Just-in-Time Data Structures

Languages and Runtimes for Big Data

Updates

- Slack Channel
  - #cse662-fall2017 @ http://ubodin.slack.com
- Reading for Monday: MCDB
  - Exactly one piece of feedback (see next slide)

Don’t parrot the paper back

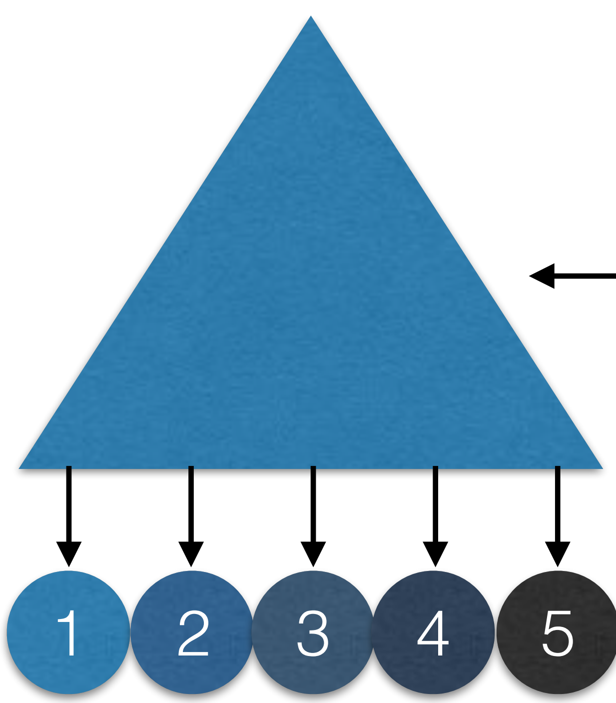
- Find something that the paper says is good and figure out a set of circumstances where it's bad.
- What else does something similar, why is the paper better, and under what circumstances?
- Think of circumstances and real-world settings where the proposed system is good.
- Evaluation: How would you evaluate their solution in a way that they didn’t.

What is best in life?

(for organizing your data)

Storing & Organizing Data

Binary Tree



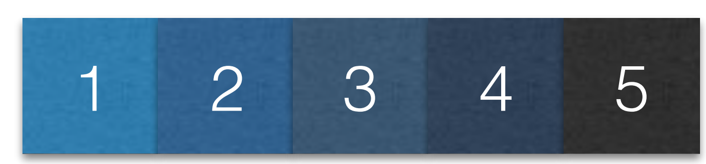
<u>API</u>

Insert

Range Scan

Heap

Sorted Array



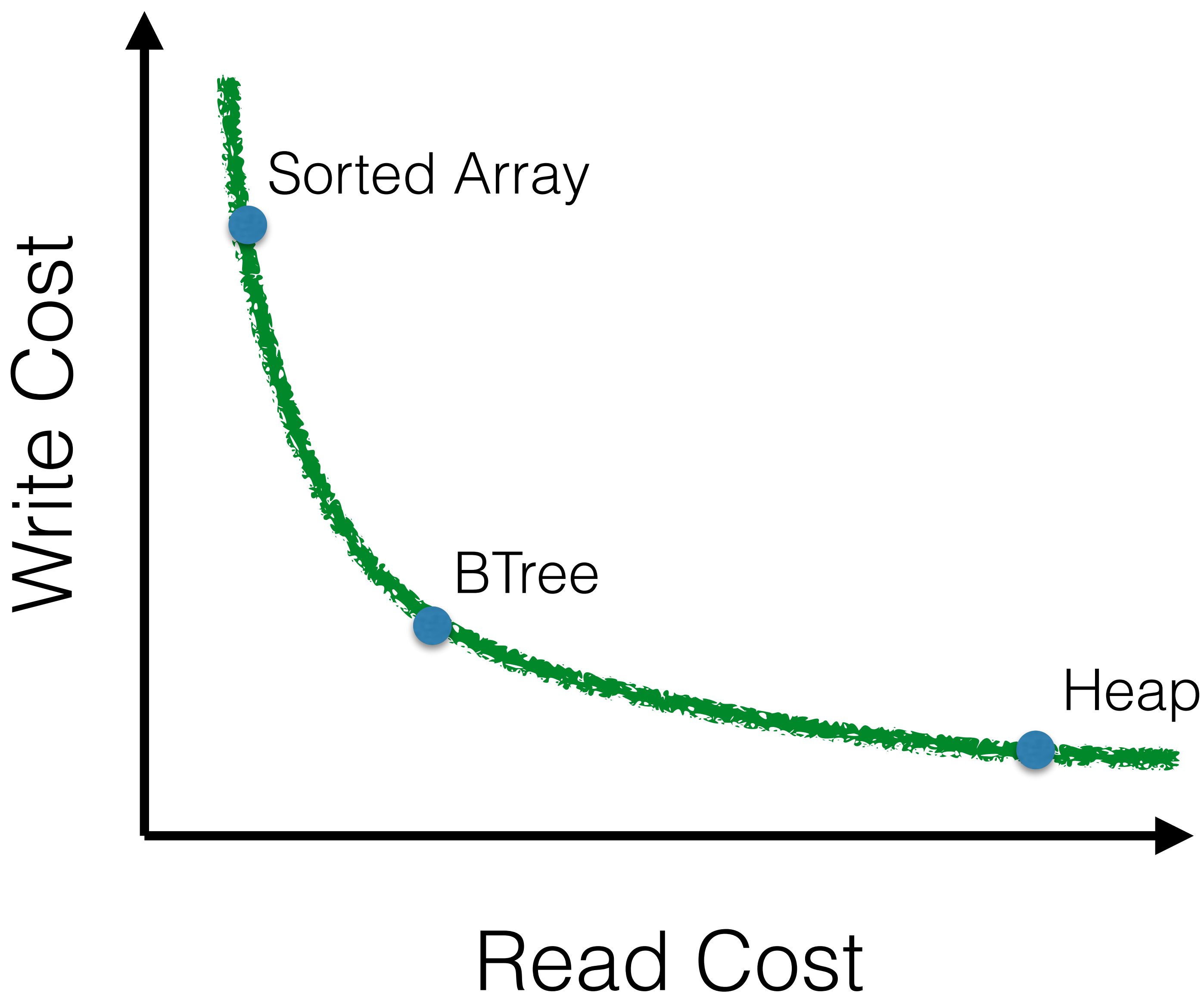
… and many more.

Which should you use?

You guessed wrong.

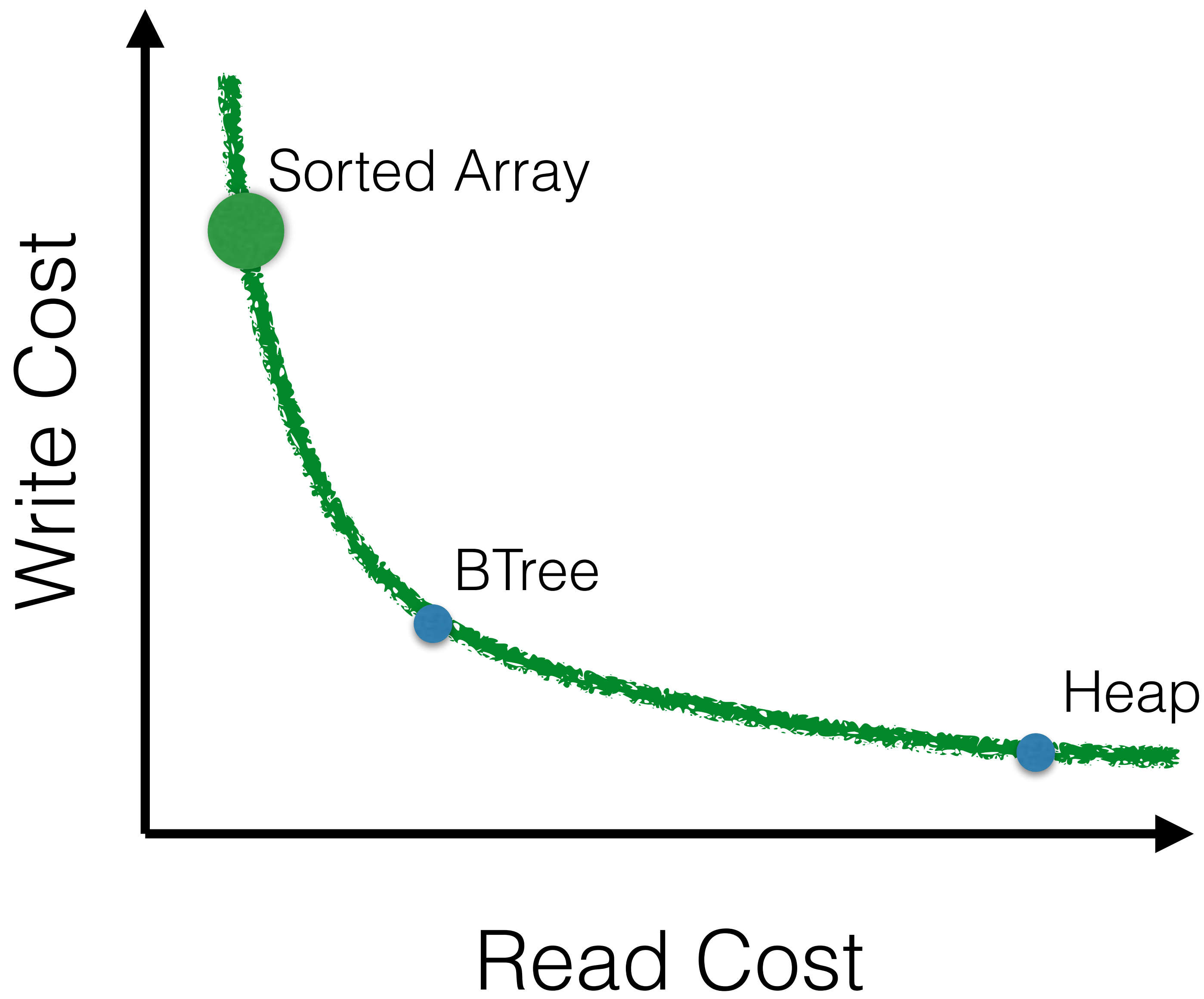
(Unless you didn't)

Workloads



Each data structure makes a fixed set of tradeoffs

Workloads



Current Workload

Many Reads

Some Writes

No Reads

Many Reads

We want to gracefully transition between different DSes

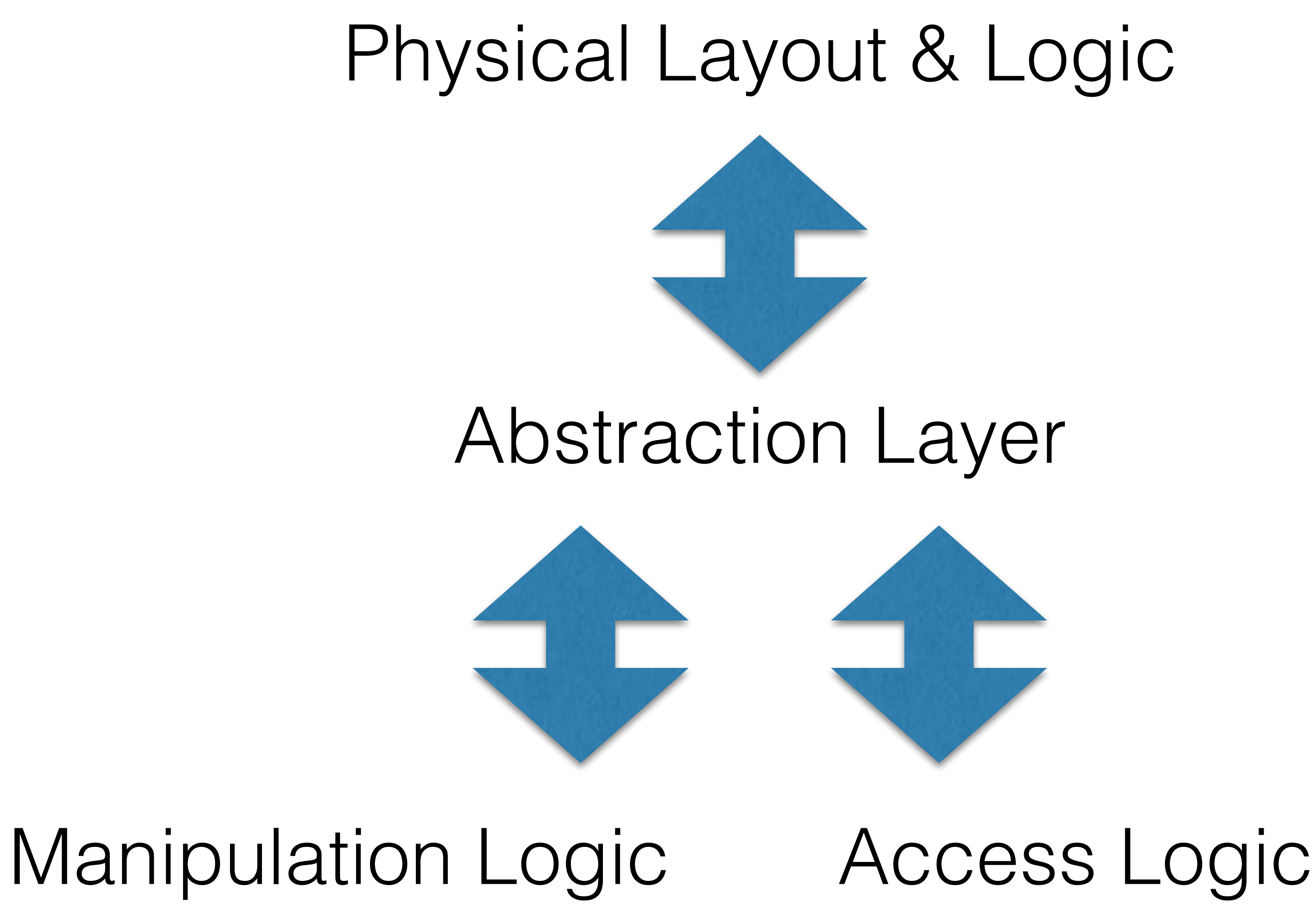
Traditional Data Structures

Physical Layout & Logic

Manipulation Logic

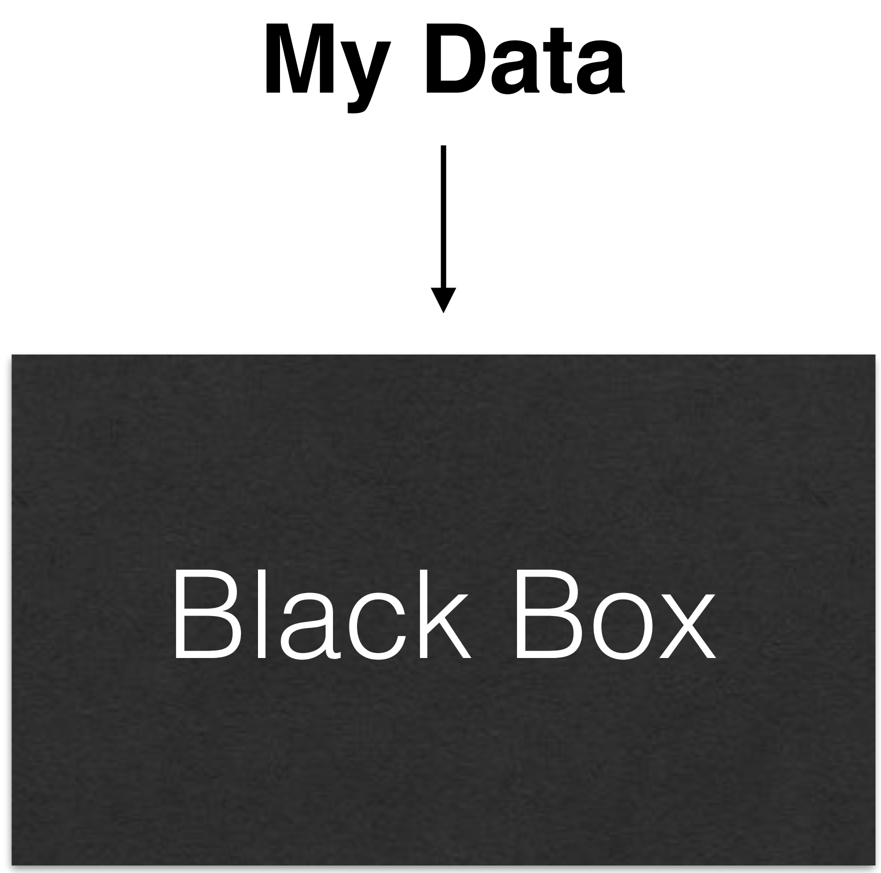
Access Logic

Just-in-Time Data Structures



- ➡ Picking The Right Abstraction
- Accessing and Manipulating a JITD
- Case Study: Adaptive Indexes
- Experimental Results
- Demo

