The WaveScope Project

Functional Programming in the Wild

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Sam Madden

MIT/CSAIL

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Stanislav Rost, Arvind Thiagarajan,
Hari Balakrishnan

http://wavescope.csail.mit.edu/

Applications:
Stream + Signal Processing

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4 channels
x 48 khz
= 400,000 bytes/sec (per node)

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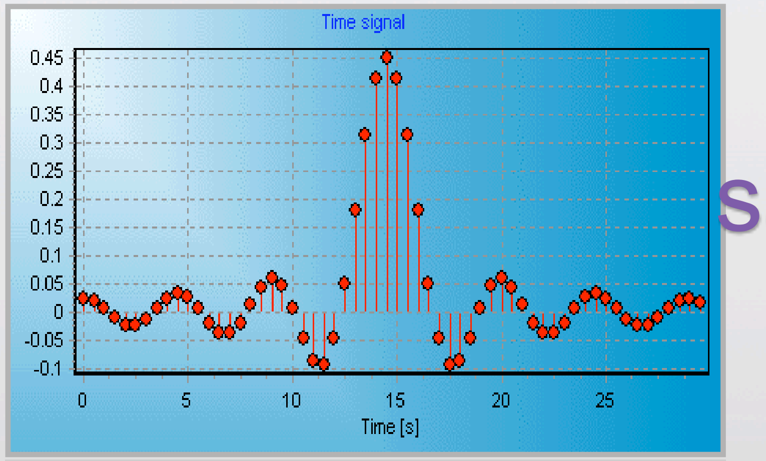

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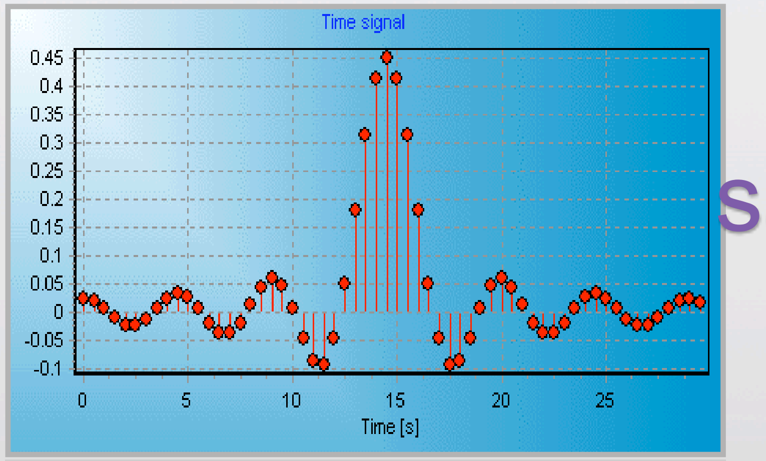

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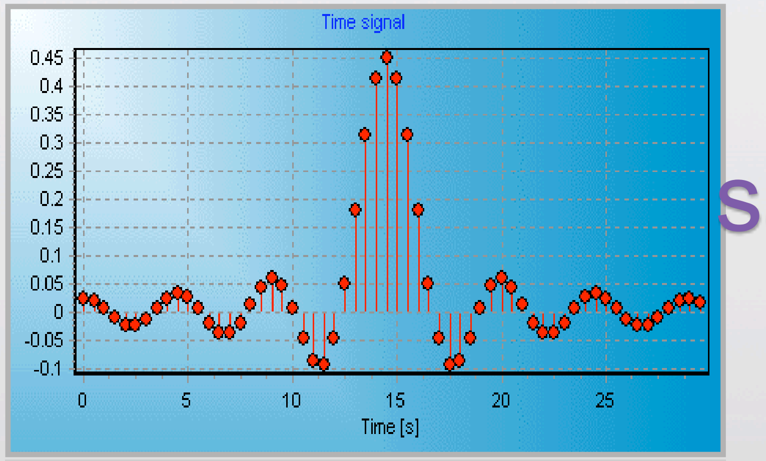

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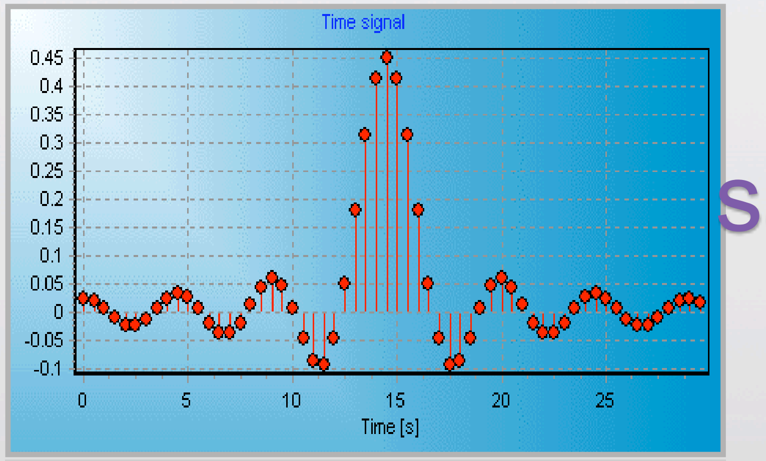

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- Higher order stream combinators (map, etc)

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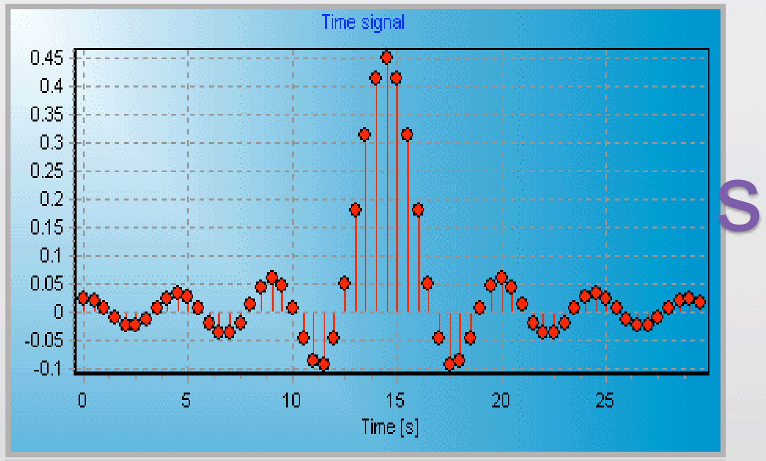

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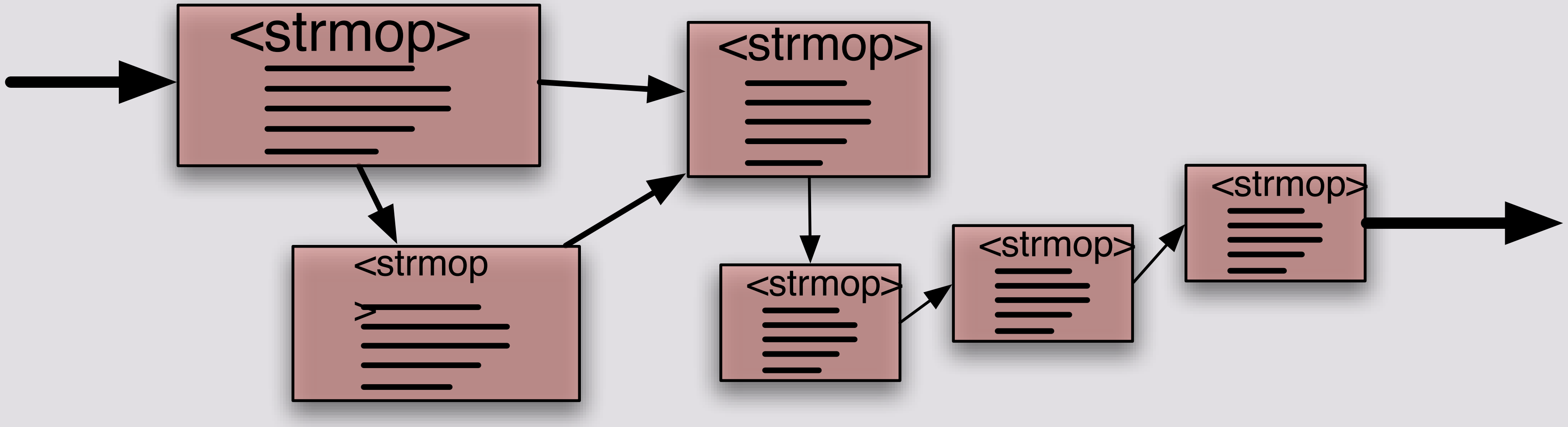
Parallelism at multiple granularities

“WaveScope” - what is it?

- WaveScript Language, Compiler
  - ML (with a few extras - generic printing, Num subkind)
  - Two-stage evaluation (metaprogramming)
  - Run-time model is a graph of stream operators
- XStream engine
  - Links to C backend, other WS backends as well
- Stream/Signal processing libraries
  - Higher order language, polymorphism, metaprogramming enables reuse, new abstractions

Execution Model

- Graph of operators (aka kernels, actors, agents)



- Many possible semantics: synchronous or asynchronous, (non)deterministic operators, shared state, atomicity/execution order, etc
- WaveScript: asynchronous streams of discrete events. Operators may fire whenever an input token is available.
  - Fairness is scheduler's only requirement.
  - NO shared state

A bit of WaveScript code

- One primary stream operator (also merge)

```
iterate x in strm {
  state { cnt = 0 }
  cnt += 1;
  emit g(x,cnt);
  emit f(x,cnt);
}
```

