The Case for Learned Index Structures

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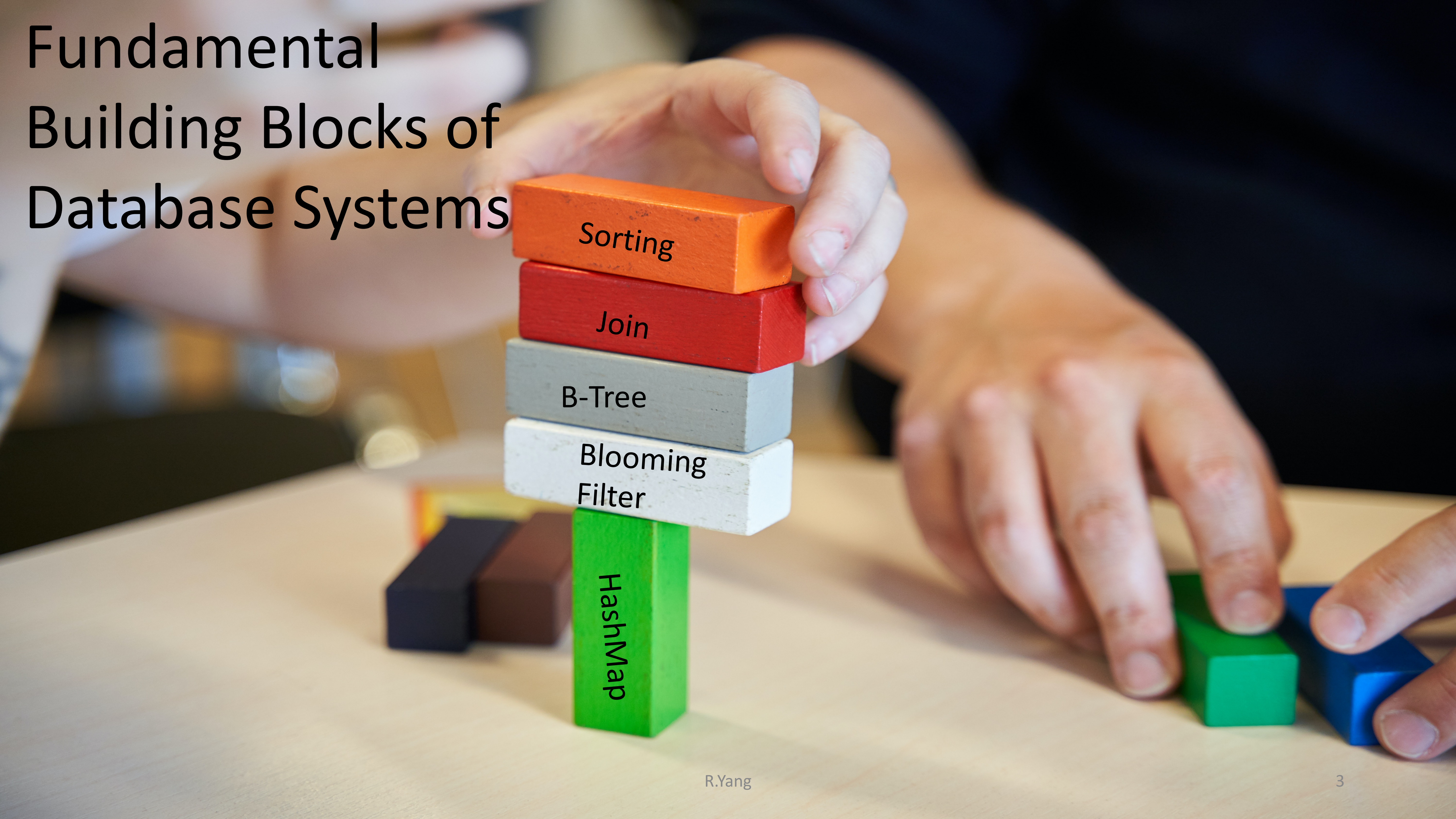
Outline

- Background on Traditional Index Structures in DBMS
  - Why do we even need index structures at all?
  - B-Tree & CDF Model
- Learned Index Structures (LIS)
  - Naïve Approach (A single NNR)
  - Reclusive Model Index (RMI)
- Conclusion

Fundamental Building Blocks of Database Systems



Index Structures

- Purpose of having these structures in DBMS?
- Hit: Tradeoff between speed and storage
- Scarifies storage reduce the # of blocks to read

