A Forest-structured Bloom Filter with Flash Memory

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Introduction to Bloom Filter

- What's it?
  - A bit vector that compactly represents a set of items (keys)
    - Support key query/insert operations
    - Tell definitely if a key is NOT present; couldn't tell with guarantee that a key is indeed present (a few false positives may exist)
- Where is Bloom Filter (BF) used for?
  - Database applications
  - Network applications
    - E.g., router
  - Backup applications
    - E.g., chunking based data dedupe (not found→new chunk!)

Extending BF to Secondary Storage Device

- Why?
  - In-RAM BF size is limited by the available RAM size on the machine. However, some Apps like dedupe needs BF size beyond RAM capacity.
- Main concept
  - Utilize a limited amount of RAM space combined with a much larger secondary storage space to form a BF
- Secondary storage device choices
  - flash memory vs. magnetic disk

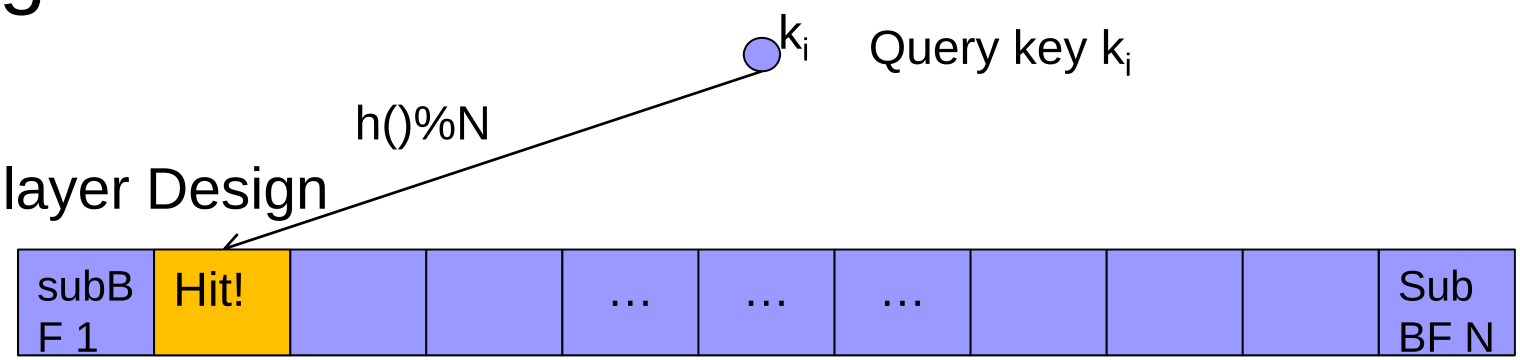
Building a BF with Flash Memory

- Special cha...
  - page-lev... se
  - random ... equential page read
  - page wri... ge update needs a flash erase firs...
  - each flas... unt during life-cycle

How is the BF design optimized for flash characteristics?

Existing Works

- Single-layer Design



- Pros
  - It requires only 1 flash page R /key query → best for key query
- Cons
  - Buffer space is very limited for each sub-BF→ many flash read-then-write ops are required for each sub-BF during the run.
  - Some sub-BFs tend to receive more keys than others (by single hash function), but buffer space is equally pre-partitioned
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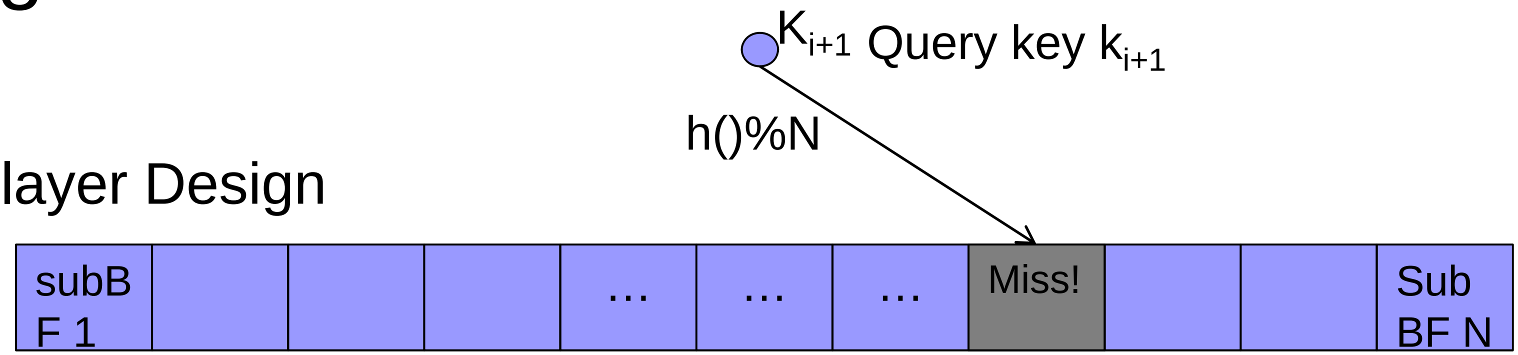

