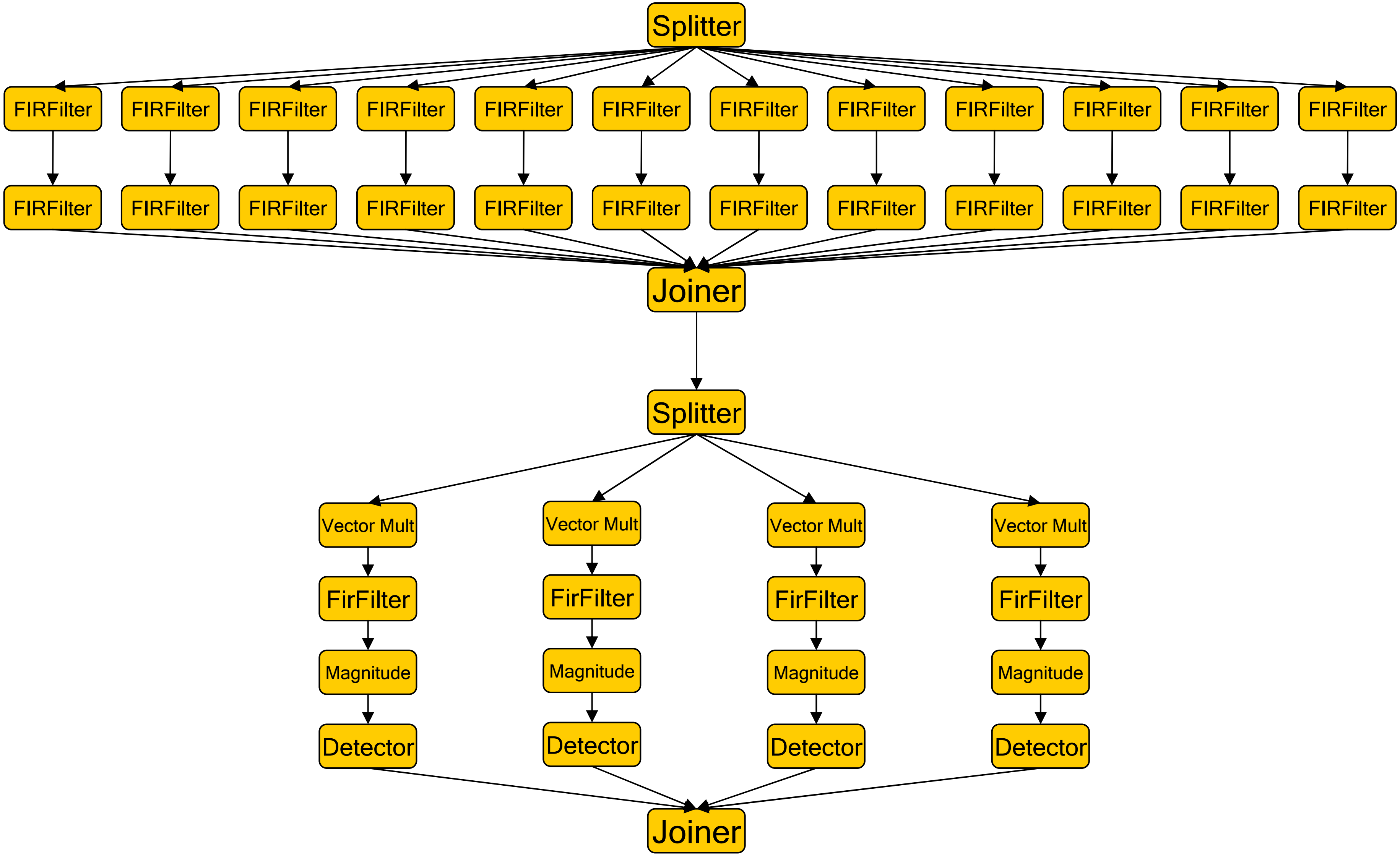
# N-Element Merge Sort (3-level)



# N-Element Merge Sort (K-level)

```
pipeline MergeSort (int N, int K) {
    if (K==1) {
        add Sort(N);
    } else {
        add splitjoin {
            split roundrobin;
            add MergeSort(N/2, K-1);
            add MergeSort(N/2, K-1);
            joiner roundrobin;
        }
    }
    add Merge(N);
  }
}
```

# Example: Radar App. (Original)



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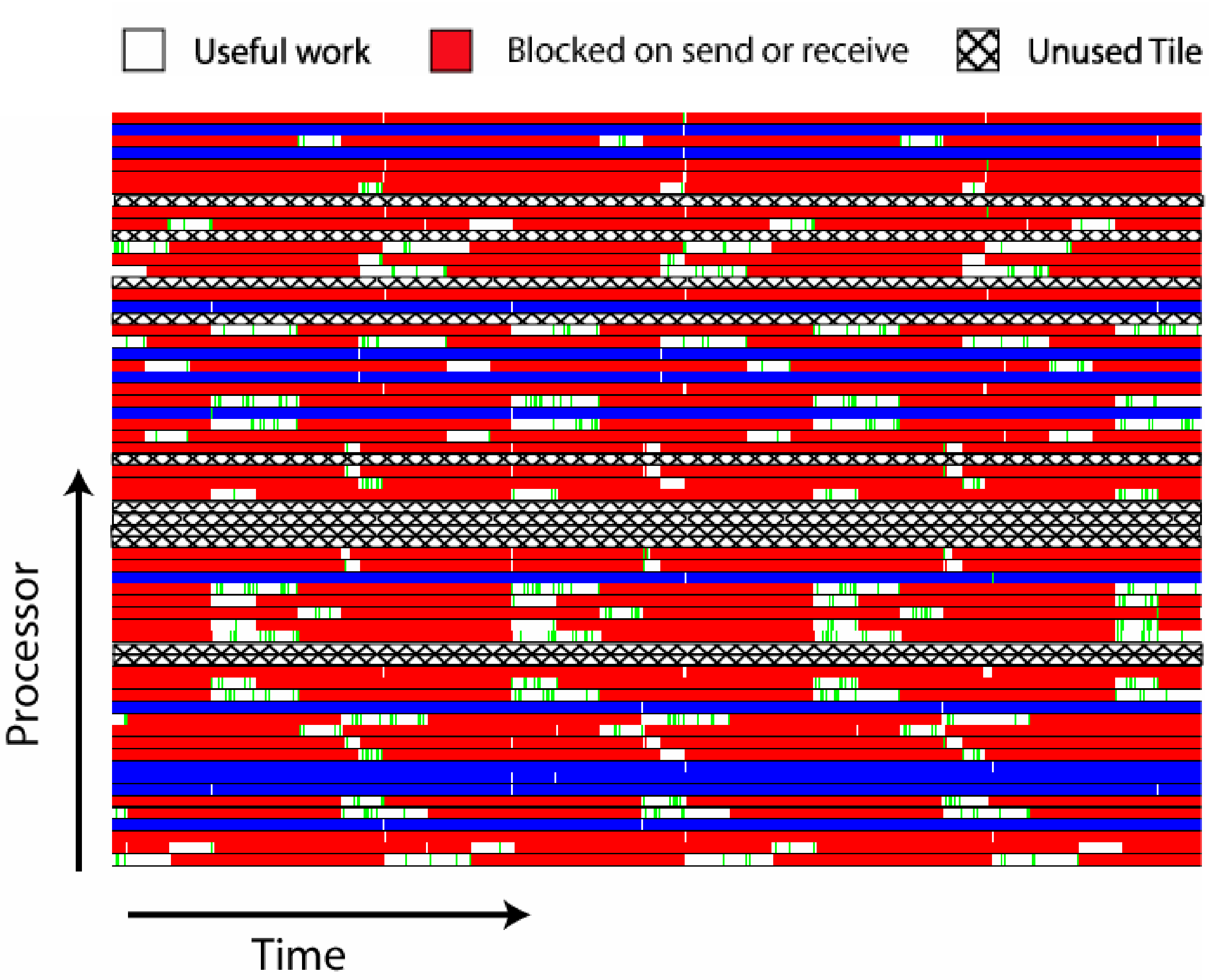