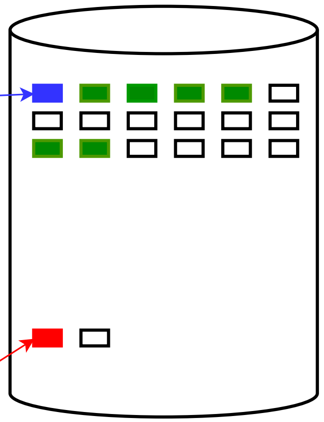
Accessing Data Without Index Structures

UVA DS School Info Table

SID	s_name	s_major	…	…	GPA
1	student_1	CS	…	…	4.0
2	student_2	DS	…	…	4.0

⋮

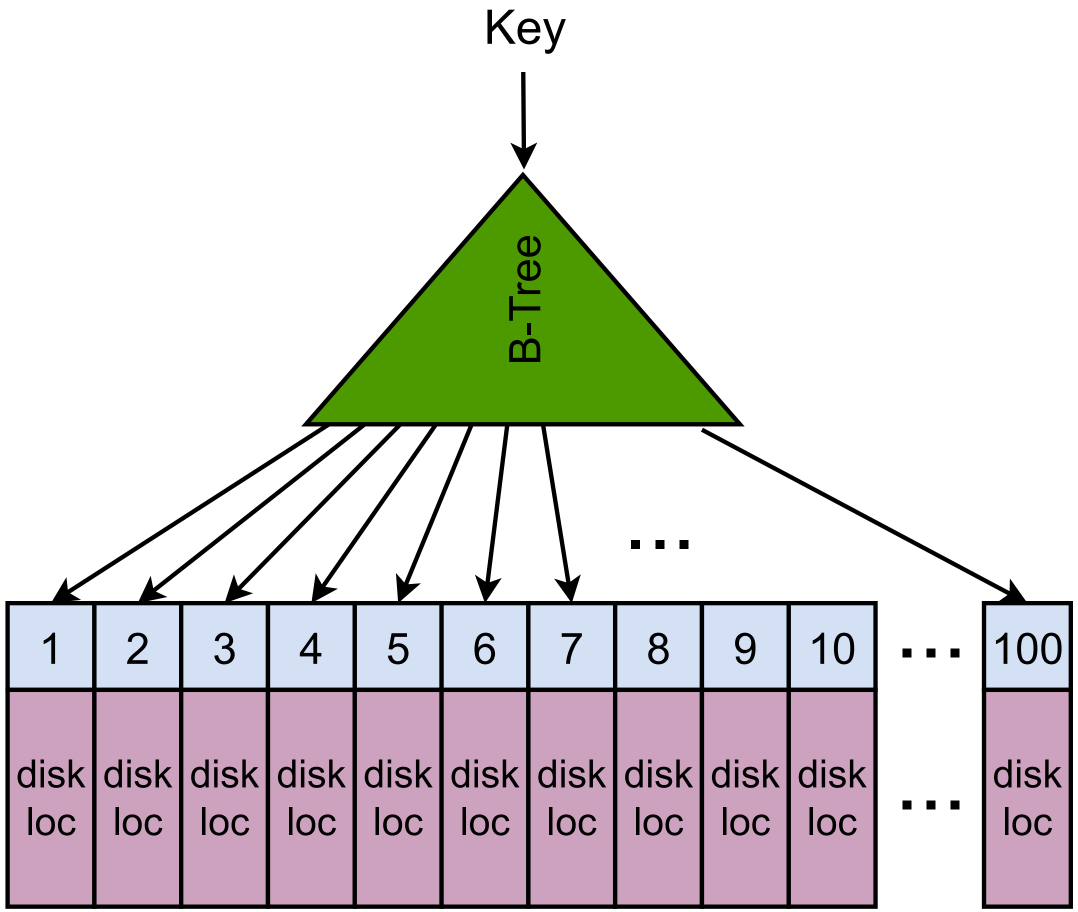
98	student_98	DA	…	…	GPA
99	student_99	CS	…	…	4.0
100	student_100	DS	…	…	4.0



100 Entries
2 Entries per Block
50 Blocks

- To access *SID==1* entry we need read at most **50 blocks** from disk. Too slow!
- Can we reduce the number of blocks to read?