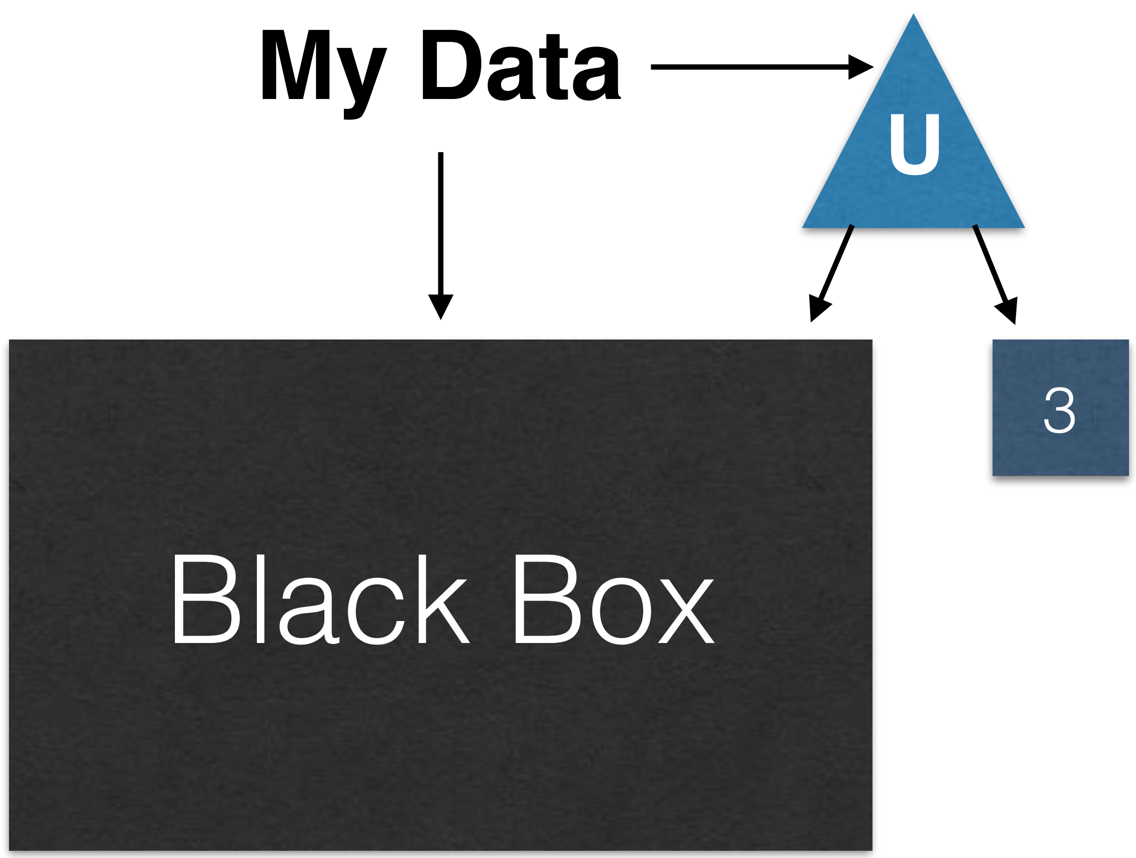
Abstractions



(A set of integer records)

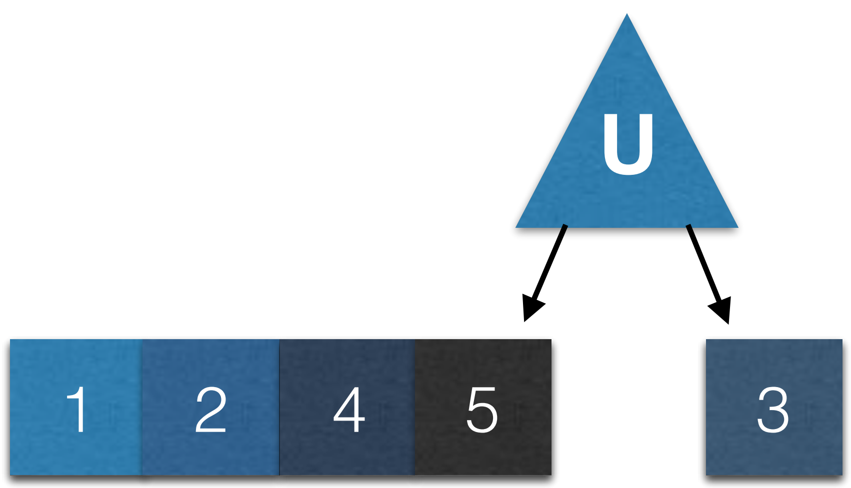
Insertions

Let’s say I want to add a 3?



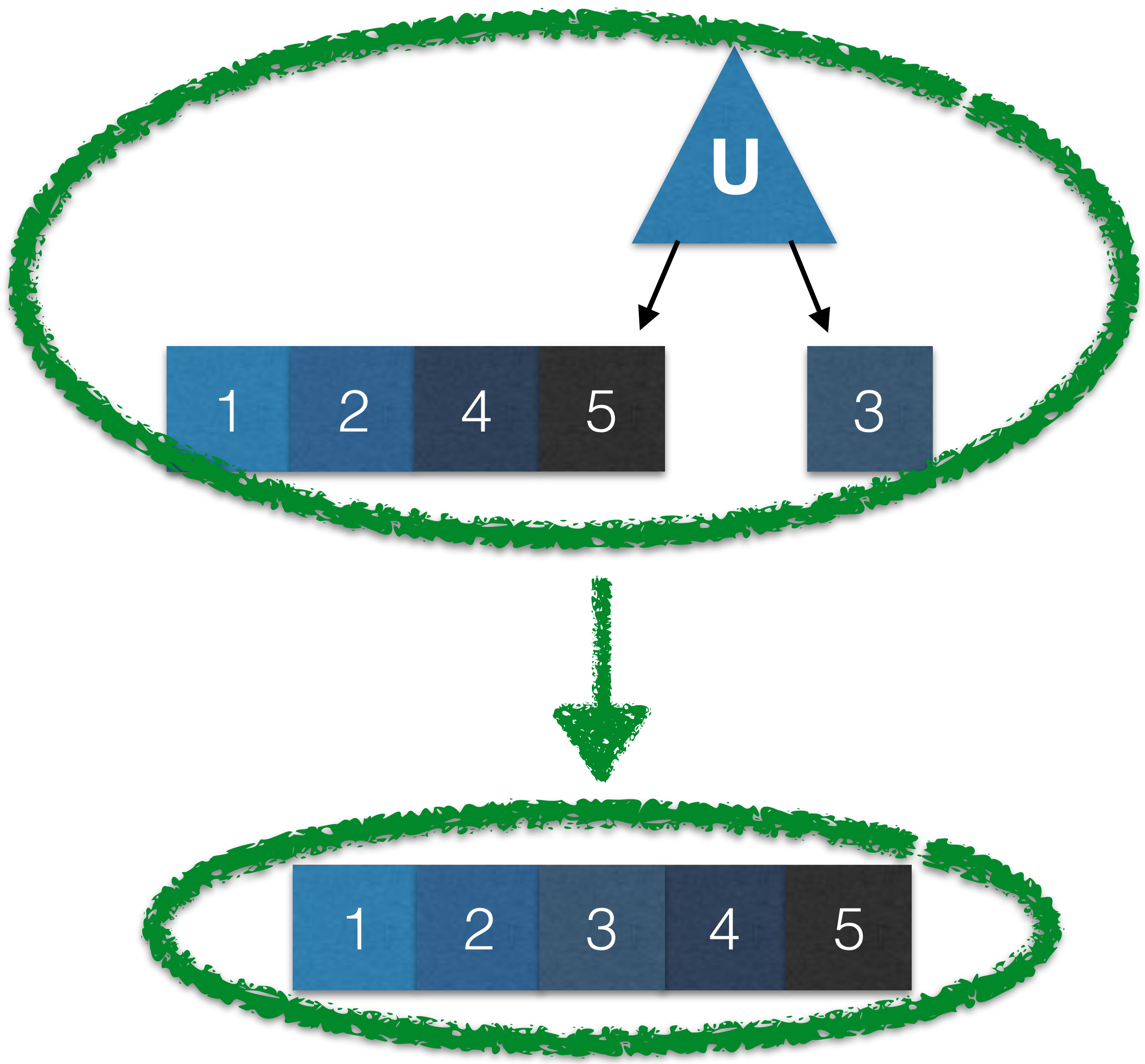
This is **correct**, but probably **not efficient**

Insertions



Insertion creates a **temporary** representation…

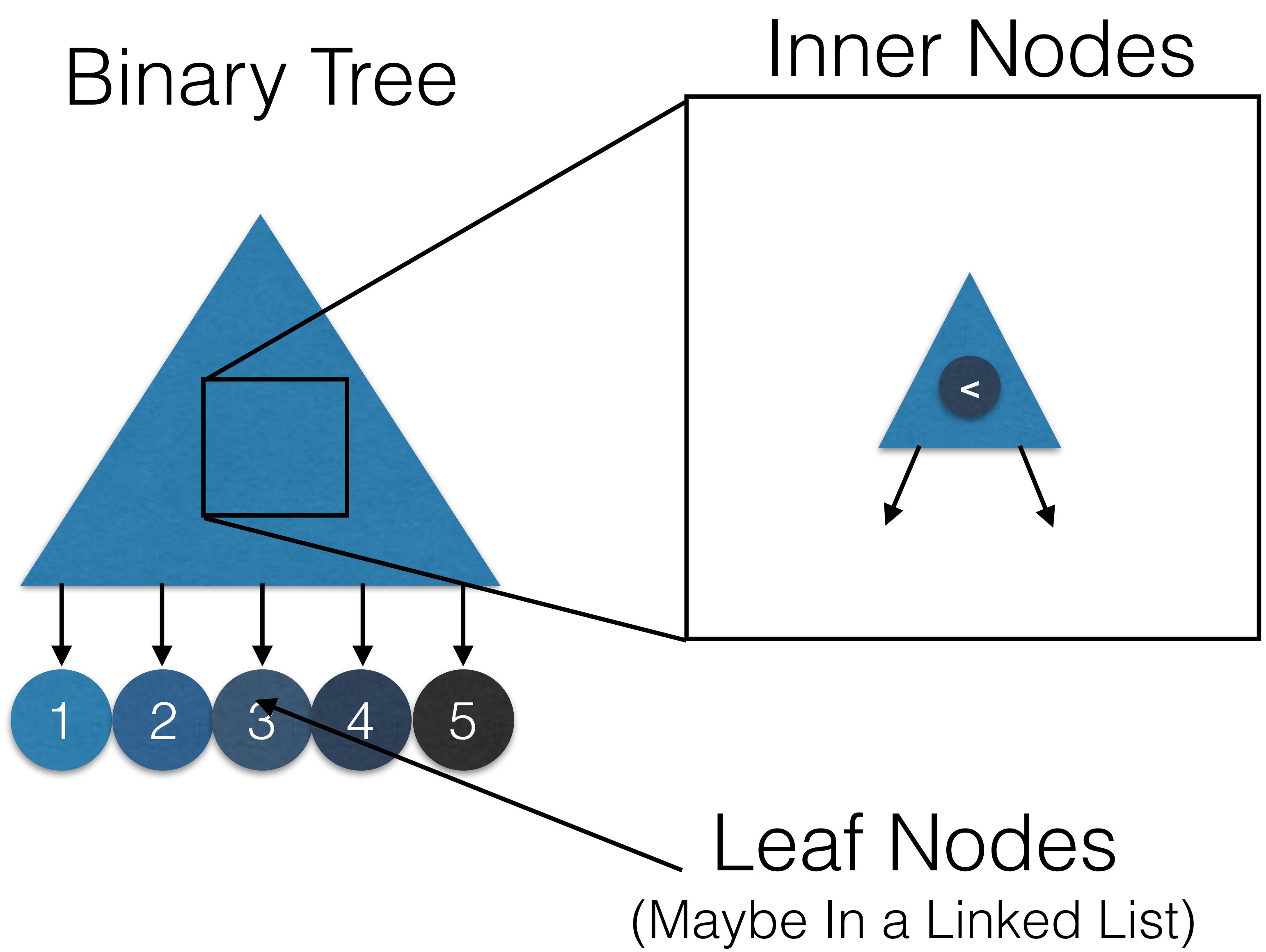
Insertions



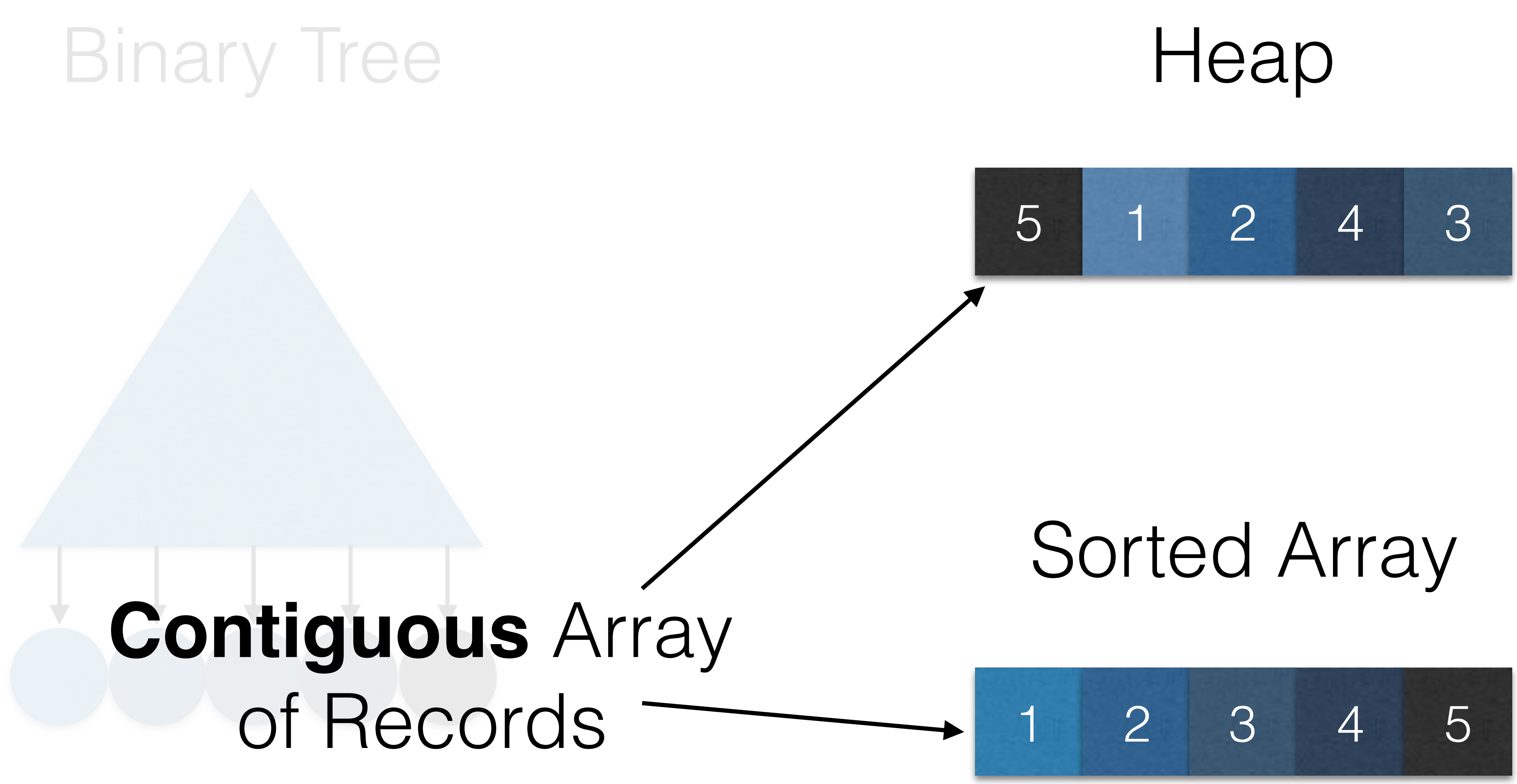
… that we can eventually **rewrite** into a form that is correct and **efficient**

(once we know what 'efficient' means)

Traditional Data Structure Design

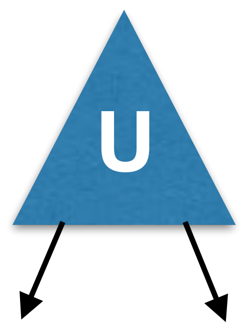


Traditional Data Structure Design

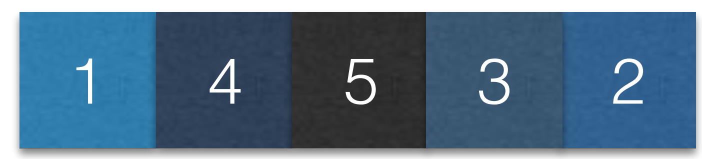


Building Blocks

Structural Properties

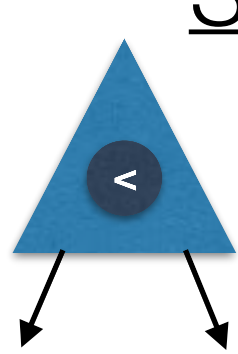


Concatenate

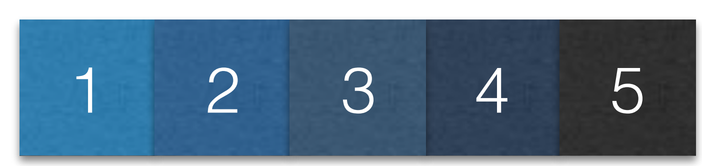


Array (Unsorted)

Semantic Properties



BinTree Node



Array (Sorted)