- iterate = Syntactic sugar
  - second class references
- iterate could be a pure combinator,

```
iterate :: ((a,s) -> ([b],s))
              -> Stream a -> Stream b
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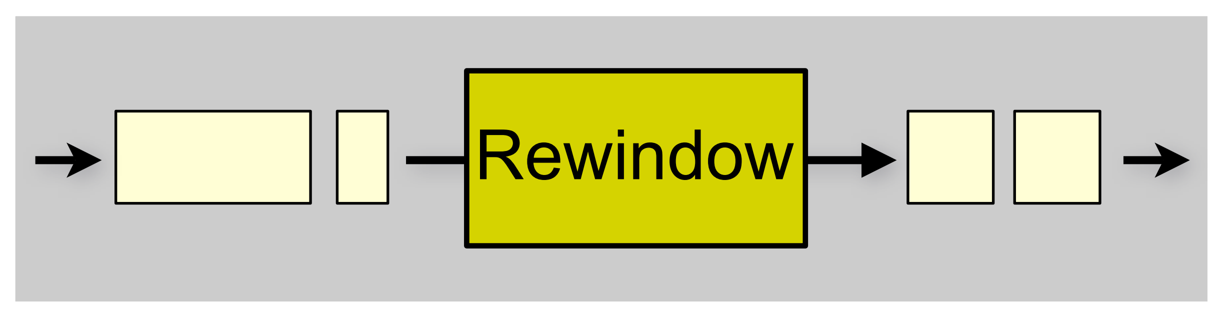

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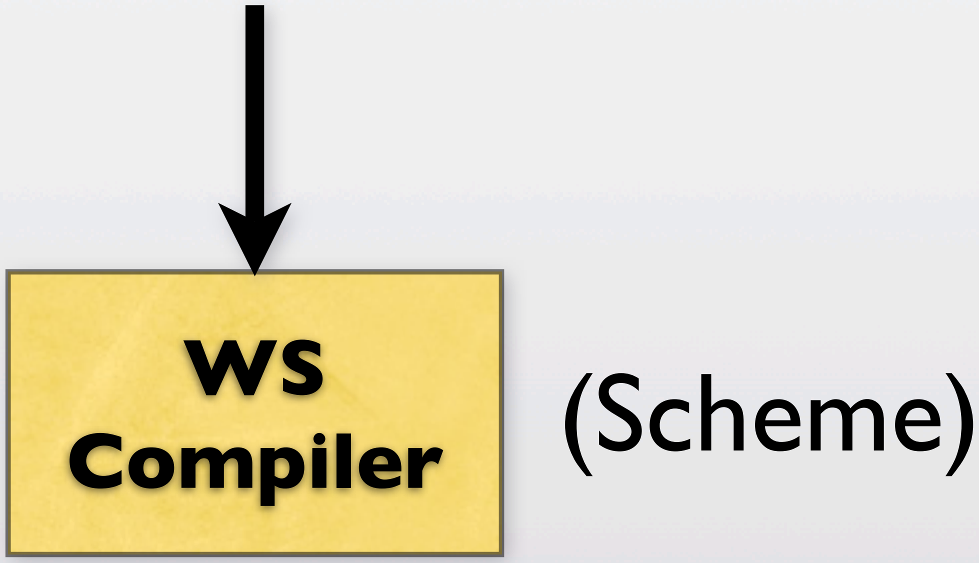

WS Compiler

(Scheme)

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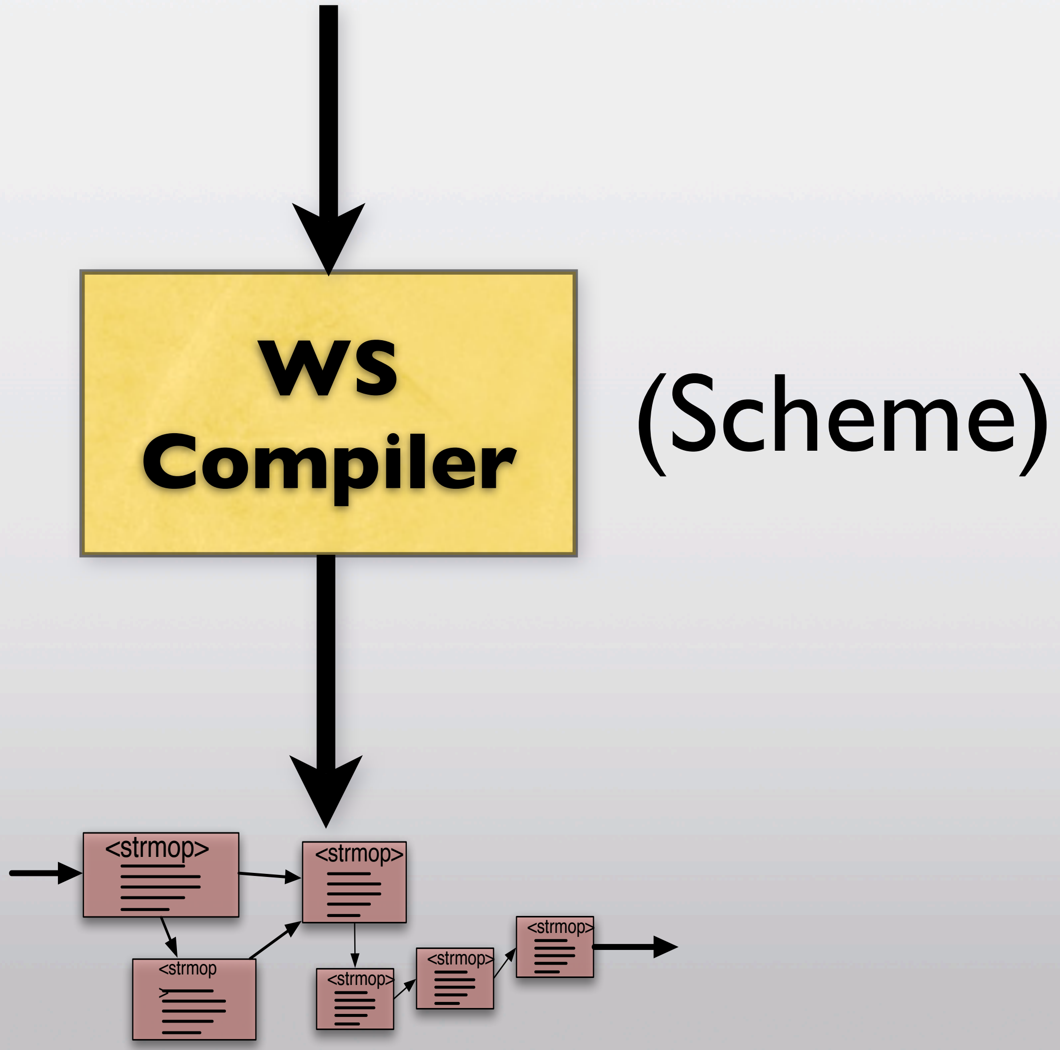

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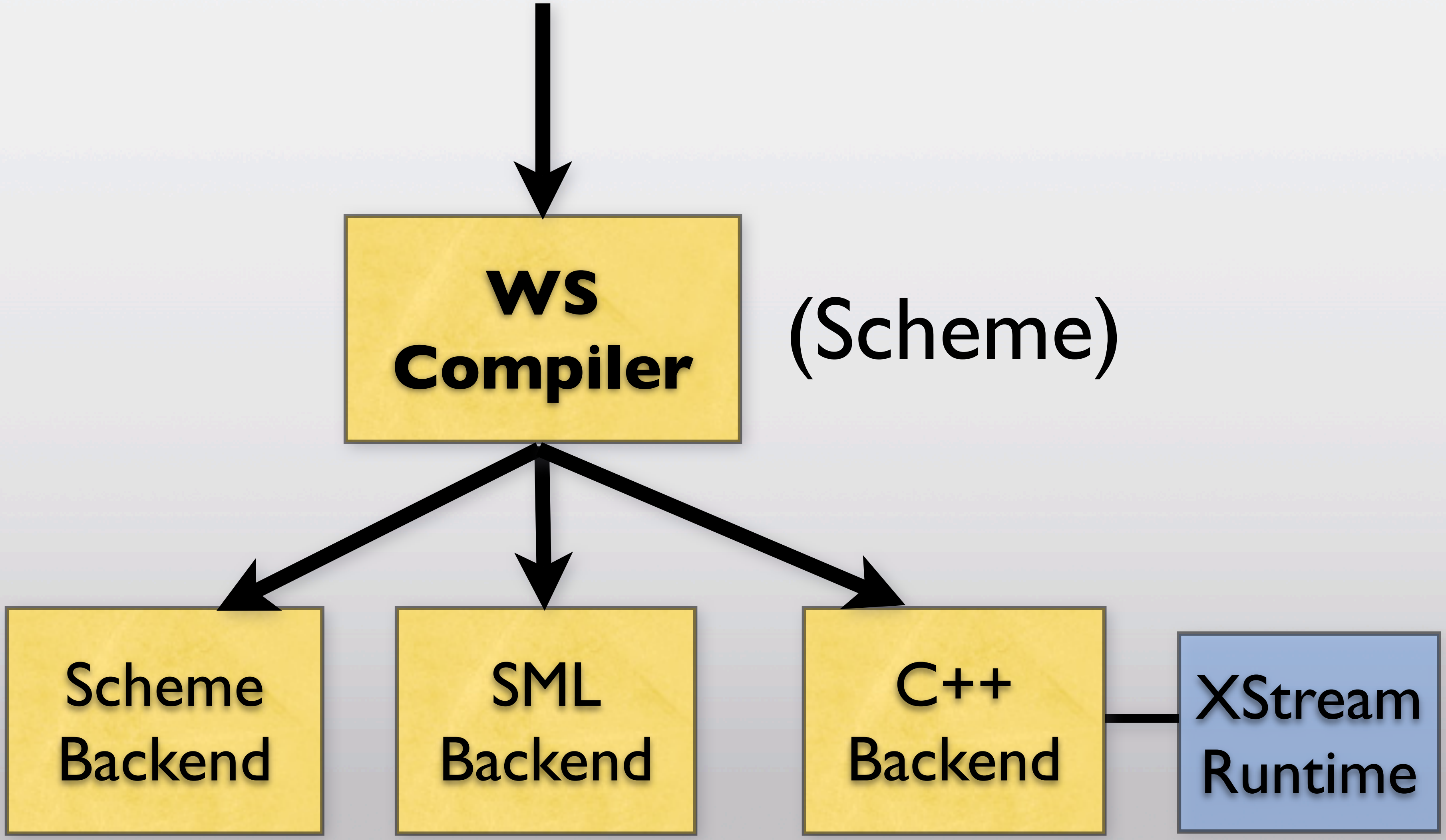

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Scheme Backend

SML Backend

C++ Backend

XStream Runtime

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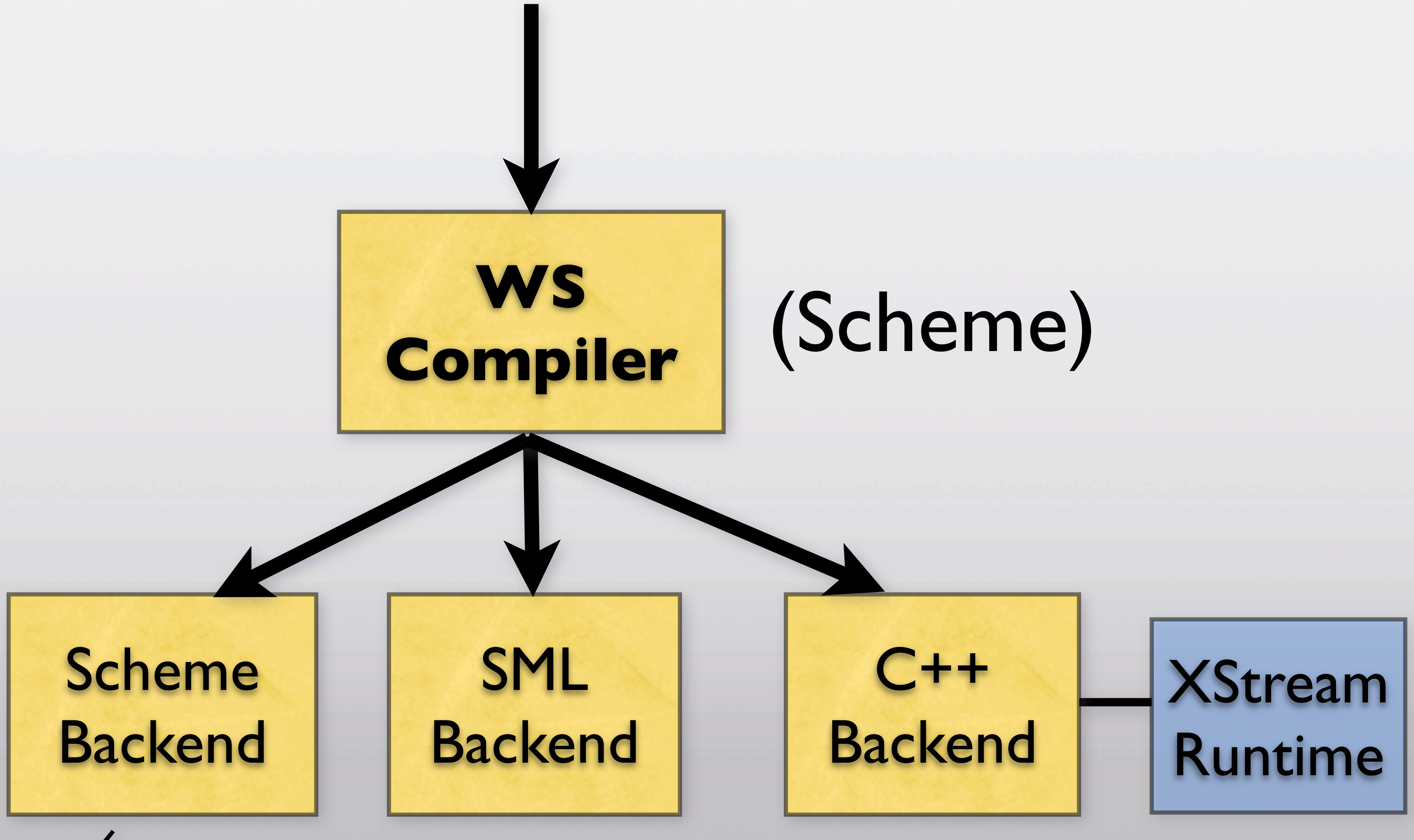

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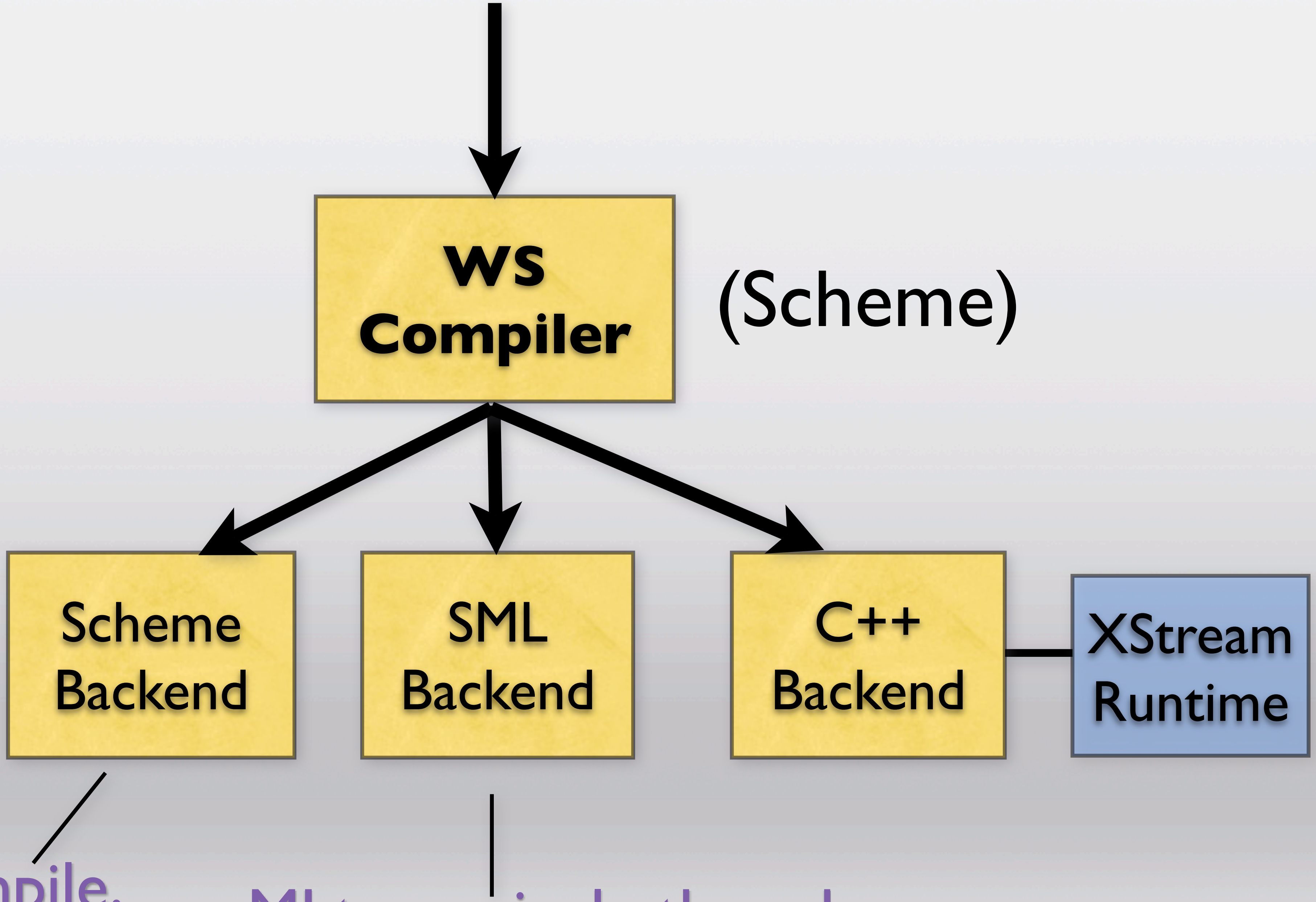

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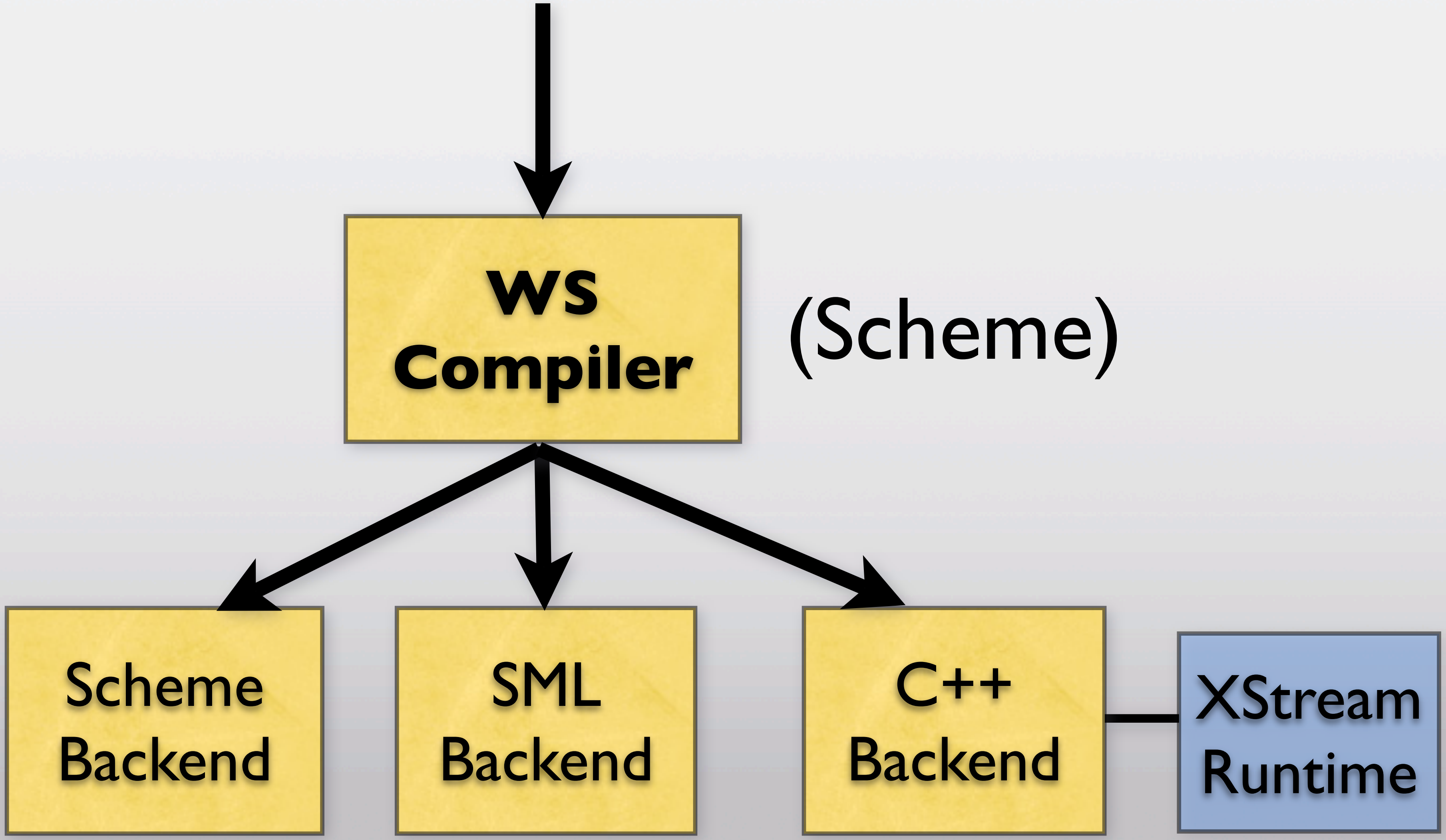

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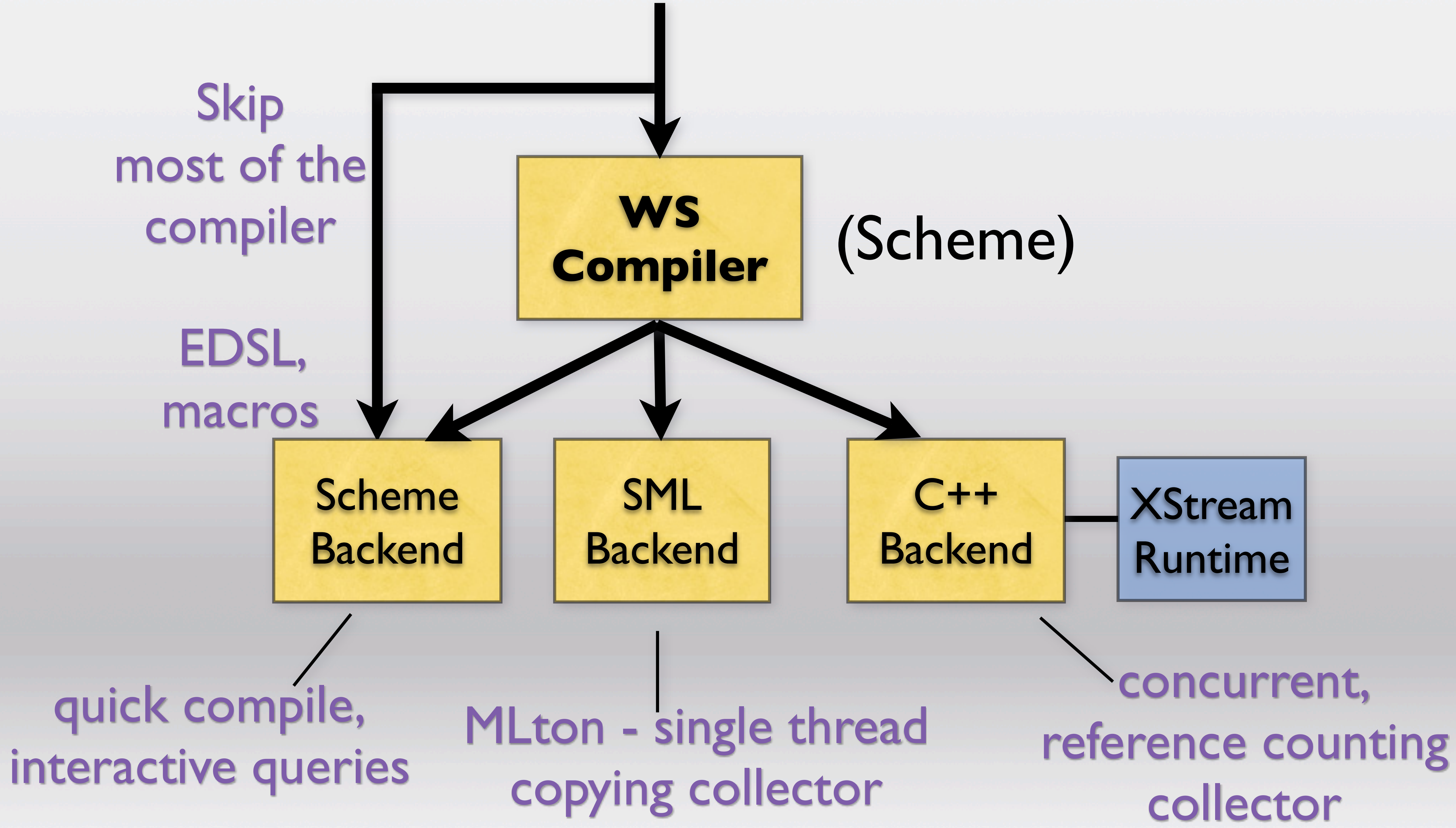

Skip most of the compiler

EDSL, macros

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  - *Parallel* runtime and garbage collector

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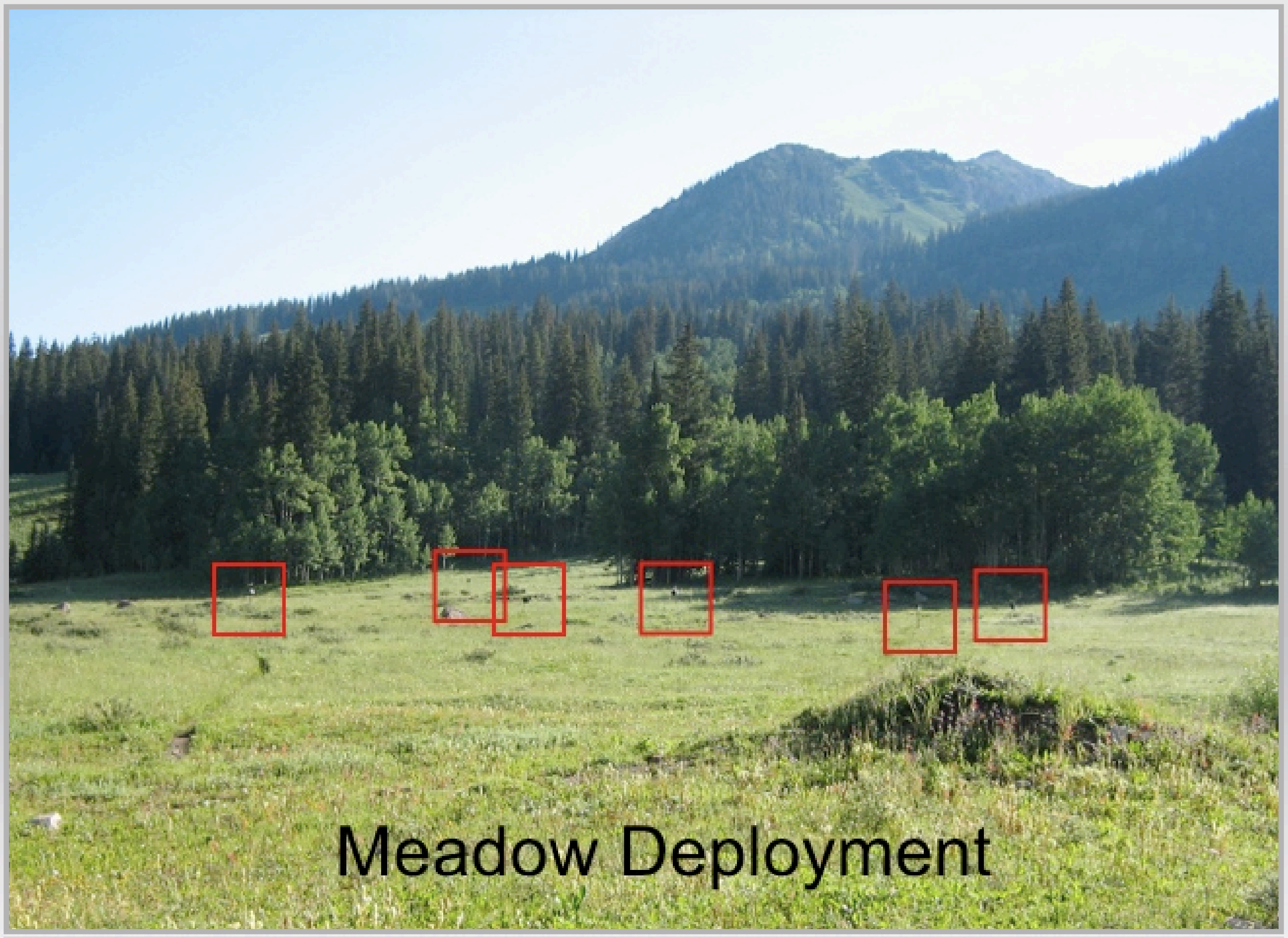
- Downside: potential code bloat

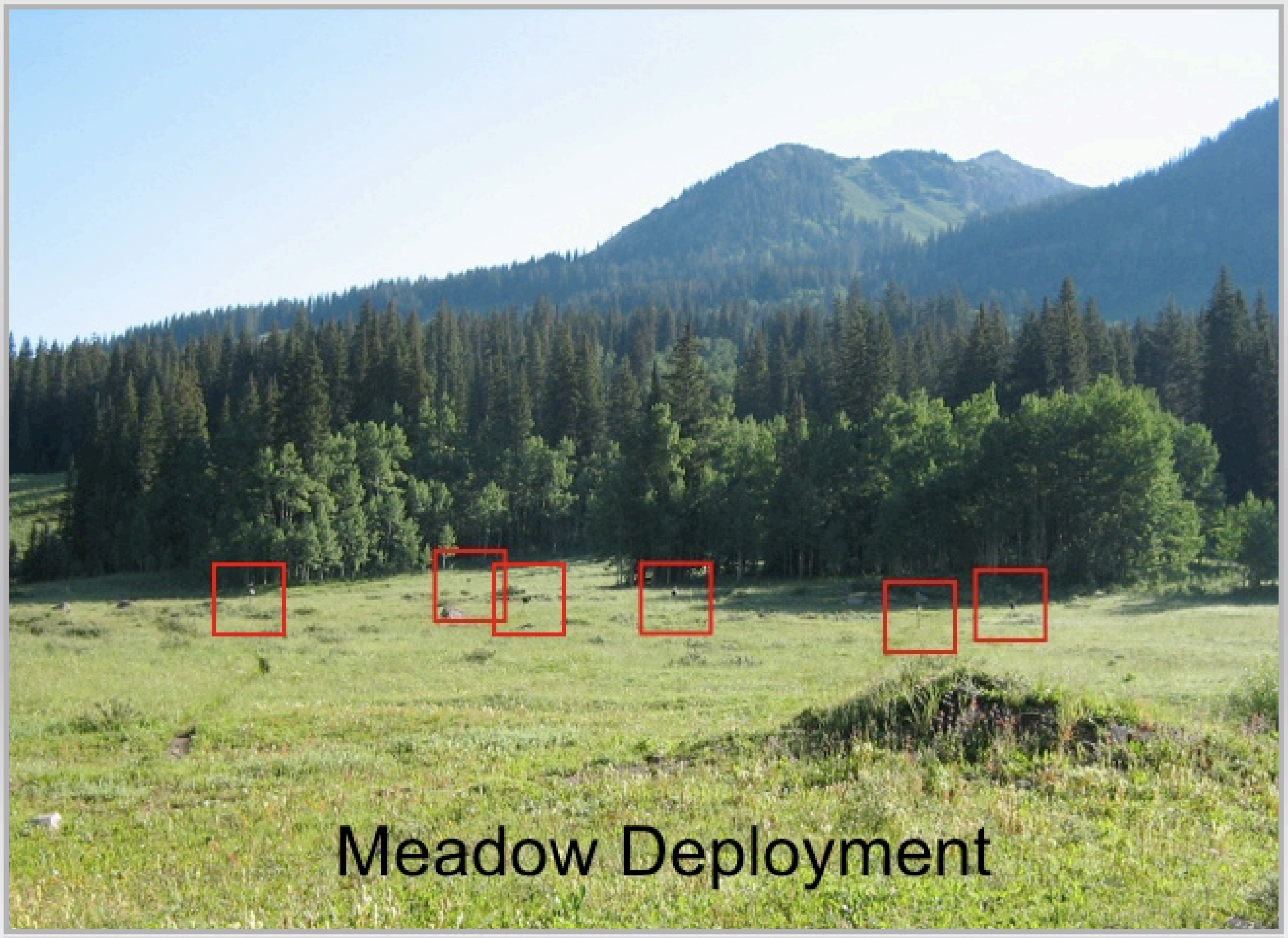
Marmot application



http://wavescope.csail.mit.edu/

Marmot application

- Goal: study calling behavior.



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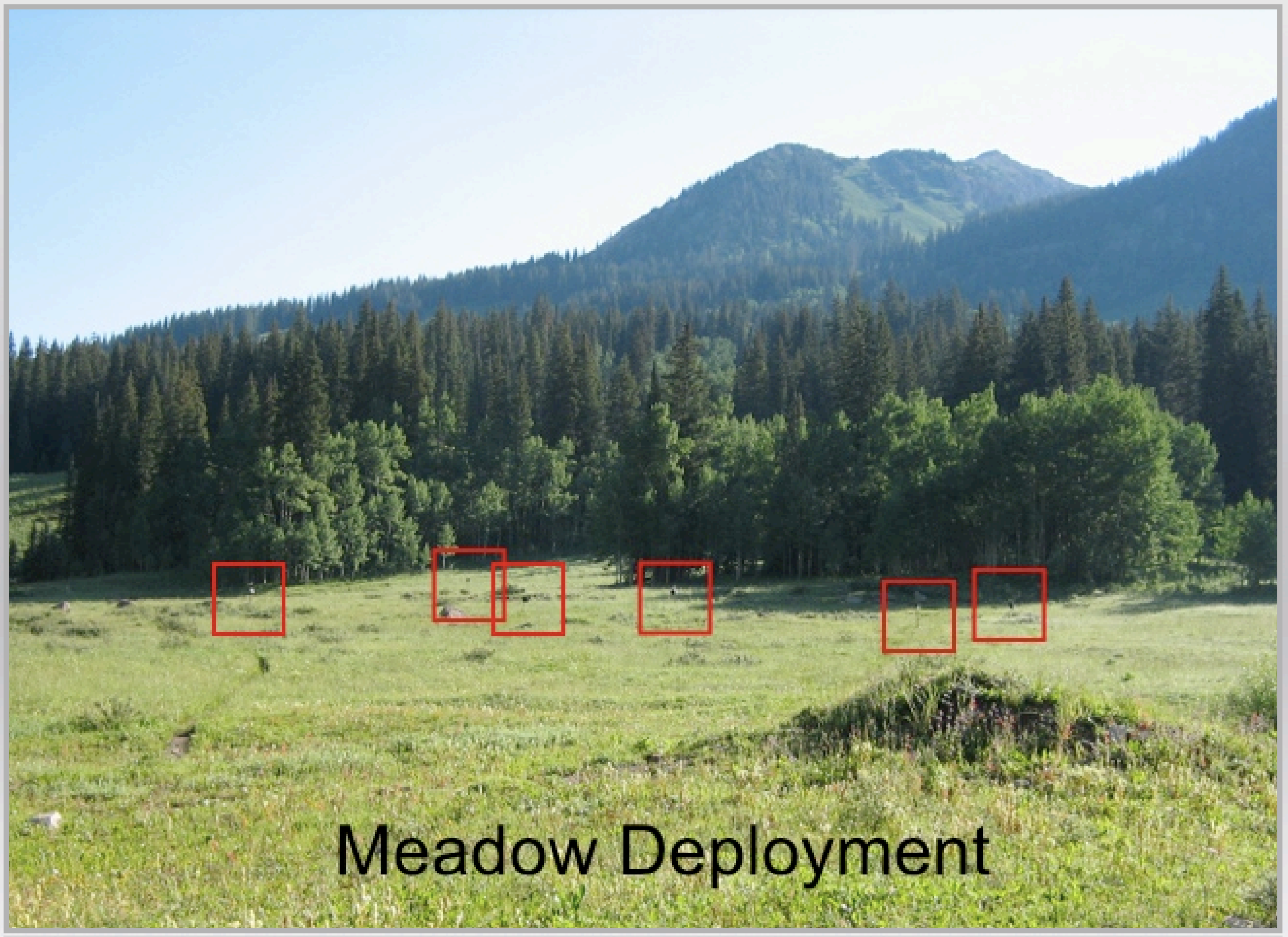