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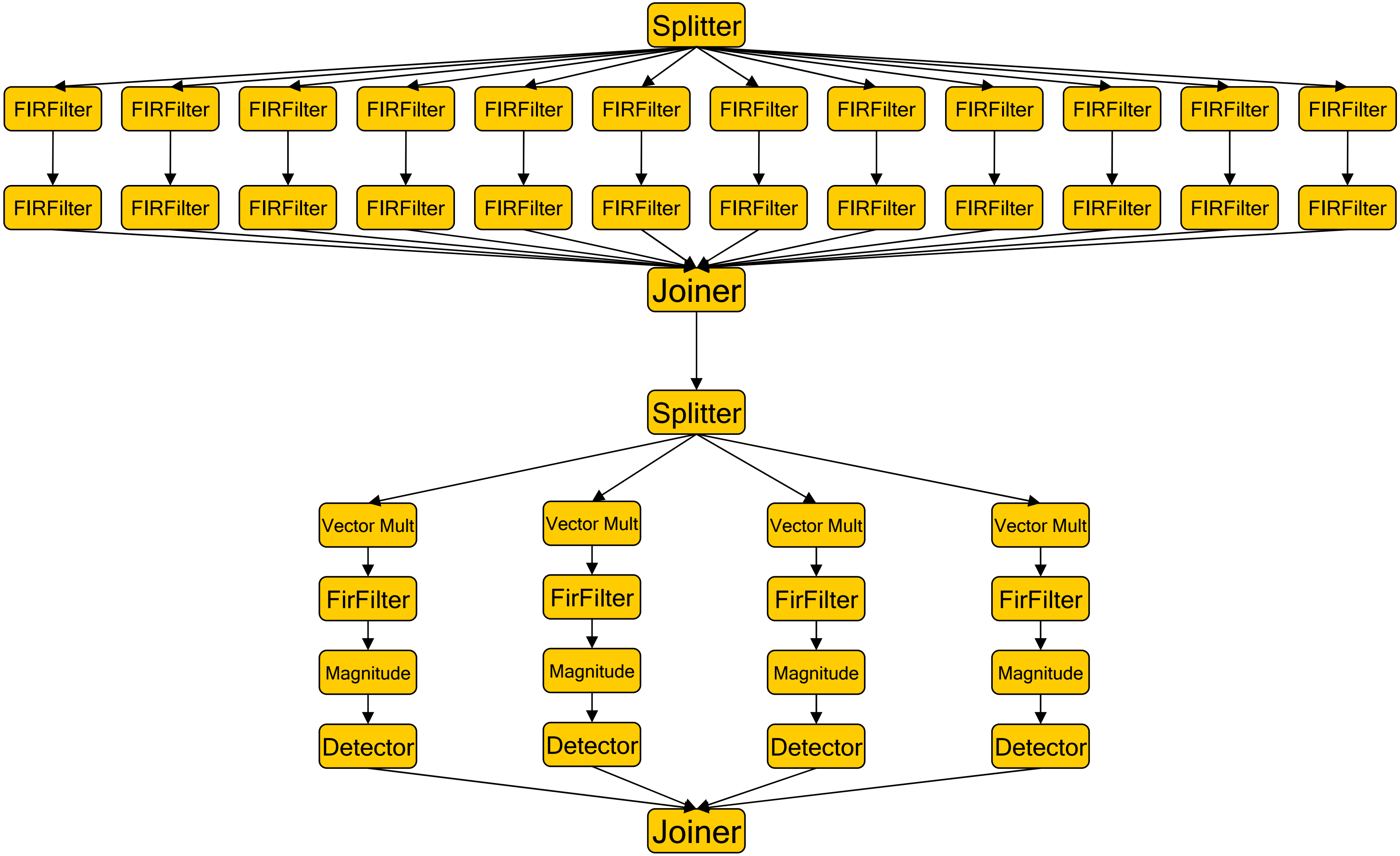

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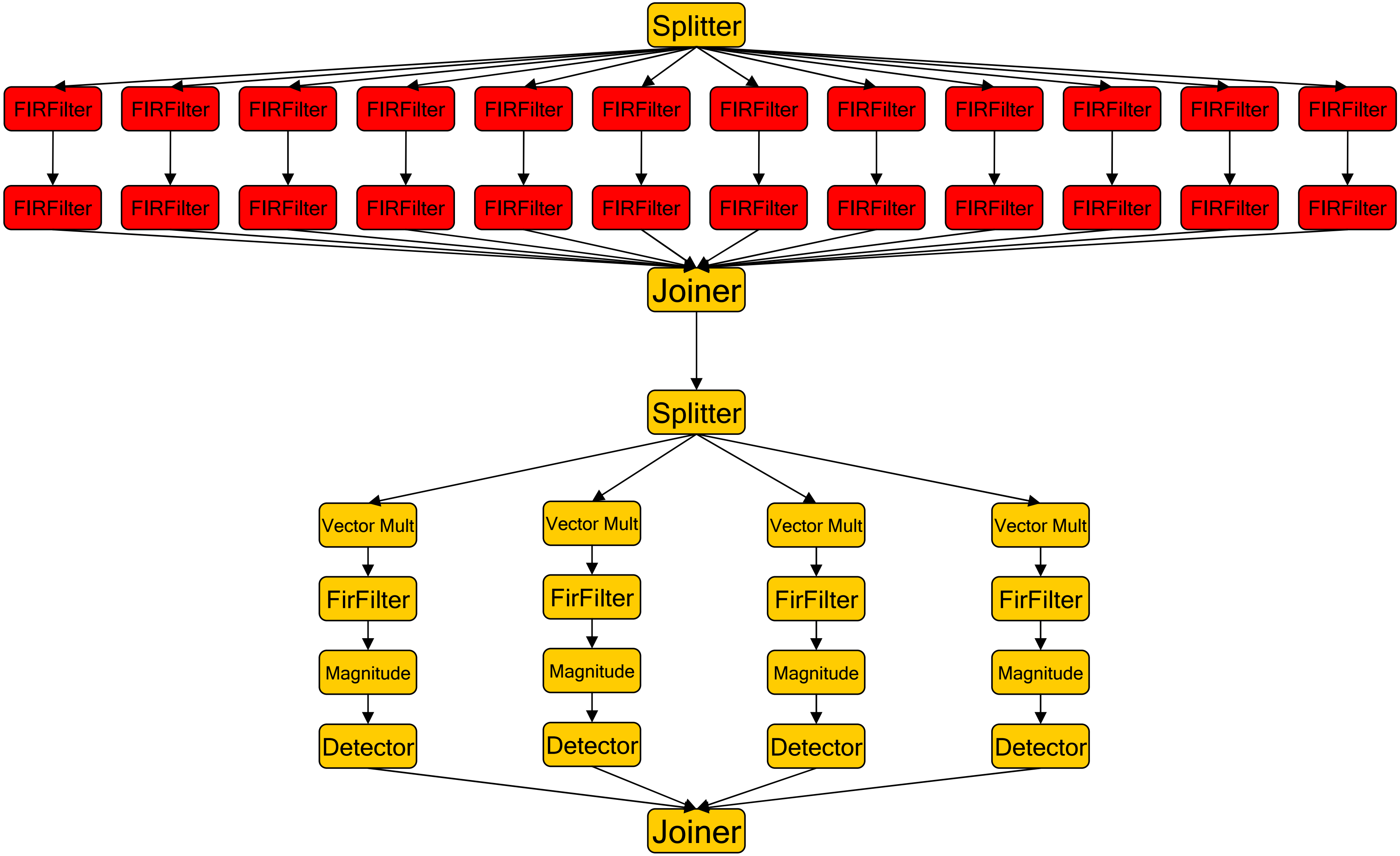

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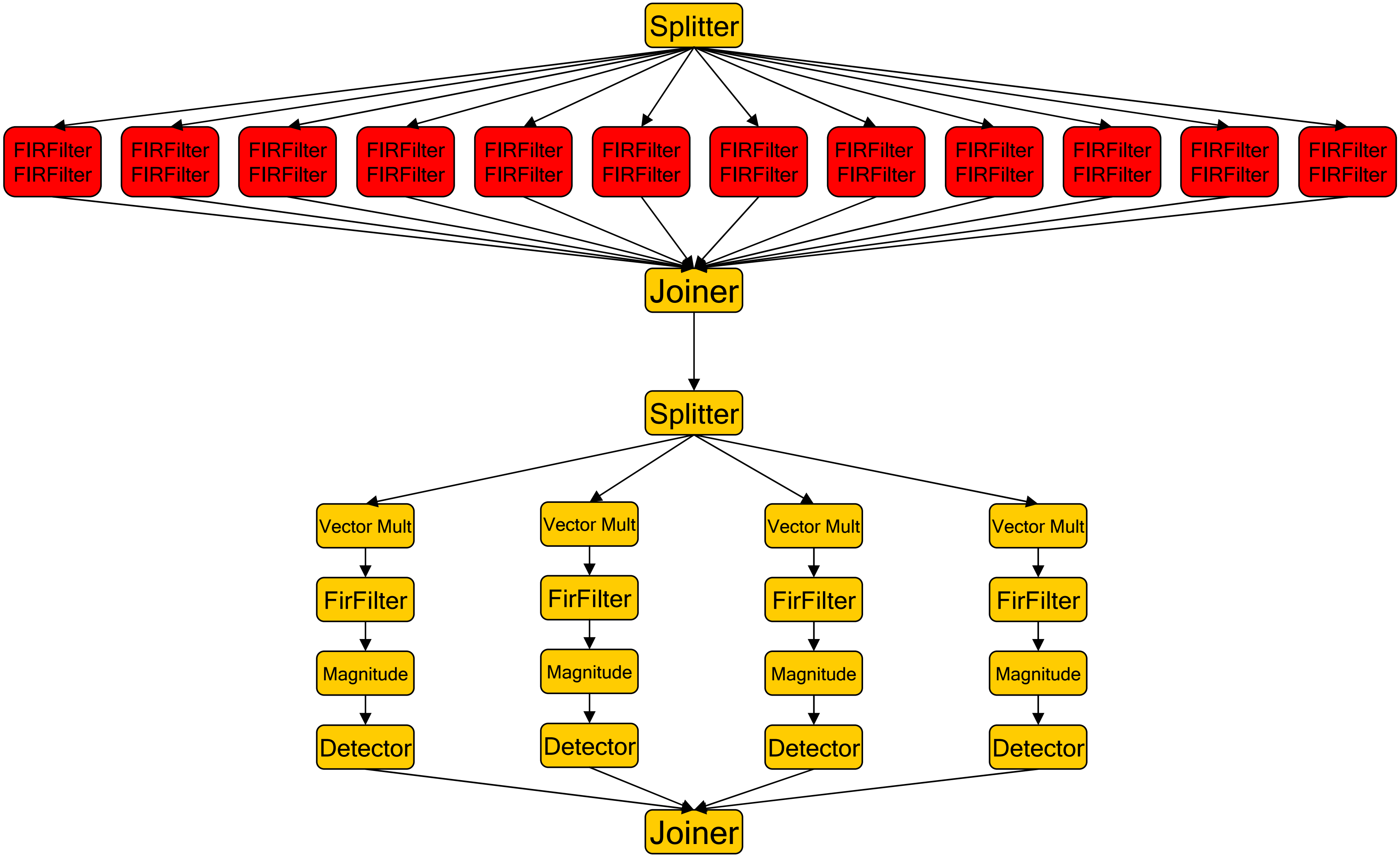