Indexing SID using B-Tree



Prepare a B-Tree index structure for SID from 1 to 100

1	2	3	4	5	6	7	8	9	10	…	100

Time: O(log n)
Space: O(n)

B-Tree Operations

- Operations: *INSERT(), LOOKUP(), DELETE(), UPDATE()*
- *LOOKUP() walk through example*
  - Visualization : https://people.ksp.sk/~kuko/gnarley-trees/Btree.html#

- No assumption about data distribution
- Knowing data distribution may increase performance significantly from both speed and storage.

Indexing all integers from 1 to 100

1	2	3	4	5	6	7	8	9	10	...	100

array[lookup - 1]

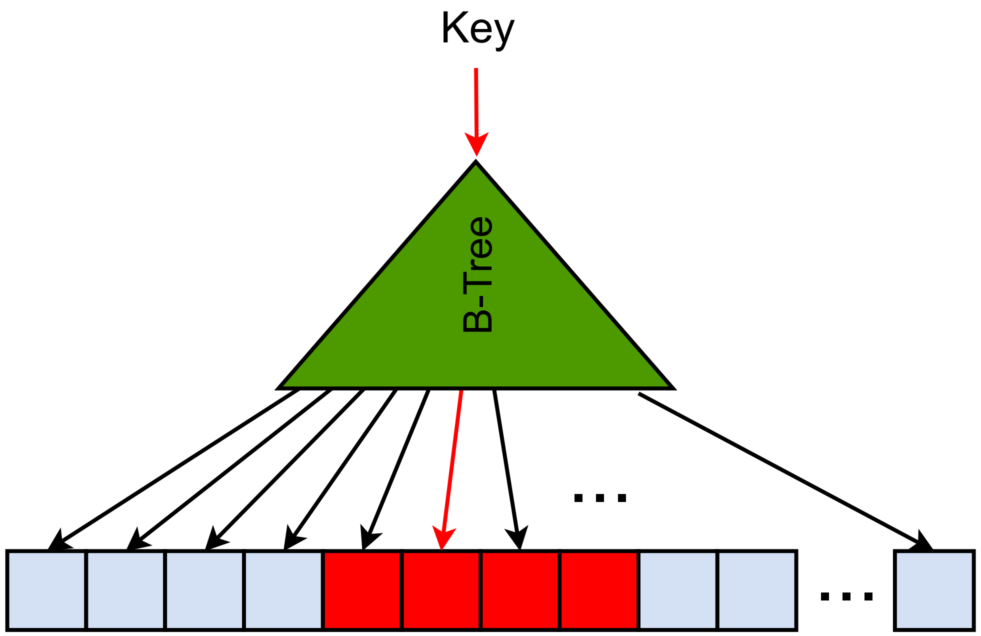
Indexing all even integers from 2 to 100

2	4	6	8	10	12	14	16	18	20	...	100

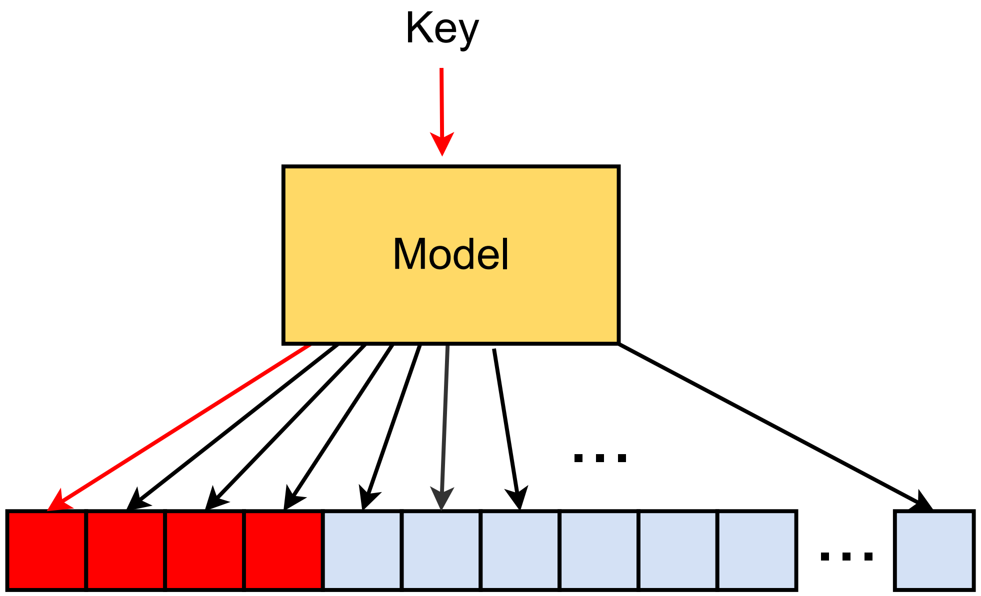
array[(lookup - 2) / 2]