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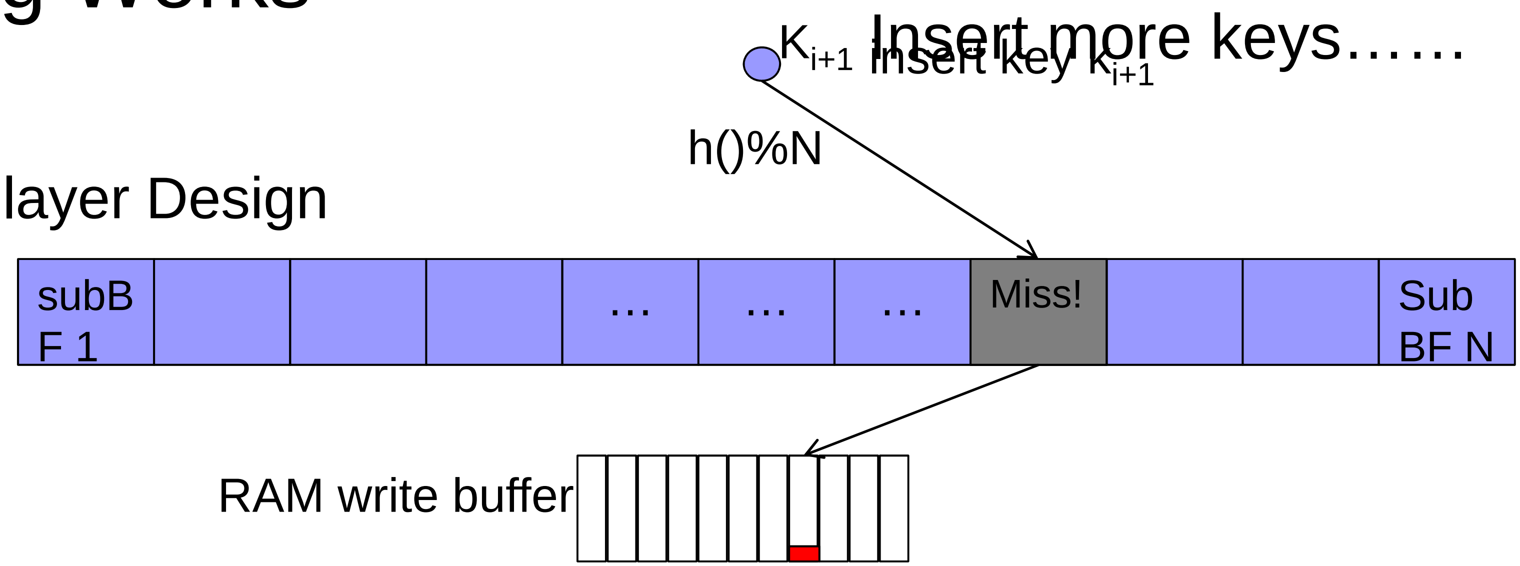