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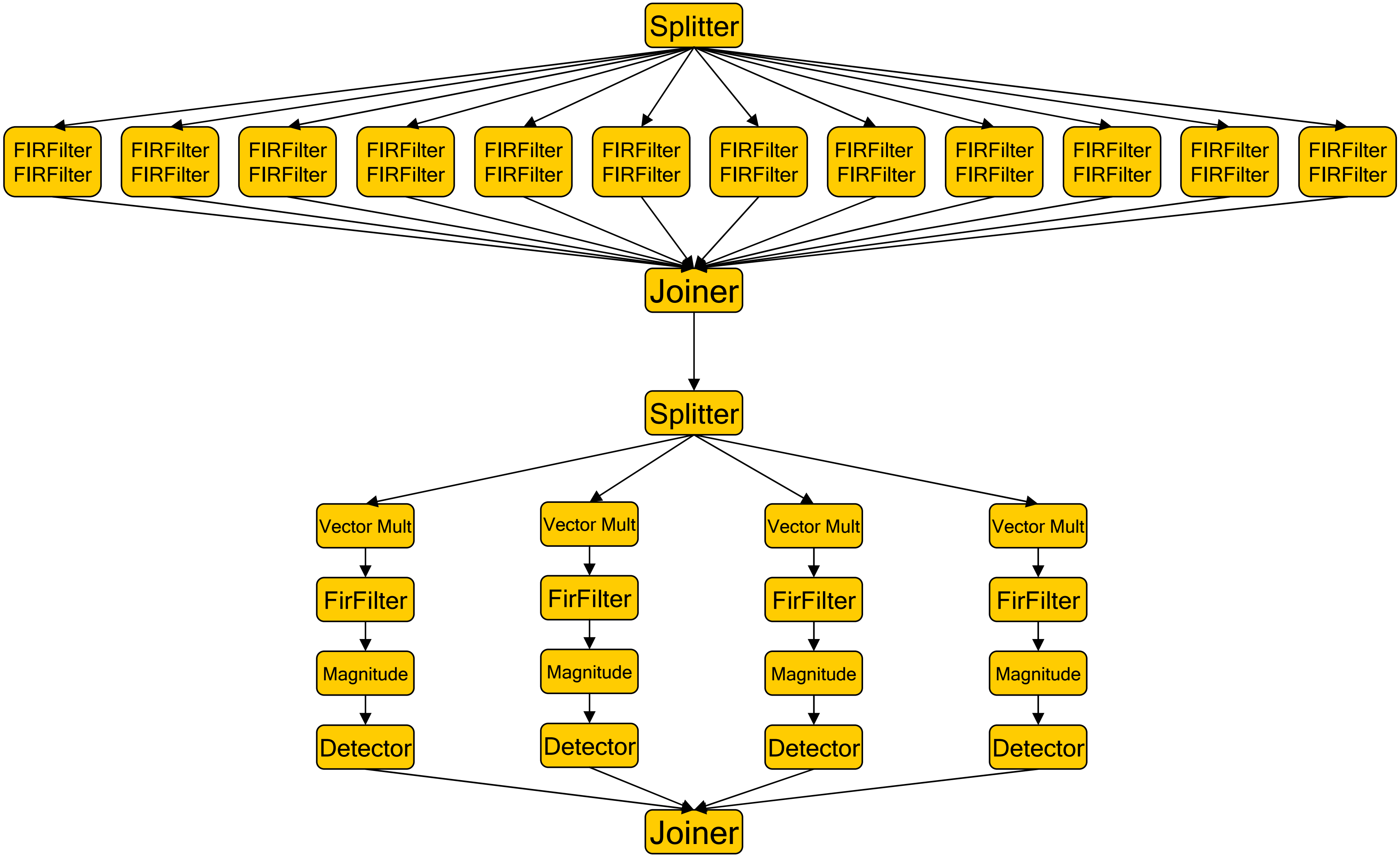

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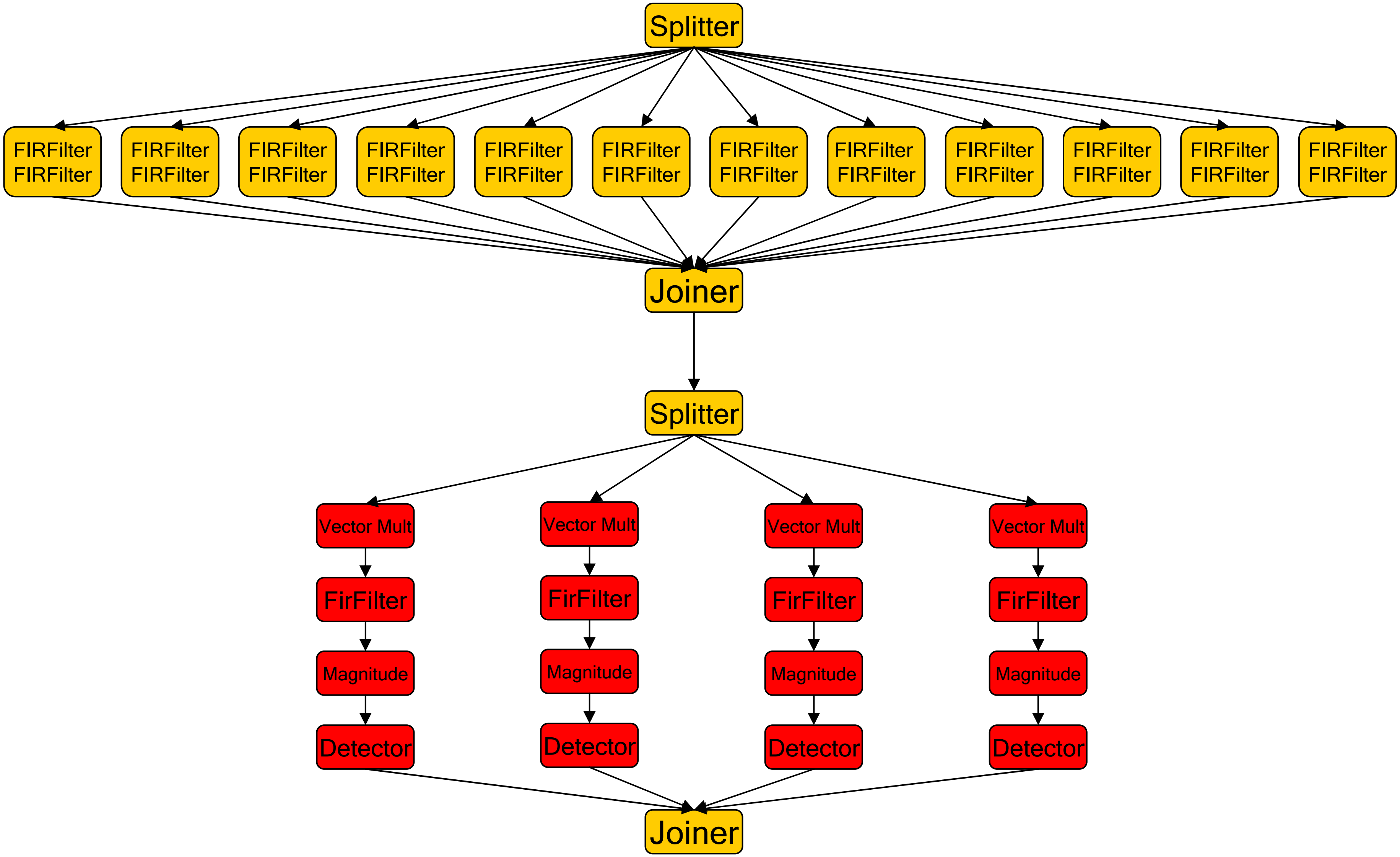