A B-Tree is A Model

B-Tree
1. Locate the pos of input key
2. Binary search within a page size



Alternative view
1. Locate the pos of input key
2. Binary search within error boundaries



Assuming data are stored in dense array in sorted order

Modeling B-Tree Functionality using CDF

- B-Tree indexes the data in a sorted order
  - *Pos = B-Tree(key)*
- CDF gives the probability of X that will have a value less than or equal to *x*
  - *Pos = CDF(Key) * N*
- Data distribution visualization: https://statdist.com/

If we can learn the CDF model of a given dataset, we can replace the B-Tree index structure with learned model

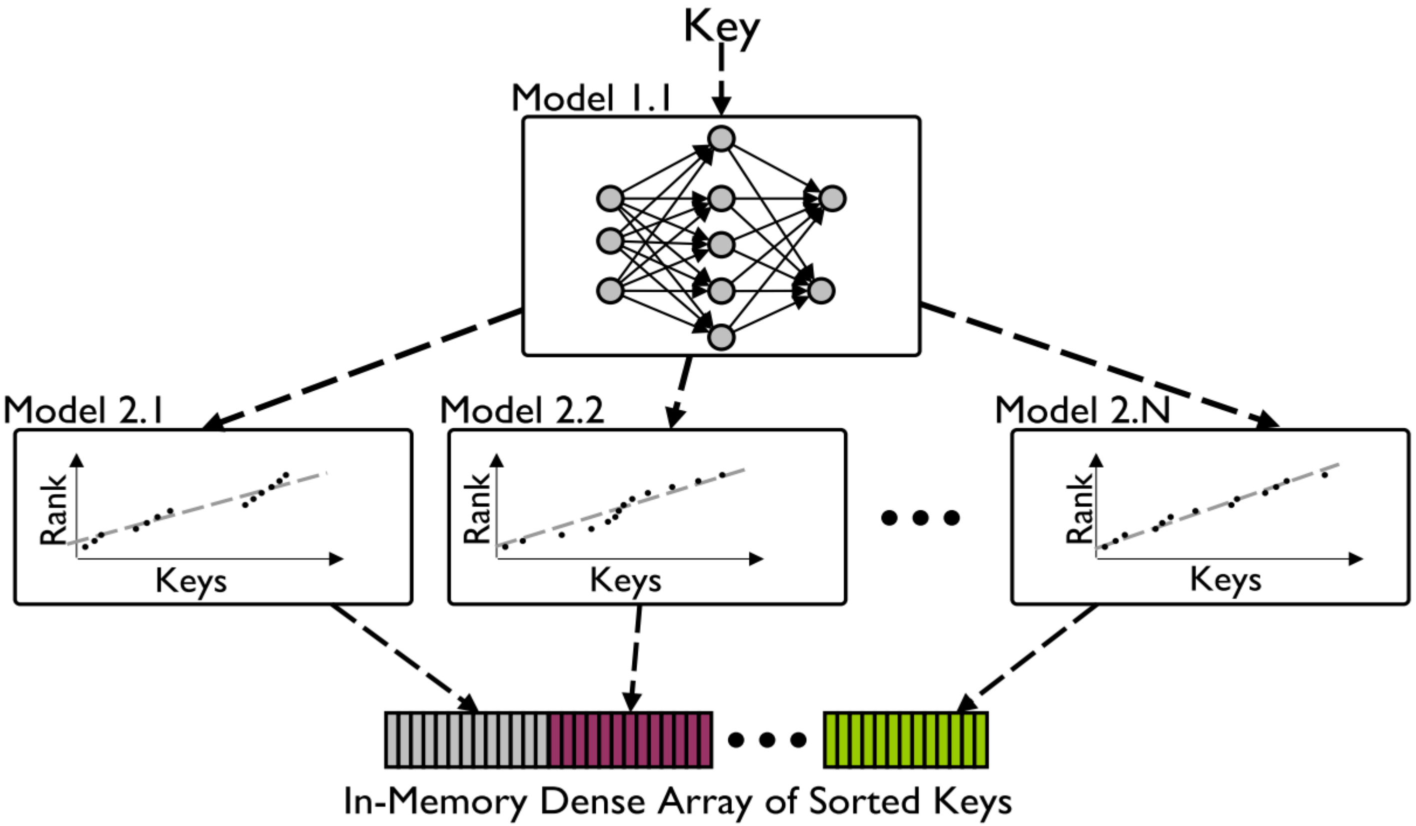
Which ML Model?