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Existing Works

update sub-BF

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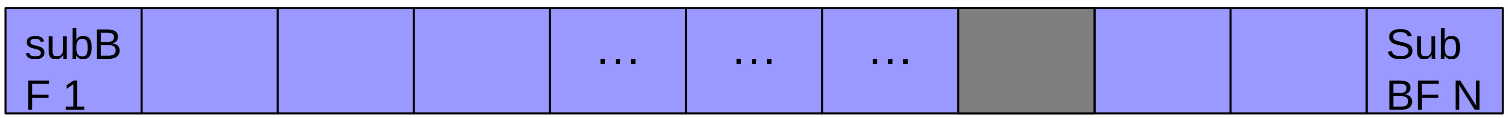
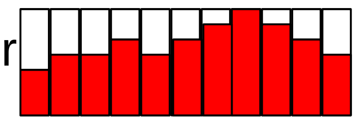


RAM write buffer



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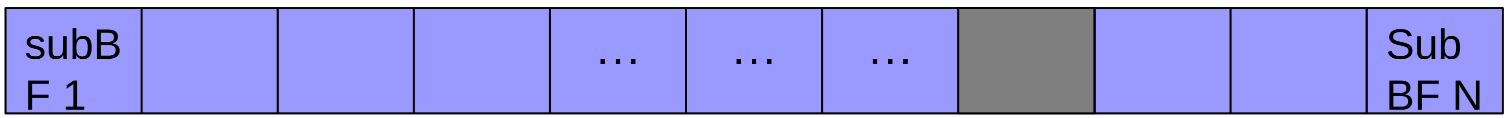

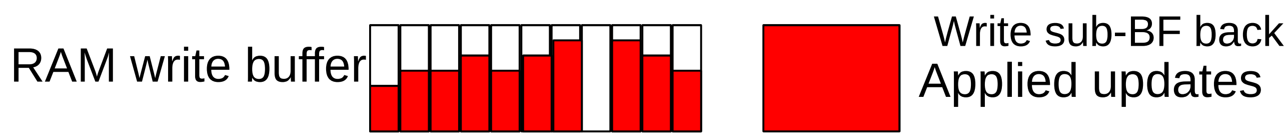

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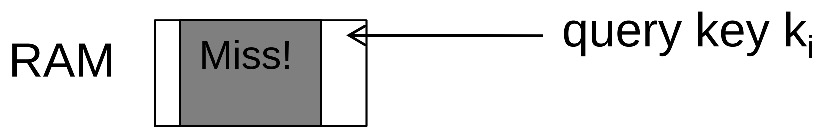
- Linear-chaining Design



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  - best for key insertion: each chained BF will be only written once, hence the flash write # is minimized
  - BF size grows dynamically as the # of chained BFs increased
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Existing Works

K_i

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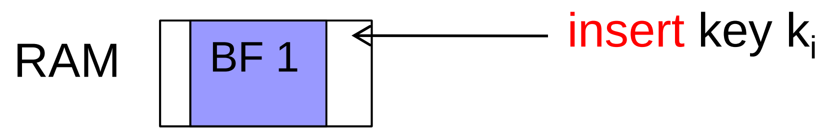

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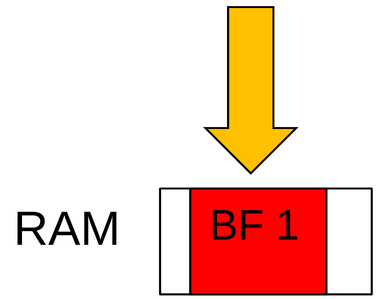