- Picking The Right Abstraction
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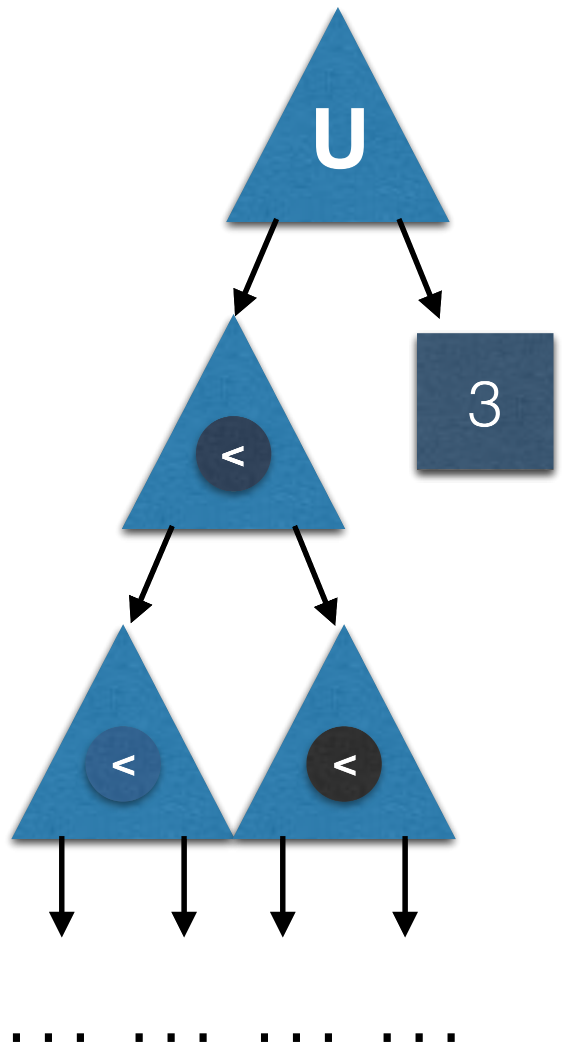
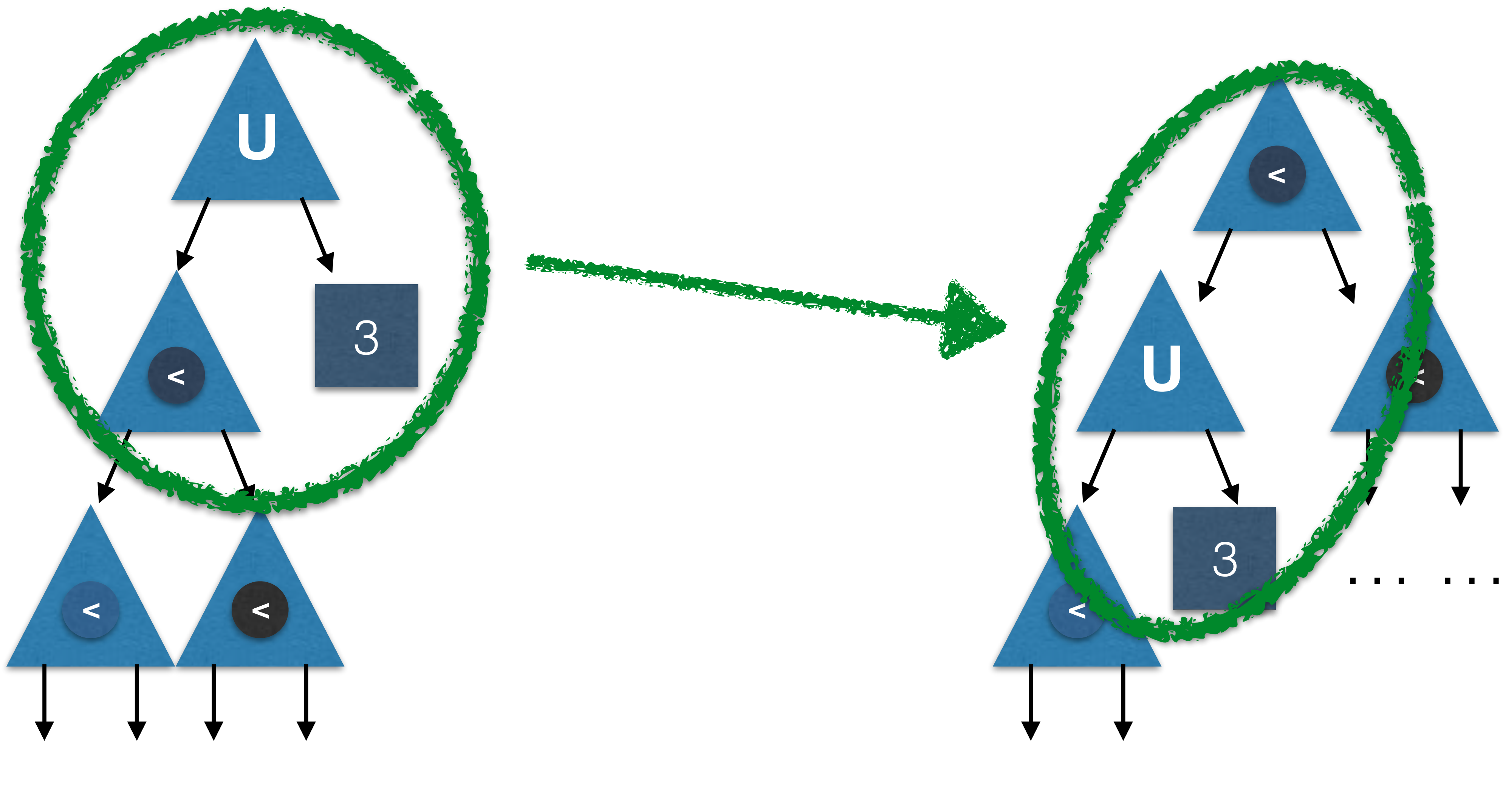
Binary Tree Insertions

Let's try something more complex: A Binary Tree



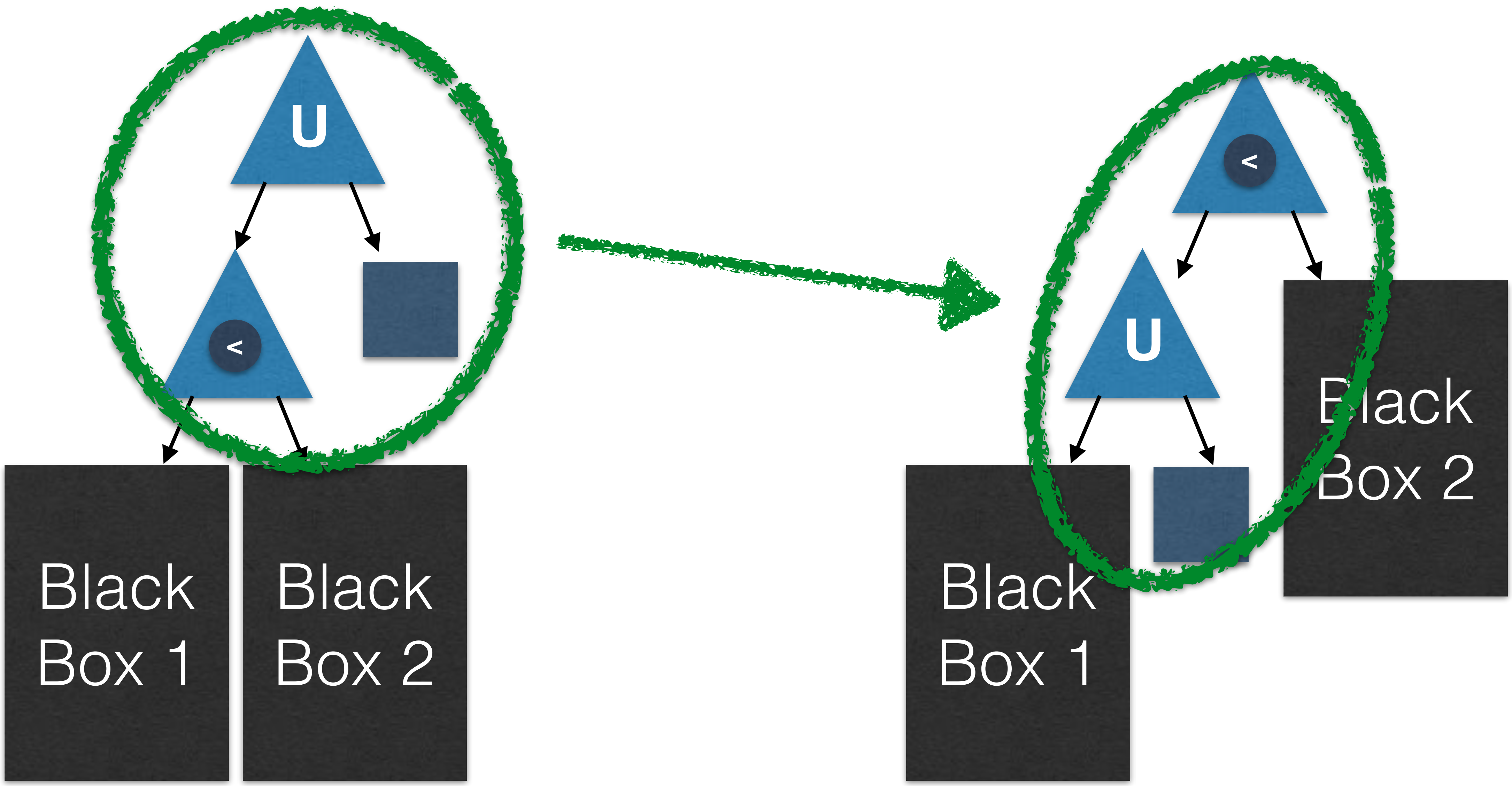
Binary Tree Insertions

A rewrite pushes the inserted object down into the tree



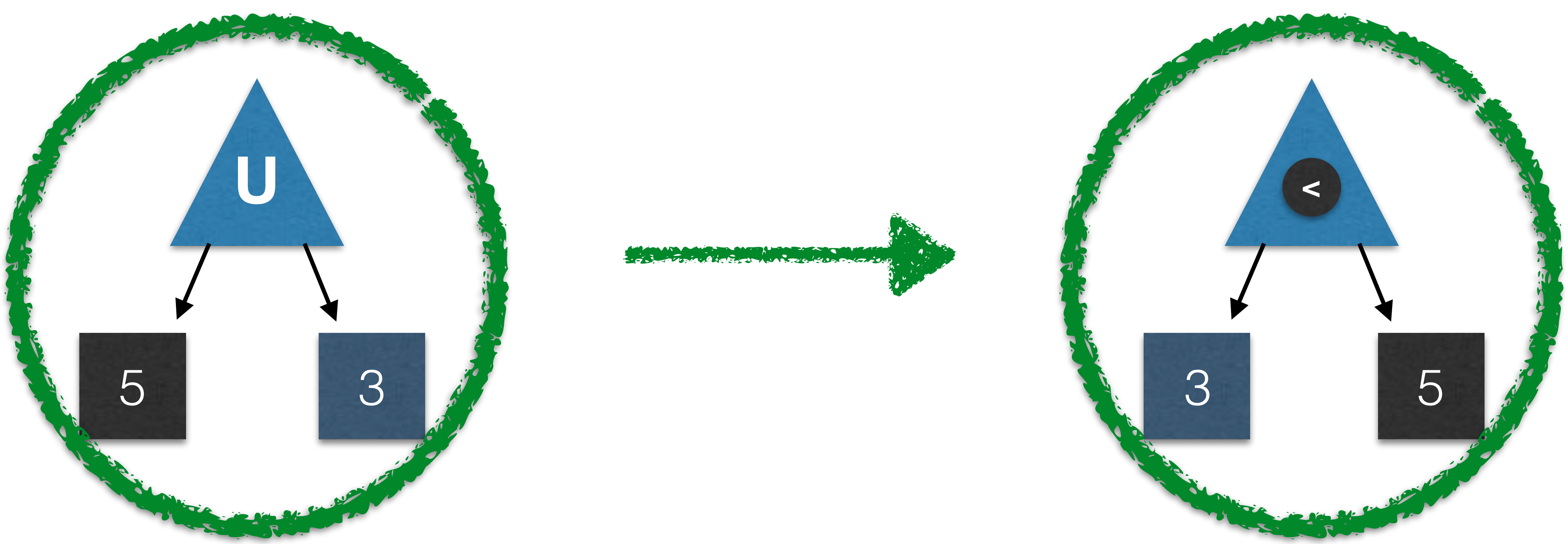
Binary Tree Insertions

The rewrites are **local**.
The rest of the data structure doesn't matter!

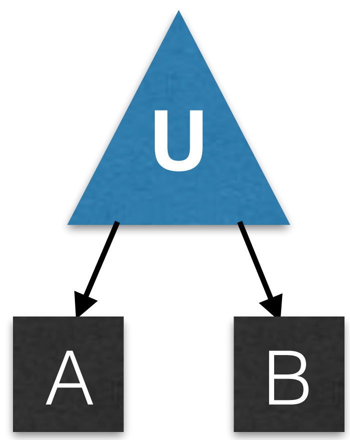


Binary Tree Insertions

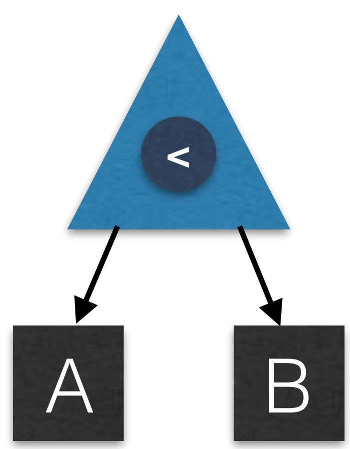
Terminate recursion at the leaves



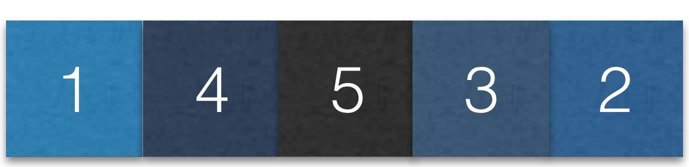
Range Scan(low, high)




```
[Recur into A]
  UNION [Recur into B]
```




```
IF(sep > high)    { [Recur into A] }
ELSIF(sep ≤ low) { [Recur into B] }
ELSE { [Recur into A]
         UNION [Recur into B] }
```