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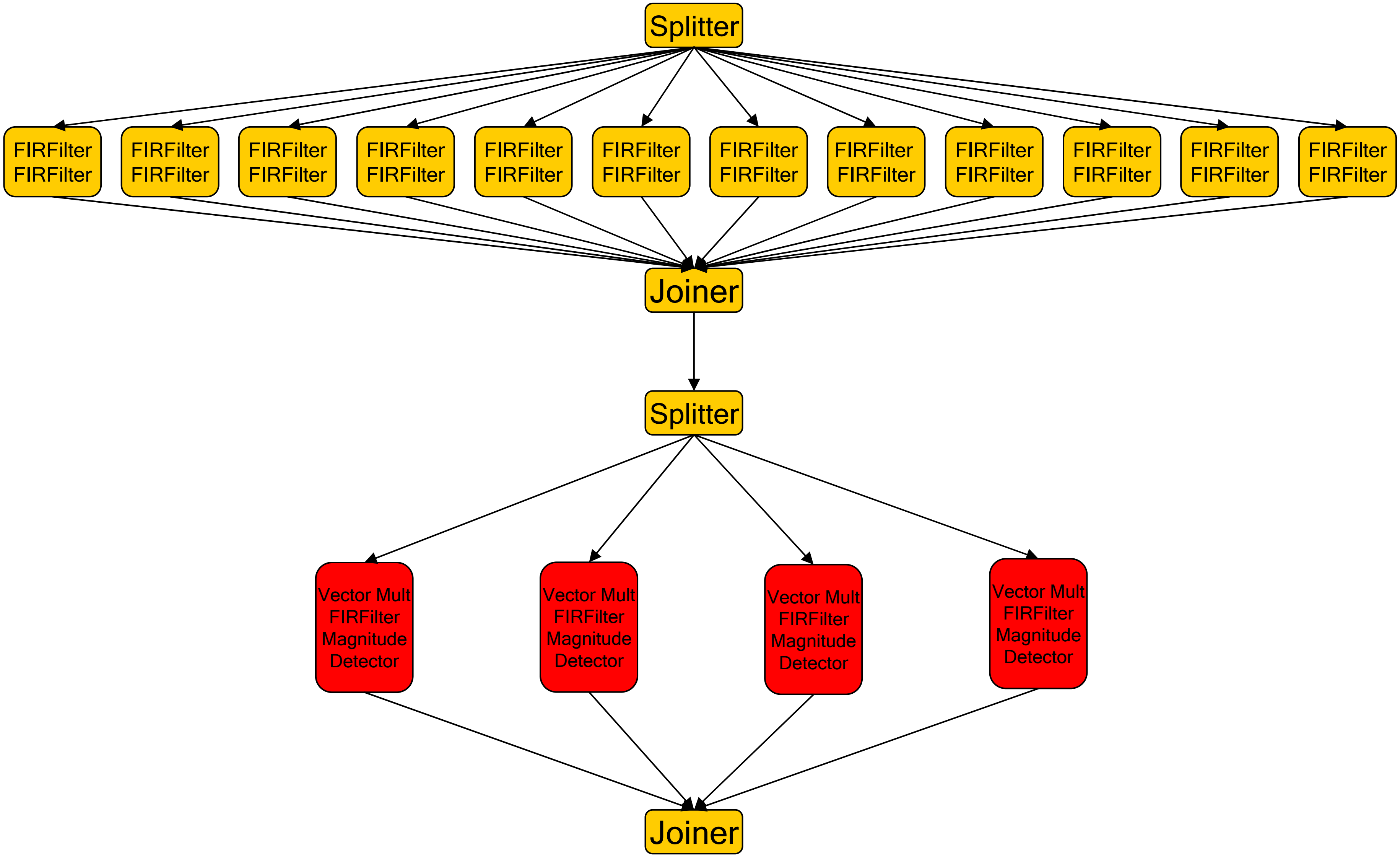


Splitter

FIRFilter<br>FIRFilter (×12)

| FIRFilter | FIRFilter | FIRFilter | FIRFilter | FIRFilter | FIRFilter | FIRFilter | FIRFilter | FIRFilter | FIRFilter | FIRFilter | FIRFilter |
|---|---|---|---|---|---|---|---|---|---|---|---|
| FIRFilter | FIRFilter | FIRFilter | FIRFilter | FIRFilter | FIRFilter | FIRFilter | FIRFilter | FIRFilter | FIRFilter | FIRFilter | FIRFilter |

Joiner

Splitter

Vector Mult
FIRFilter
Magnitude
Detector

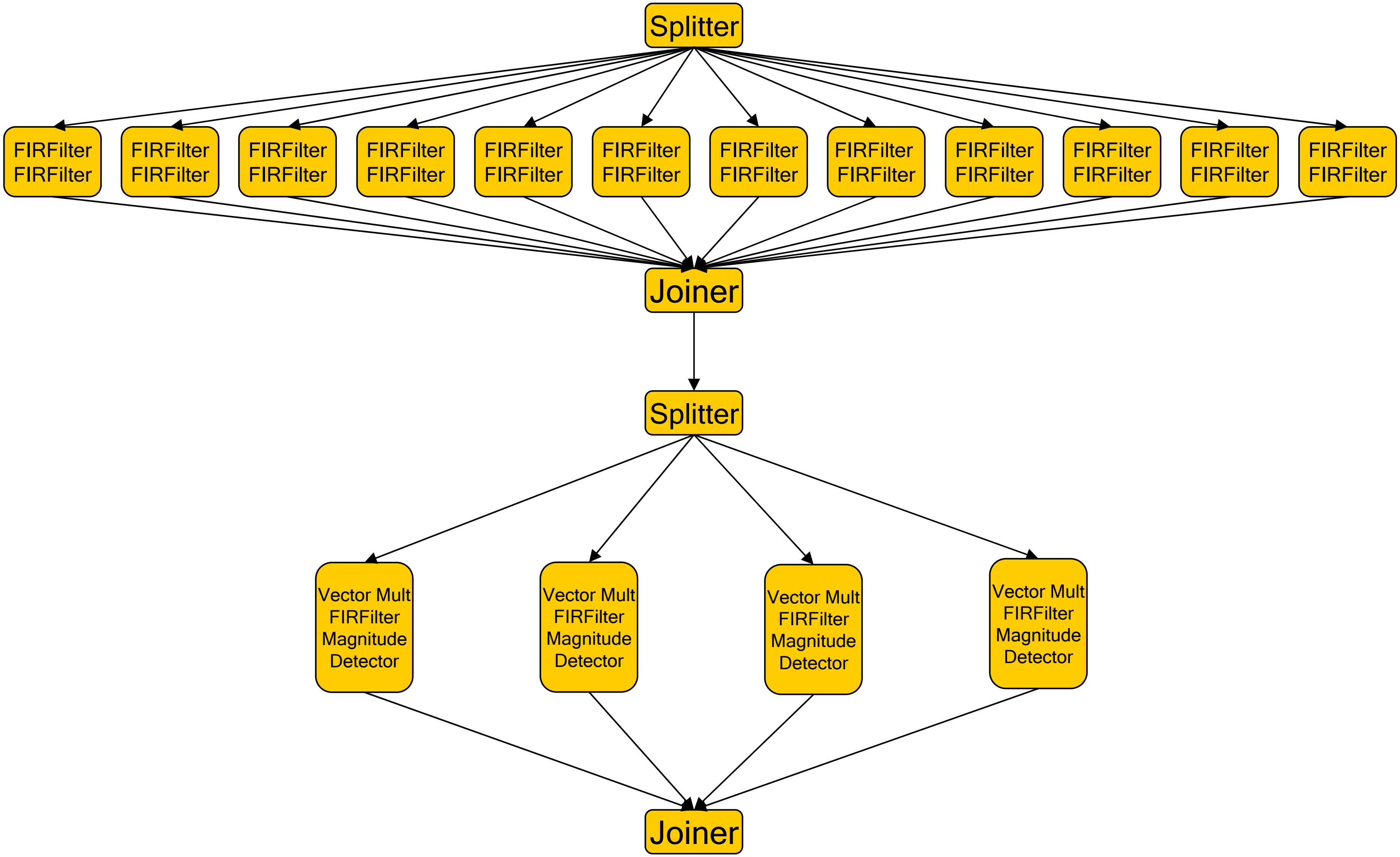
Vector Mult
FIRFilter
Magnitude
Detector