Meadow Deployment

Some Marmots

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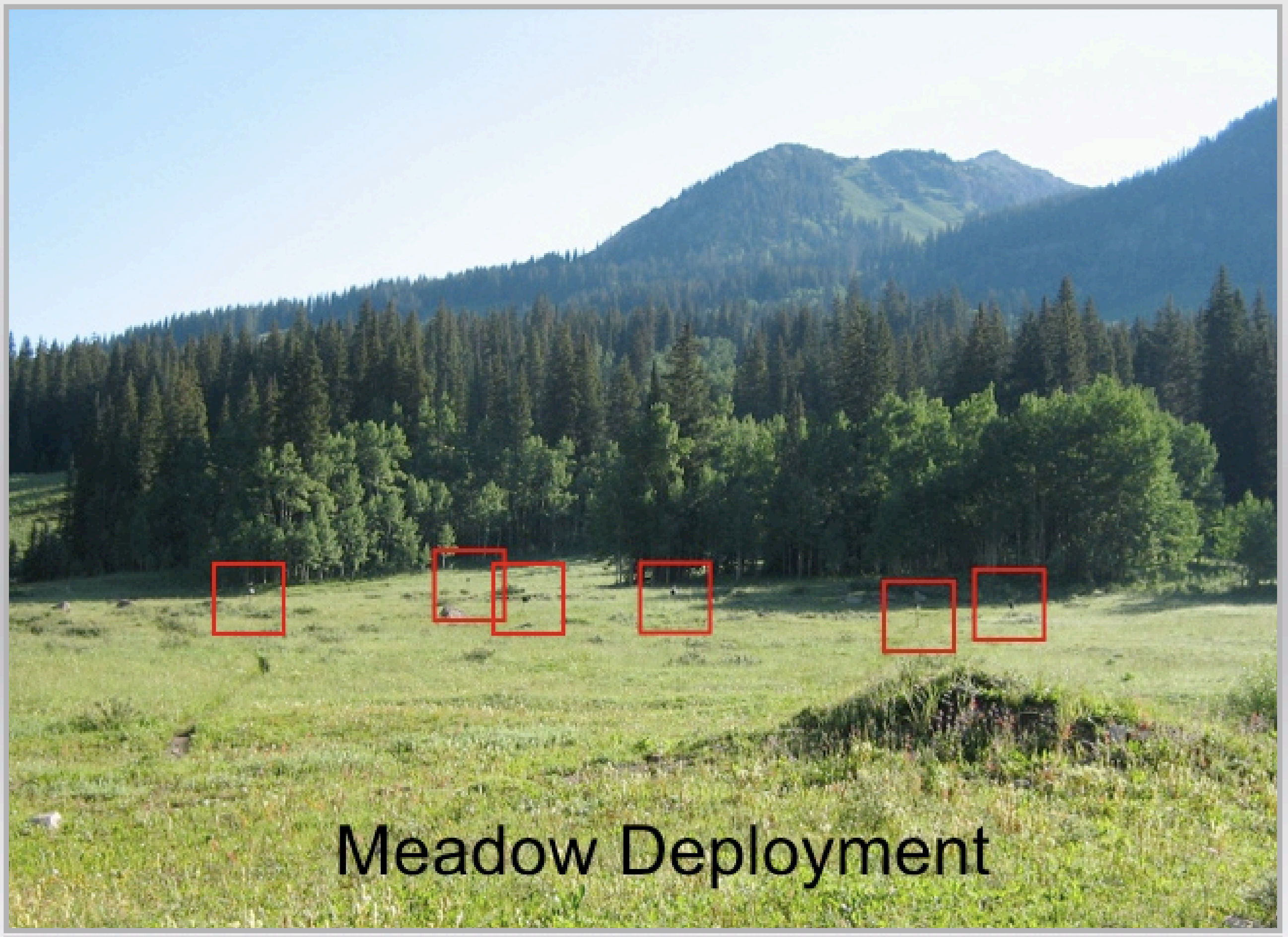

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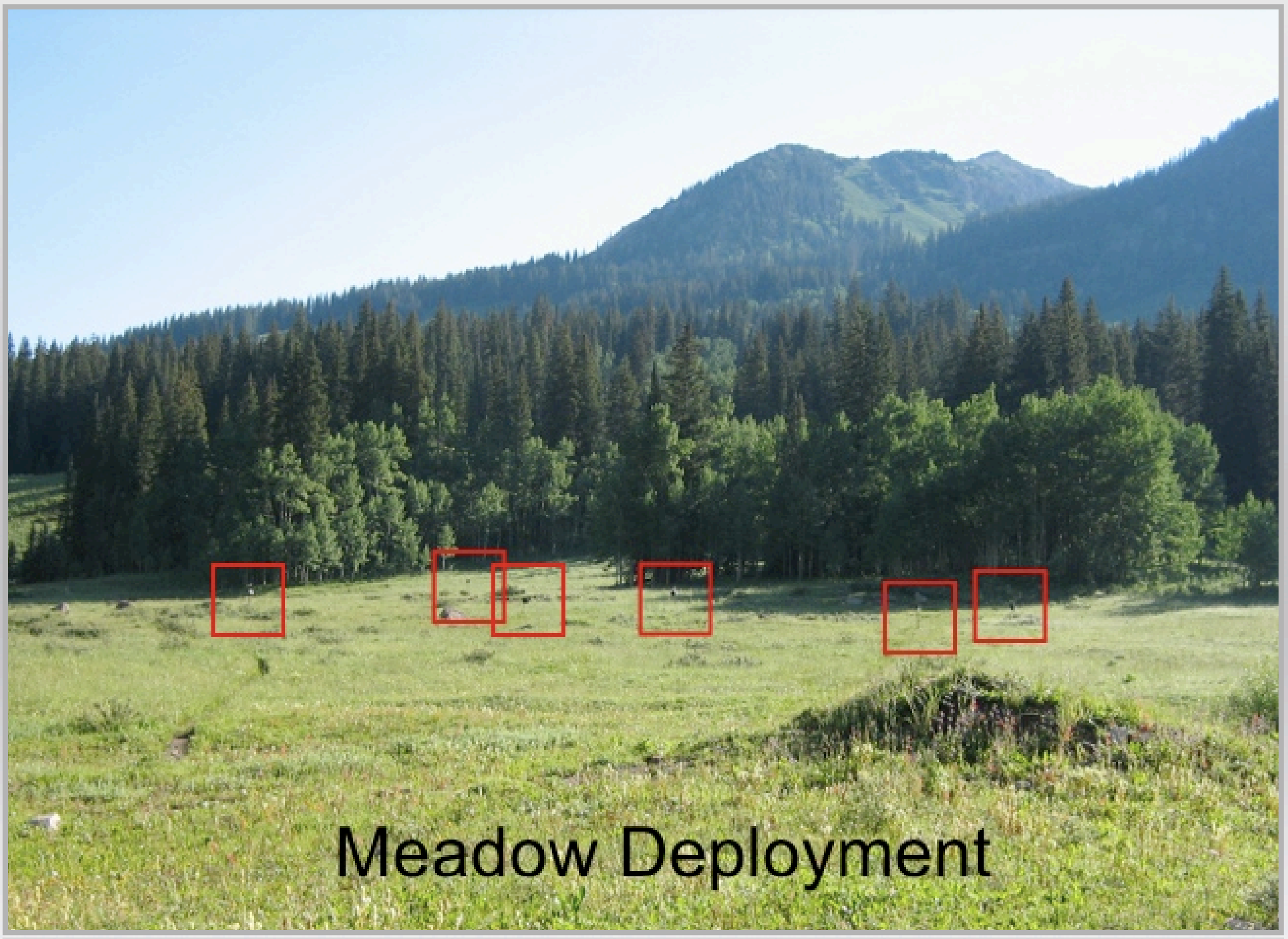
Marmot application

- Goal: study calling behavior.
- Detect, record, localize, classify.



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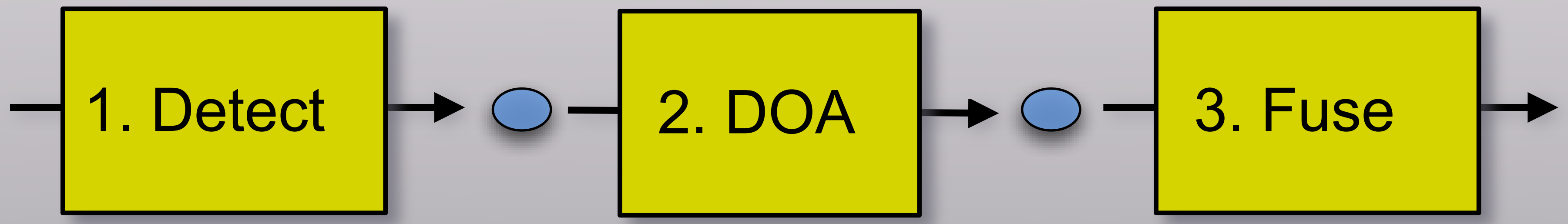
Three phases to marmot localization



1. Detect

2. DOA

3. Fuse

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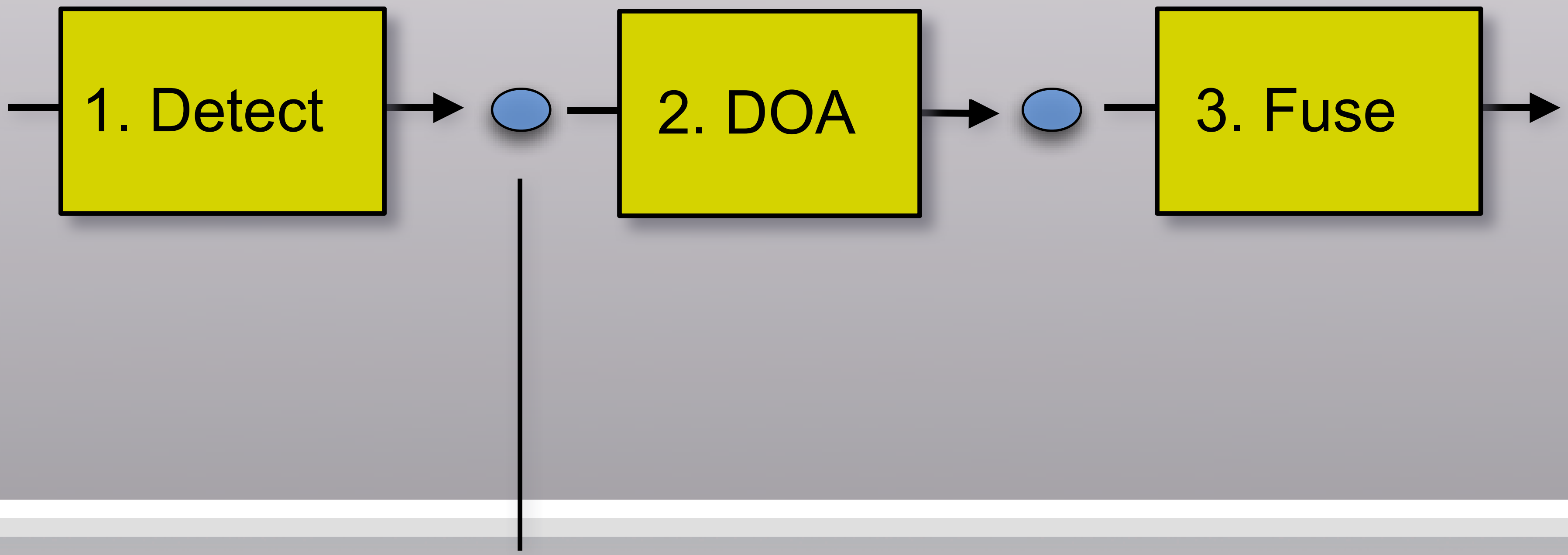

Snippet of
4-channel
Audio

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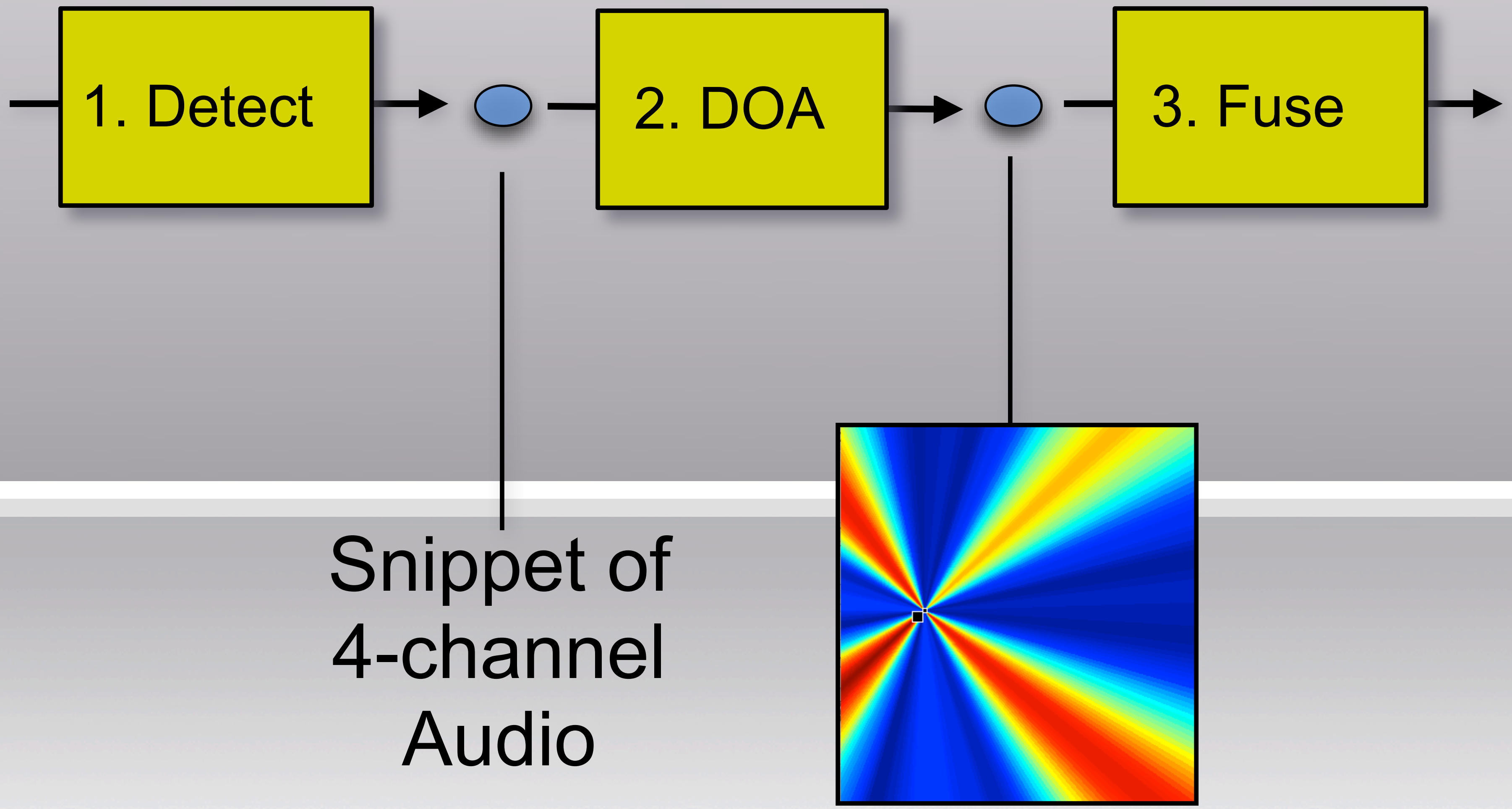

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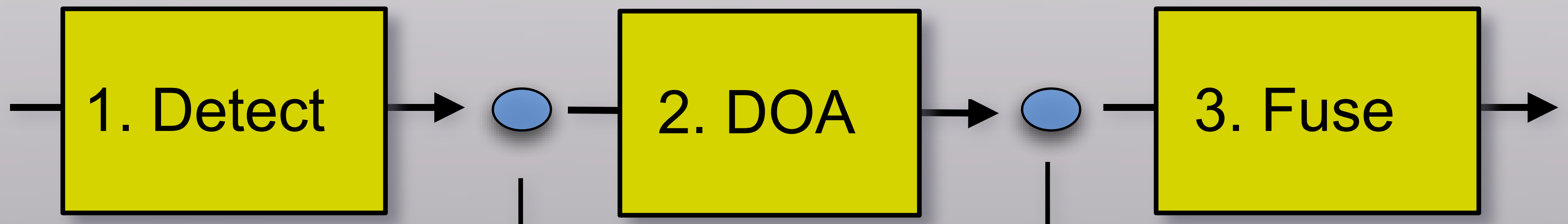

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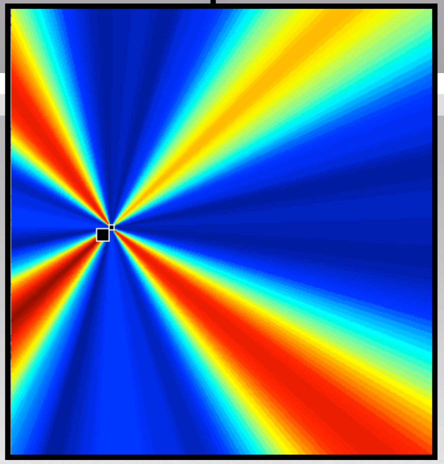

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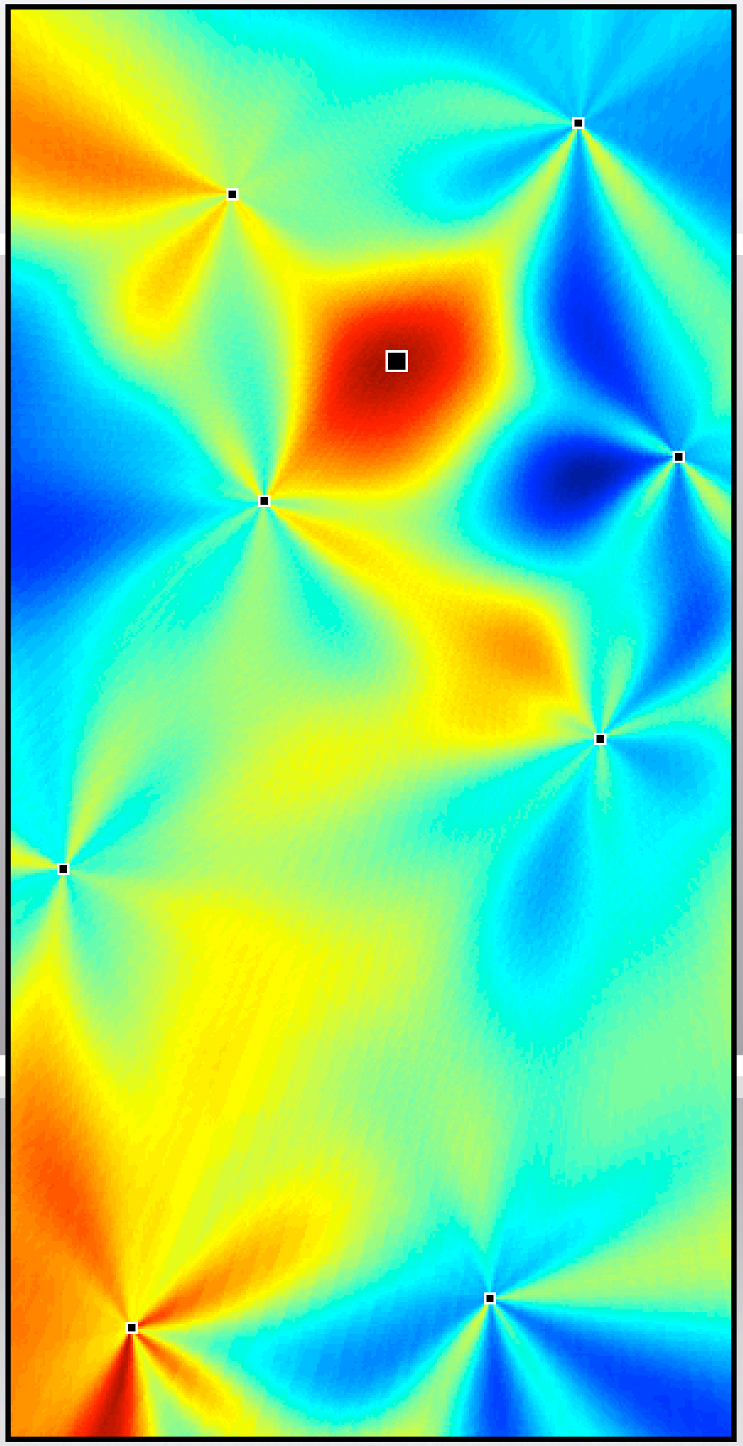

Probability Map

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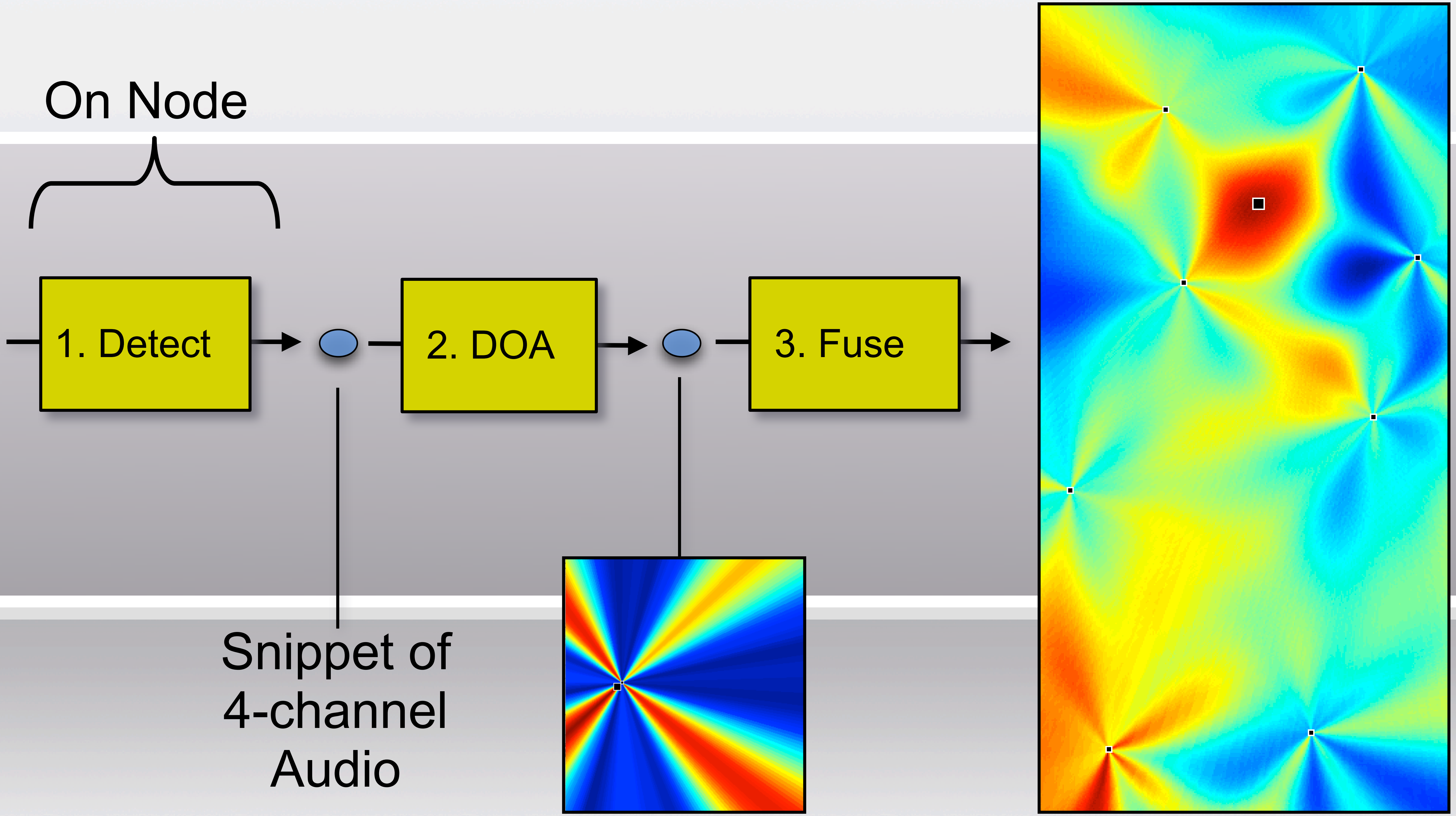

On Node

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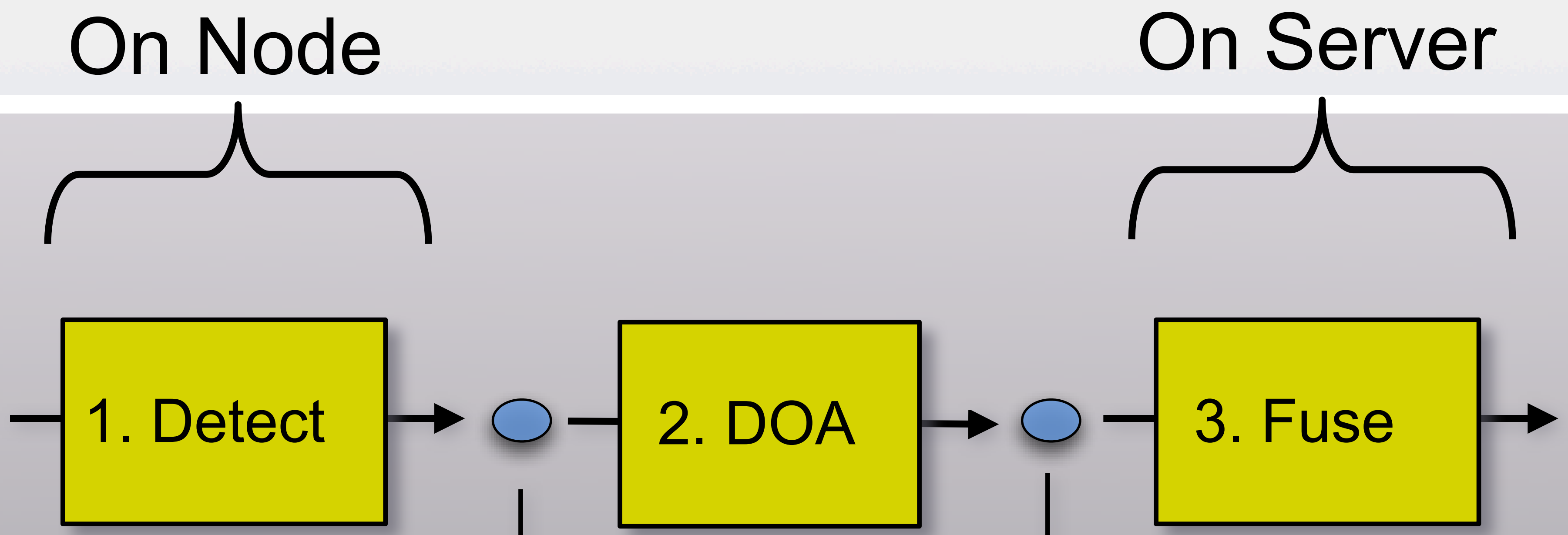

On Node

On Server

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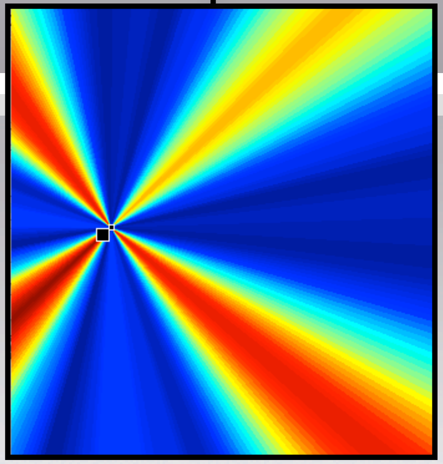

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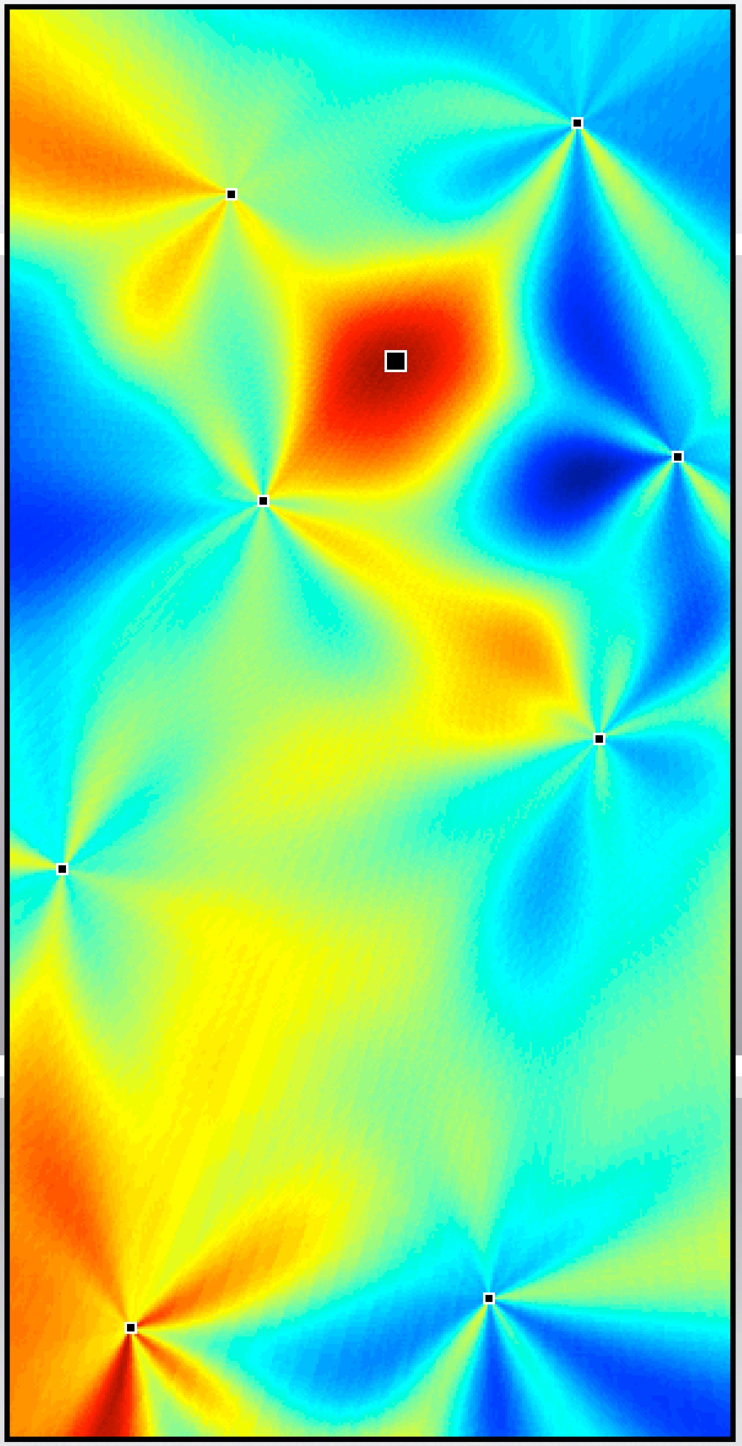

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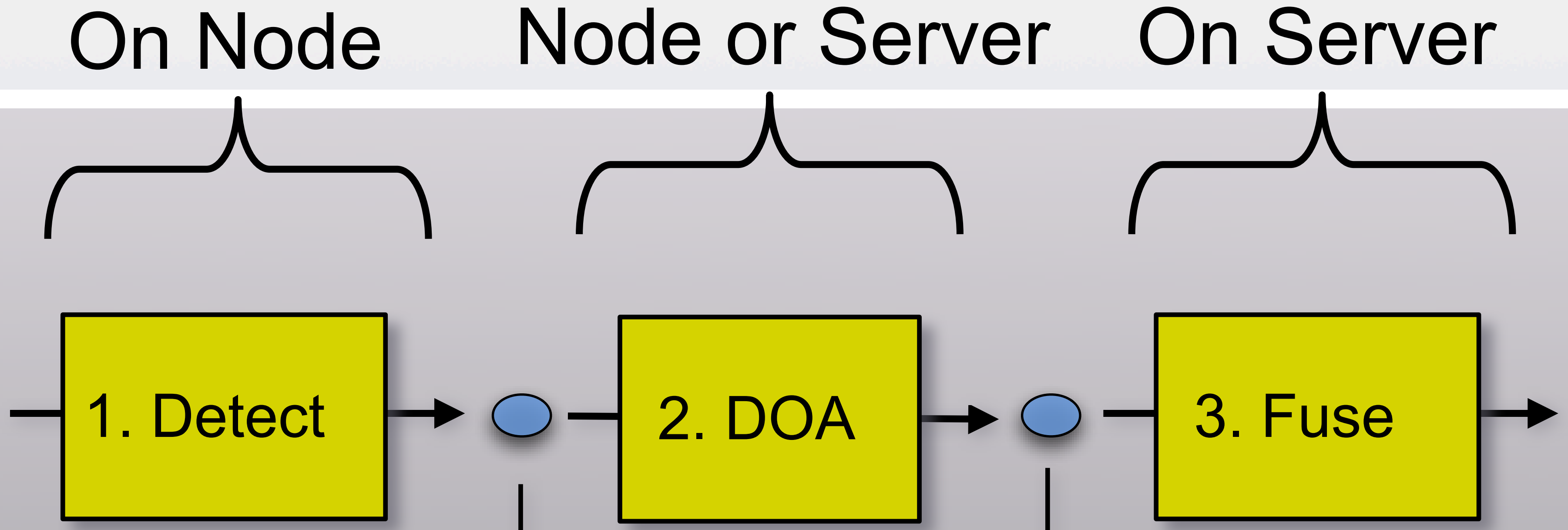