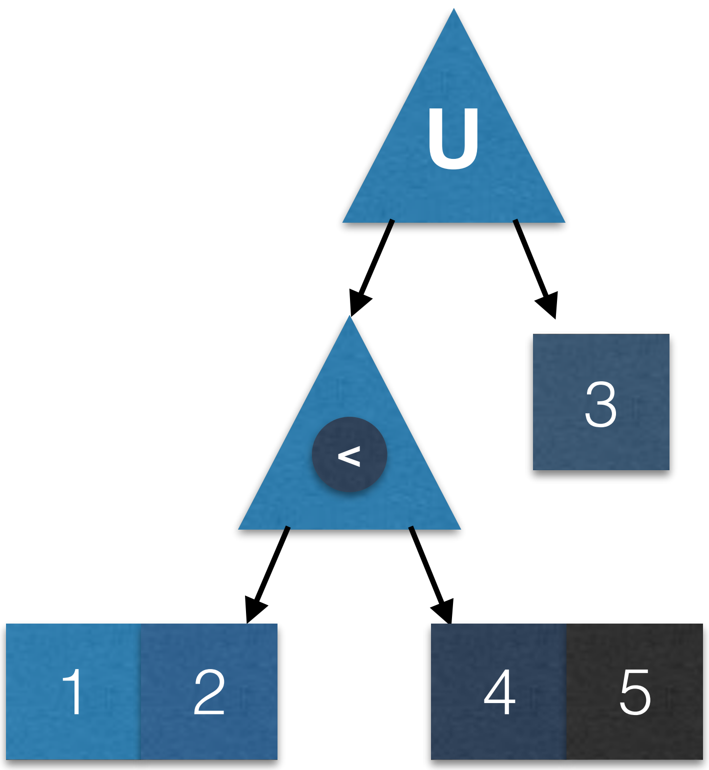


Full Scan

2x Binary Search

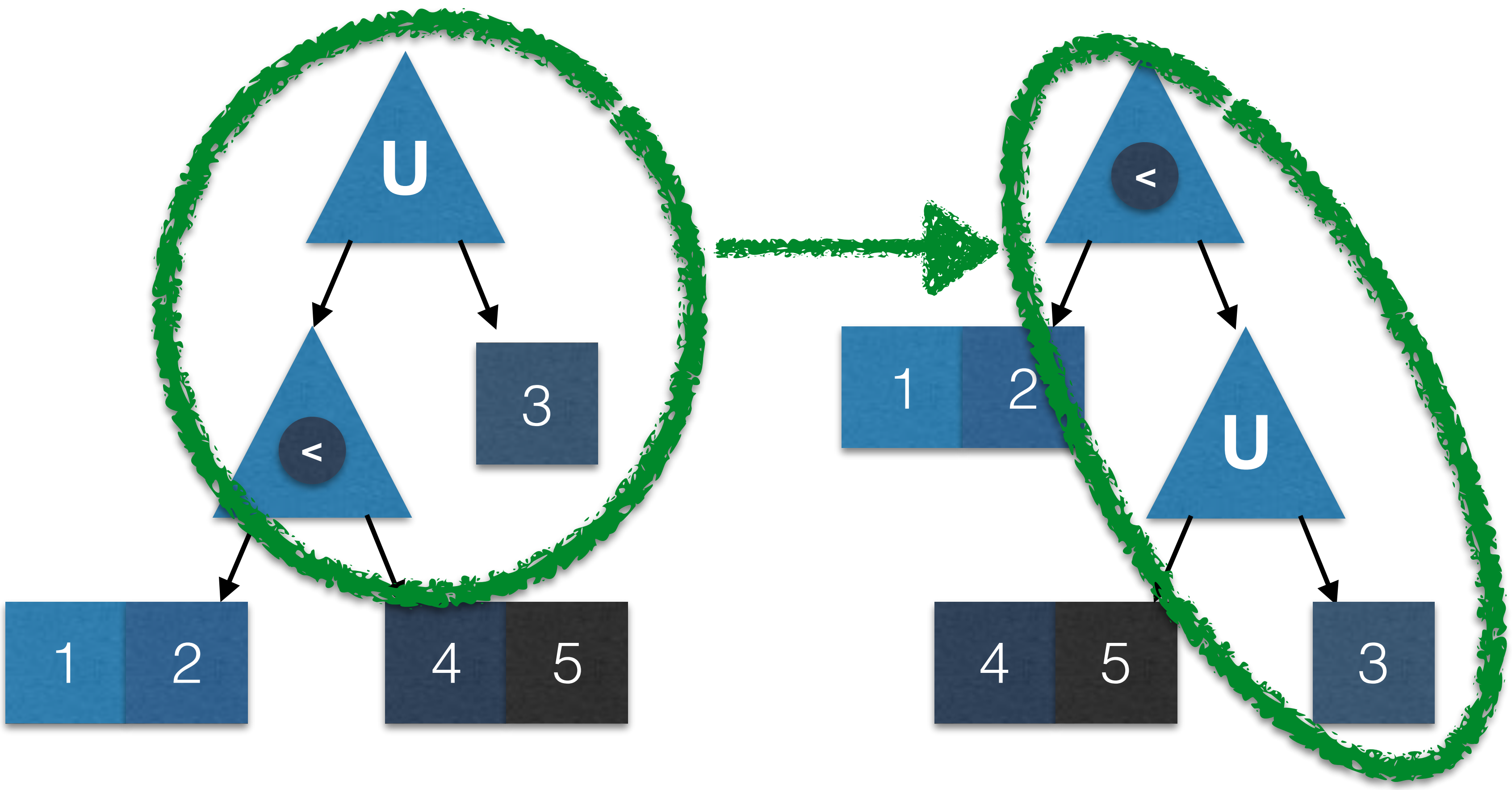
Synergy

Hybrid Insertions



Hybrid Insertions

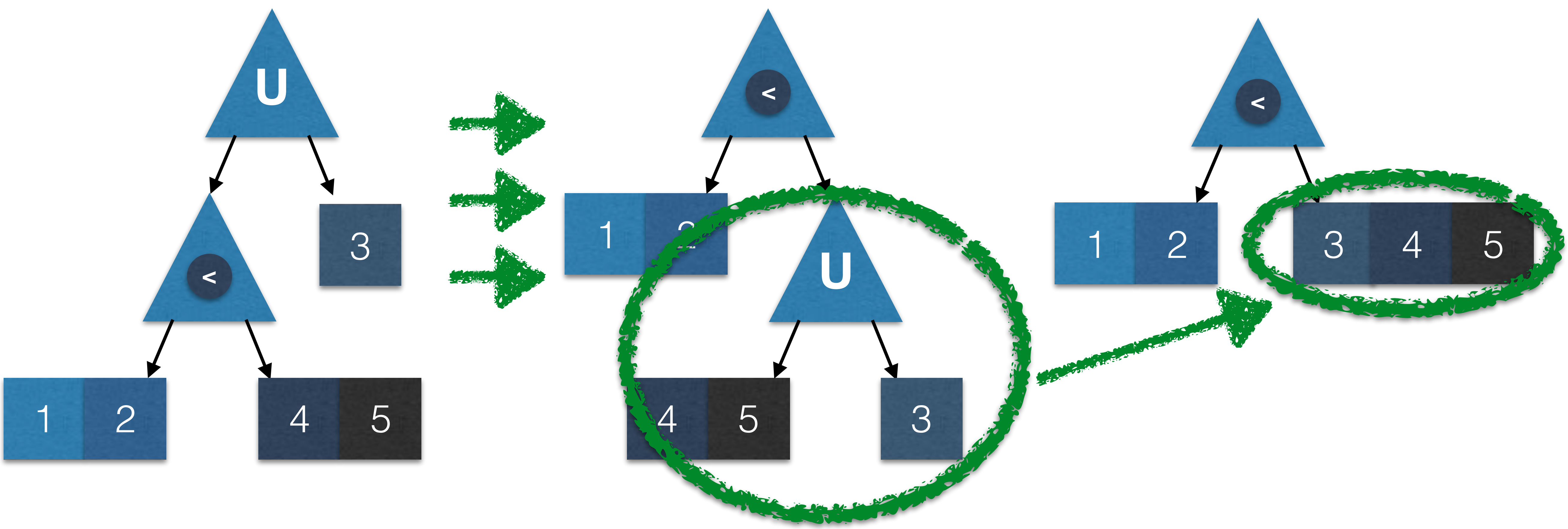
BinTree
Rewrite



Hybrid Insertions

Binary Tree Rewrite

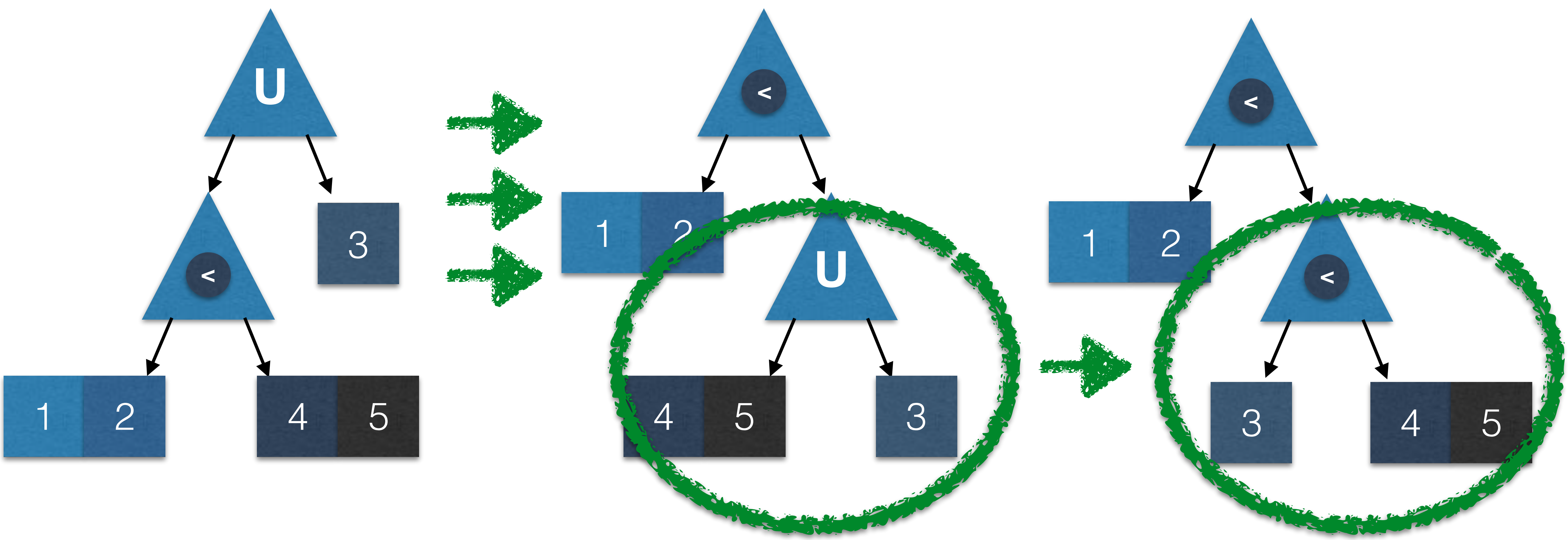
Sorted Array Rewrite



Synergy

Binary Tree Rewrite

Binary Tree Leaf Rewrite



Which rewrite gets used depends on workload-specific policies.

- Picking The Right Abstraction
- Accessing and Manipulating a JITD
- ➡ Case Study: Adaptive Indexes
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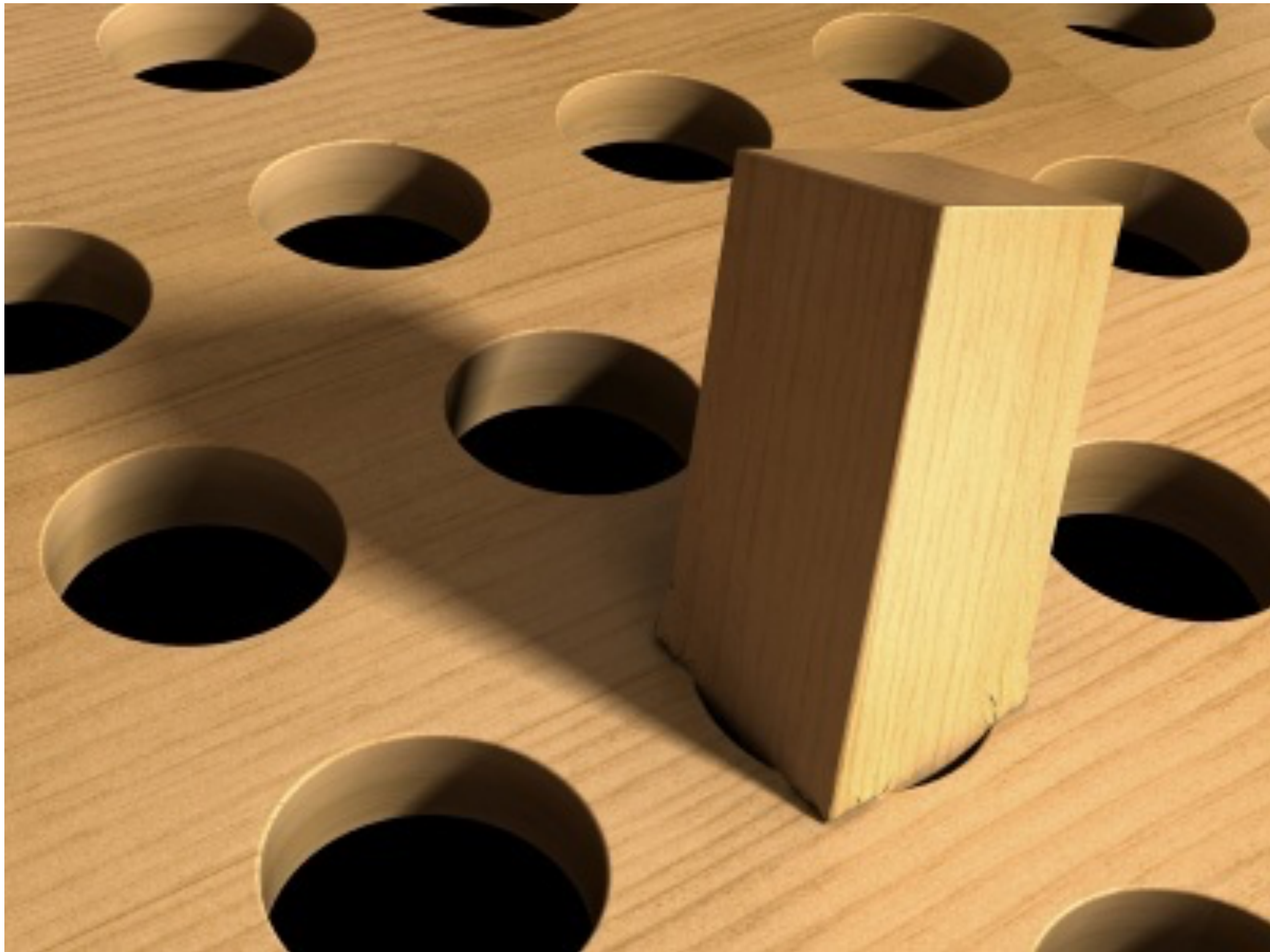
- Demo