- *Pos = CDF(Key) * N*
  - Approximate the position given a key inside a sorted array
  - Learn the relationship between *Key* and *Pos* -> *Regression*
  - Position range: 0 to N-1
  - Key range: smallest to largest value
- Which regression model should we pick and why?
  - Linear Regression, Neural Network Regression, and etc.
- Discussion (2 mins)

Naïve LIS

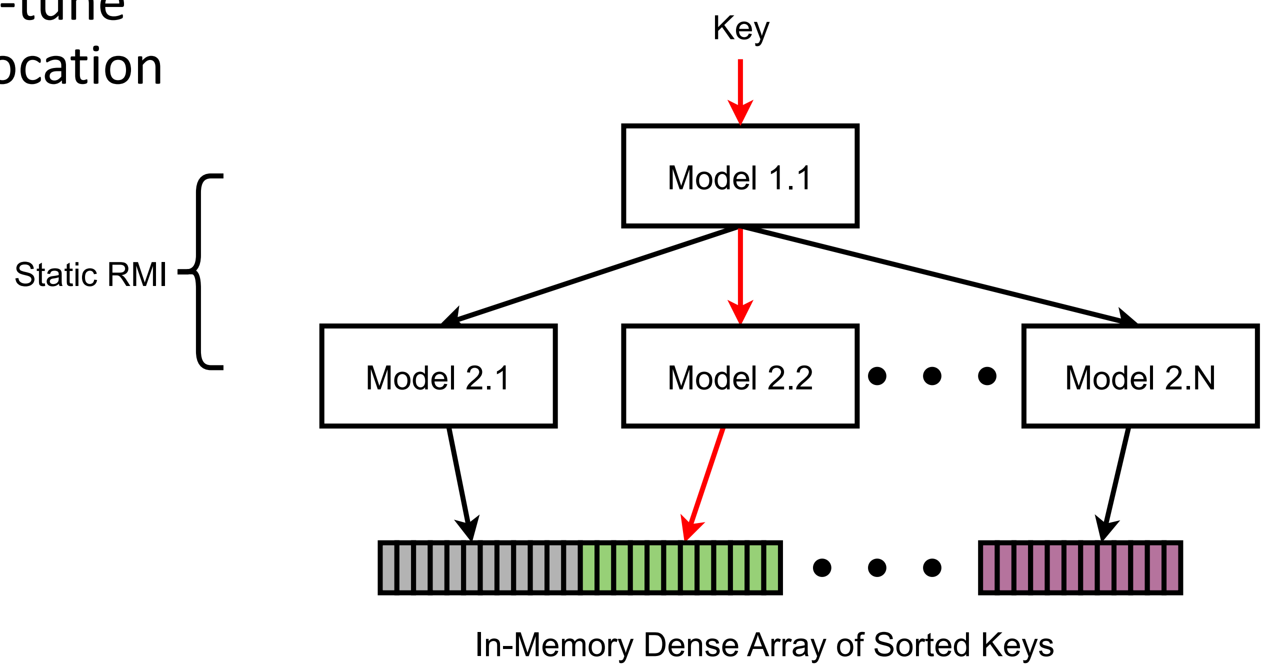
- Use a single neural network regression model
- Good at approximate the general shape of a CDF
- Large error at the last mile of predicting the actual position
- Solution: RMI