On Node

Node or Server

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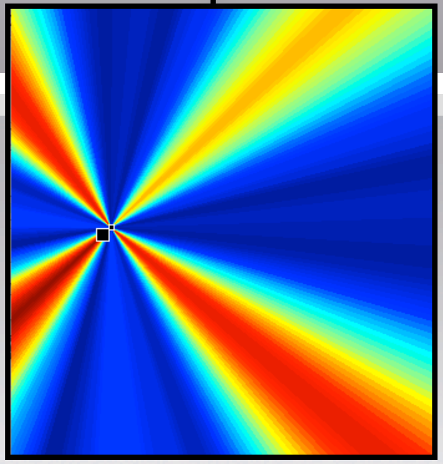

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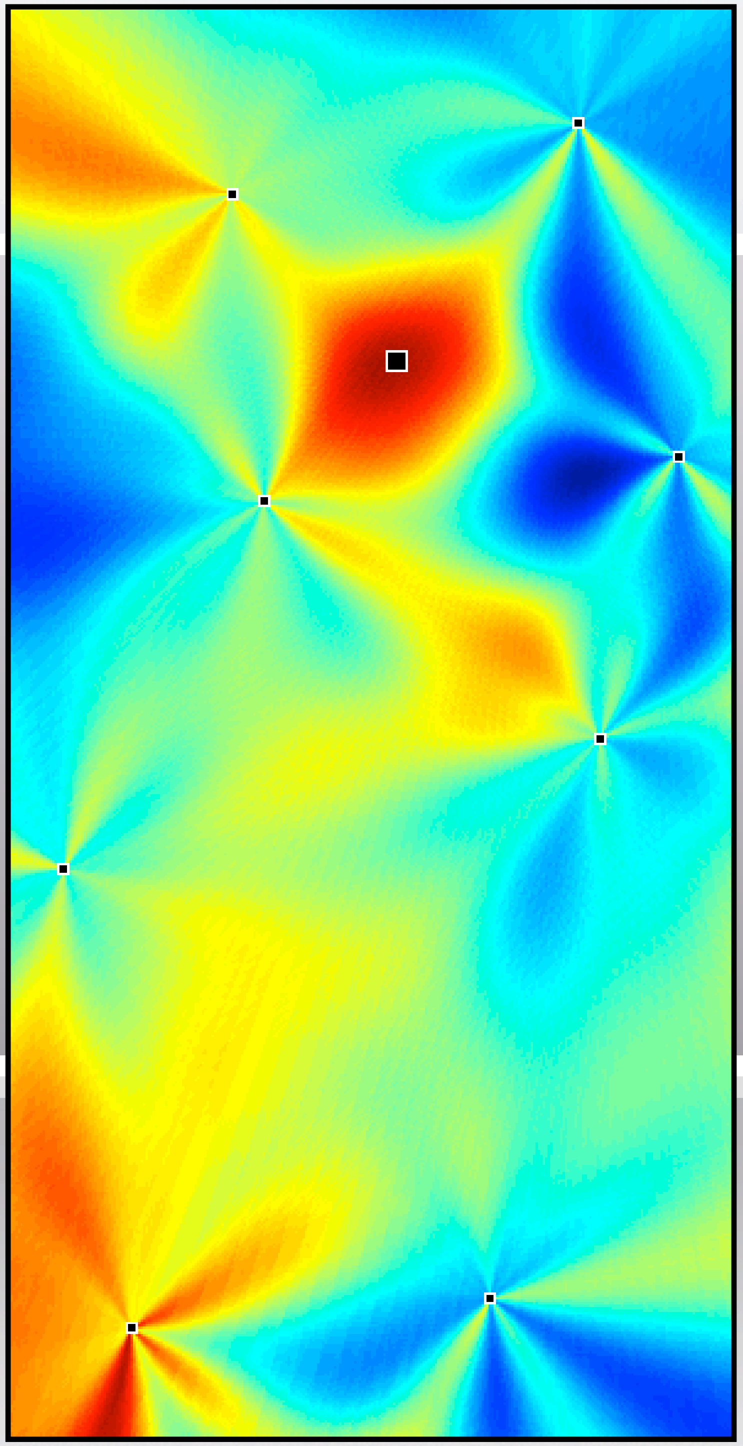

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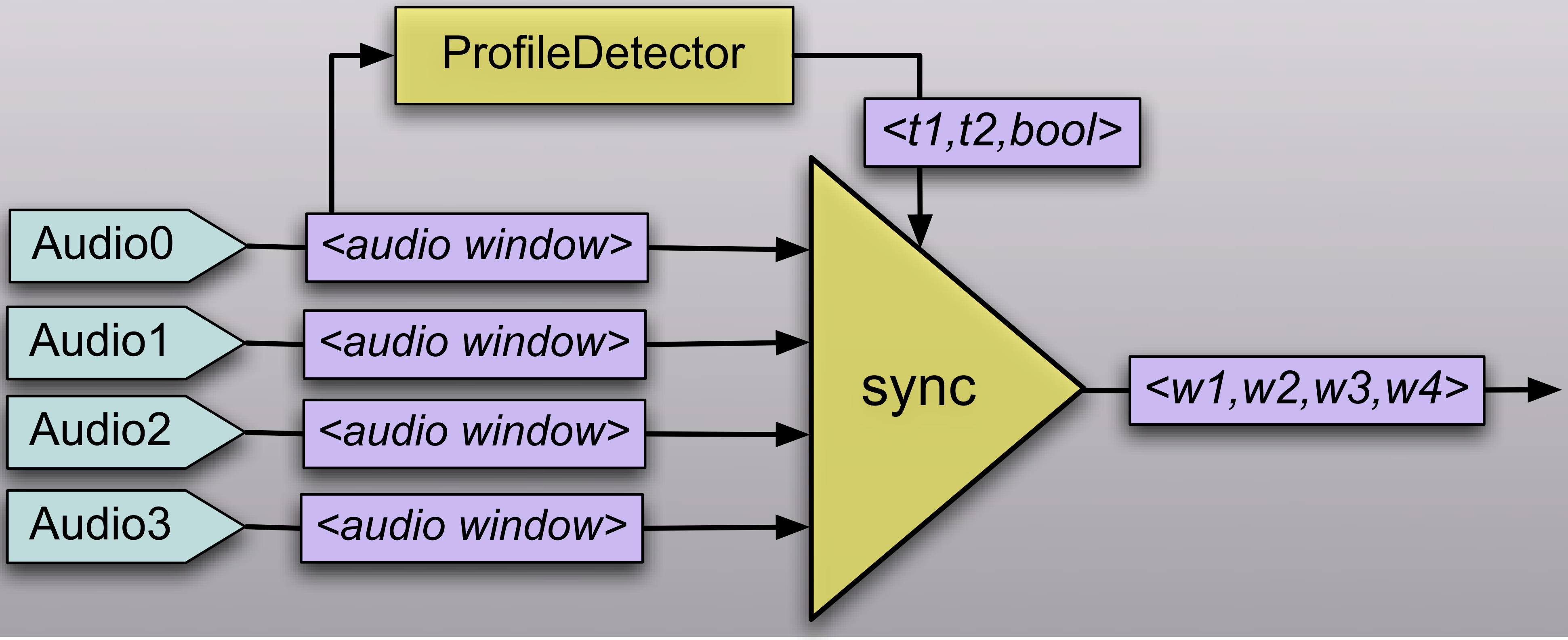
Schematic of Marmot-detector

(Phase1)



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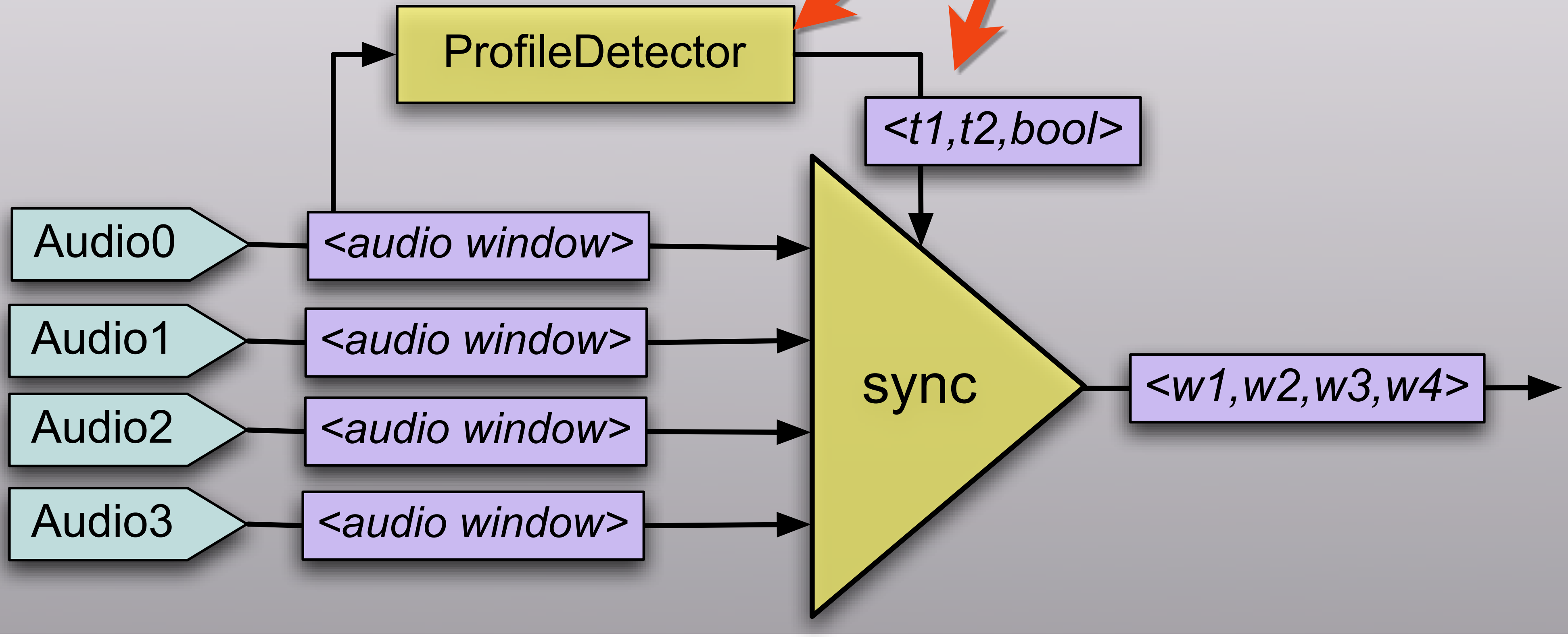
Fast-path DSP to determine temporal ranges for marmot calls



ProfileDetector

<t1,t2,bool>

Audio0

Audio1

Audio2

Audio3

<audio window>

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sync

<w1,w2,w3,w4>

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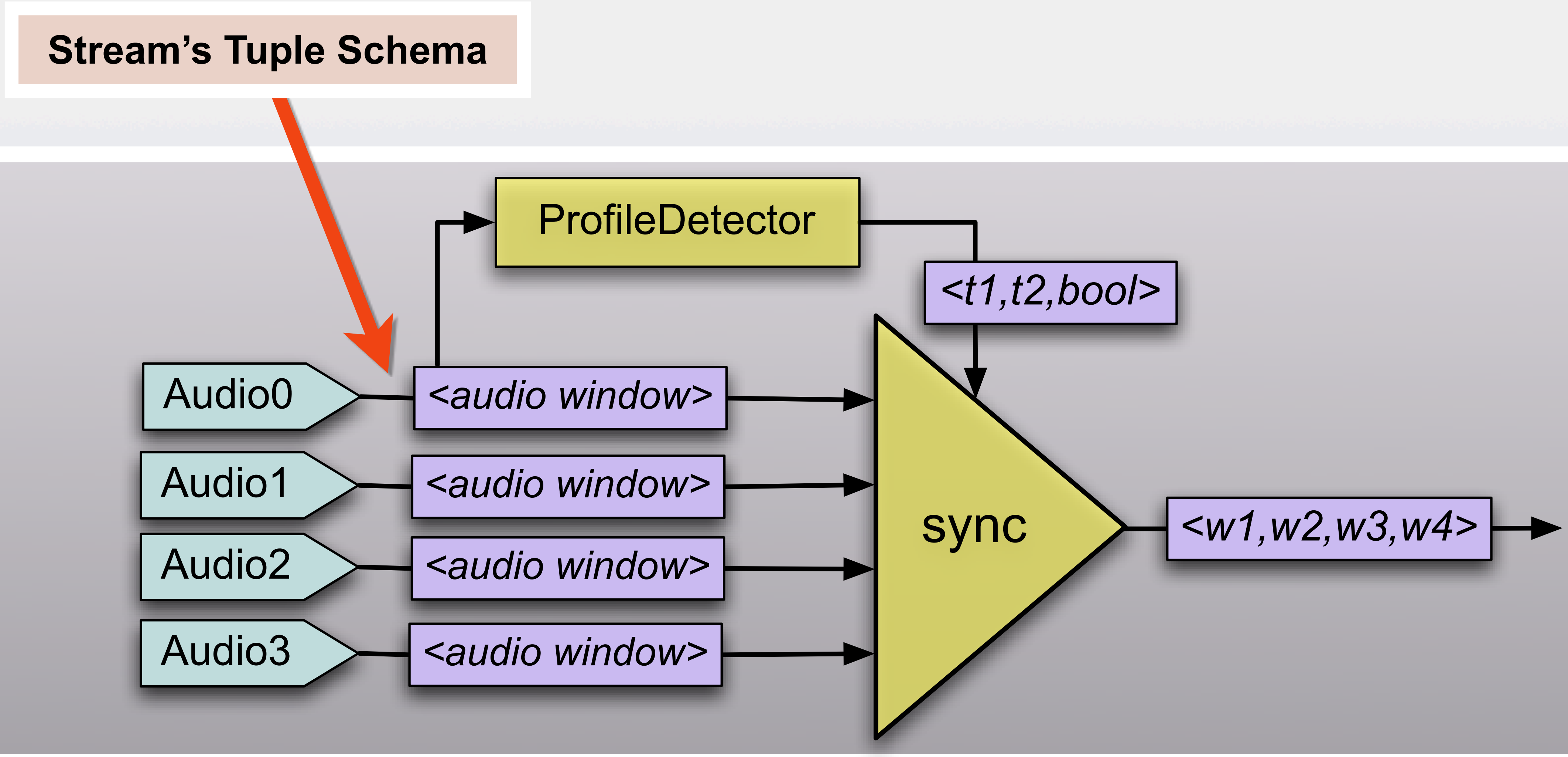

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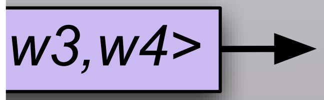
Stream’s Tuple Schema

Data Model:

- **Streams are first-class values.**

- **Streams contain any type but Stream**
  - Algebraic data-types (but not recursive)
  - Size of every type is statically known
  - Dynamic allocation allowed

- **SigSegs: efficiently managed windows of samples**
  - cheap to append, copy, forward, rewindow
  - fewer timestamps



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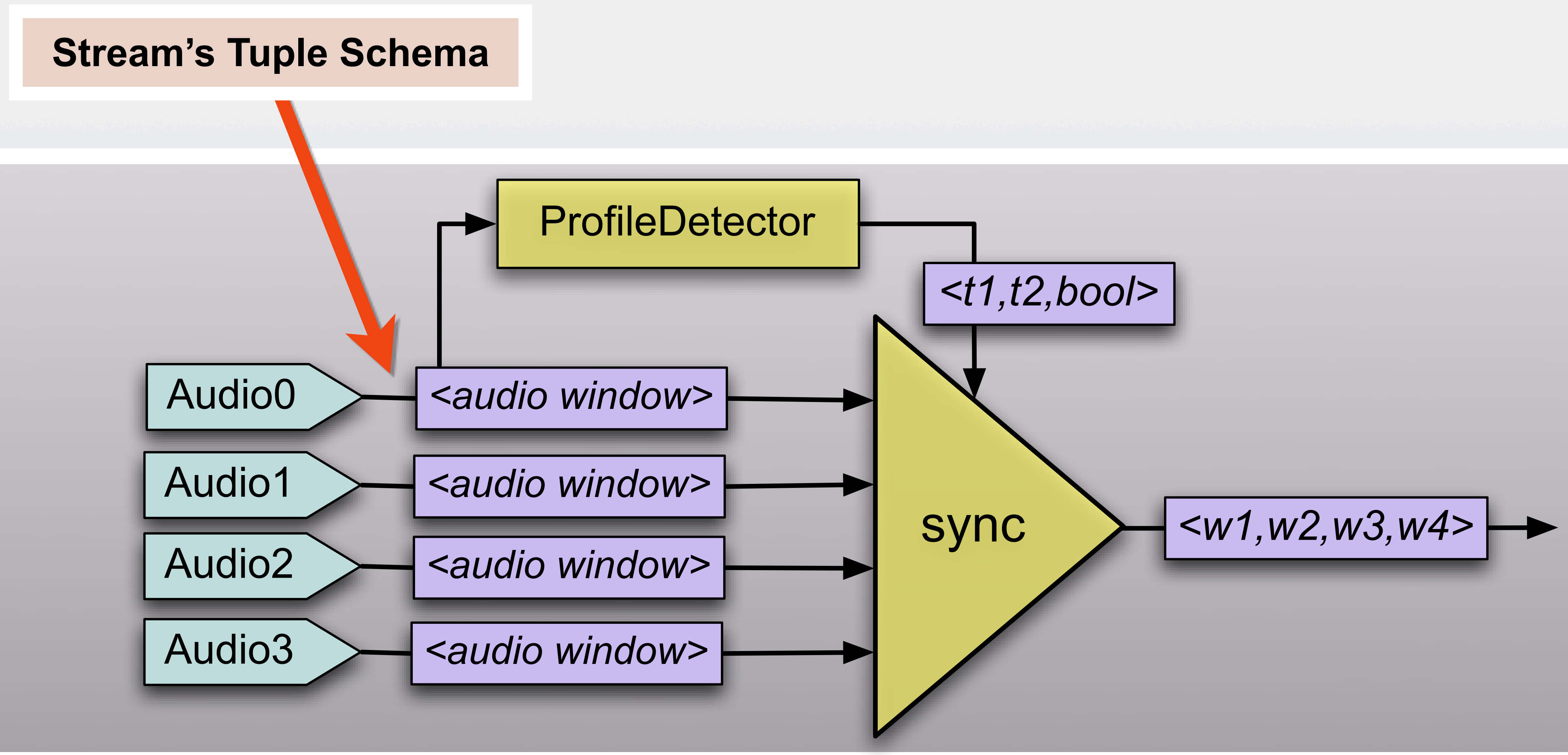

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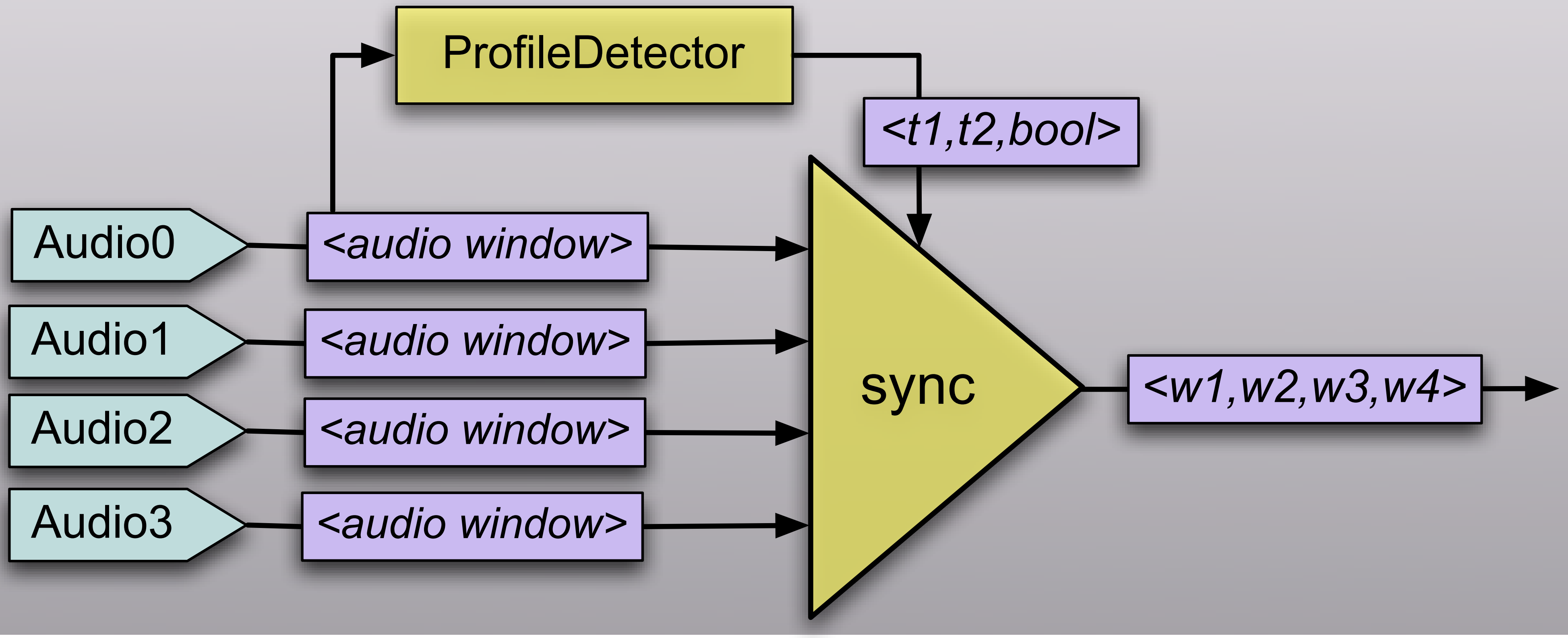
WaveScript detector code



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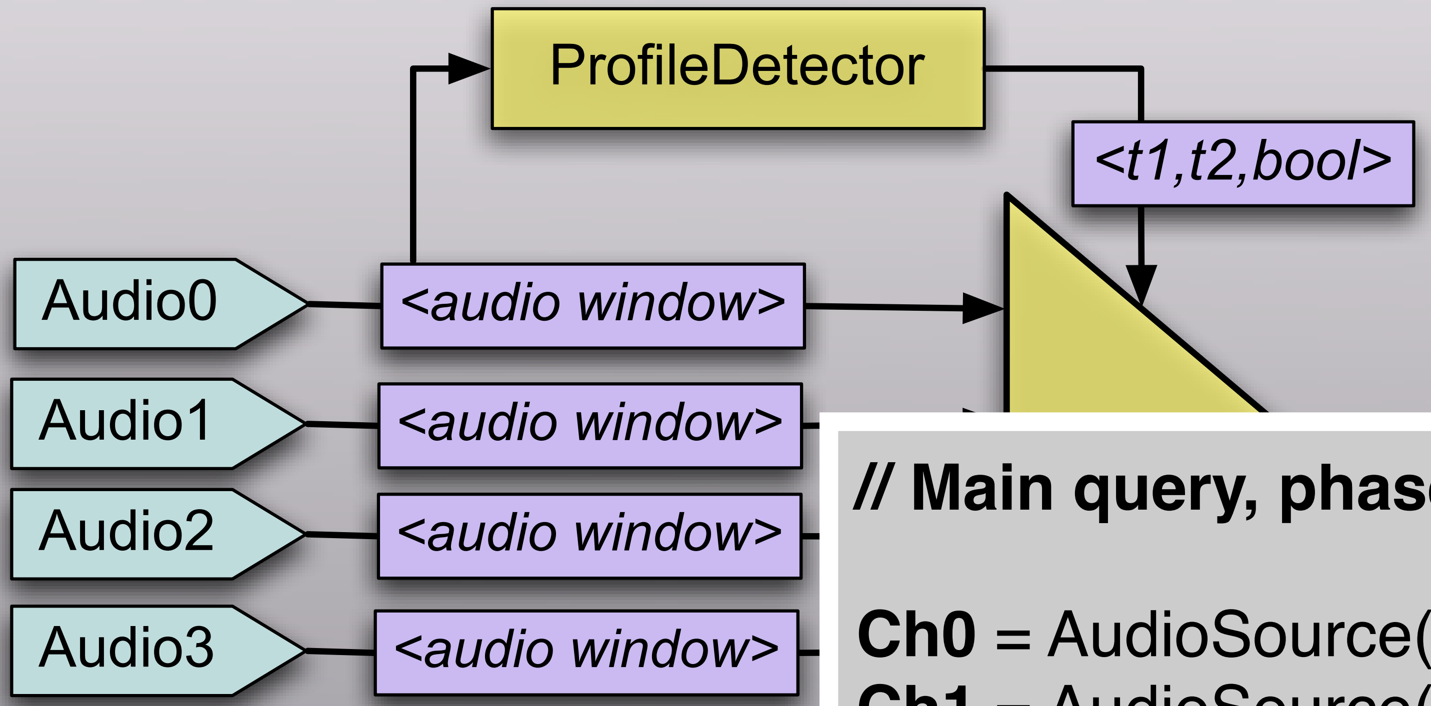