Adaptive Indexes

Your Index

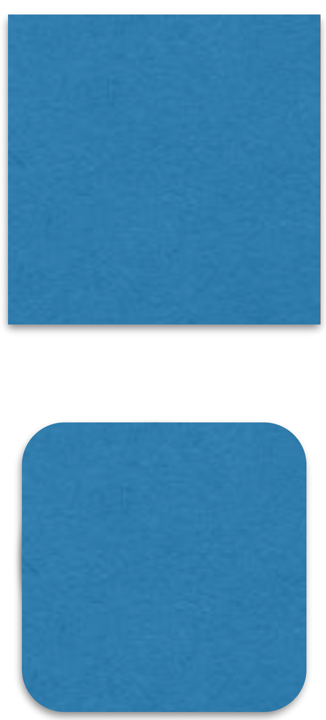
Your Workload



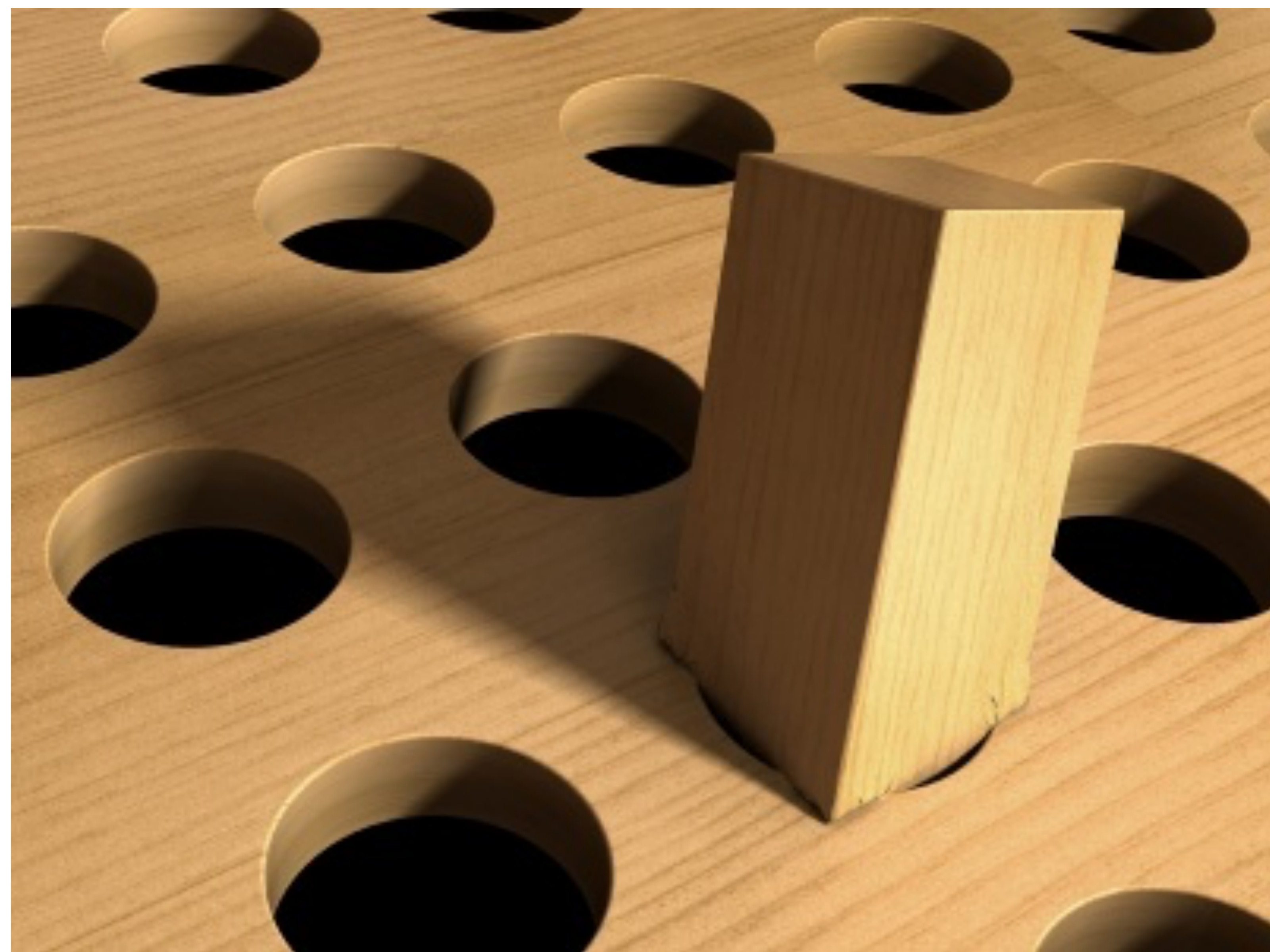
Adaptive Indexes

<u>Your Index</u>

Time ↓



<u>Your Workload</u>

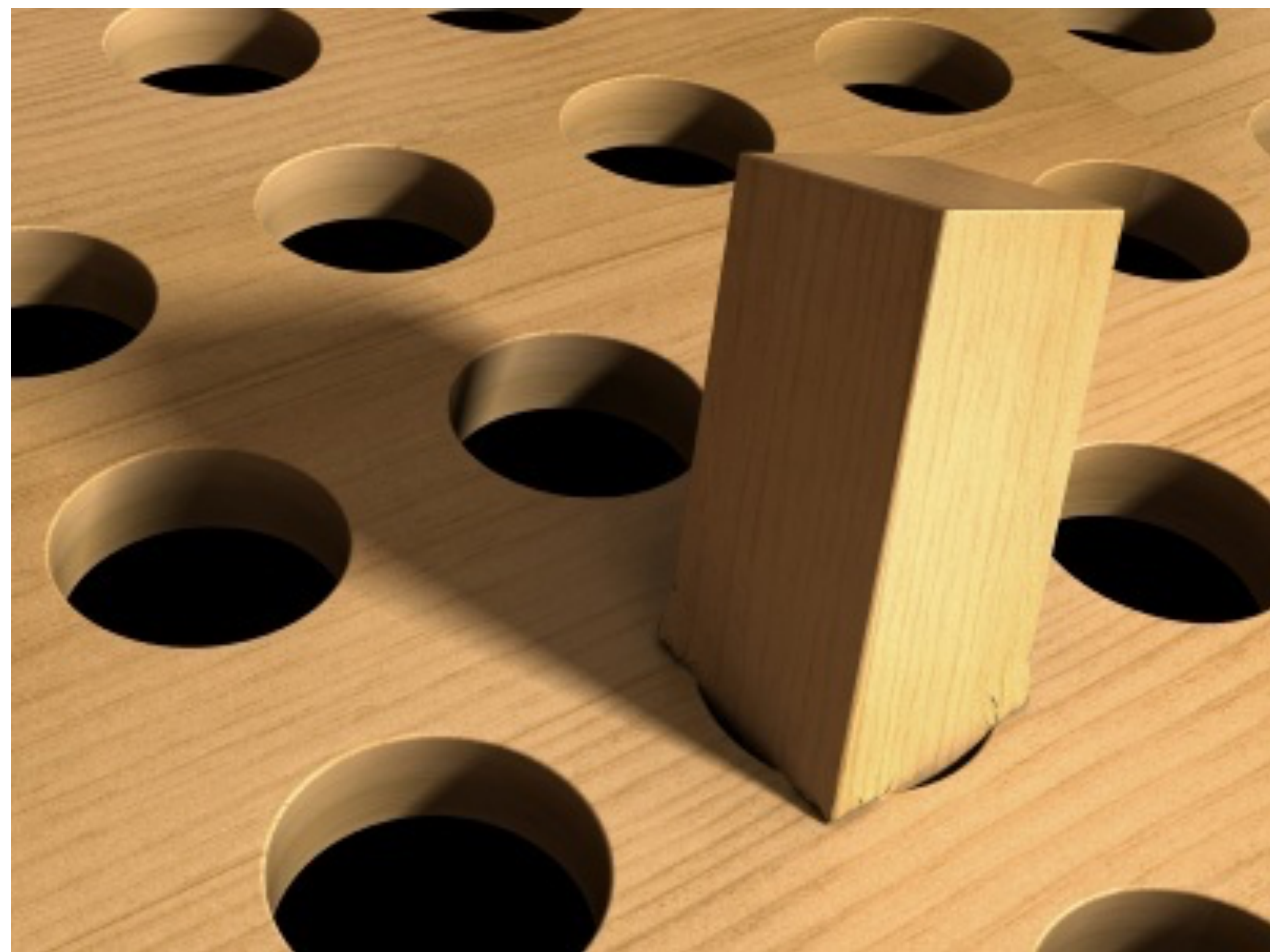


Adaptive Indexes

Your Index

Your Workload

Time ↓



Range-Scan Adaptive Indexes

Start with an Unsorted List of Records

Converge to a Binary Tree or Sorted Array

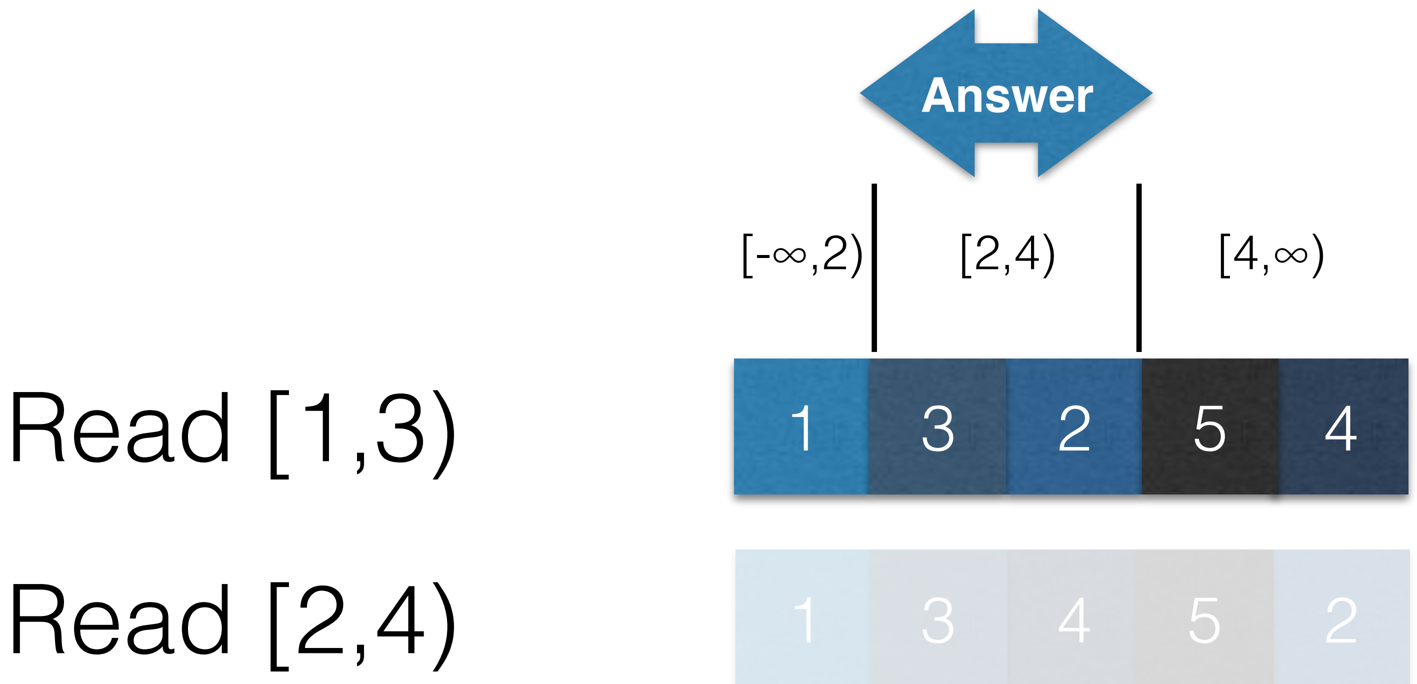
- Cracker Index
  - Converge by emulating quick-sort
- Adaptive Merge Trees
  - Converge by emulating merge-sort

Cracker Indexes

Read [2,4)

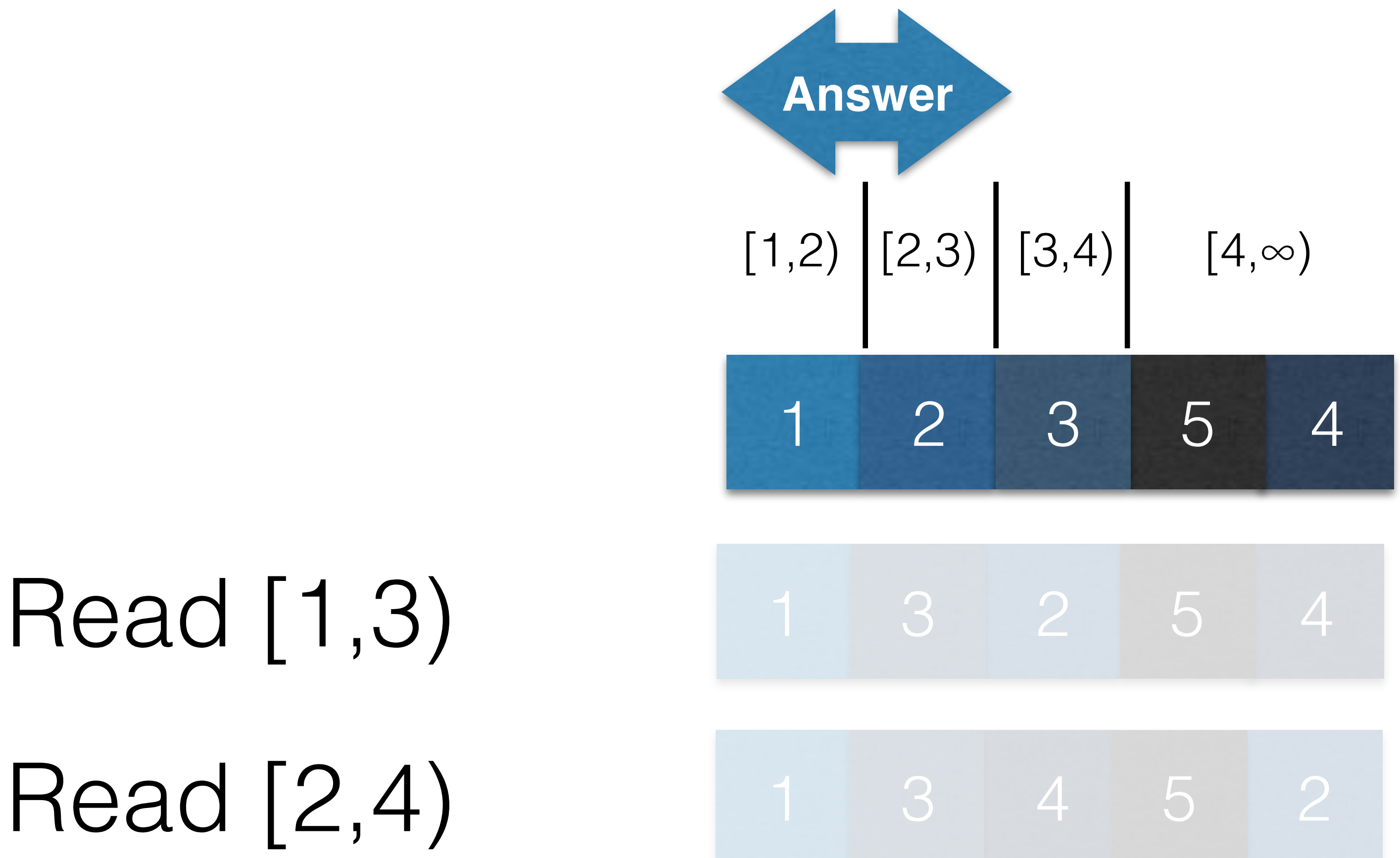
1	3	4	5	2

Cracker Indexes



Radix Partition on Query Boundaries (Don't Sort)

Cracker Indexes



Each query does less and less work

Rewrite-Based Cracking

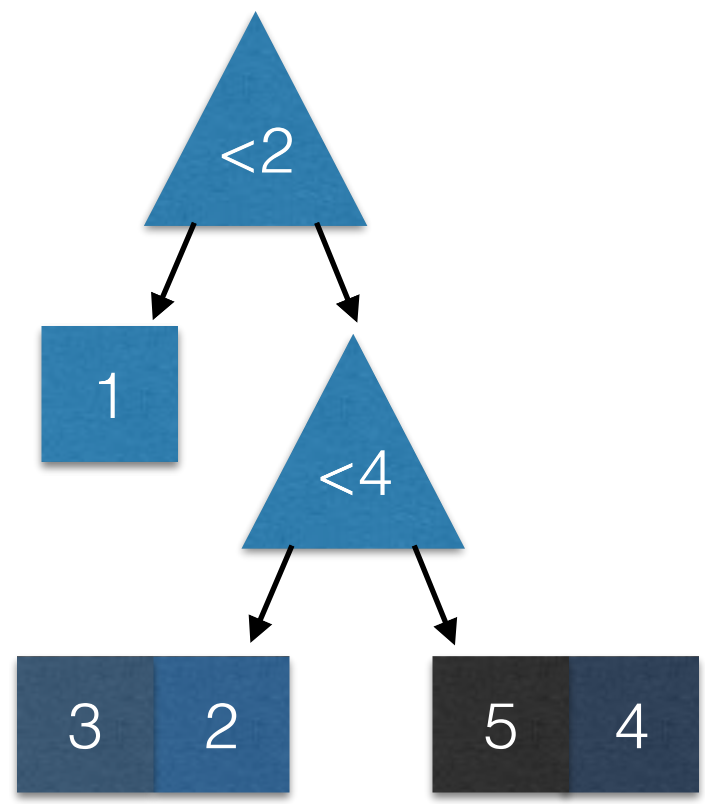
Read [2,4)

1	3	4	5	2

Rewrite-Based Cracking

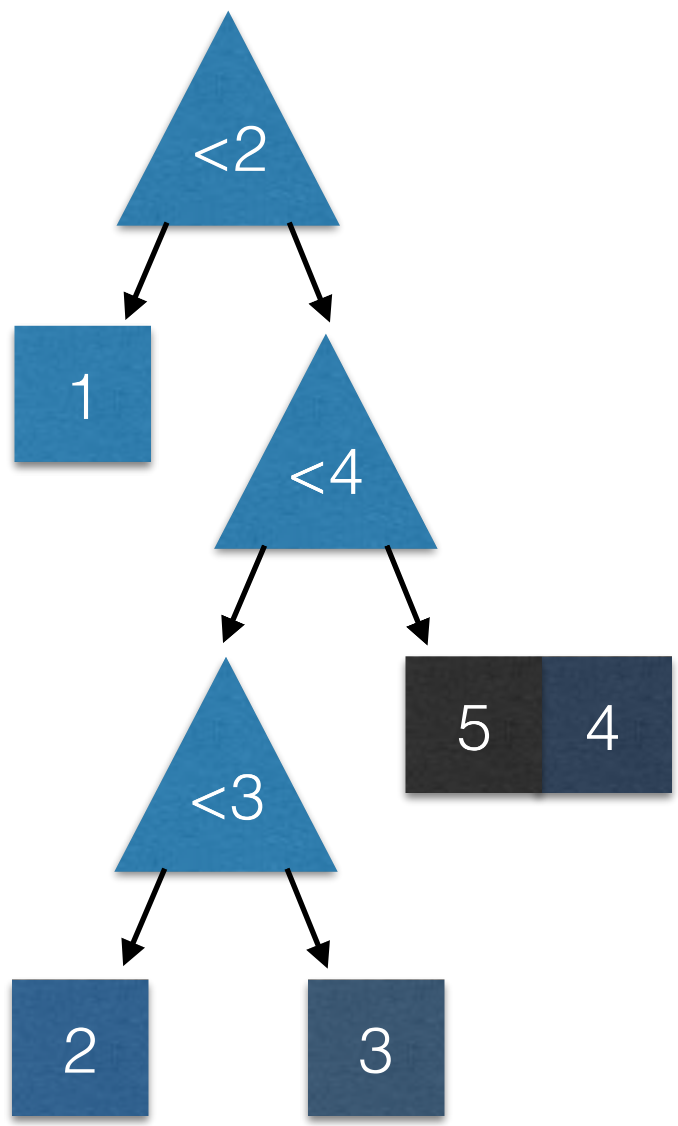
In-Place Sort as Before

Rewrite-Based Cracking



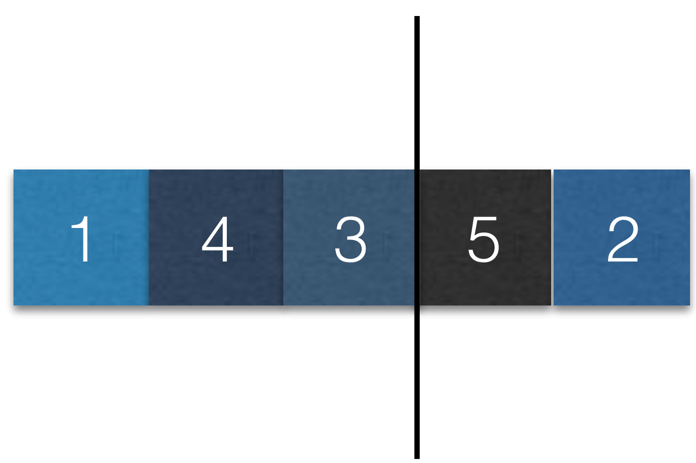
Fragment and Organize

Rewrite-Based Cracking



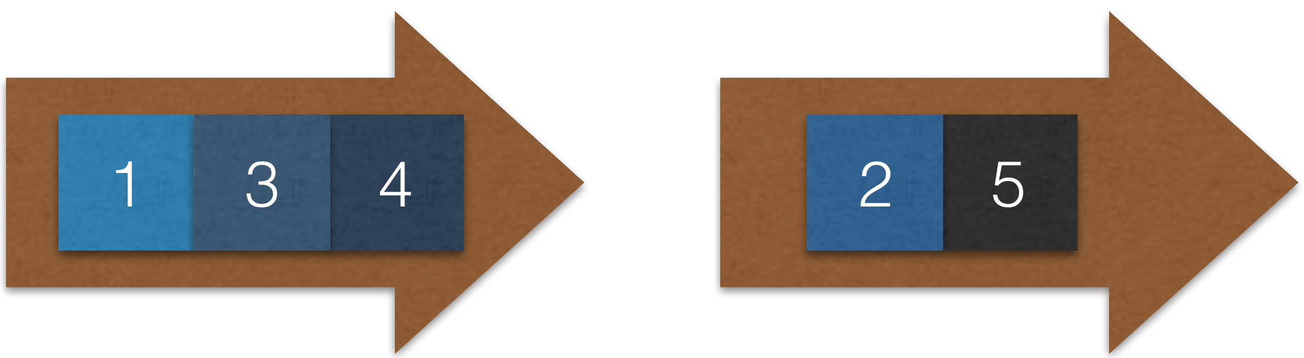
Continue fragmenting as queries arrive.
(Can use Splay Tree For Balance)