Vector Mult
FIRFilter
Magnitude
Detector

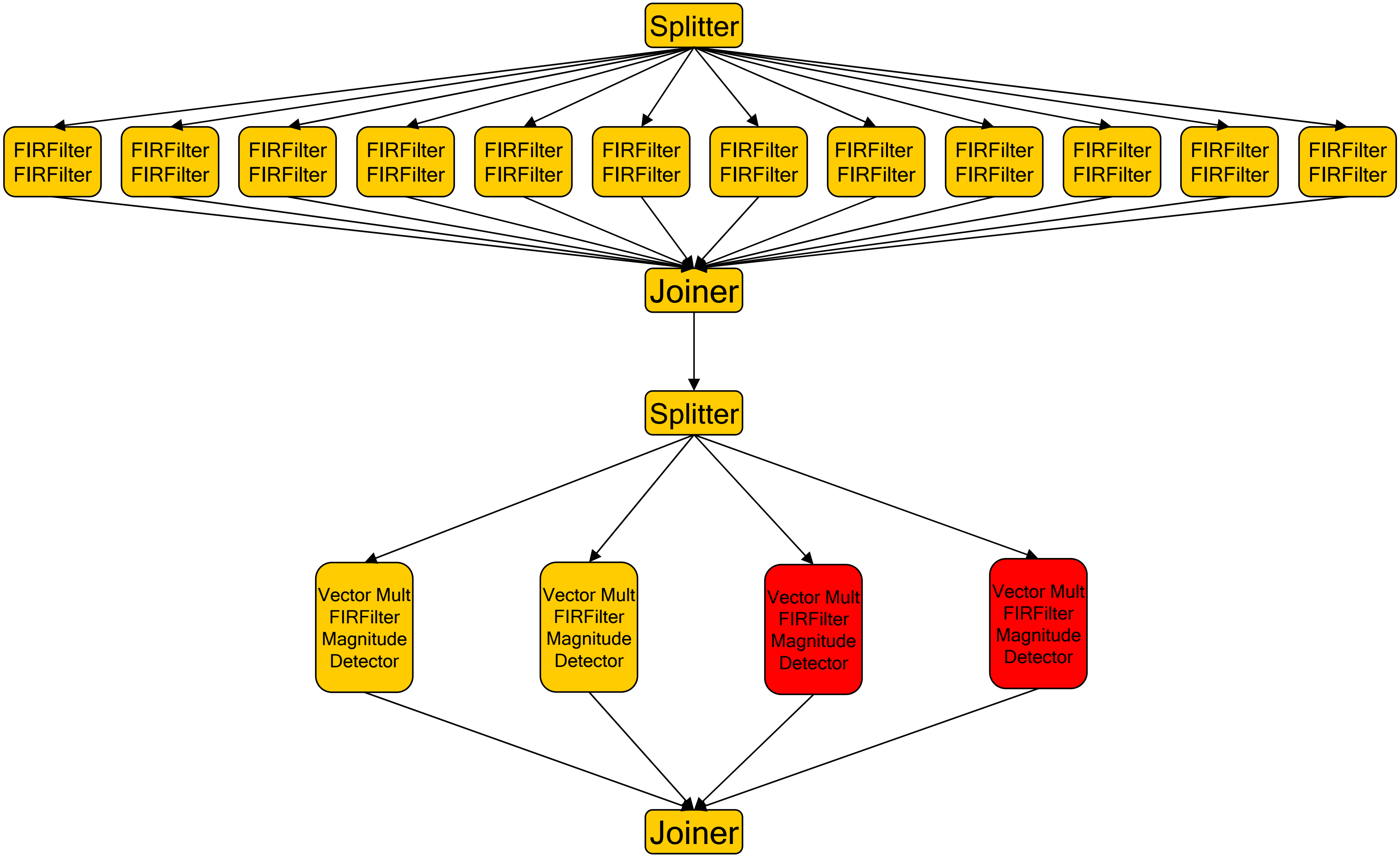
Vector Mult
FIRFilter
Magnitude
Detector

Joiner

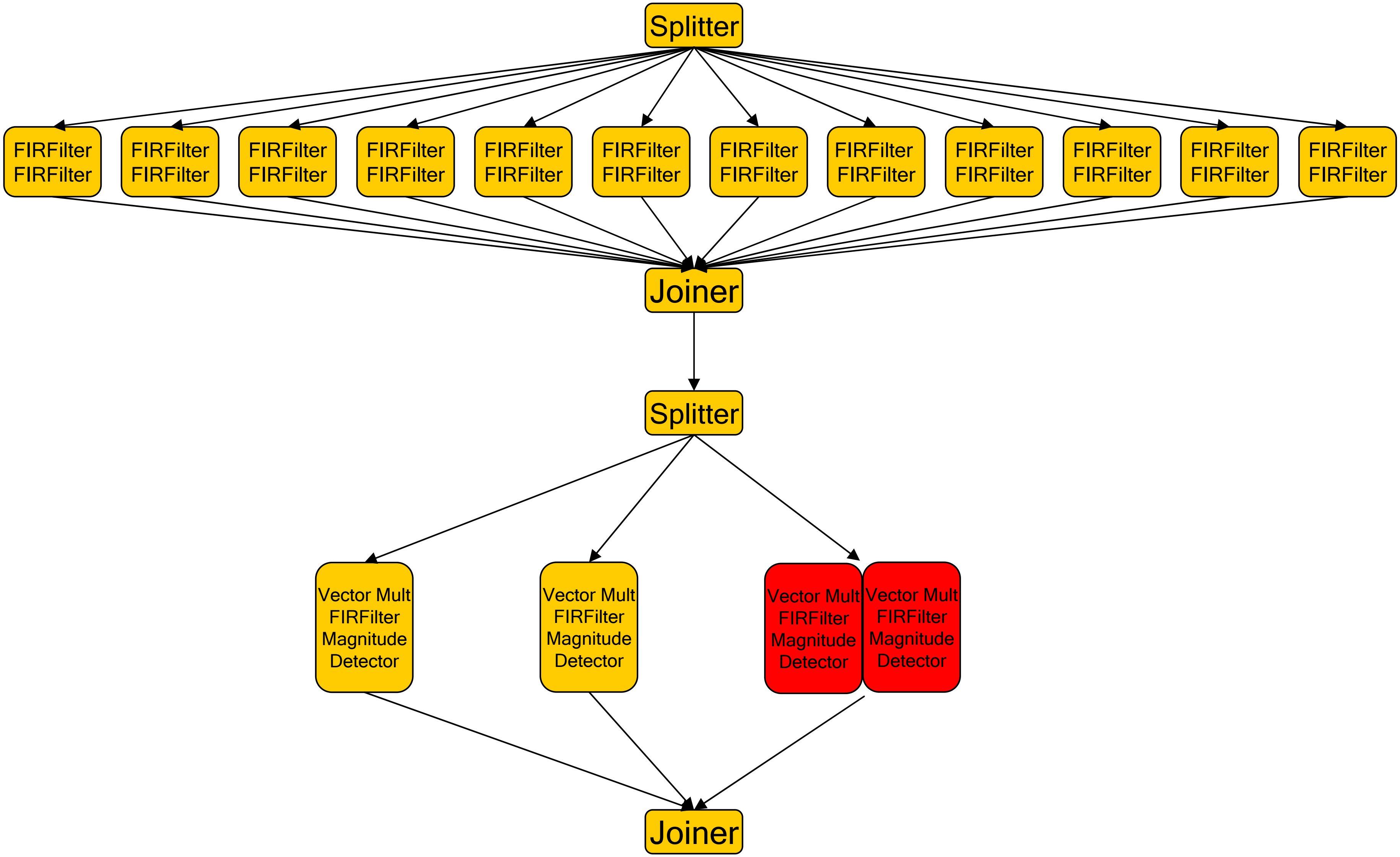
# Example: Radar App.