Two-stage-RMI

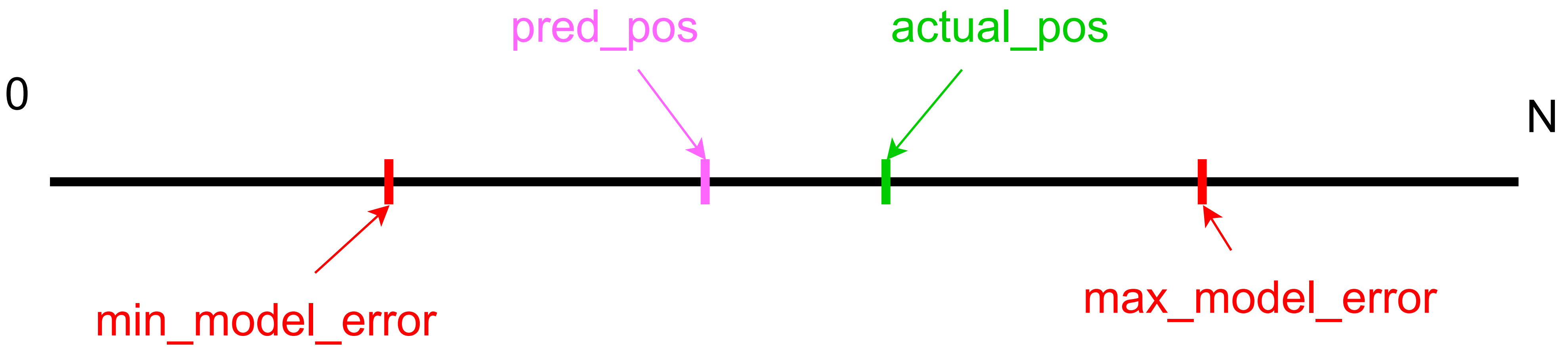


Lookup() on A Two-stage-RMI

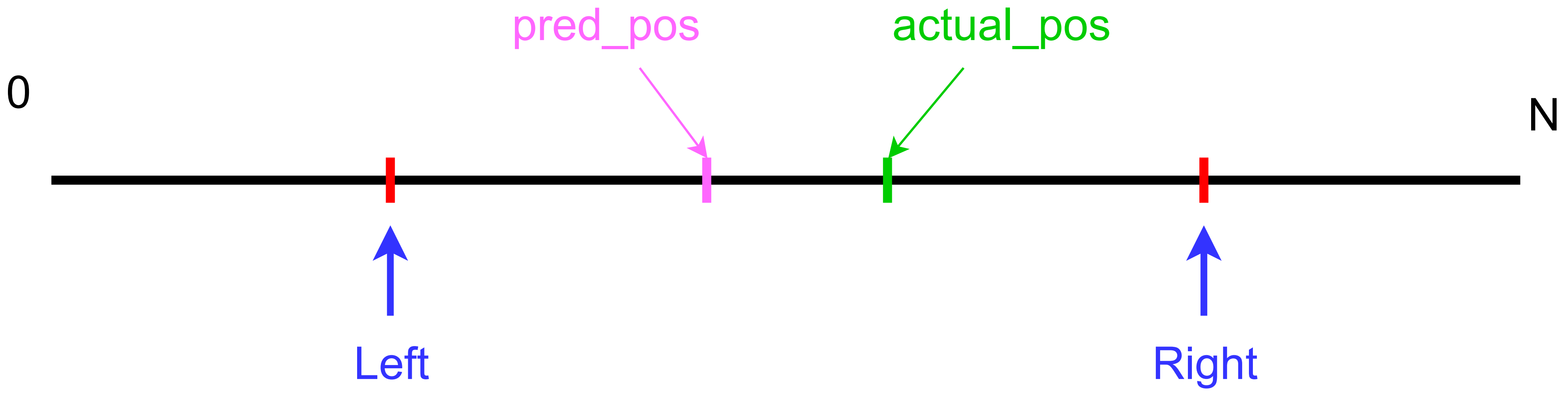
- Two stage RMI
- A higher stage model directs a lookup operation to a lower stage model to fine-tune the precision of the predicted memory location
- learned_index_lookup(key)
  - ret_1 = first_stage_lookup(key)
  - ret_2 = second_statge_lookup(ret_1)
  - predicted_pos = array[ret_2]



Local Search



Binary Search



Conclusion

- DBMS index structures
  - B-Tree & CDF model
- LIS
  - Abstracting functionality of B-Tree using regression models
  - Naïve approach: using single regression model
  - RMI: a hierarchical architecture
  - Performing a local search if the predicted pos is off actual pos
  - Using binary search or other search algorithms to find the actual key