```
// Main query, phase 1

Ch0 = AudioSource(0, 48000, 1024);
Ch1 = AudioSource(1, 48000, 1024);
Ch2 = AudioSource(2, 48000, 1024);
Ch3 = AudioSource(3, 48000, 1024);

control = profileDetect(Ch0, marmotScore,
                        (64,192));
datawindows = sync4(control, Ch0, Ch1,
                              Ch2, Ch4);
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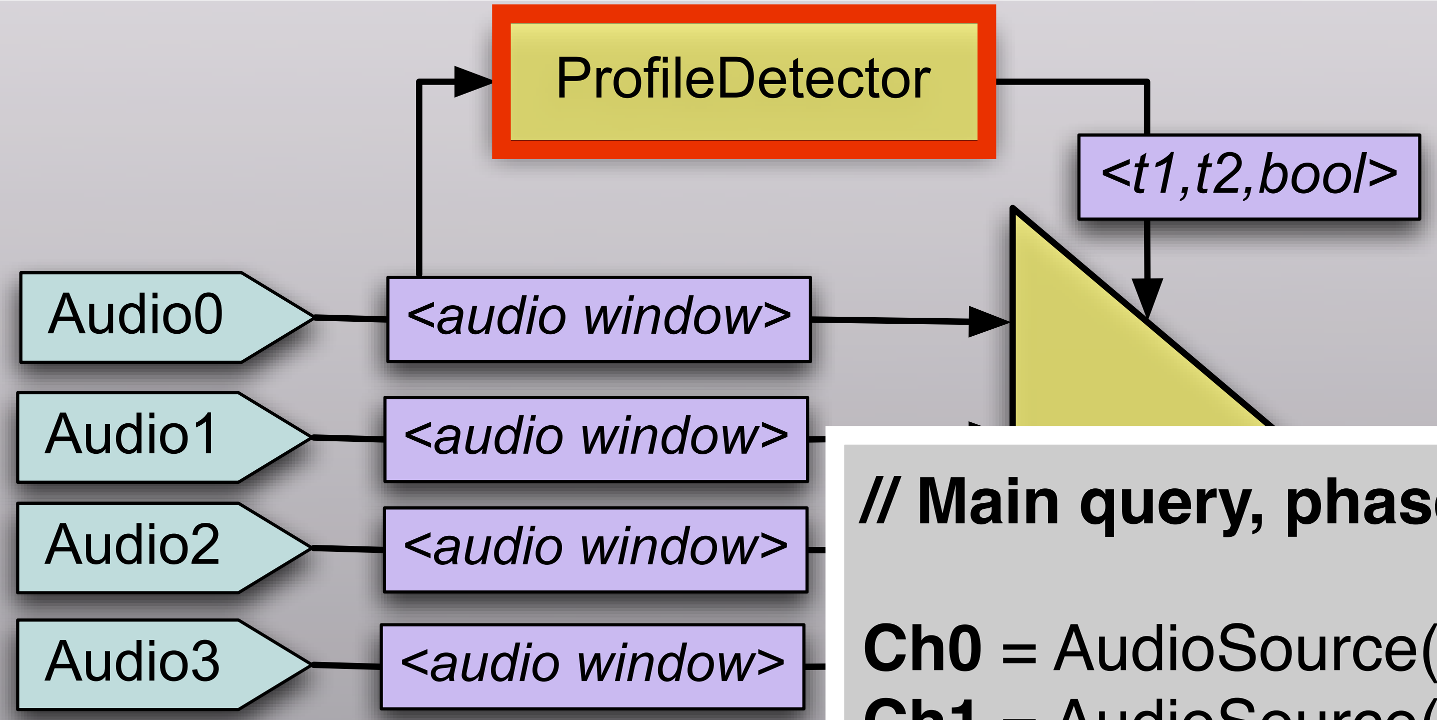

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http://wavescope.csail.mit.edu/

WaveScript detector code

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fun profileDetect(S : Stream (SigSeg Int16),
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   withscores : Stream (Float, SigSeg Int16)
   withscores = zip2(scores, wins);
   return threshFilter(withscores);
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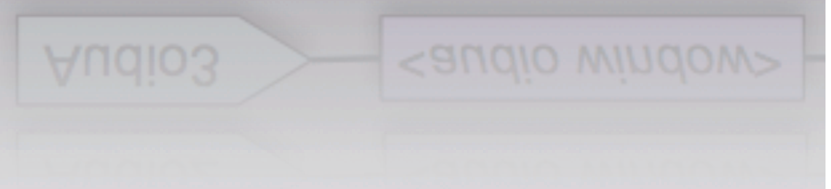

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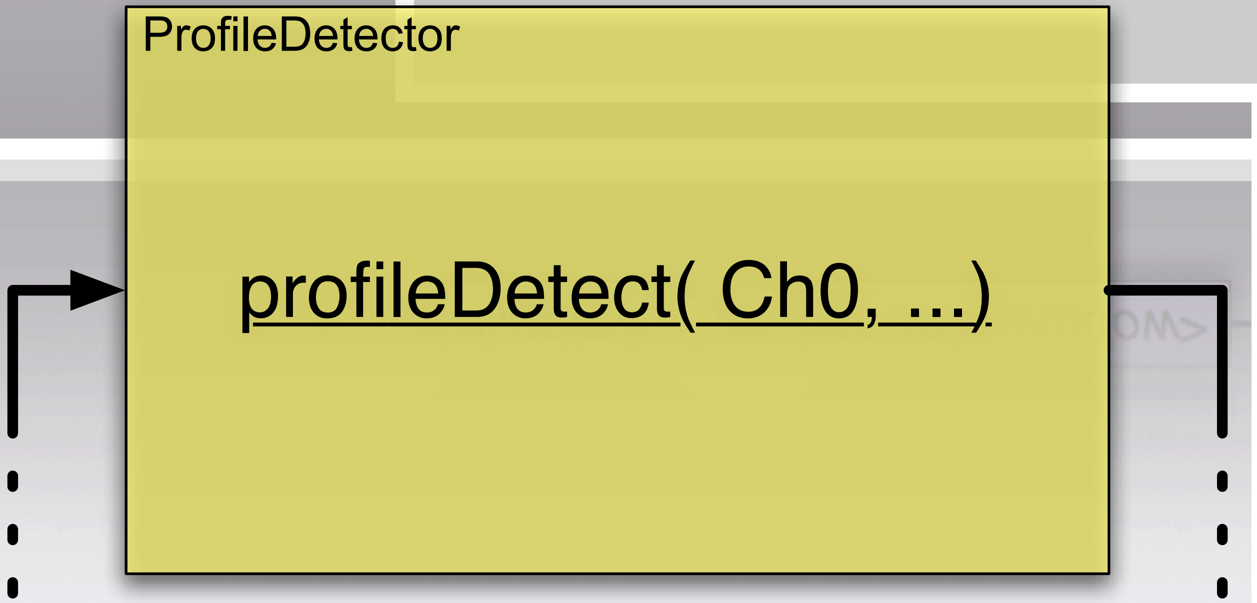

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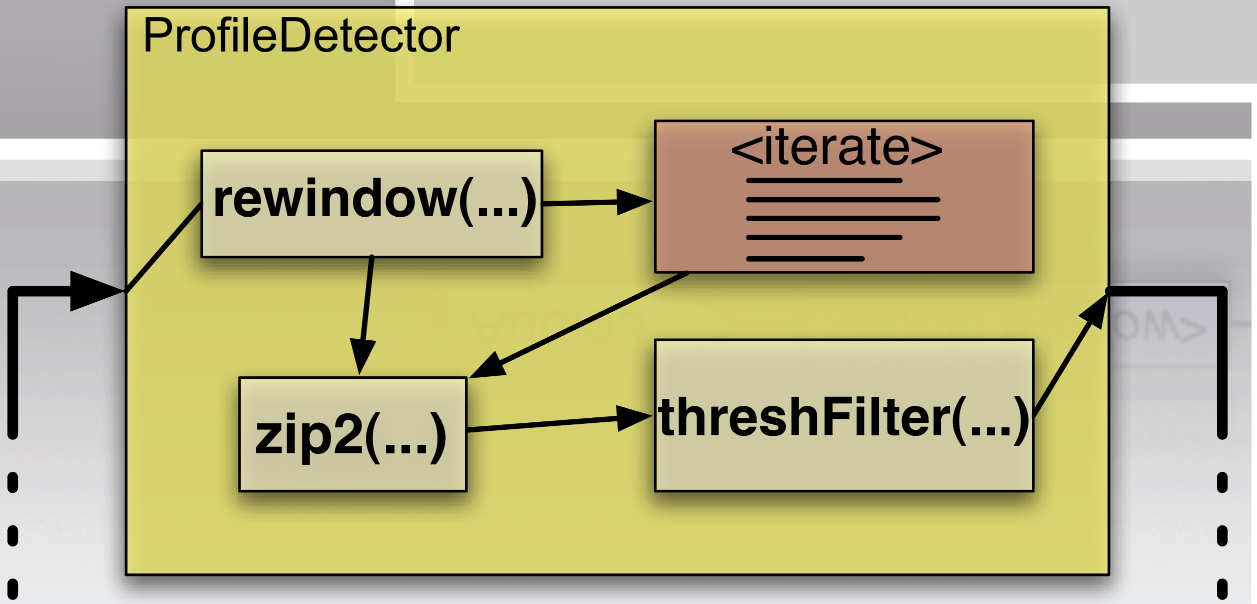

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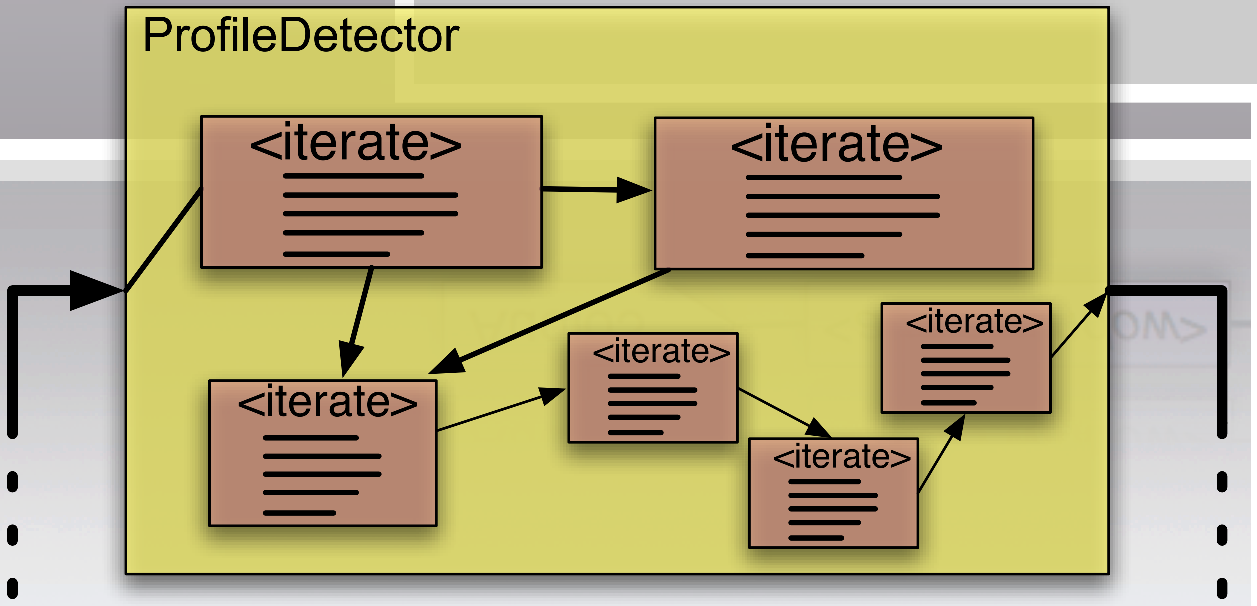

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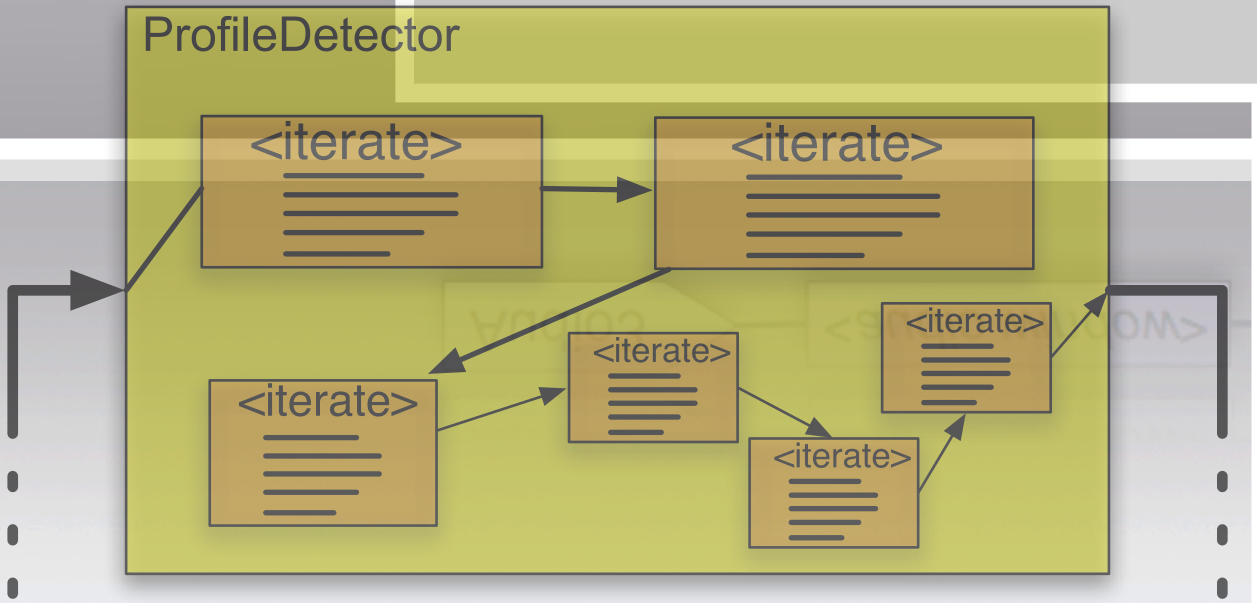