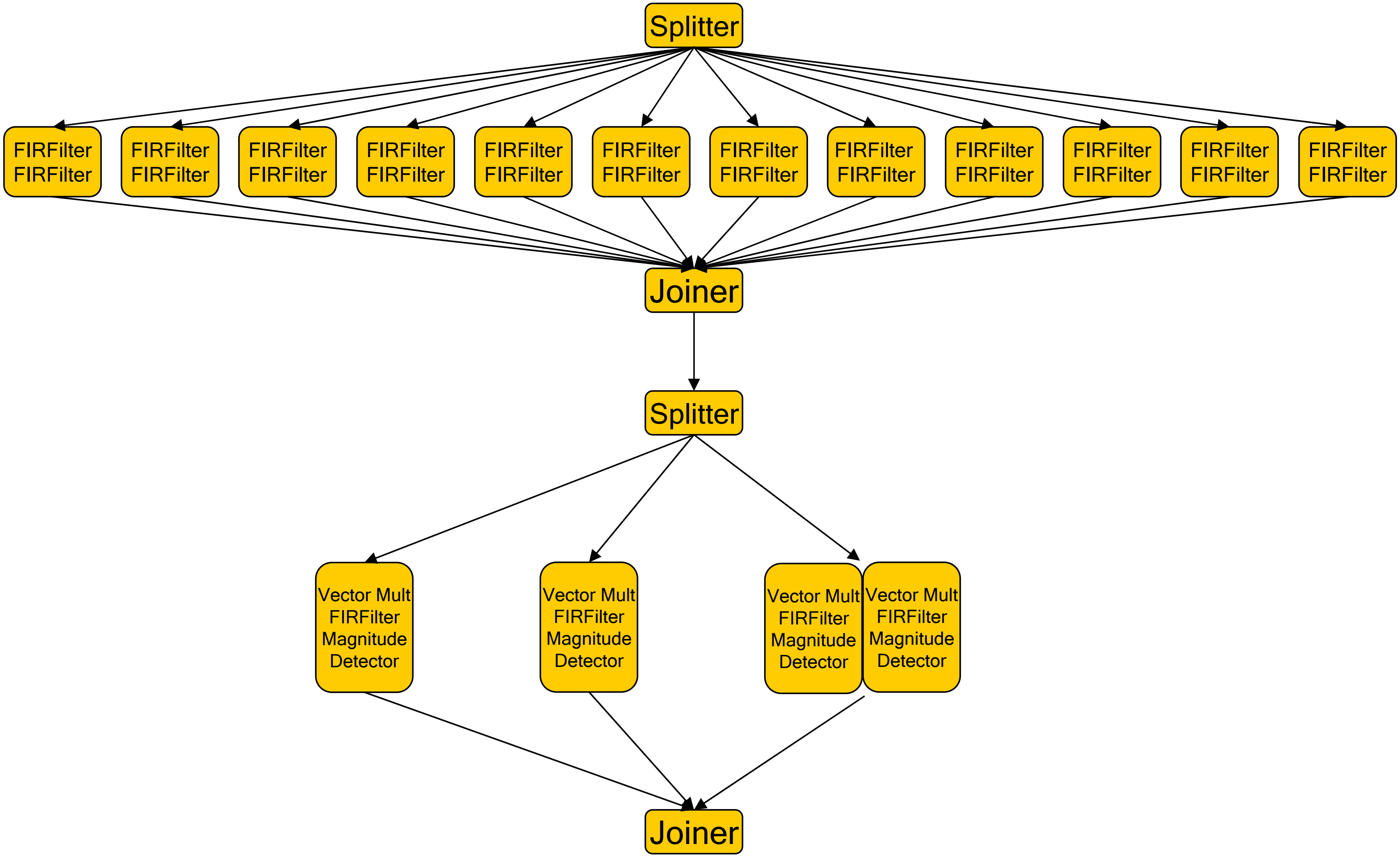
# Example: Radar App.



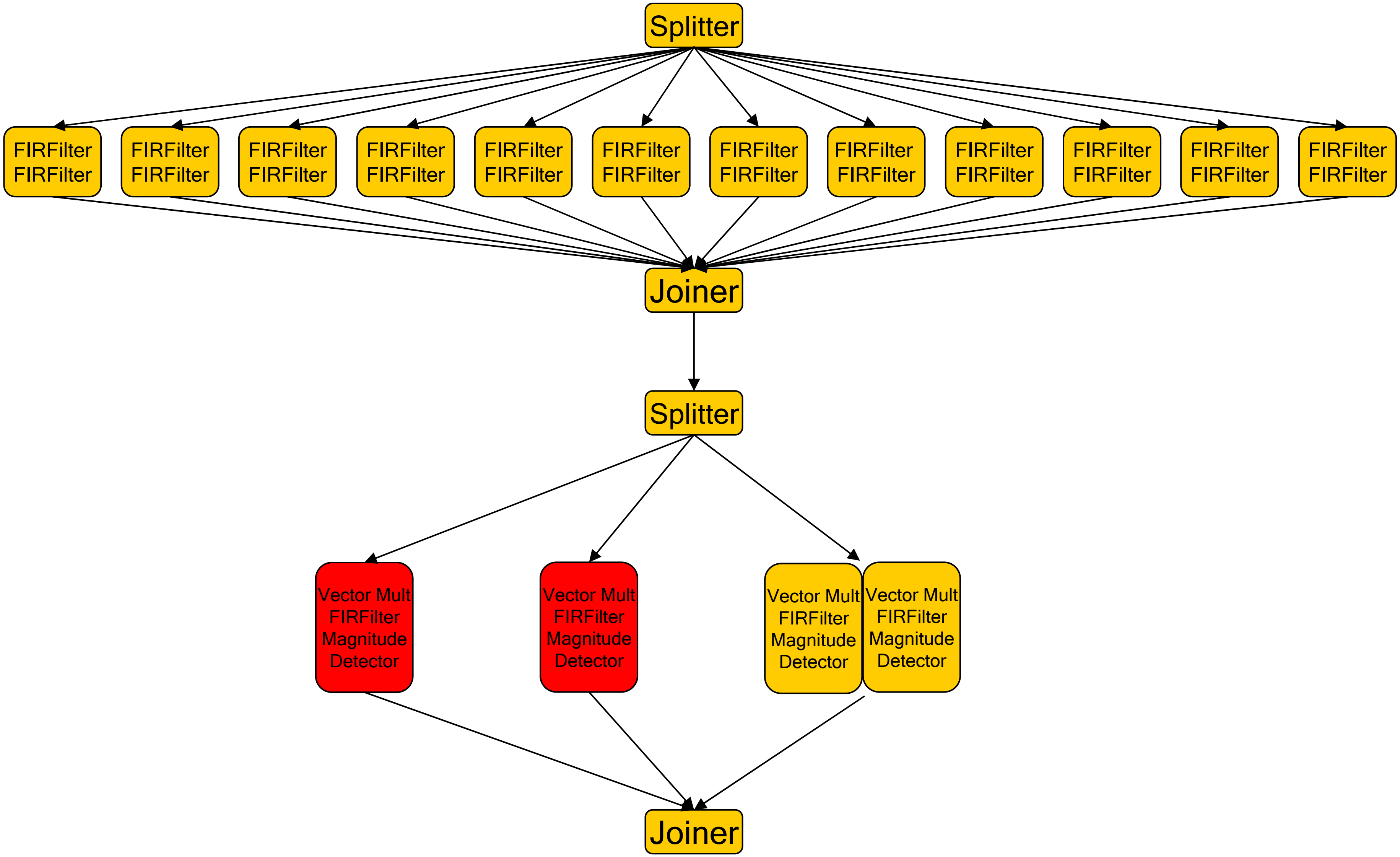
# Example: Radar App.



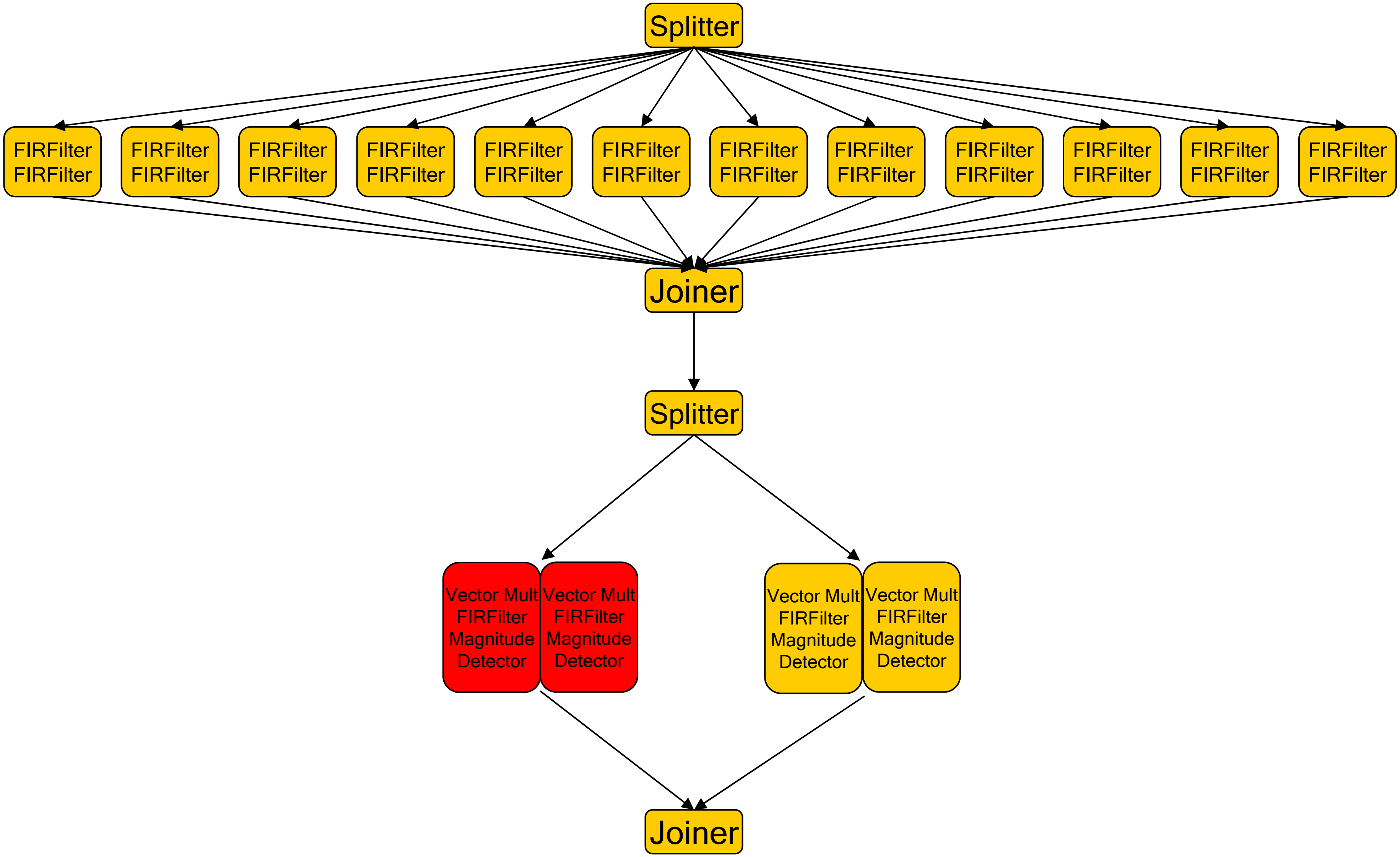
# Example: Radar App.