Adaptive Merge Trees



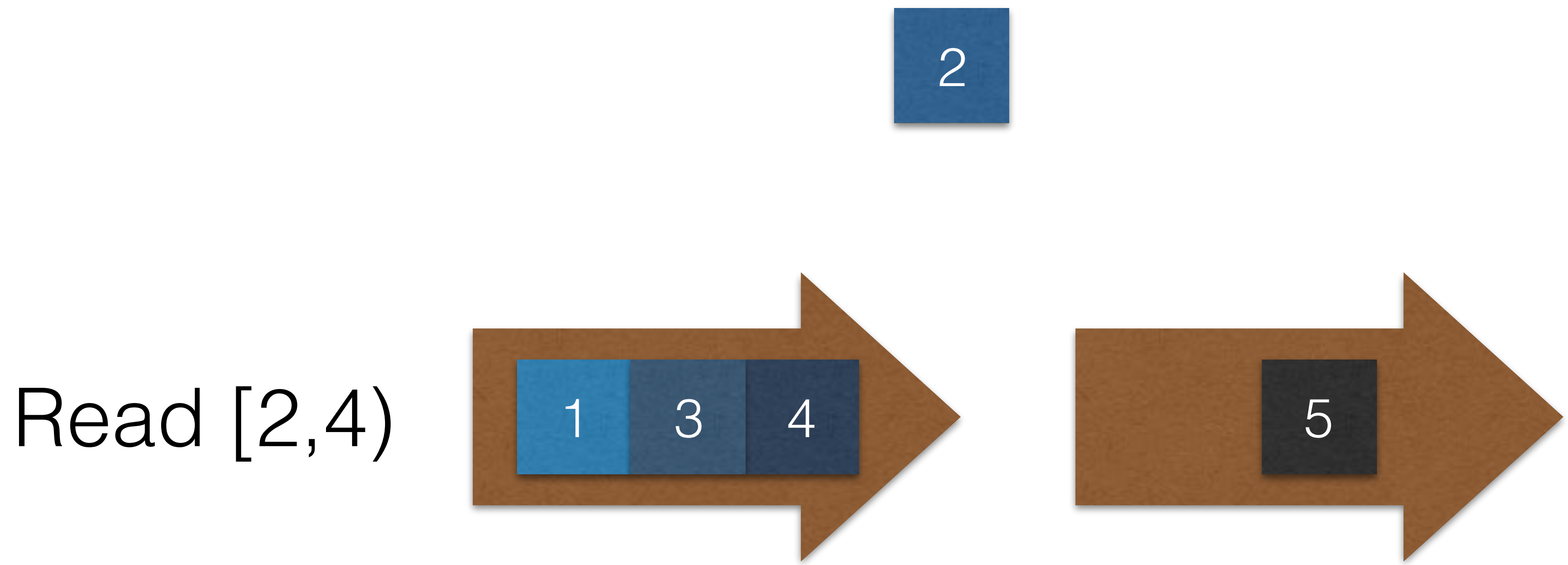
Before the first query, partition data…

Adaptive Merge Trees



…and build fixed-size sorted runs

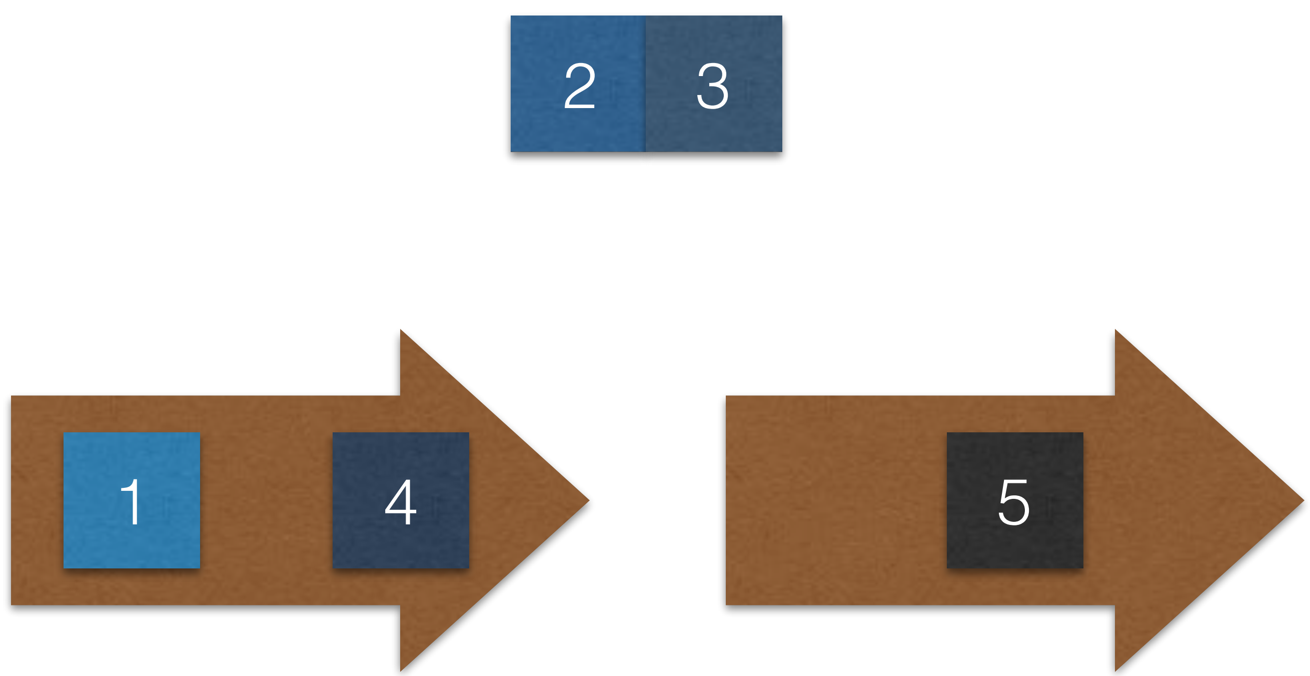
Adaptive Merge Trees



Merge only relevant records into target array

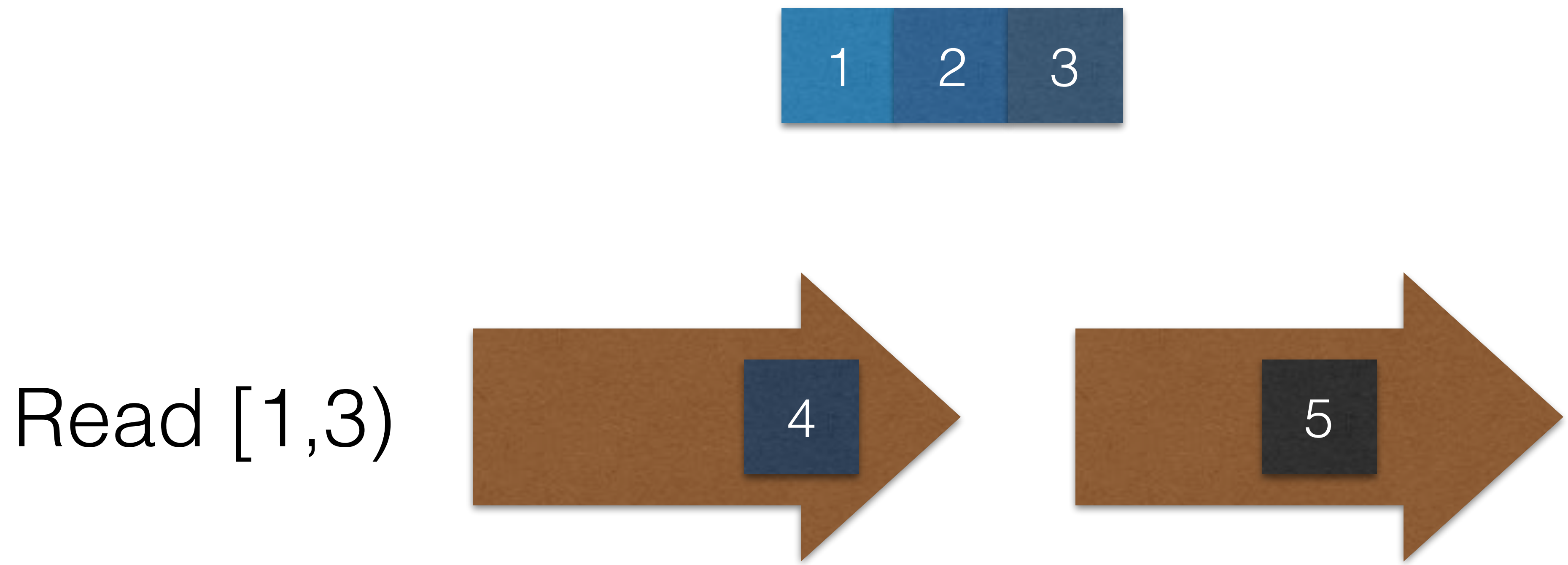
Adaptive Merge Trees

Read [2,4)



Merge only relevant records into target array

Adaptive Merge Trees

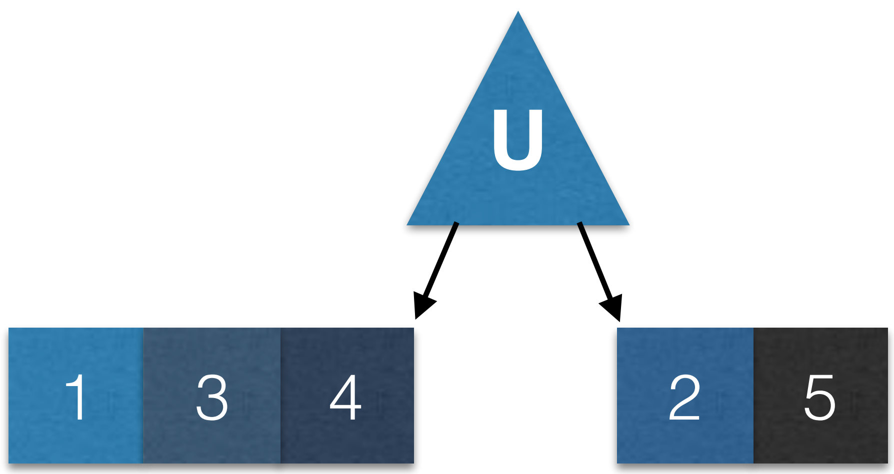


Continue merging as new queries arrive

Rewrite-Based Merging

1	4	3	5	2

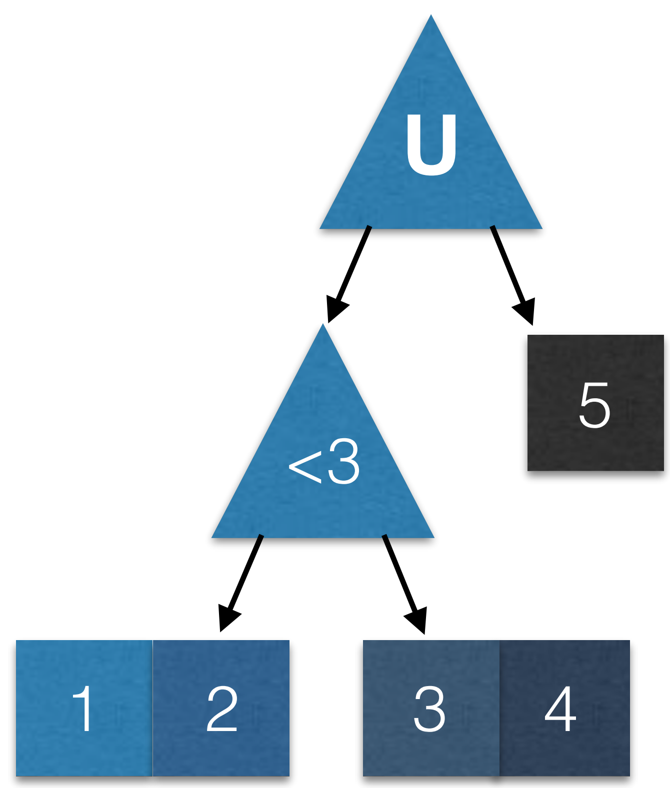
Adaptive Merge Trees



Rewrite any unsorted array into a union of sorted runs

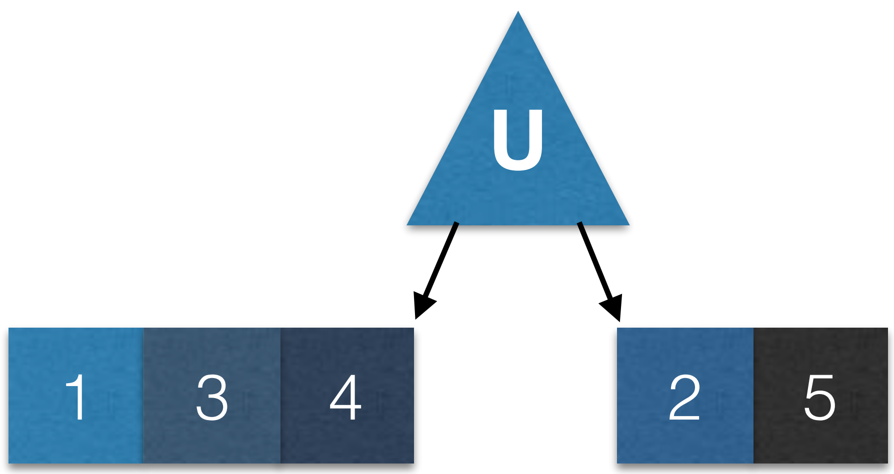
Adaptive Merge Trees

Read [2,4)



Method 1: Merge Relevant Records into LHS Run (Sub-Partition LHS Runs to Keep Merges Fast)

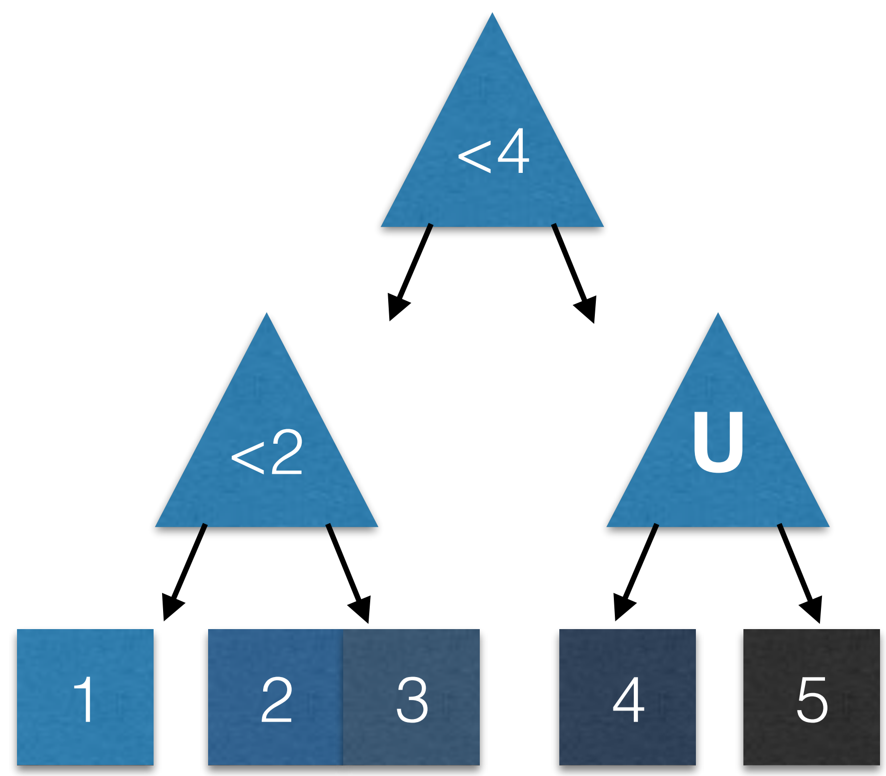
Adaptive Merge Trees



or…

Adaptive Merge Trees

Read [2,4)



Method 2: Partition Records into High/Mid/Low (Union Back High & Low Records)

Synergy

- Cracking creates smaller unsorted arrays, so fewer runs are needed for adaptive merge
- Sorted arrays don't need to be cracked!
- Insertions naturally transformed into sorted runs.
- (not shown) Partial crack transform pushes newly inserted arrays down through merge tree.

- Picking The Right Abstraction
- Accessing and Manipulating a JITD
- Case Study: Adaptive Indexes
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Experiments

Cracker Index

vs

Adaptive Merge Tree

vs

JITDs

API

- RangeScan(low, high)
- Insert(Array)

Gimmick

- Insert is Free.
- RangeScan uses work done to answer the query to also organize the data.