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                  (
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  scores = map(s
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  withscores = zi
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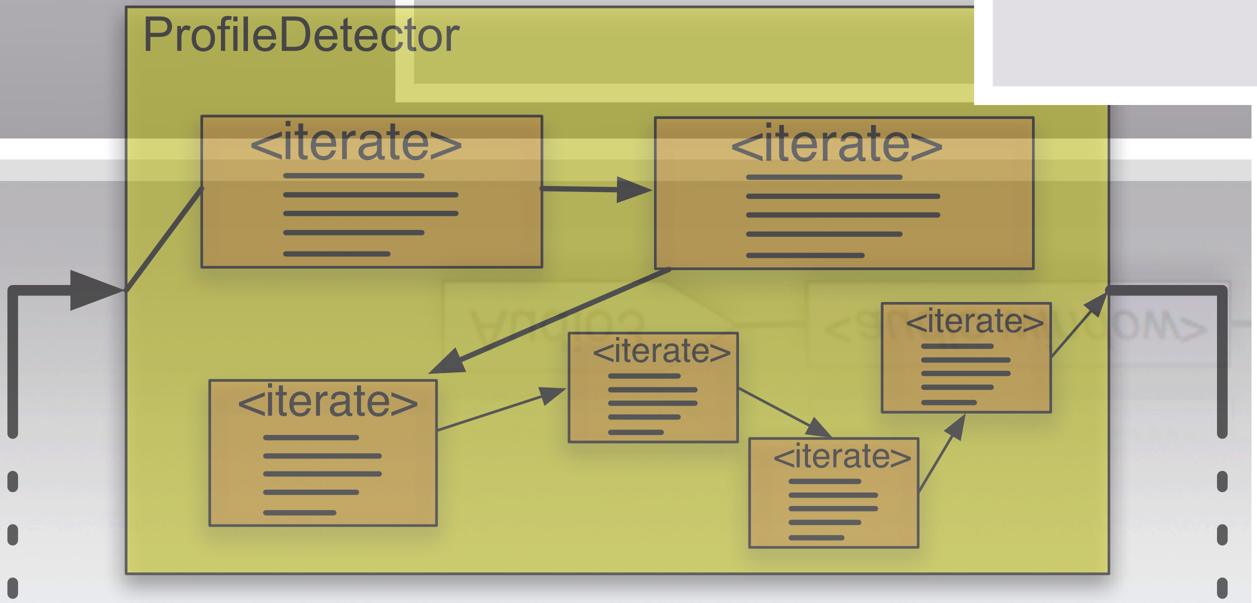
```

“Wide-band” Language



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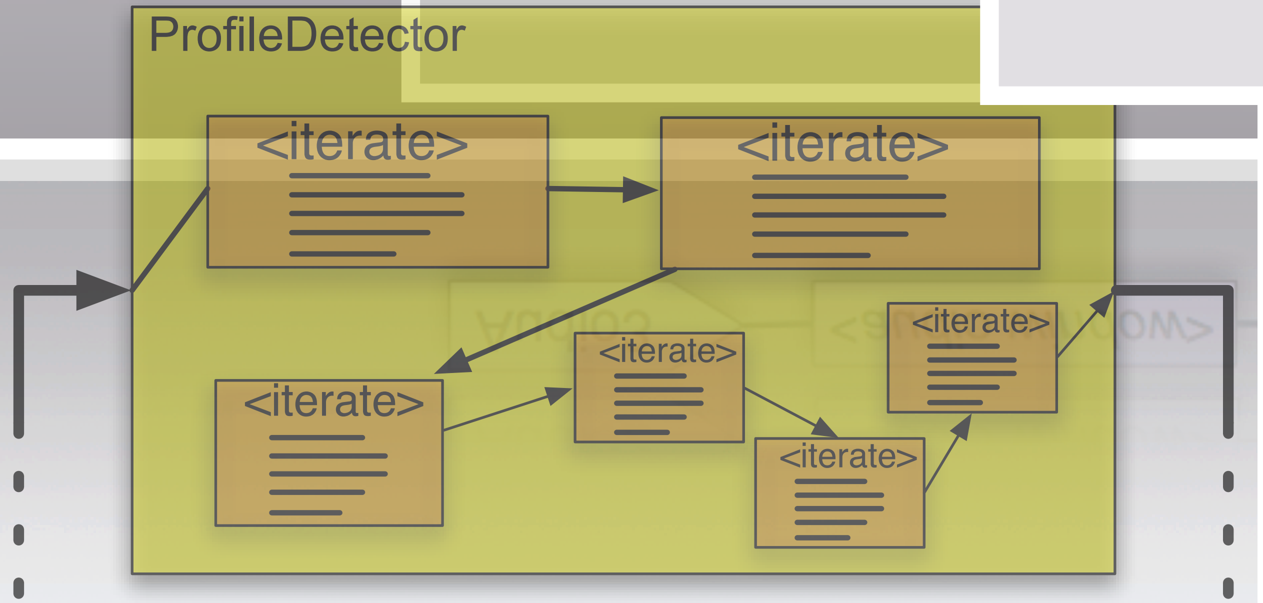

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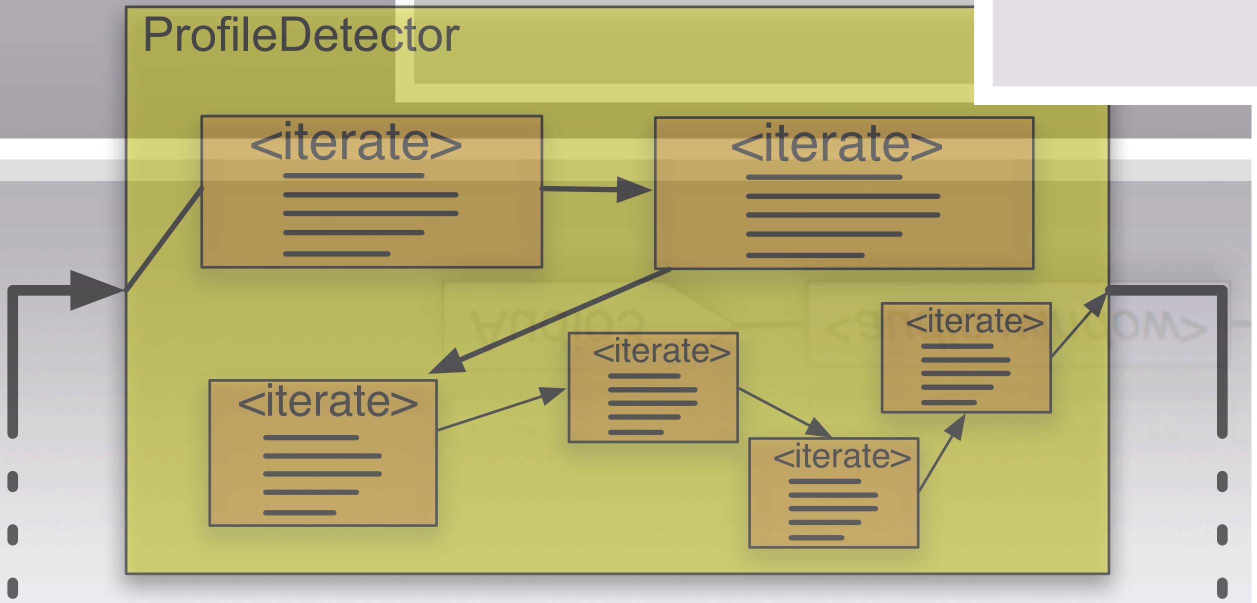
“Wide-band” Language

- High-level, query-like declarative programs
  - map, project, filter streams
  - apply library signal-processing ops
- Low-level, imperative code within custom-operators
  - use iterate to introduce



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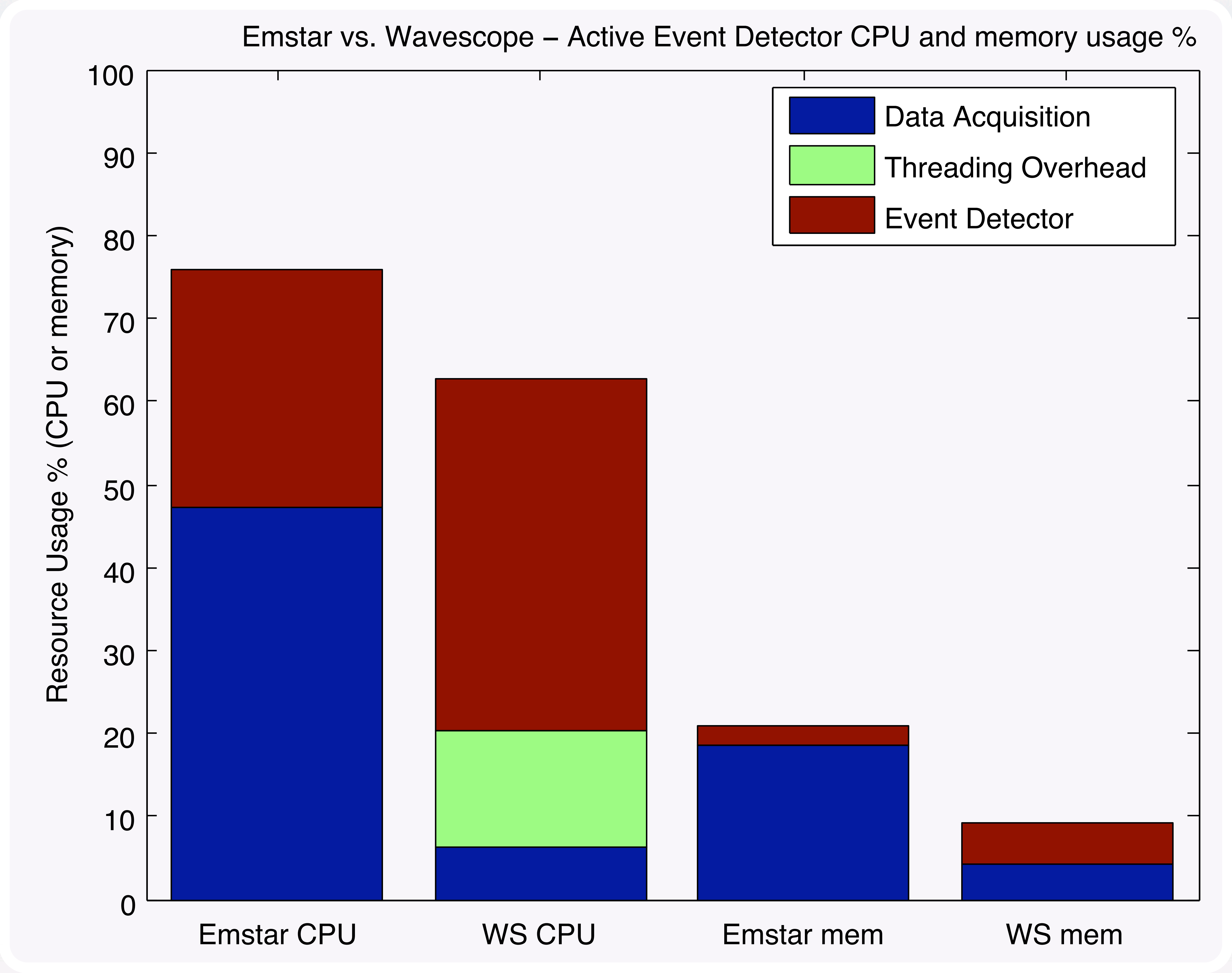
Comparing to handwritten C



Comparing to handwritten C

Step 2. Direction of arrival search exec times in seconds

	Min	Mean	Max
C	2.85	3.05	3.4
WS	2.2	2.4	2.8

(Using MLton backend)

Implementation: *Leveraging the DS in DSL*

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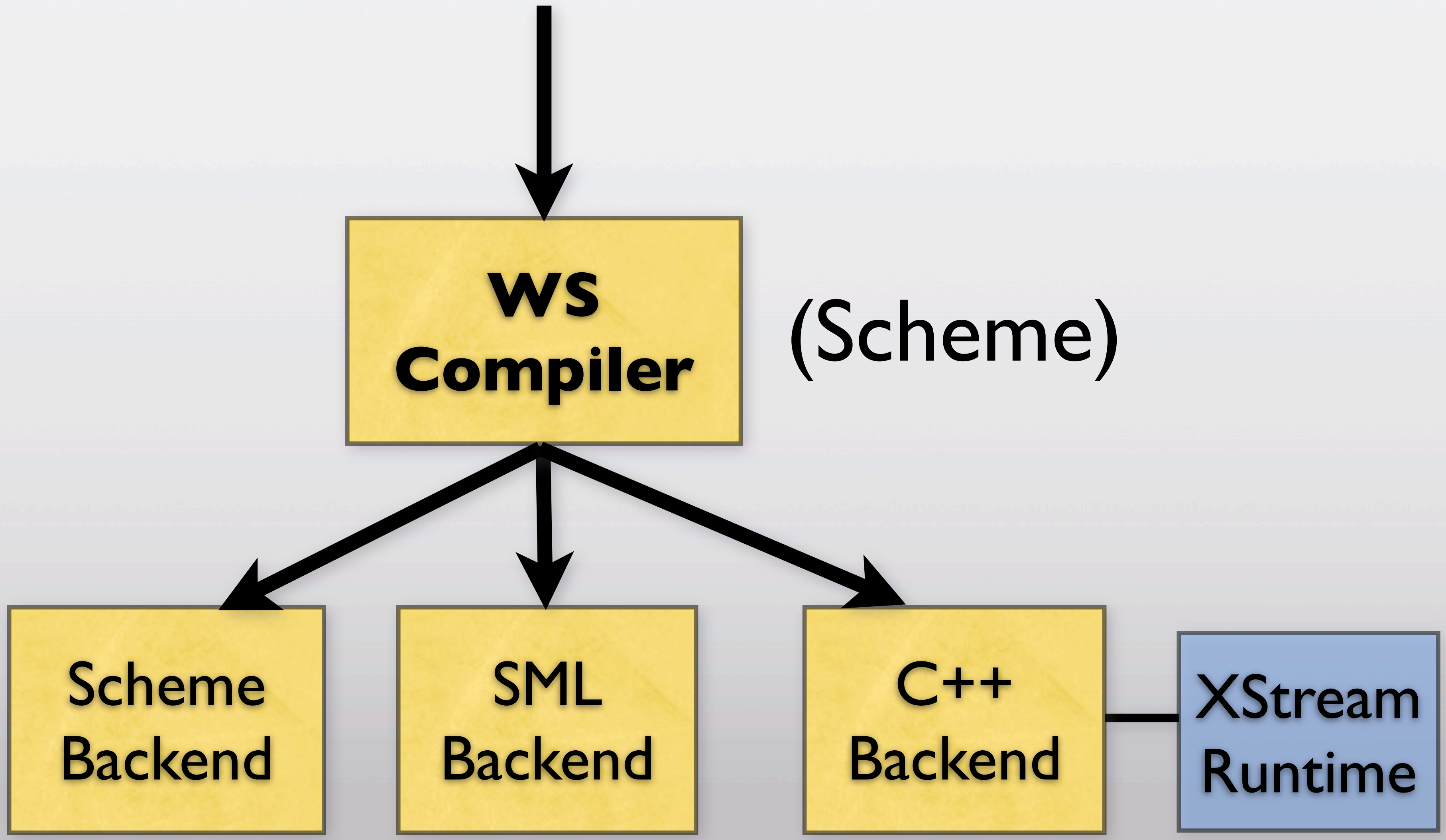
  - Stream graph executes across multiple machines
- Intra-machine parallelism (multicore/processor)
  - For example, processing terabytes of offline data

Backends, Cont.



WS Compiler

(Scheme)

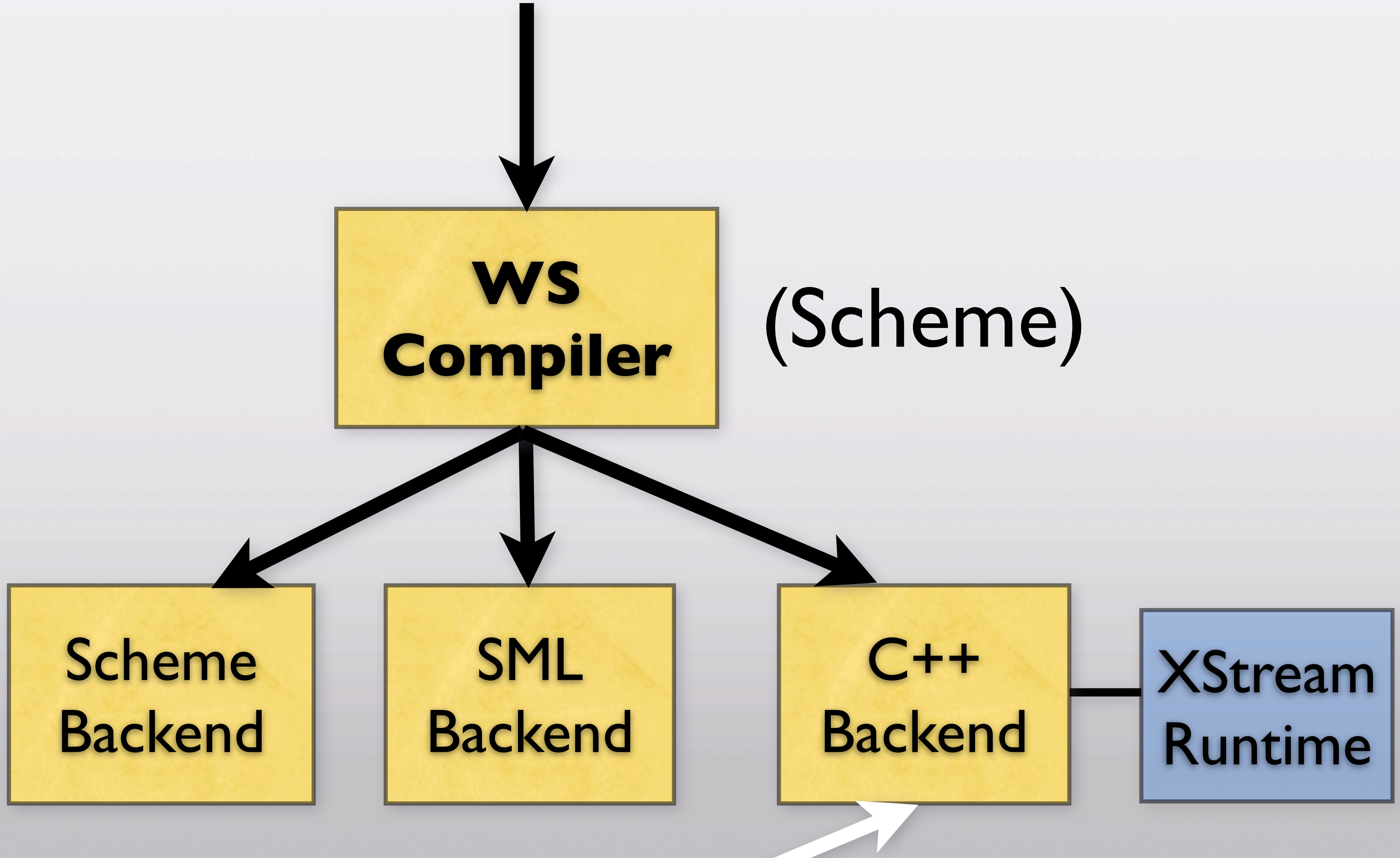
Scheme Backend

SML Backend

C++ Backend

XStream Runtime

Backends, Cont.



WS Compiler

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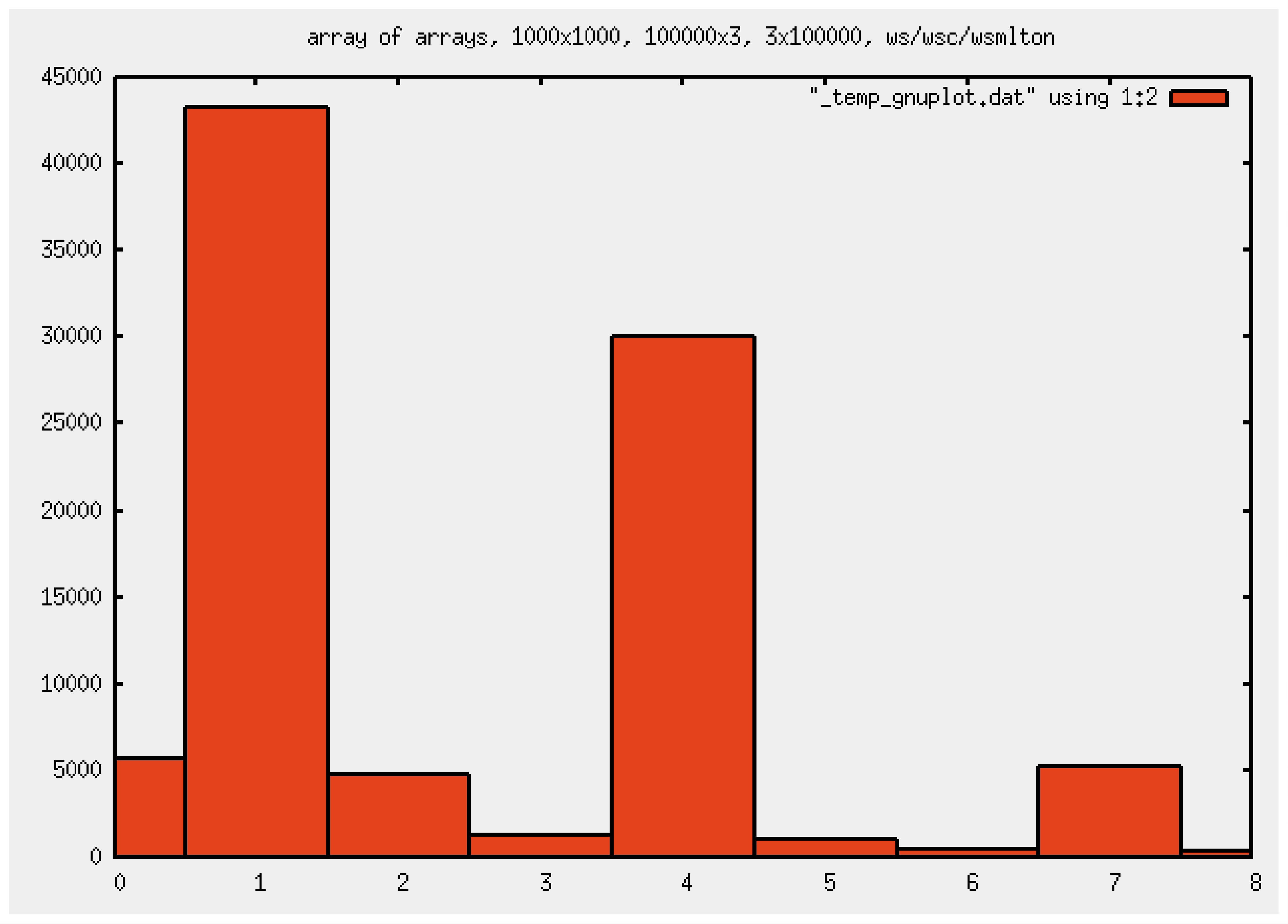