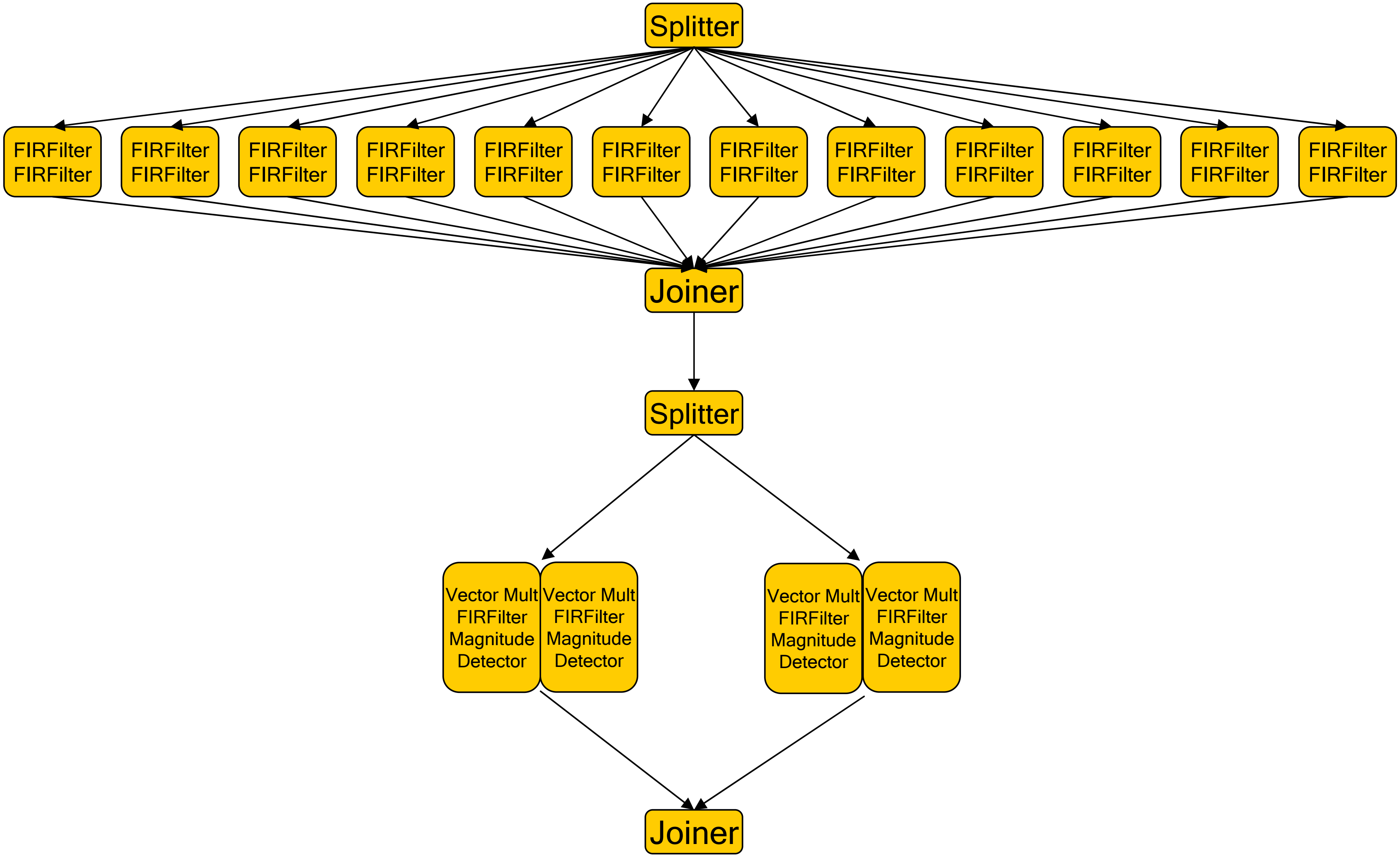
# Example: Radar App.



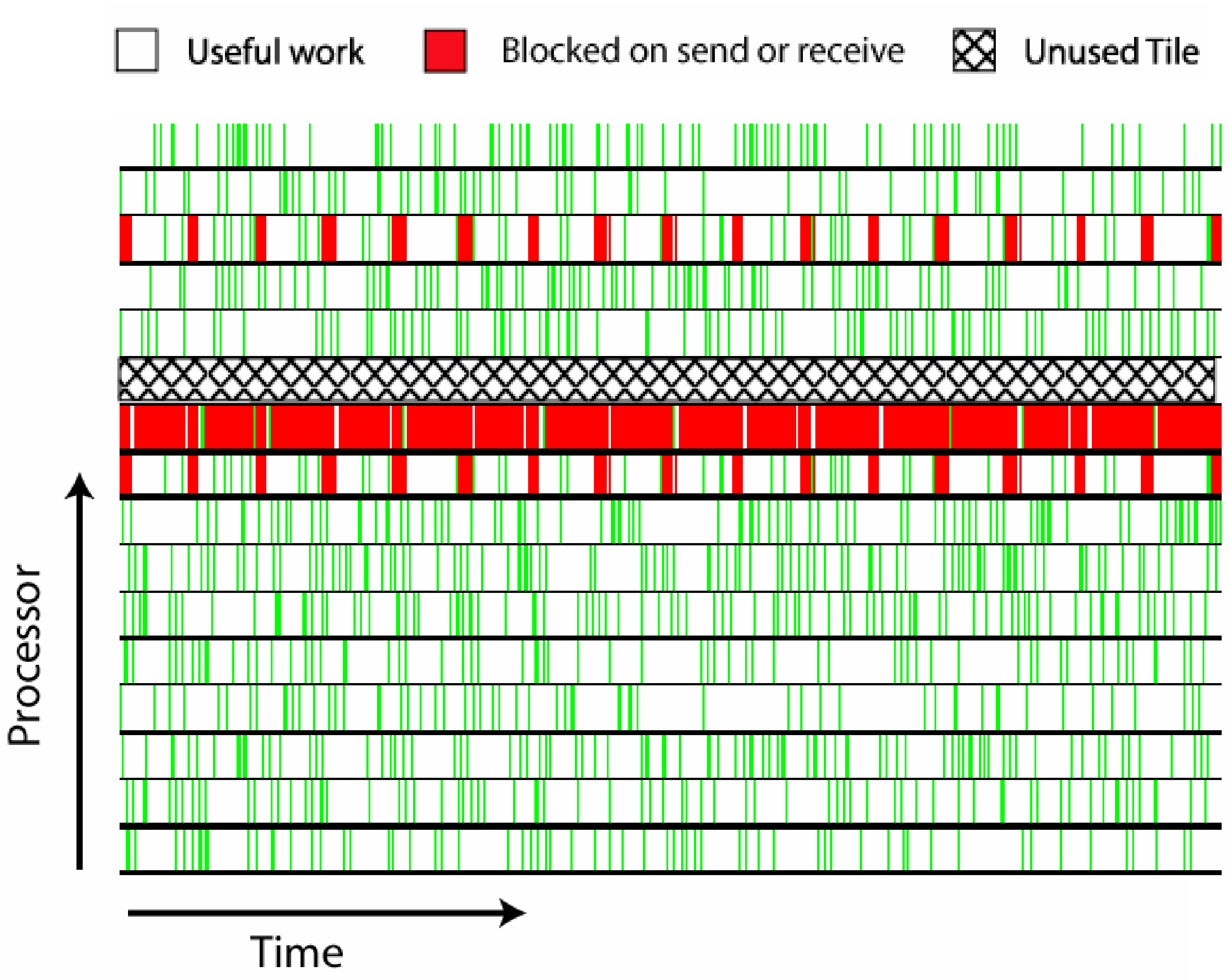
# Example: Radar App.