Experiments

Cracker Index ← **Less** organization per-read

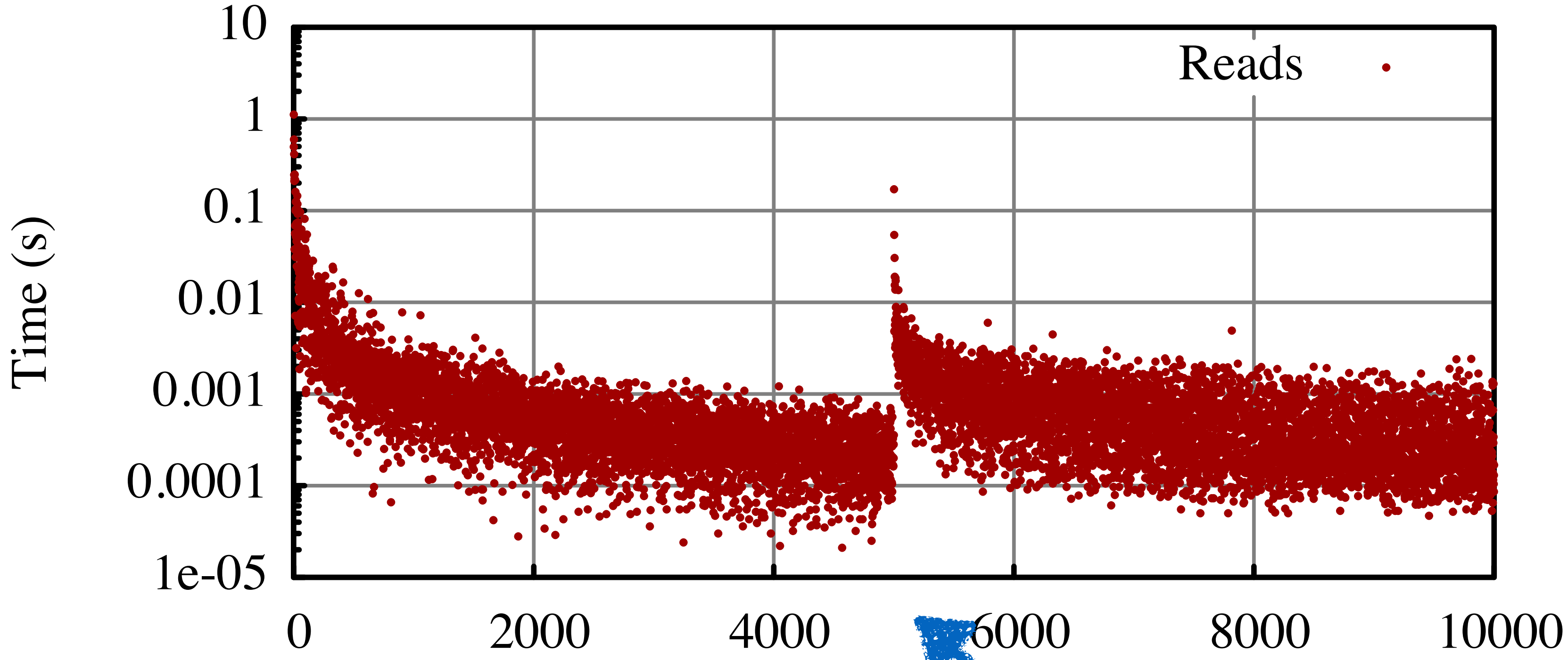
vs

Adaptive Merge Tree ← **More** organization per-read

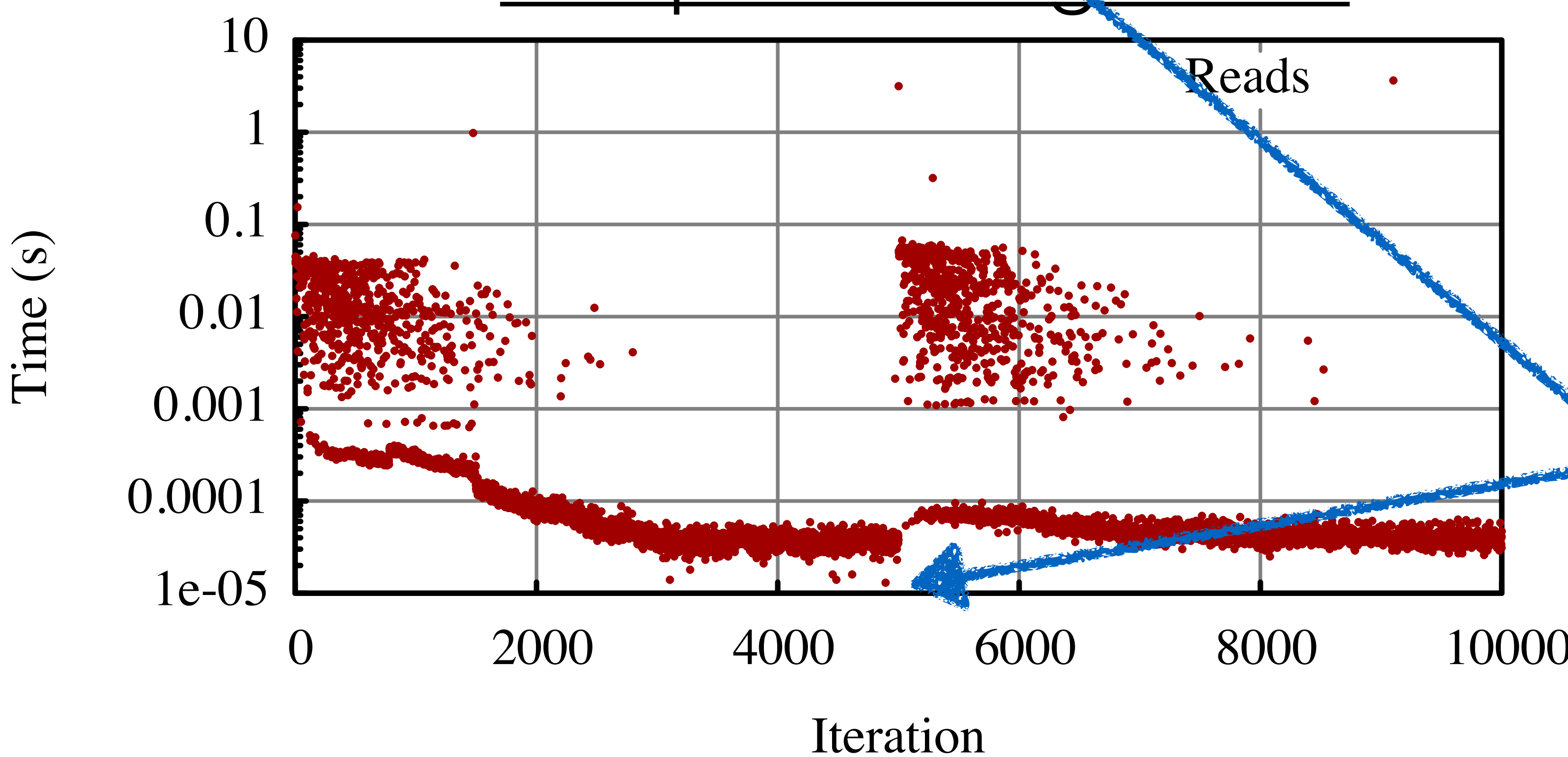
vs

JITDs

Cracker Index



Adaptive Merge Tree

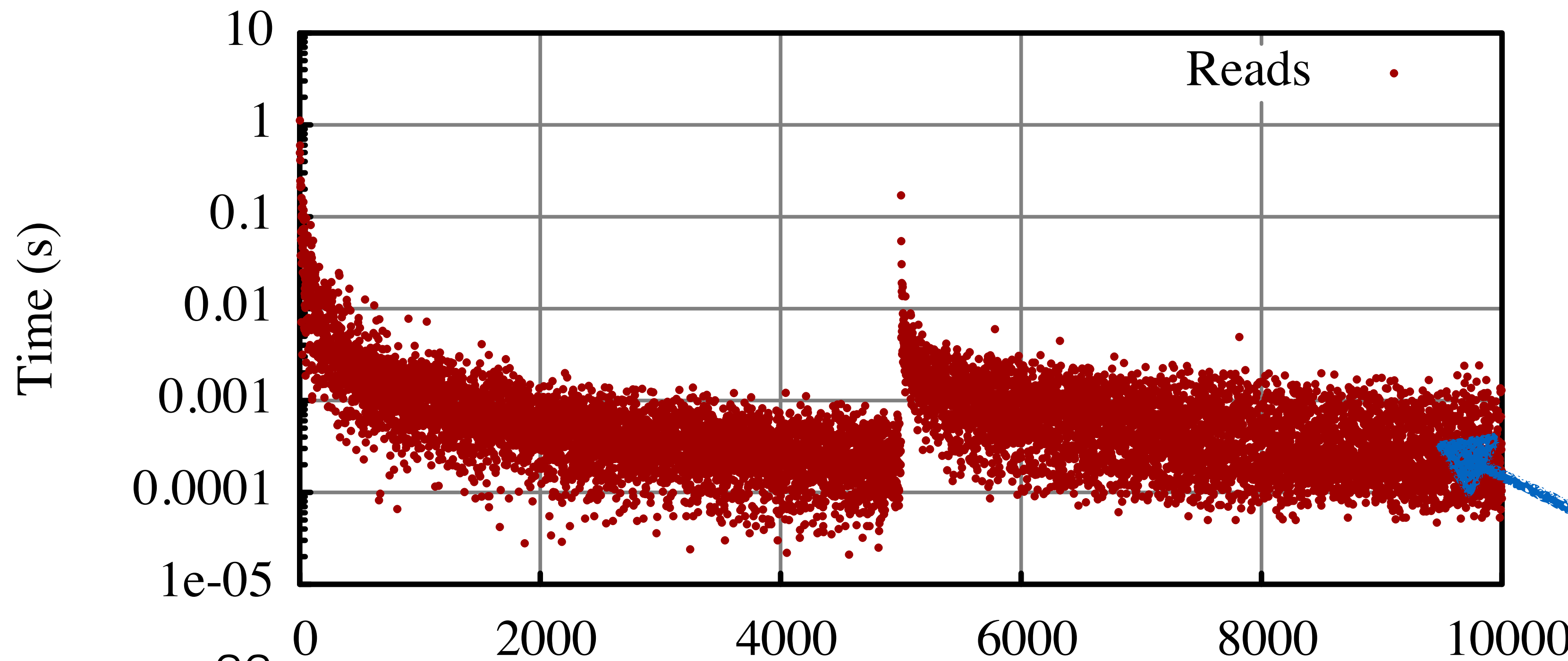


100 M records (1.6 GB)

10,000 reads for 2-3 k records each

10M additional records written after 5,000 reads

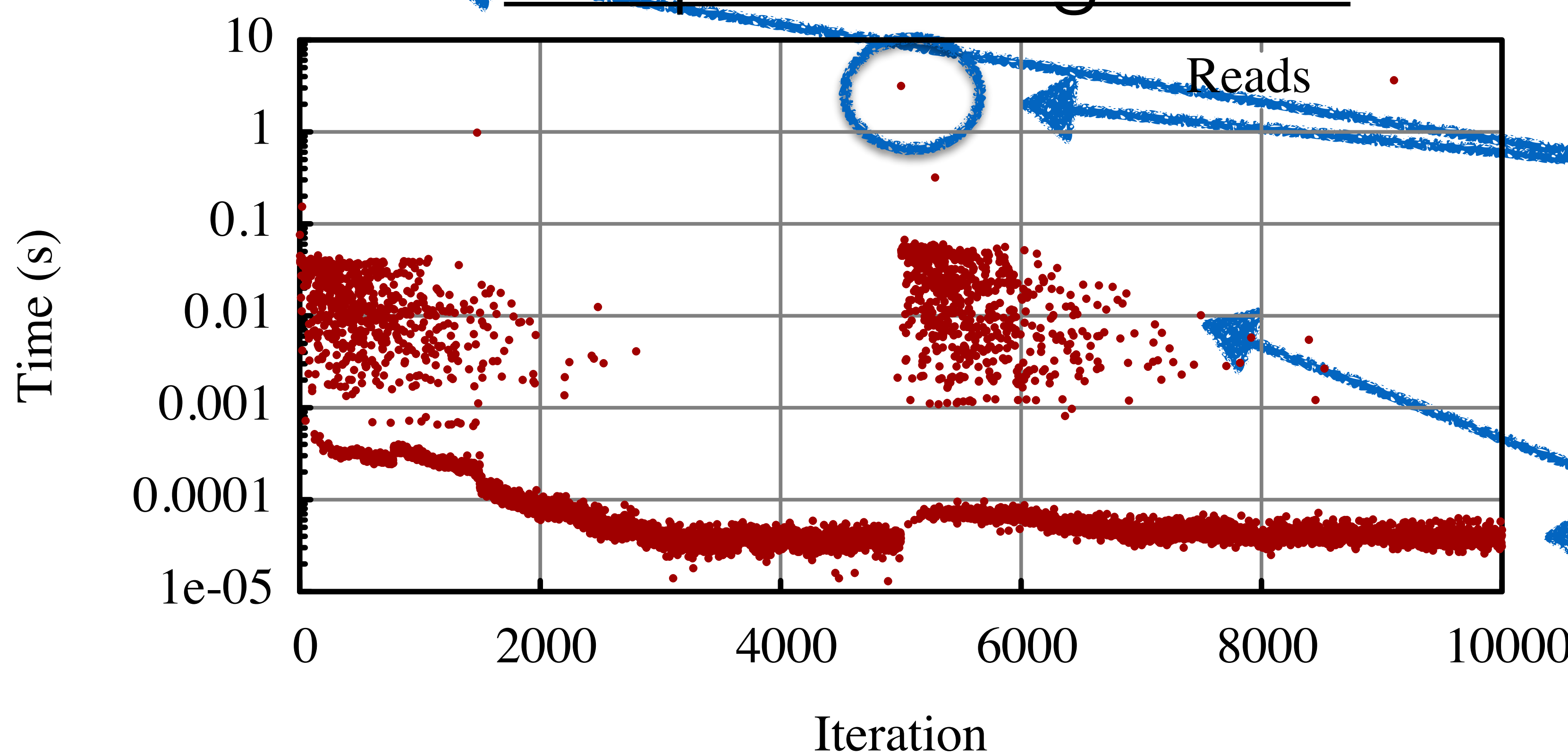
Cracker Index



Slow Convergence

33s (not shown)

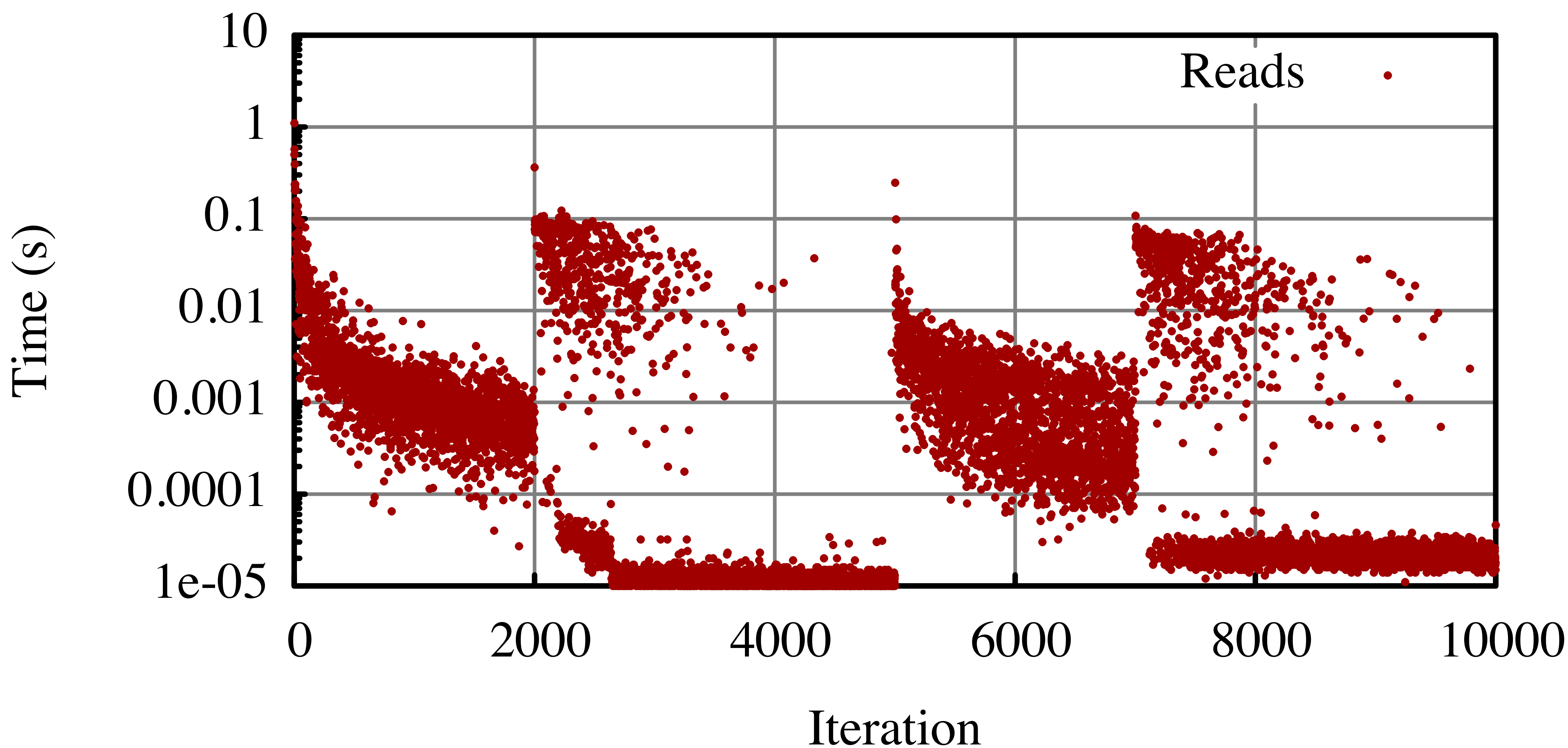
Adaptive Merge Tree



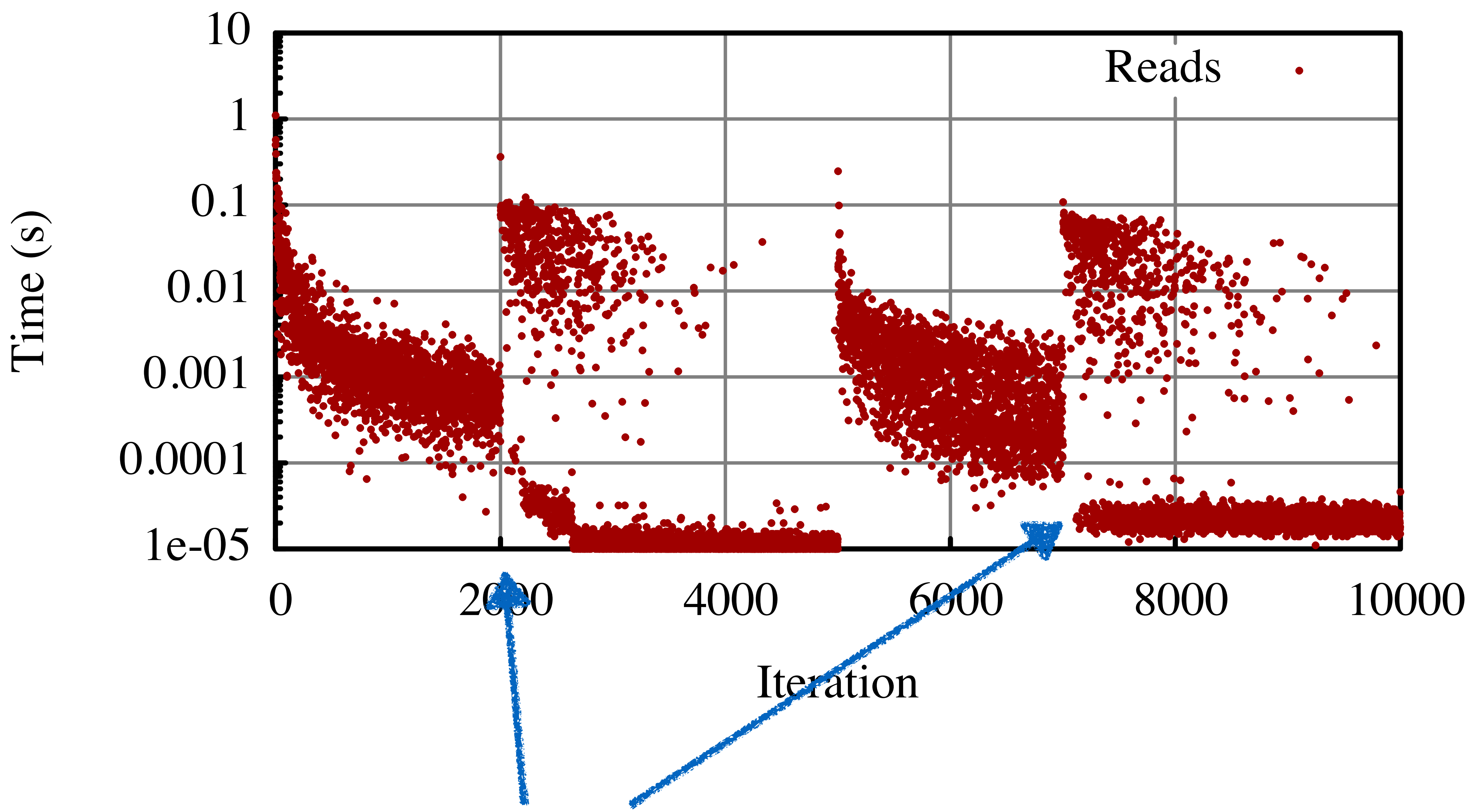
Super-High Initial Costs

Bimodal Distribution

Policy 1: Swap (Crack for 2k reads after write, then merge)