XStream Runtime

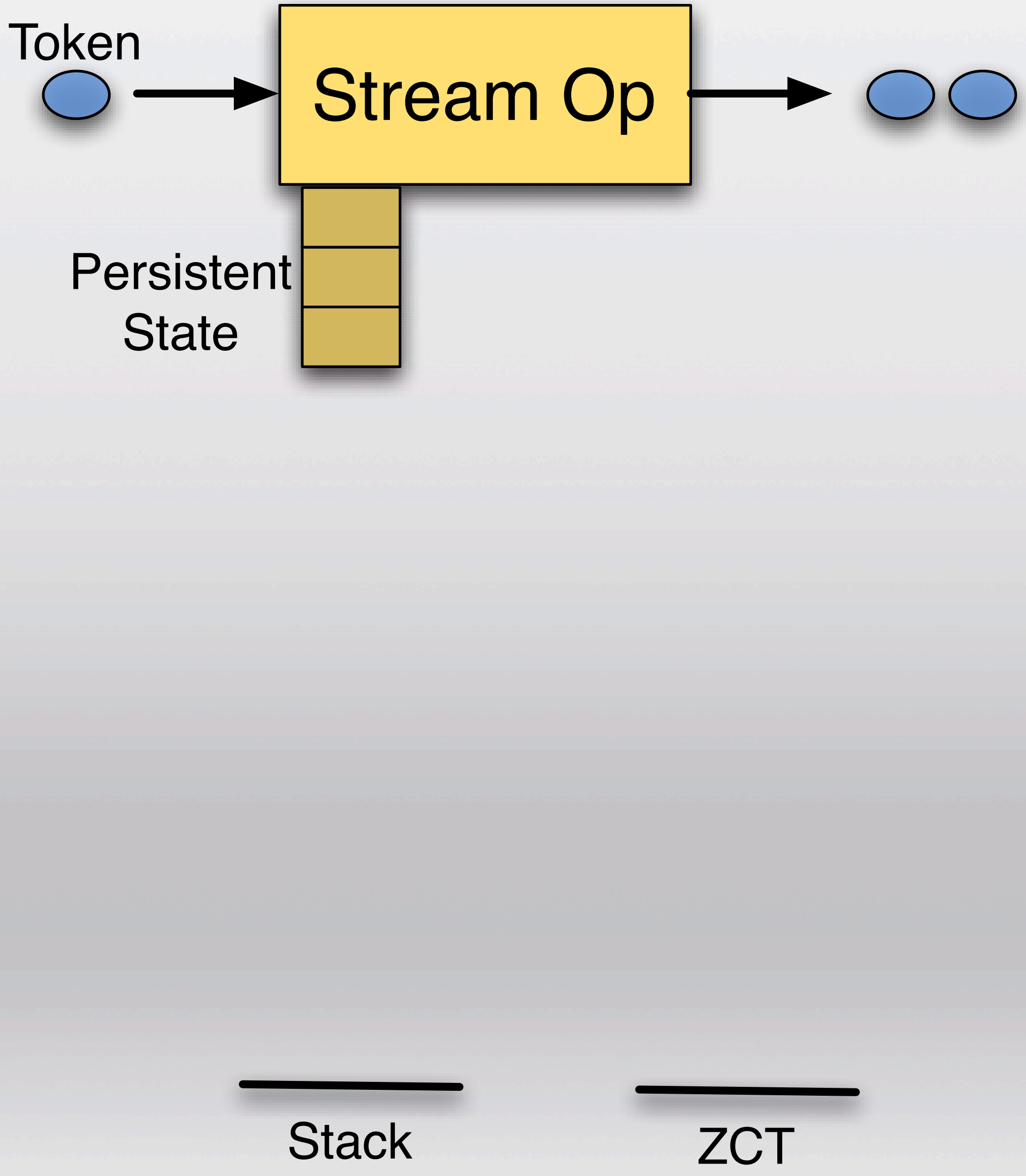
Currently: naive reference counting

Backends, Cont.



Current work: efficient GC

- Delayed RC: don't track stack references
  - But then you need to trace occasionally



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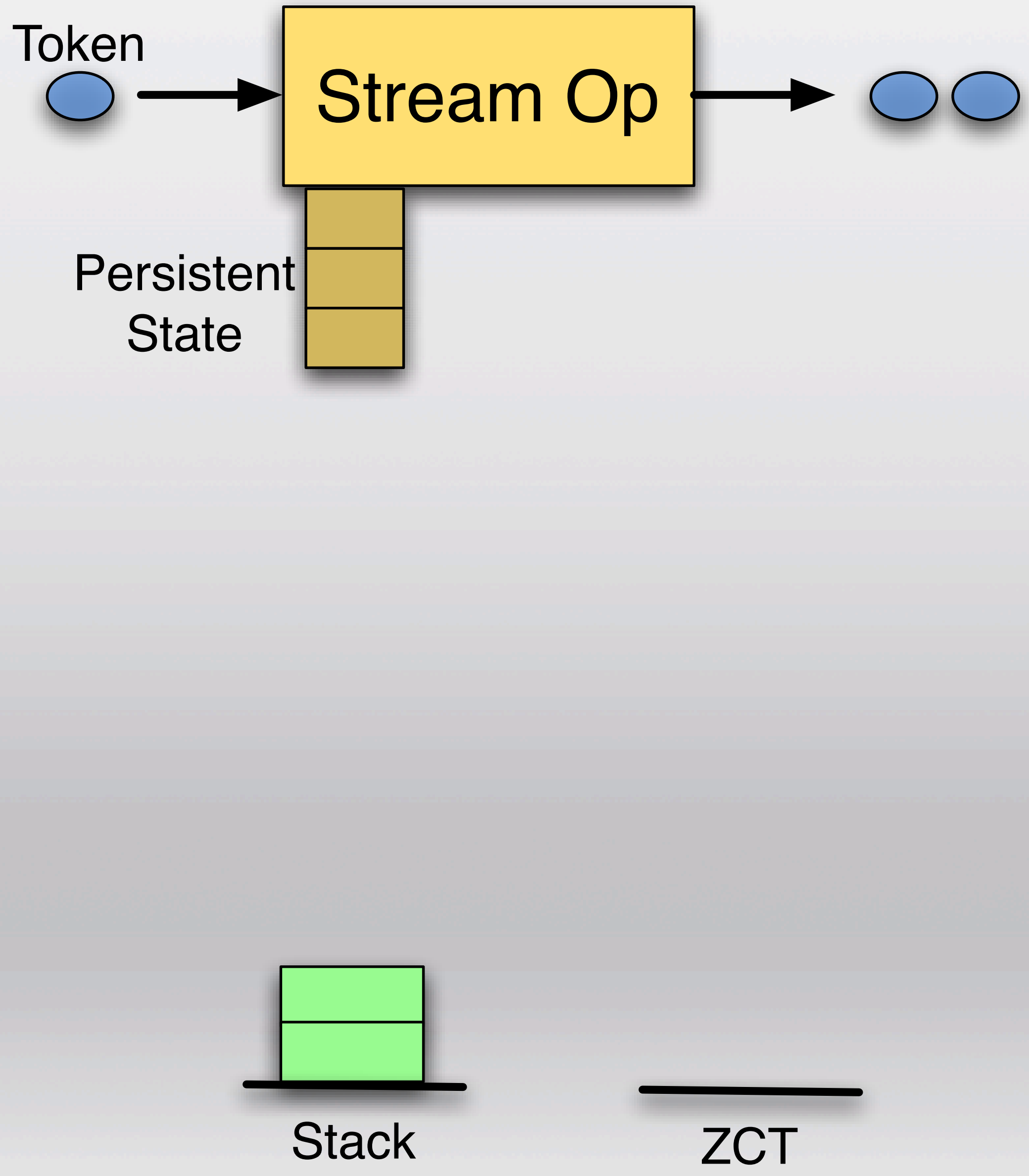

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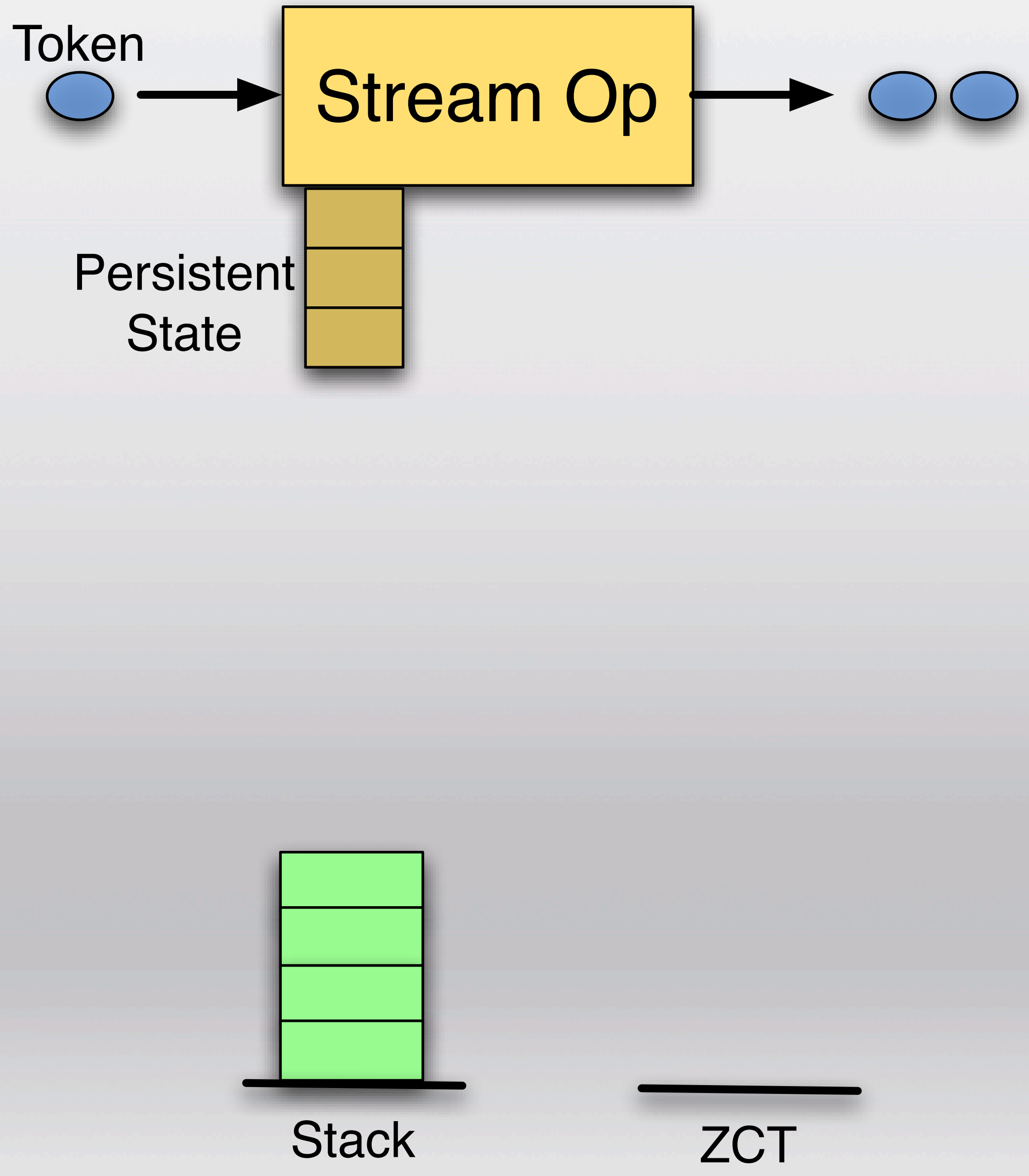

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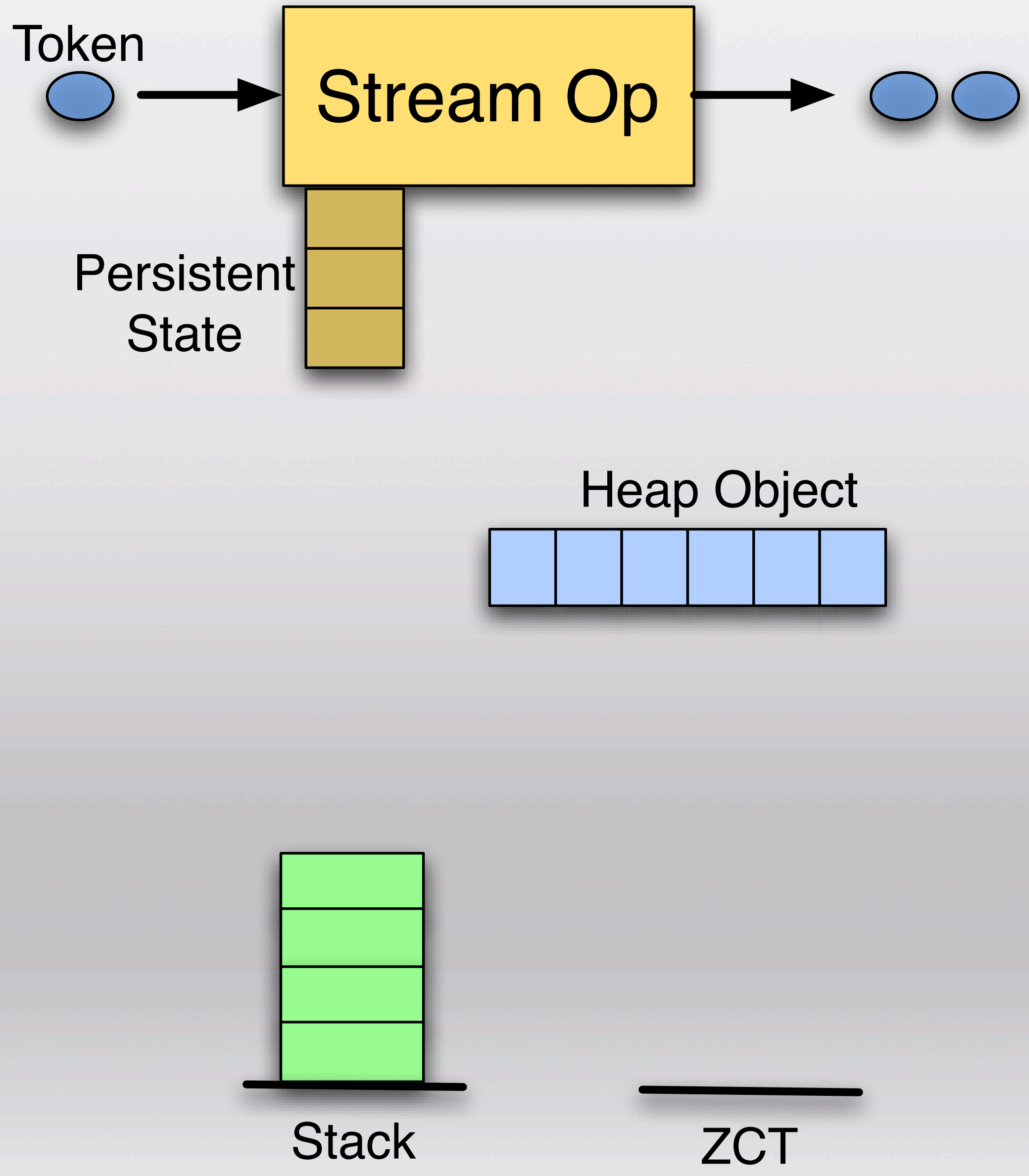

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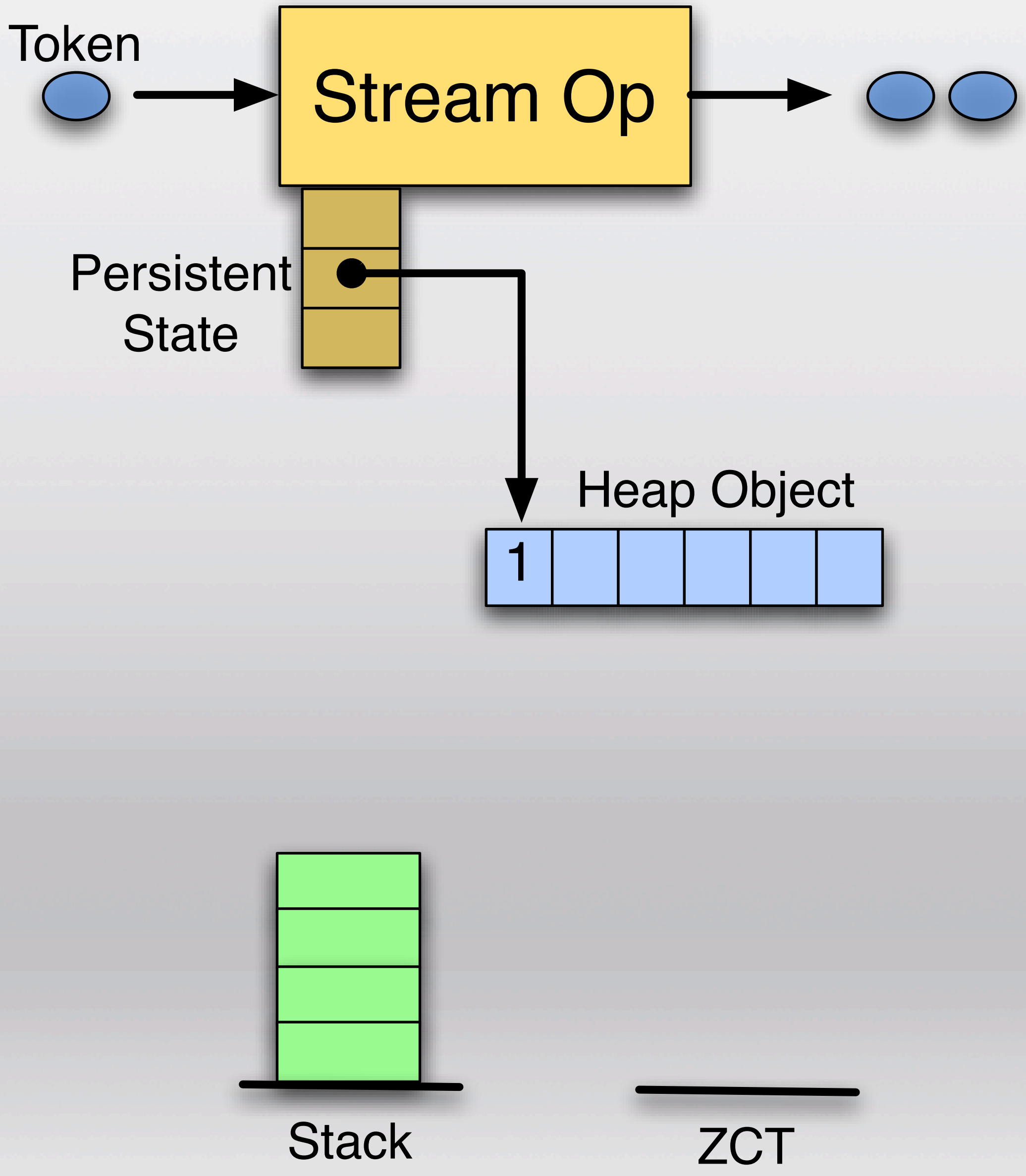

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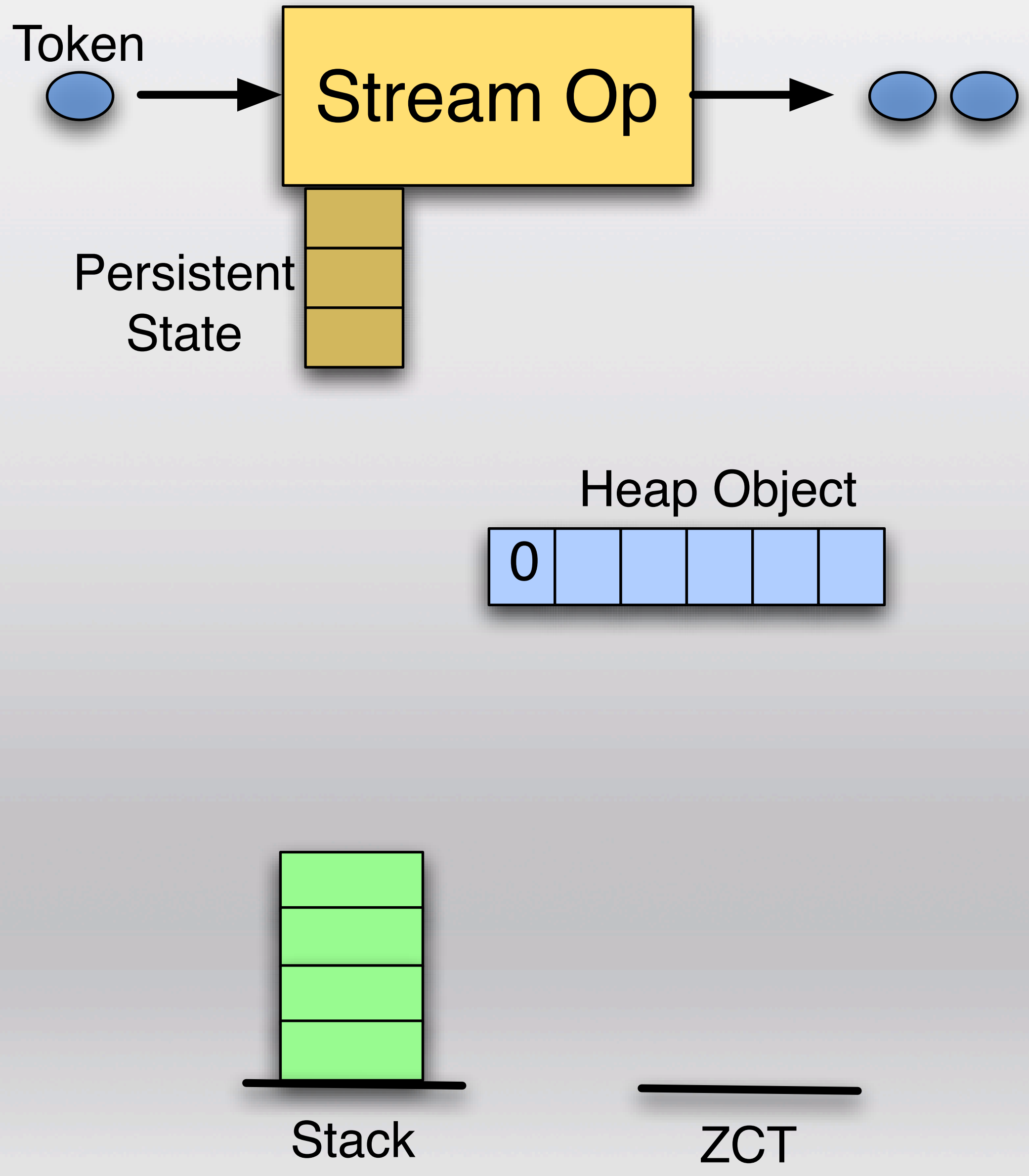

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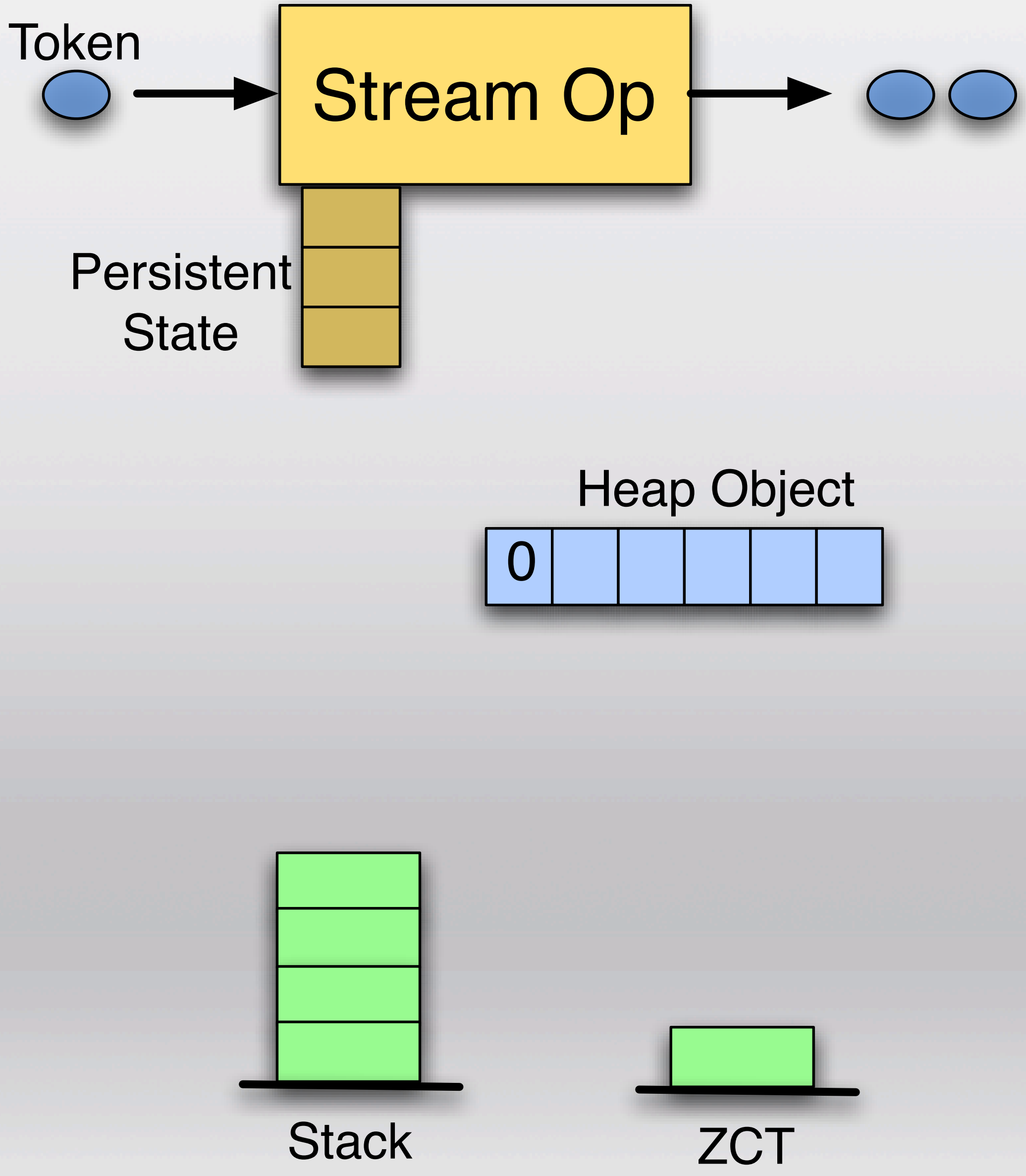

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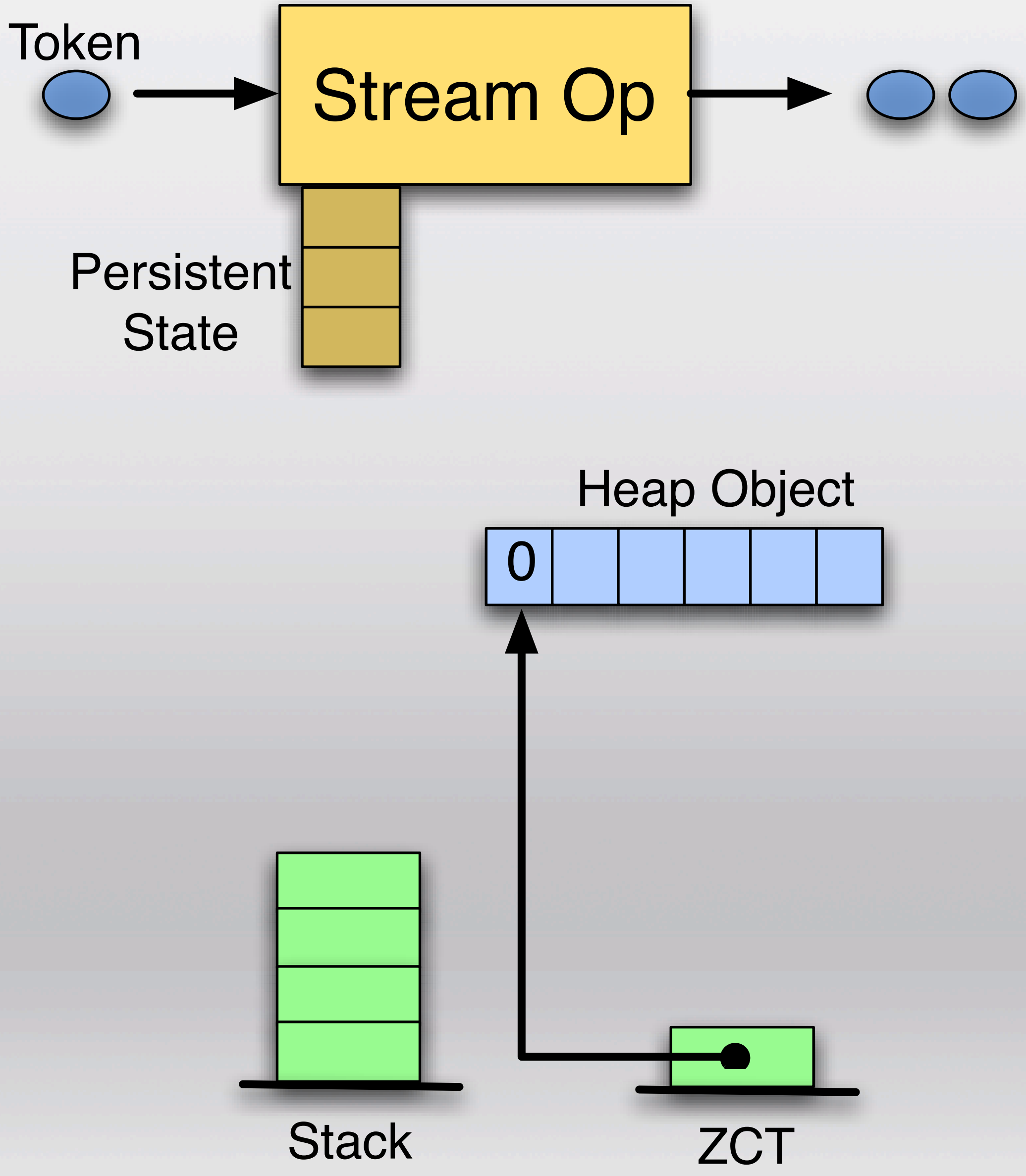

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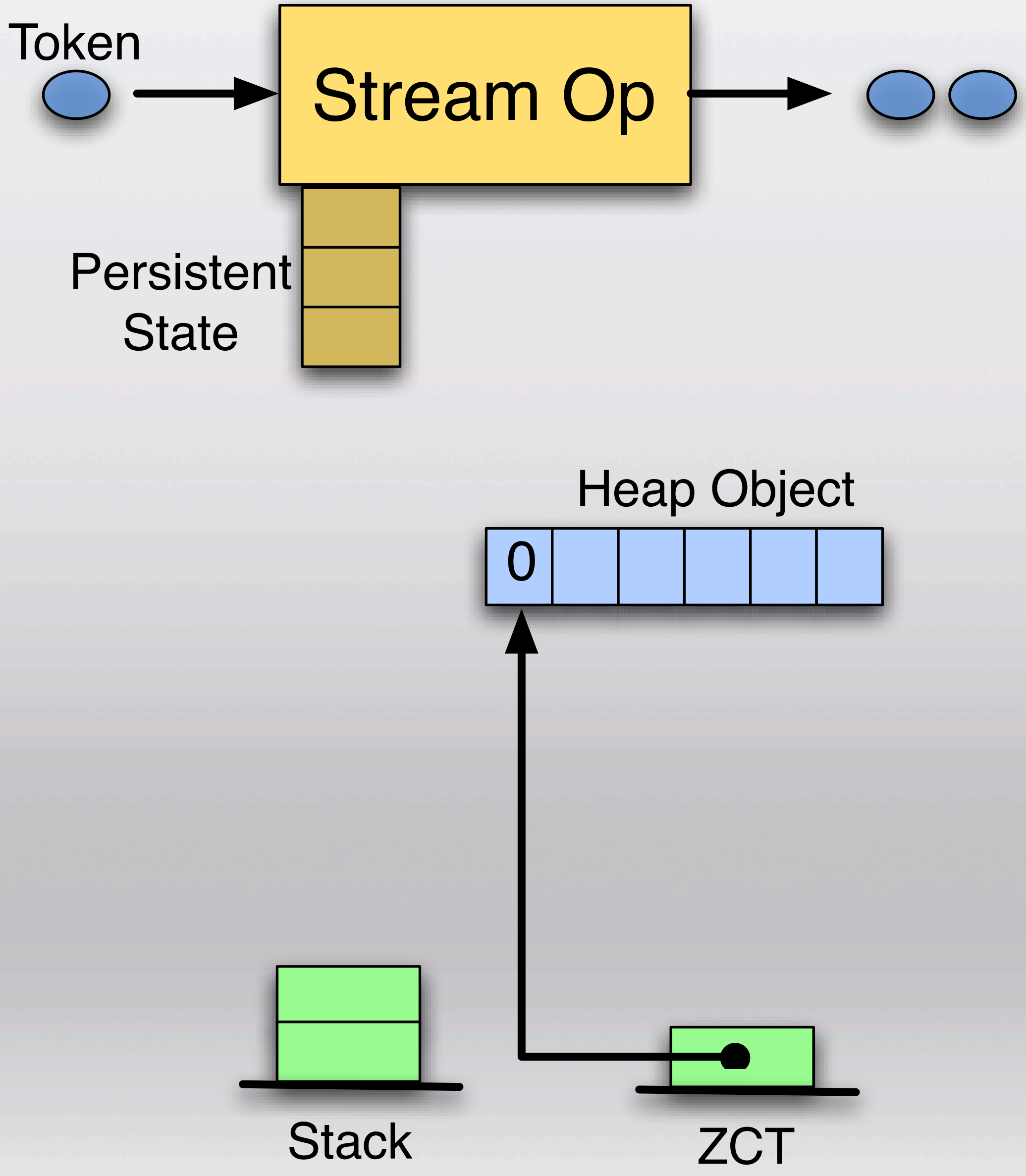

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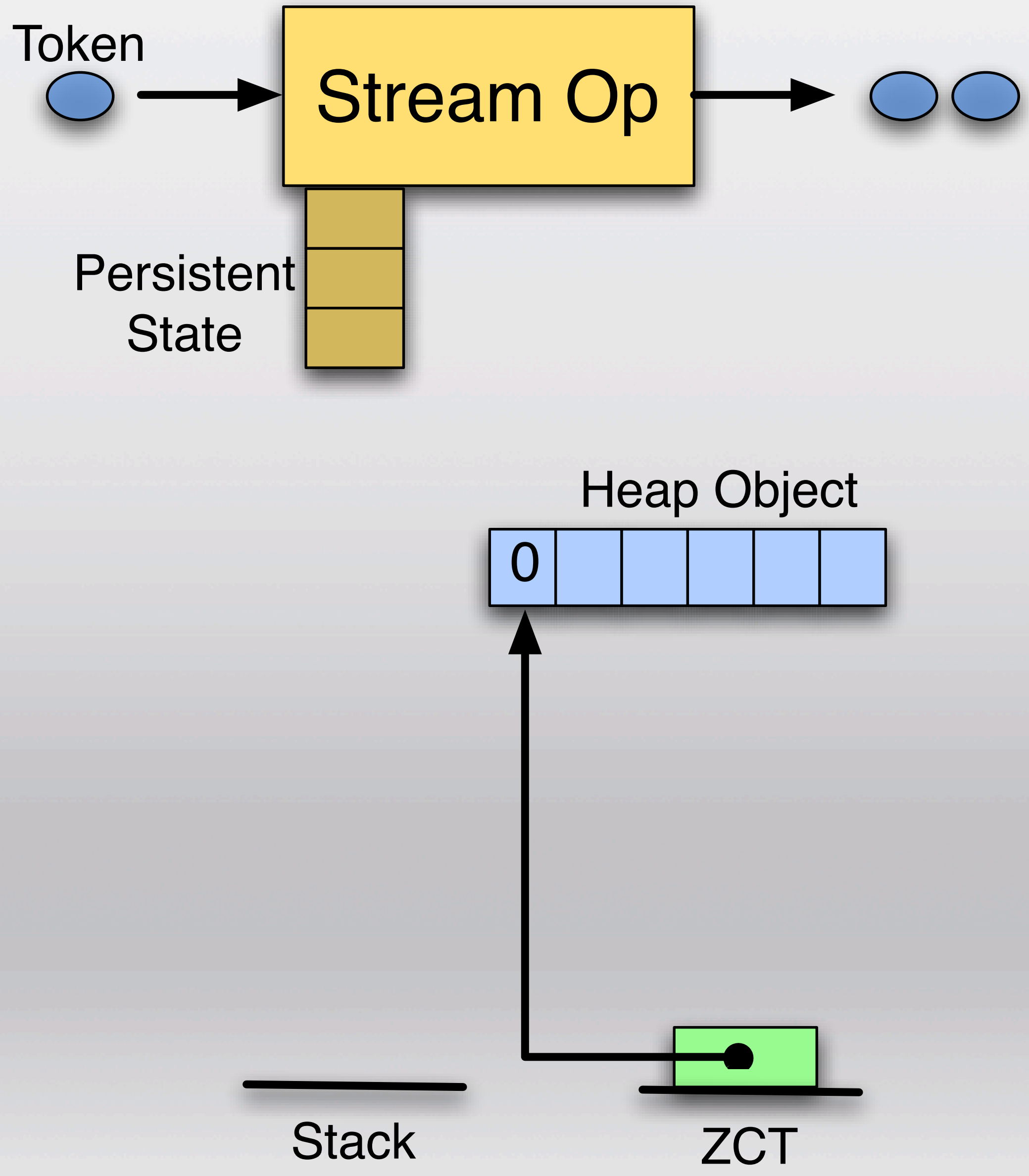

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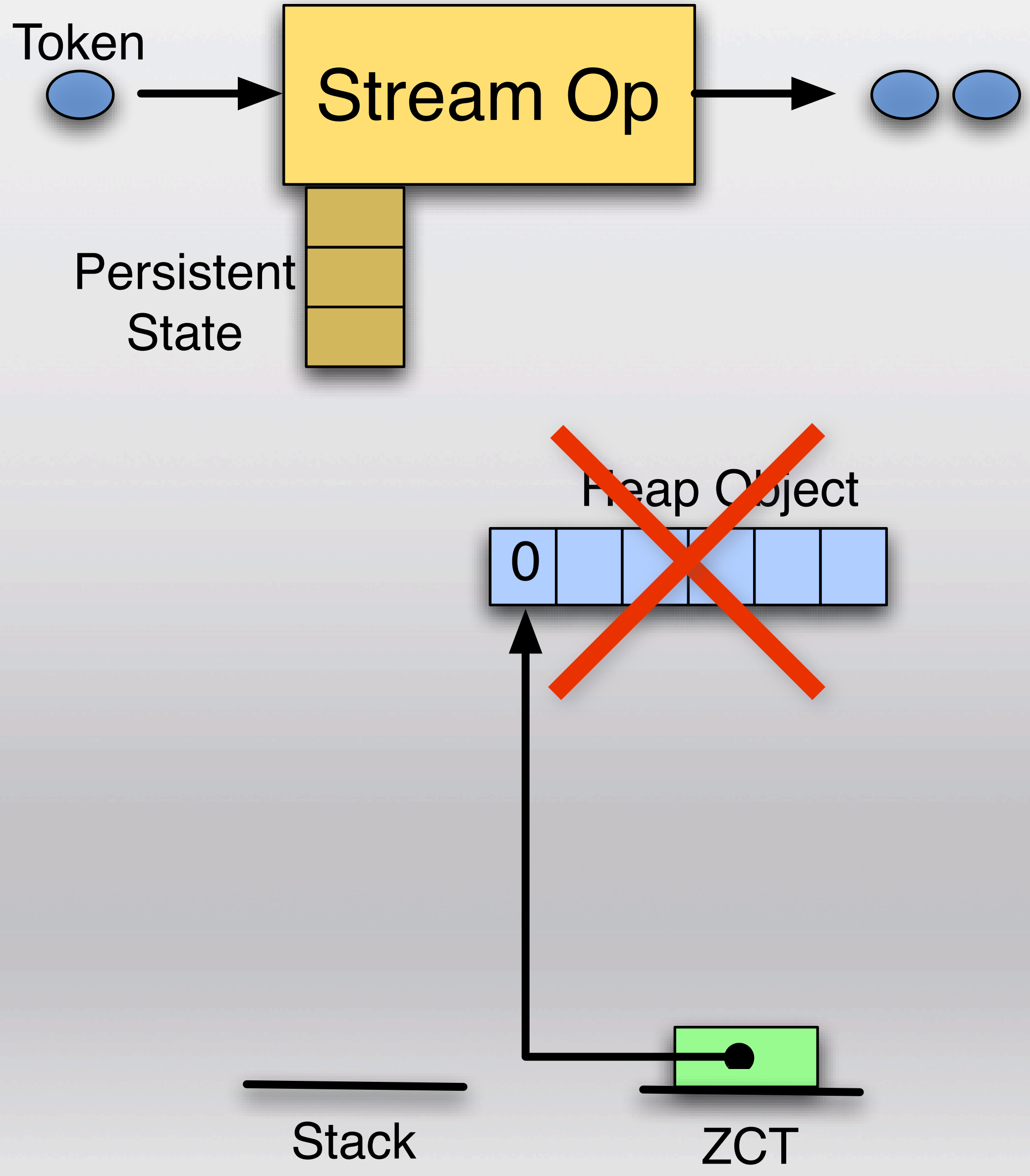

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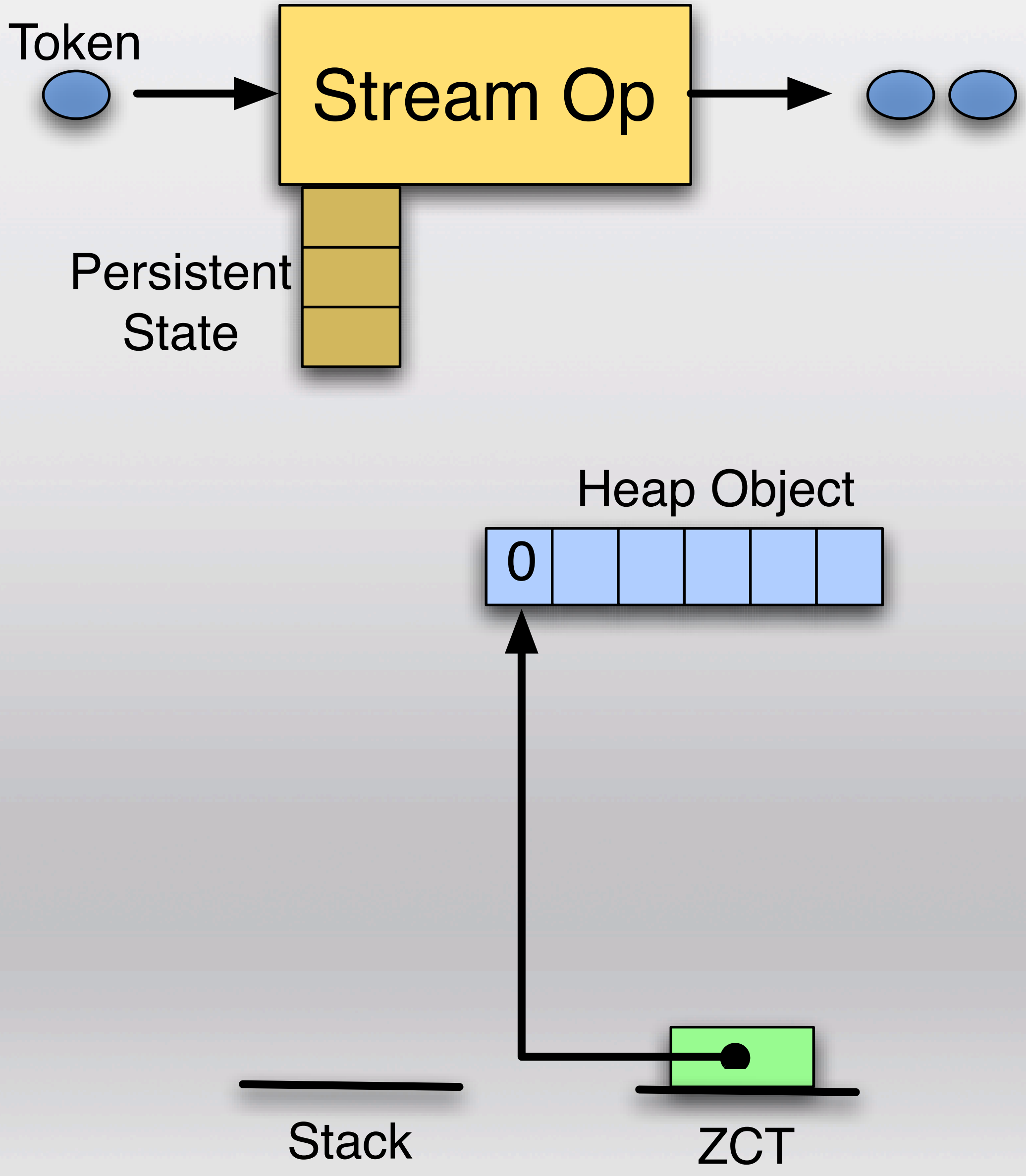

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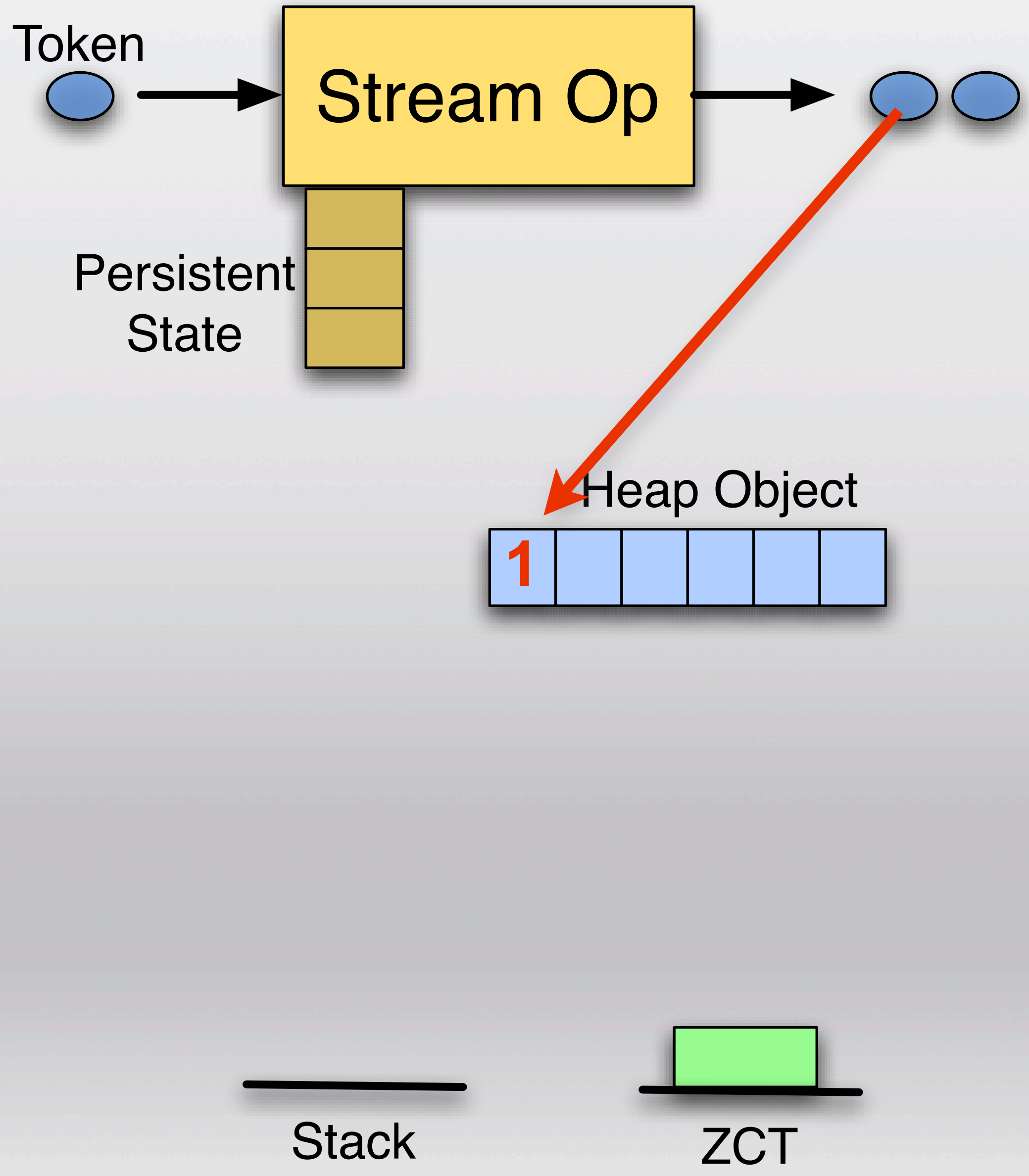

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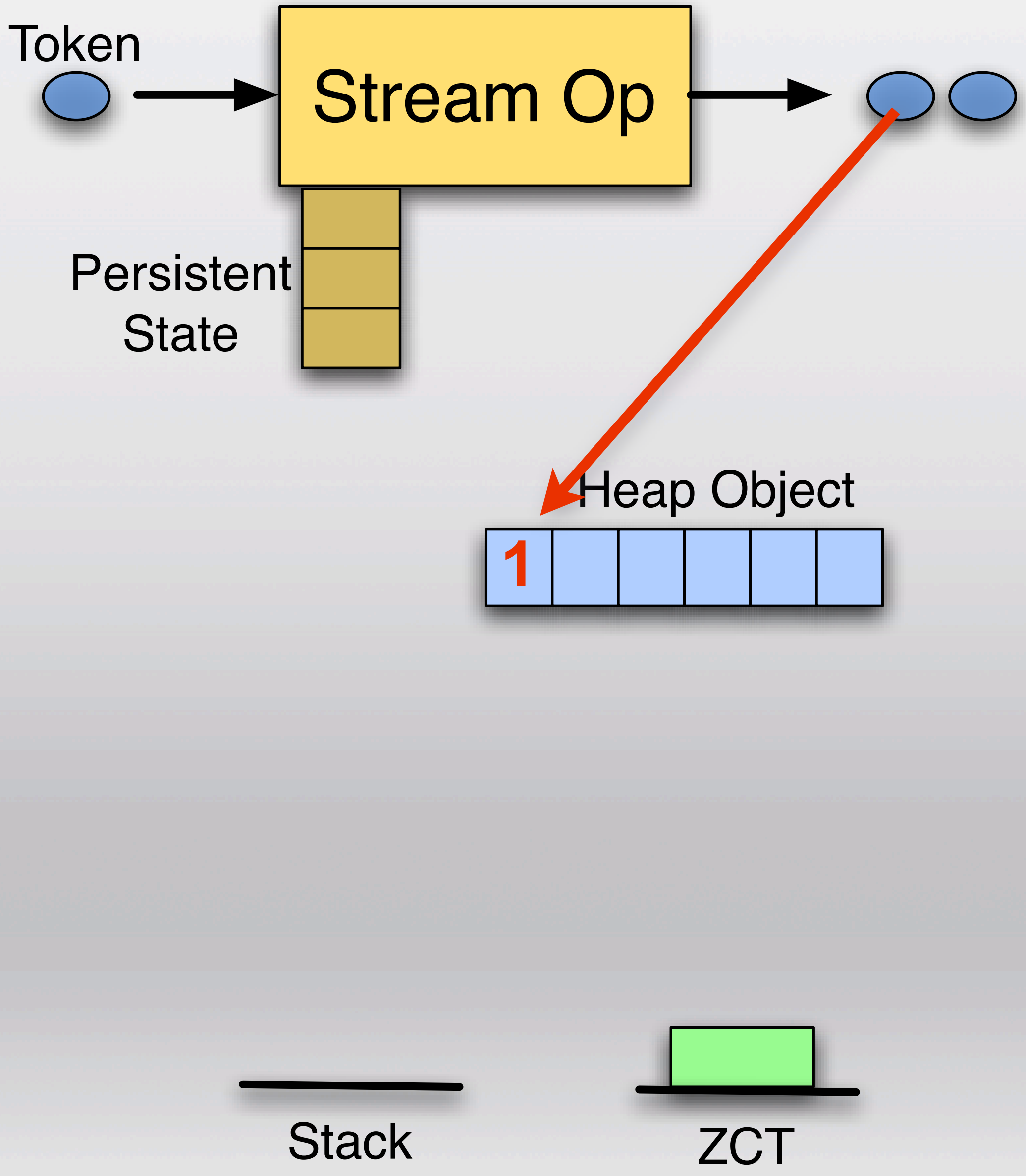
- Delayed RC: don’t track stack references
  - But then you need to trace occasionally
- We can manage separate heaps efficiently