# Example: Radar App. (Balanced)

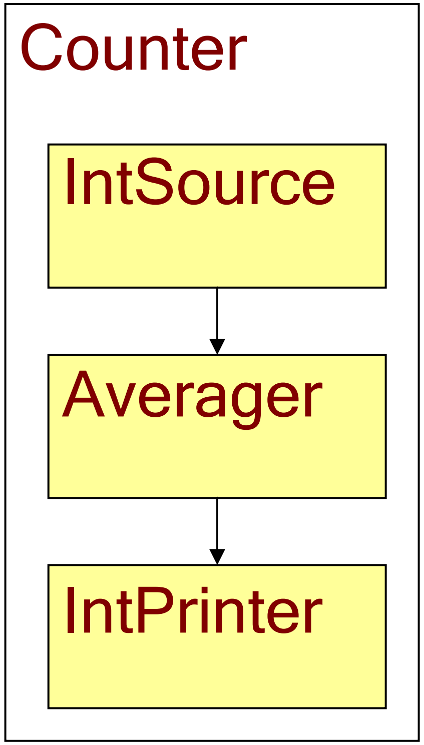


# Example: Radar App. (Balanced)



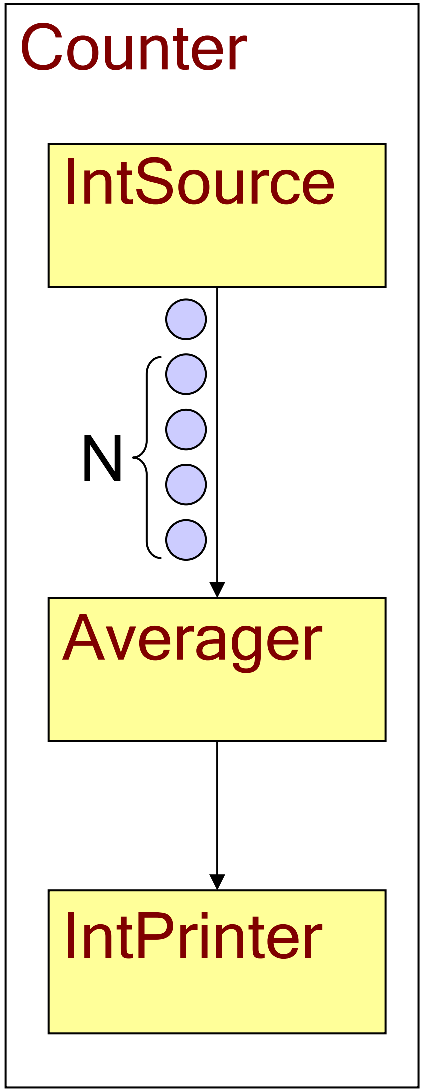
# A Moving Average

```
void->void pipeline MovingAverage() {
    add IntSource();
    add Averager(10);
    add IntPrinter();
}
int->int filter Averager(int N) {
    work pop 1 push 1 peek N-1 {
      int sum = 0;
      for (int i=0; i<N; i++) {
        sum += peek(i);
      }
    push(sum/N);
    pop();
}
```



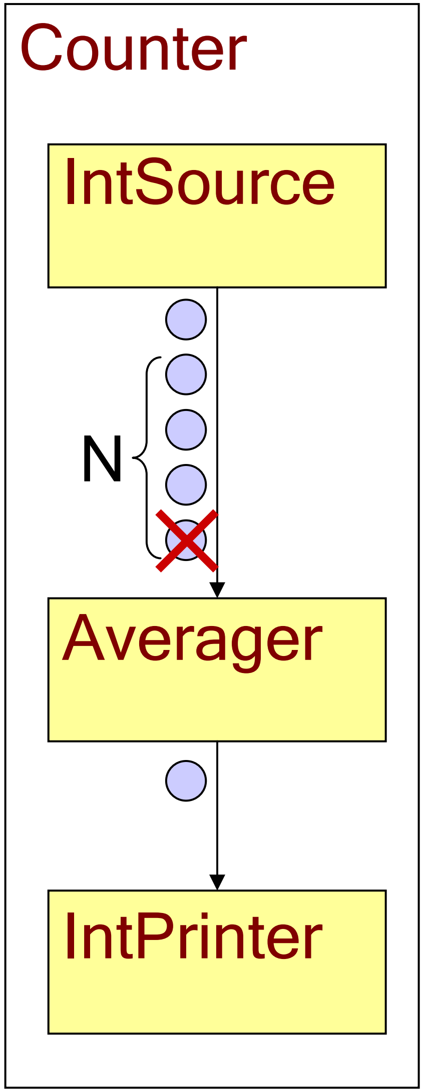
# A Moving Average

```
void->void pipeline MovingAverage() {
    add IntSource();
    add Averager(4);
    add IntPrinter();
}
int->int filter Averager(int N) {
    work pop 1 push 1 peek N-1 {
      int sum = 0;
      for (int i=0; i<N; i++) {
        sum += peek(i);
      }
    push(sum/N);
    pop();
}
```



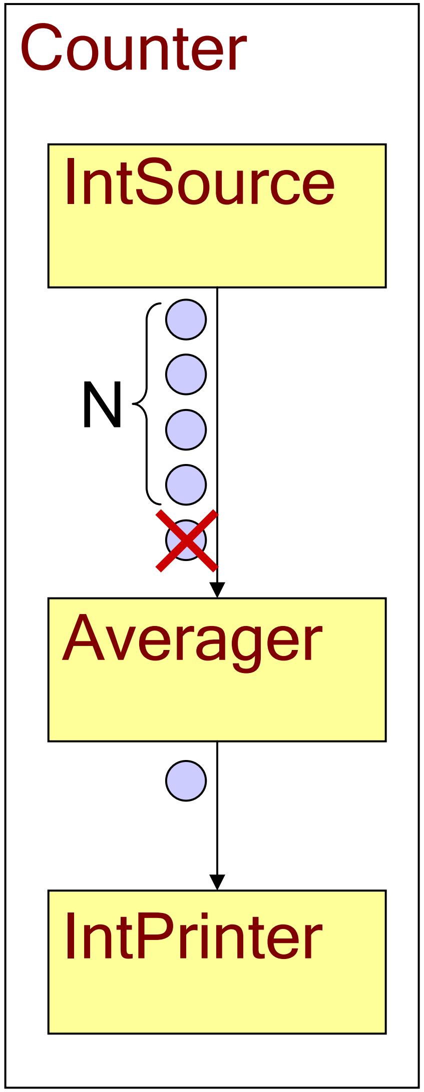
# A Moving Average

```
void->void pipeline MovingAverage() {
    add IntSource();
    add Averager(4);
    add IntPrinter();
}
int->int filter Averager(int N) {
    work pop 1 push 1 peek N-1 {
      int sum = 0;
      for (int i=0; i<N; i++) {
        sum += peek(i);
      }
    push(sum/N);
    pop();
}
```



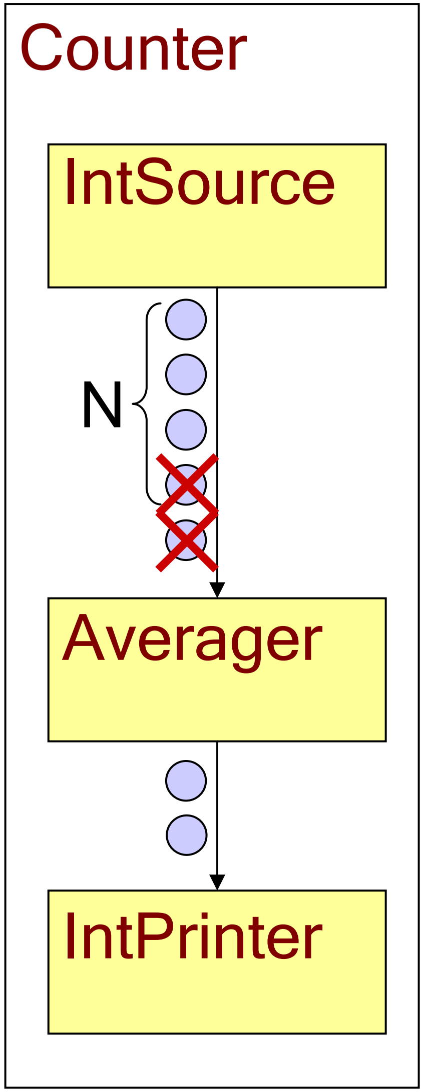
# A Moving Average

```
void->void pipeline MovingAverage() {
    add IntSource();
    add Averager(4);
    add IntPrinter();
}
int->int filter Averager(int N) {
    work pop 1 push 1 peek N-1 {
      int sum = 0;
      for (int i=0; i<N; i++) {
        sum += peek(i);
      }
    push(sum/N);
    pop();
}
```



# A Moving Average

```
void->void pipeline MovingAverage() {
    add IntSource();
    add Averager(4);
    add IntPrinter();
}
int->int filter Averager(int N) {
    work pop 1 push 1 peek N-1 {
      int sum = 0;
      for (int i=0; i<N; i++) {
        sum += peek(i);
      }
    push(sum/N);
    pop();
}
```


Counter
IntSource
N
Averager
IntPrinter