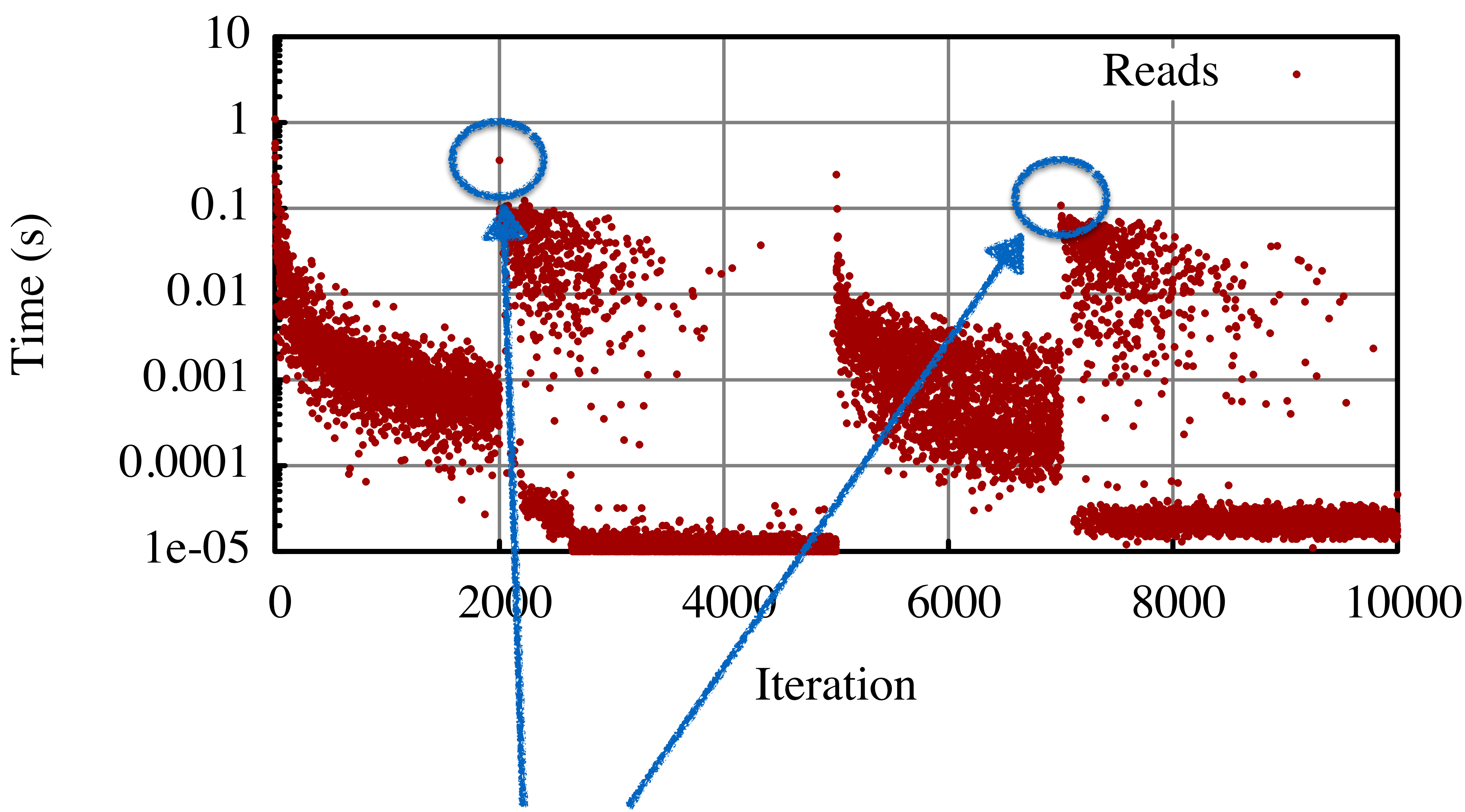


Policy 1: Swap (Crack for 2k reads after write, then merge)



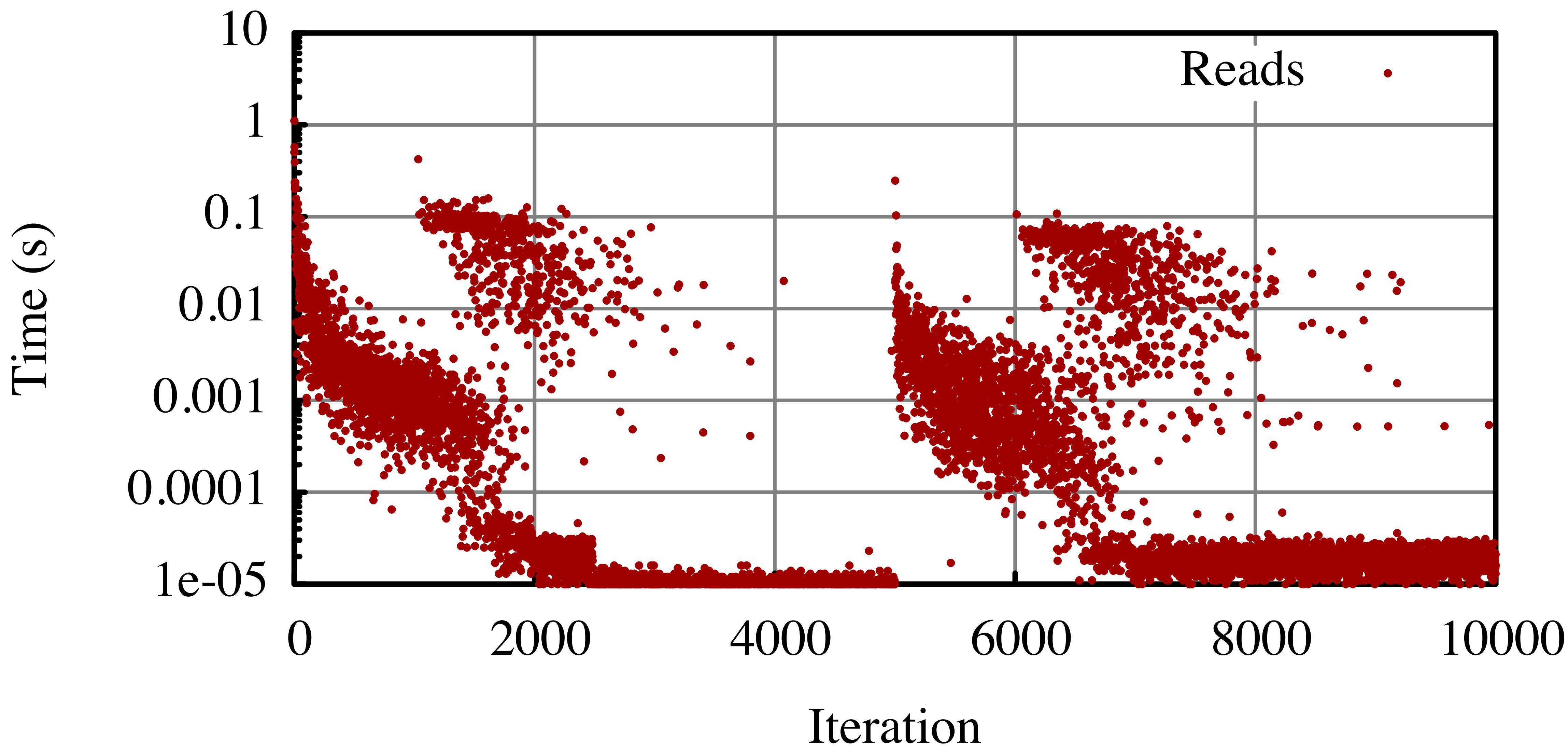
Switchover from Crack to Merge

Policy 1: Swap (Crack for 2k reads after write, then merge)

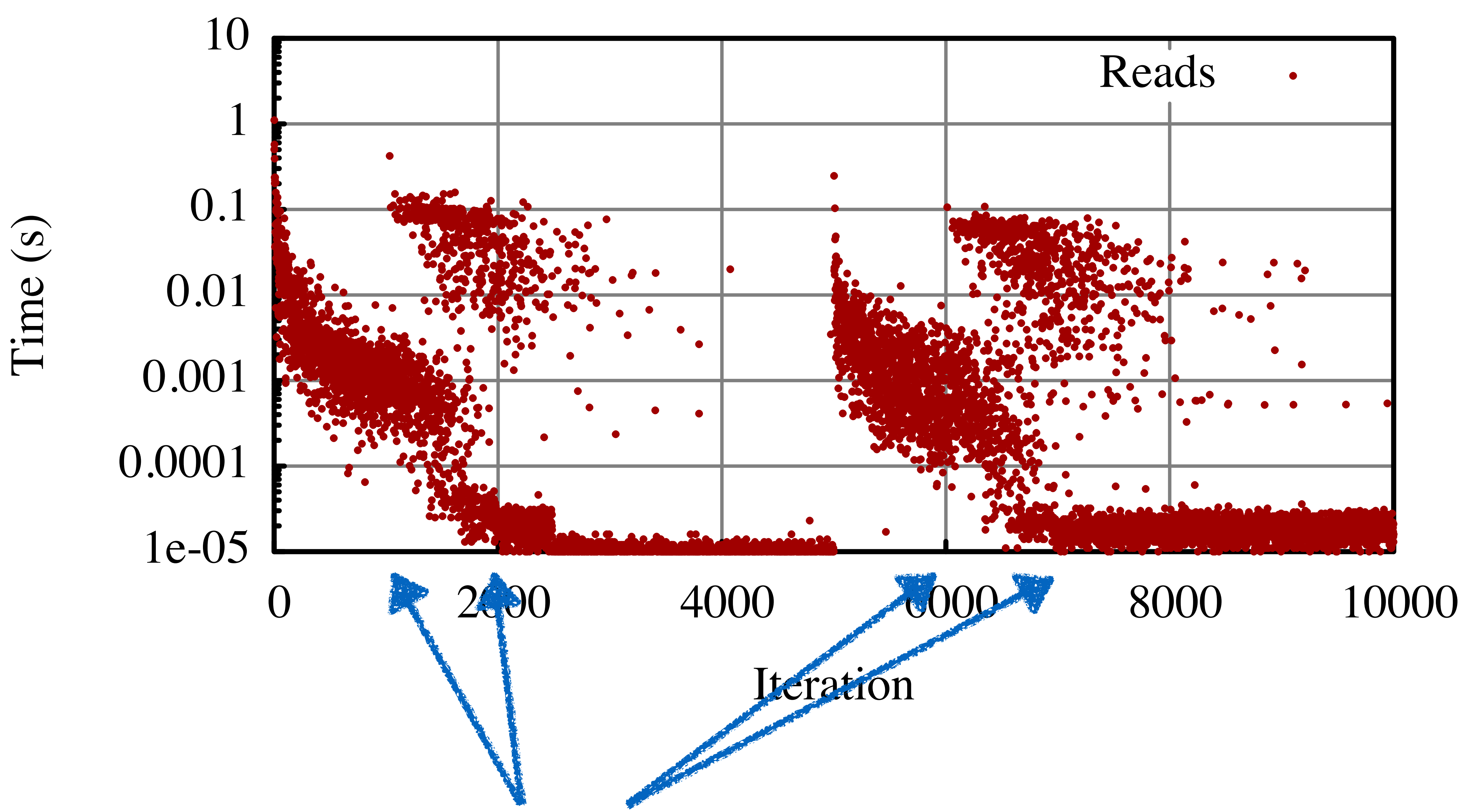


Synergy from Cracking (lower upfront cost)

Policy 2: Transition (Gradient from Crack to Merge at 1k)

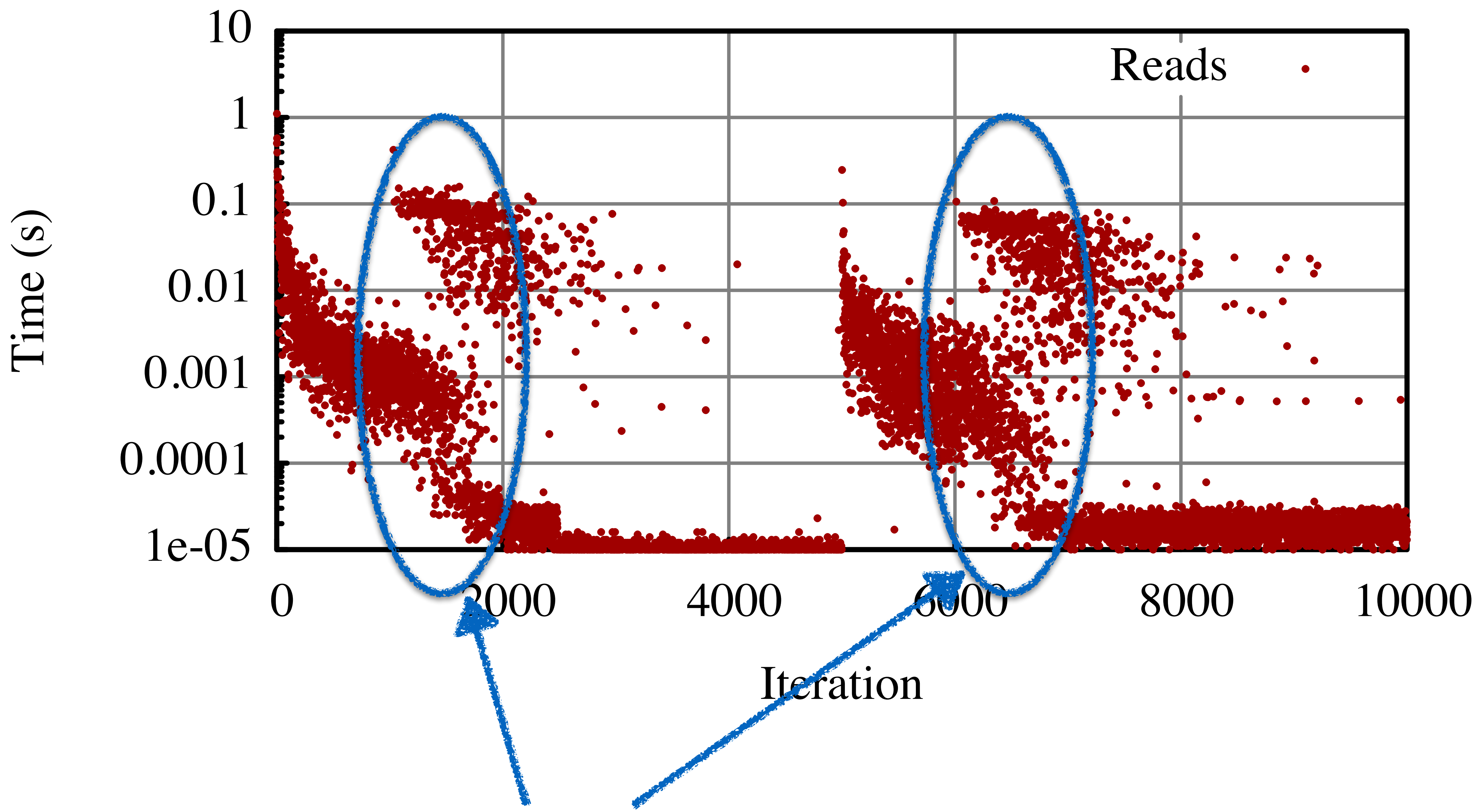


Policy 2: Transition (Gradient from Crack to Merge at 1k)



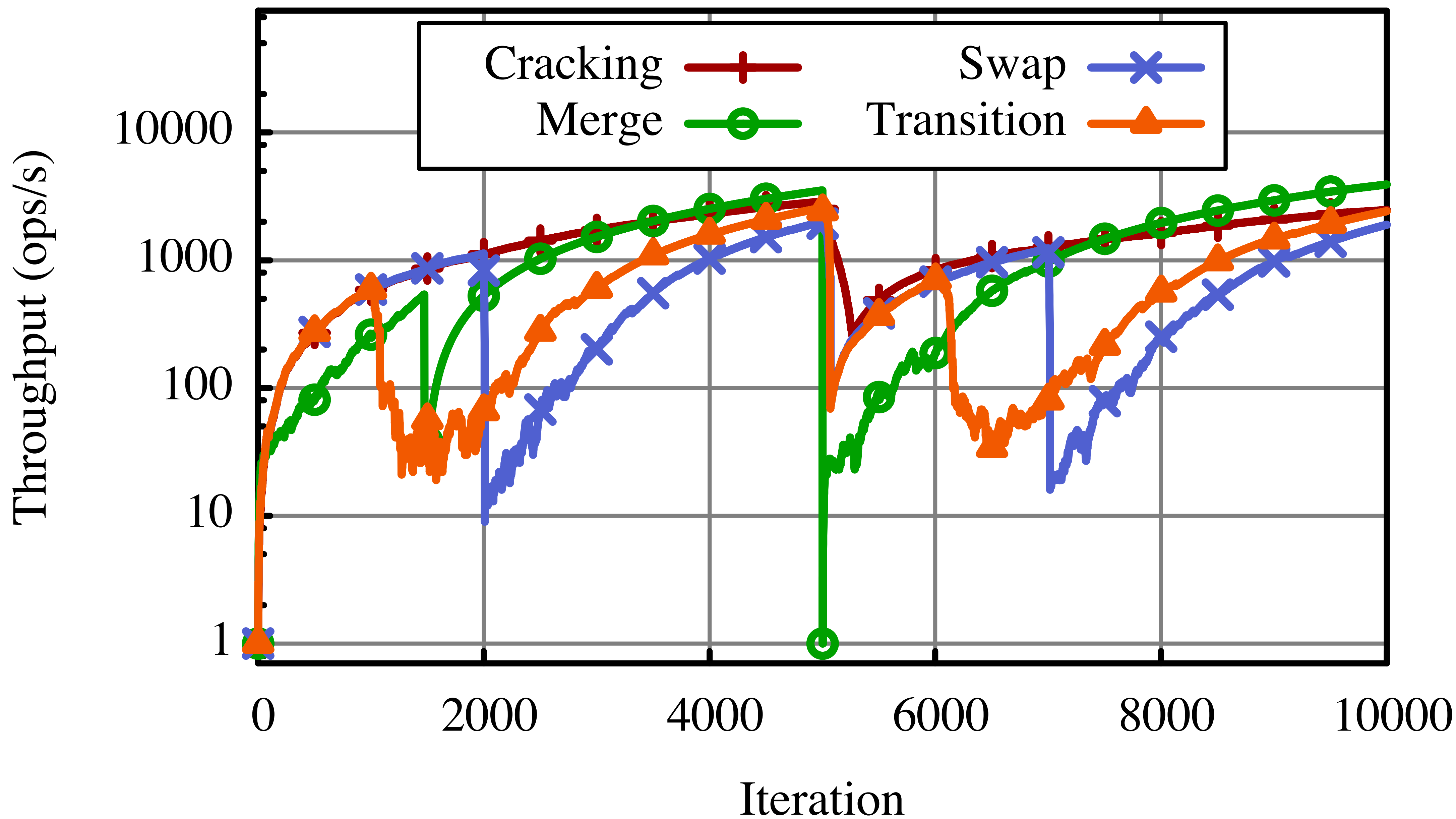
Gradient Period (% chance of Crack or Merge)

Policy 2: Transition (Gradient from Crack to Merge at 1k)



Tri-modal distribution: Cracking and Merging
on a per-operation basis

Overall Throughput



JITDs allow fine-grained control over DS behavior

Just-in-Time Data Structures

- Separate **logic** and **structure/semantics**
  - Composable Building Blocks
  - Local Rewrite Rules
- Result: Flexible, hybrid data structures.
- Result: Graceful transitions between different behaviors.
- https://github.com/UBOdin/jitd

Questions?