  - Therefore we can collect at the end of an operator’s execution



Task, Data, and Pipeline Parallelism

(Intra-machine parallelism)

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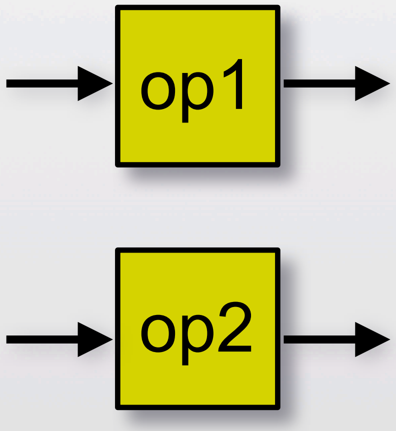

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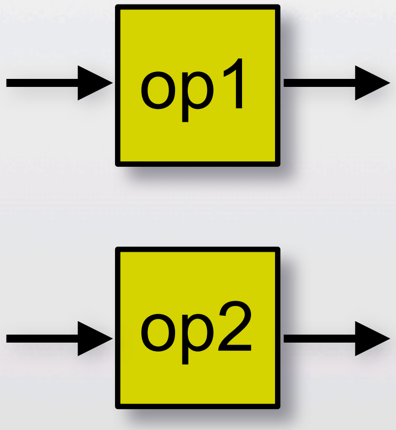
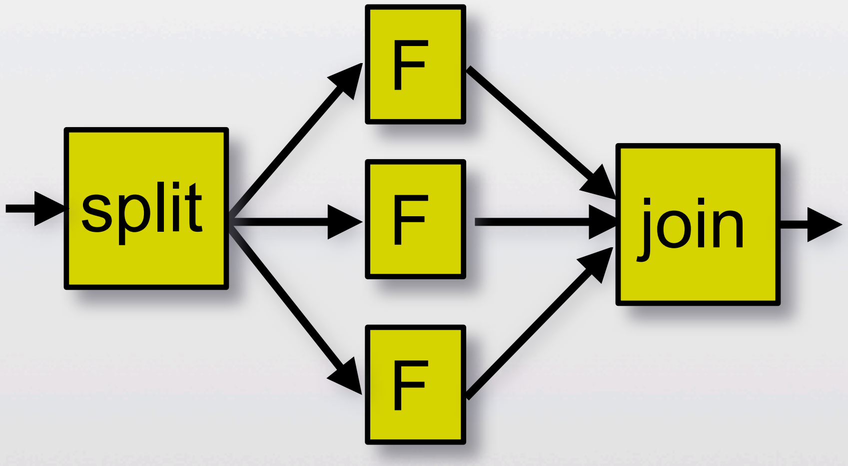


Data



`map(F,strm)`

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(Intra-machine parallelism)

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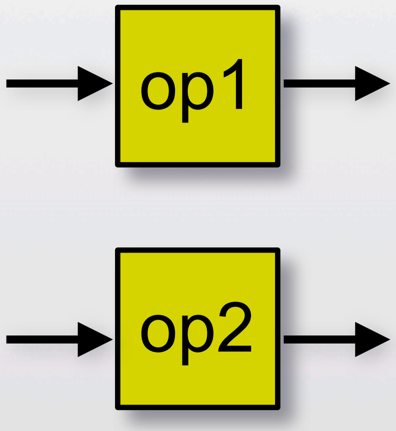
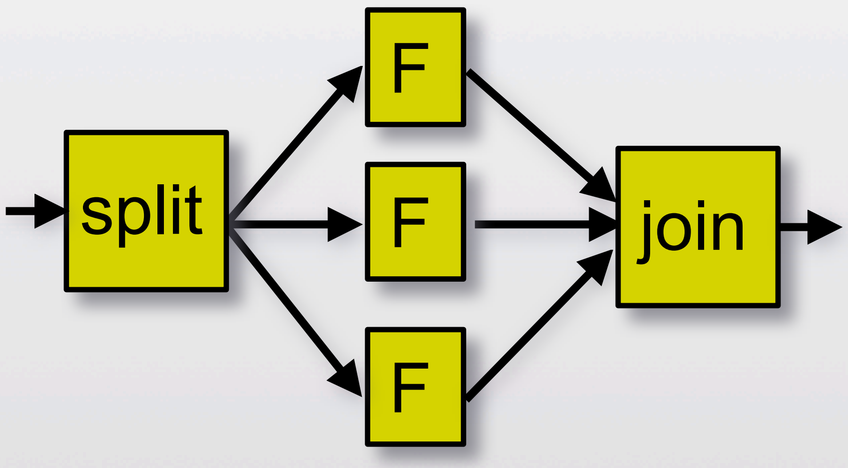

op1

op2

Data


split

F

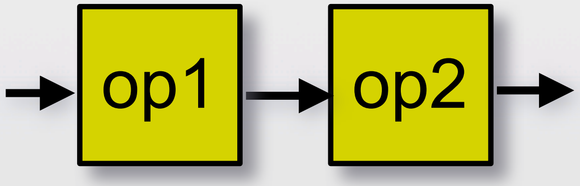
F

F

join

`map(F,strm)`

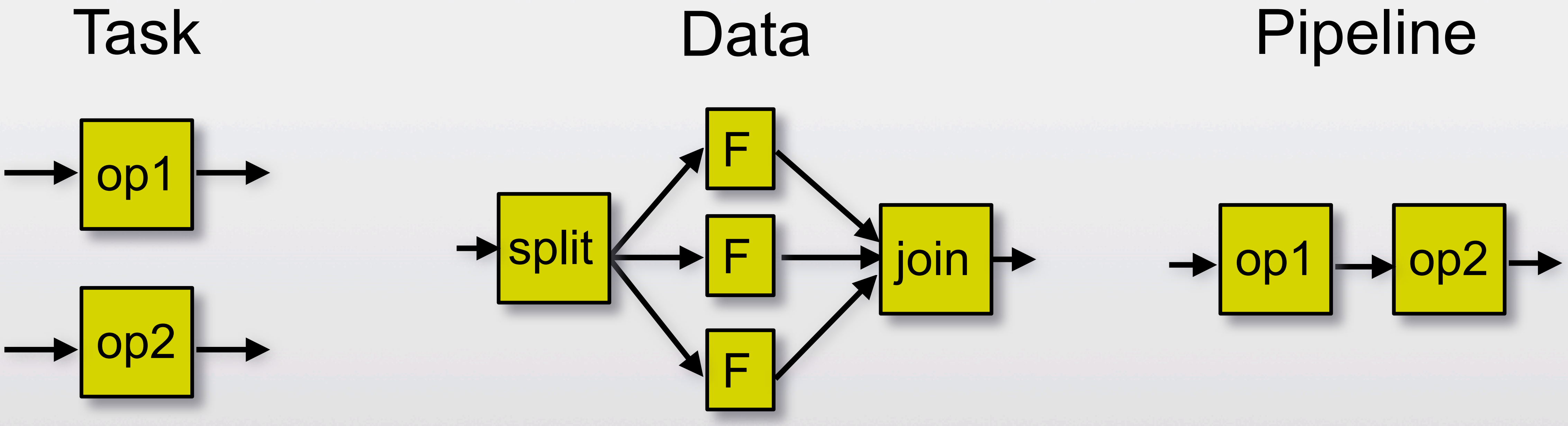
Pipeline


op1

op2

Task, Data, and Pipeline Parallelism

(Intra-machine parallelism)



`map(F,strm)`

- See StreamIT for good work on optimizing parallelism
  - You need information on *data rates*
- We use PROFILING based on *sample data*
  - Helps with other optimizations: e.g. data representation transforms

Building Stream Abstractions

- Further abstract the representation of a stream, enable changing the “glue”.

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  - Pull based streams.
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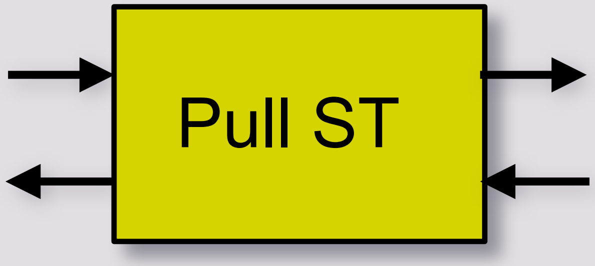

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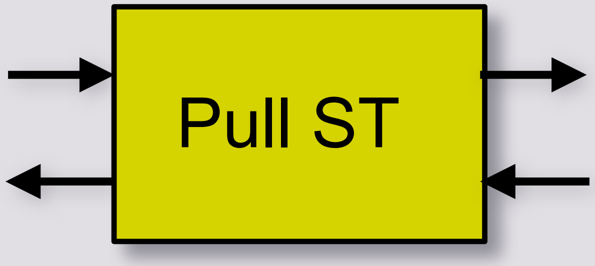

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Conclusions

End.

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