insert more keys …

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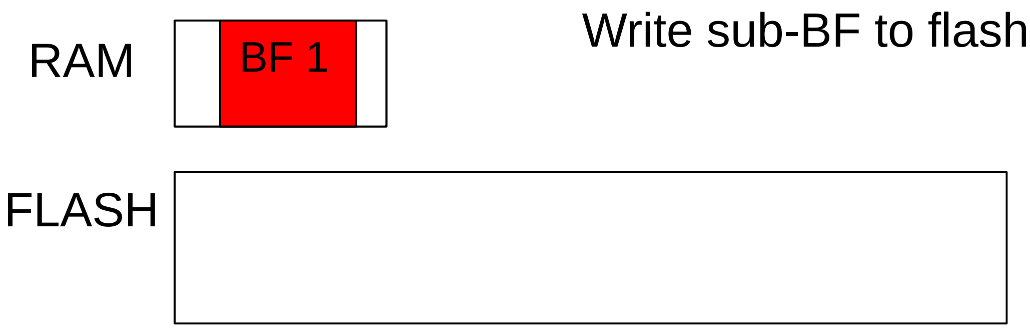

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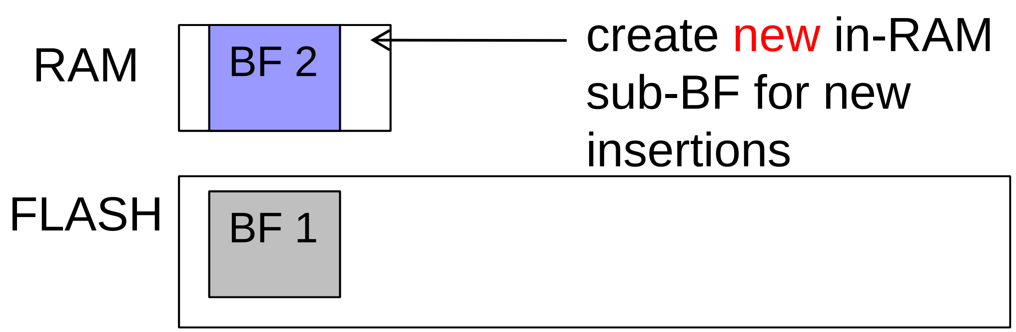

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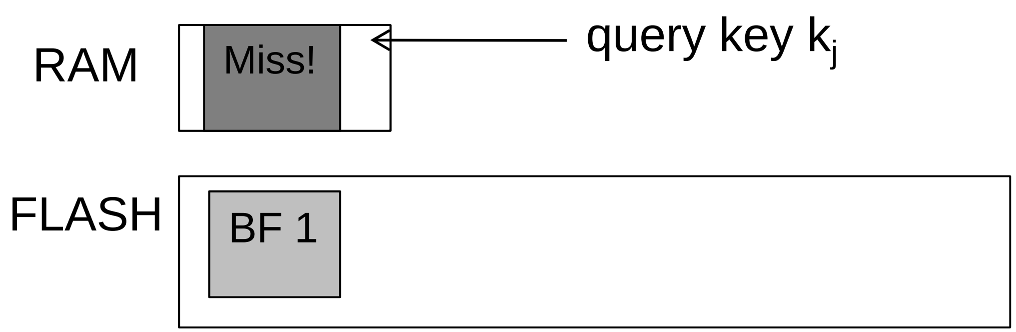

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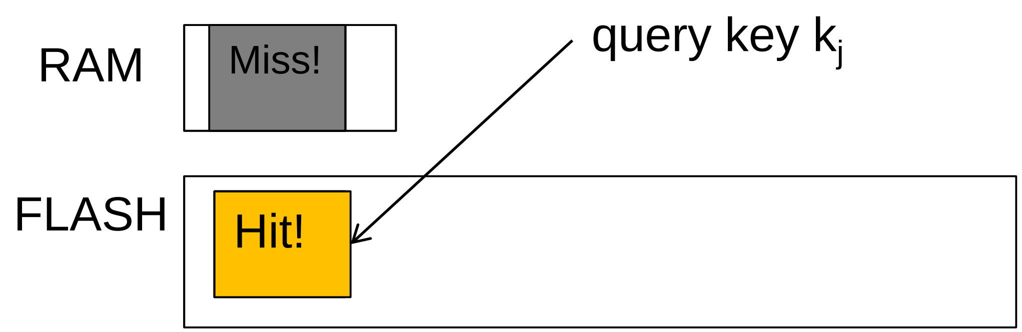

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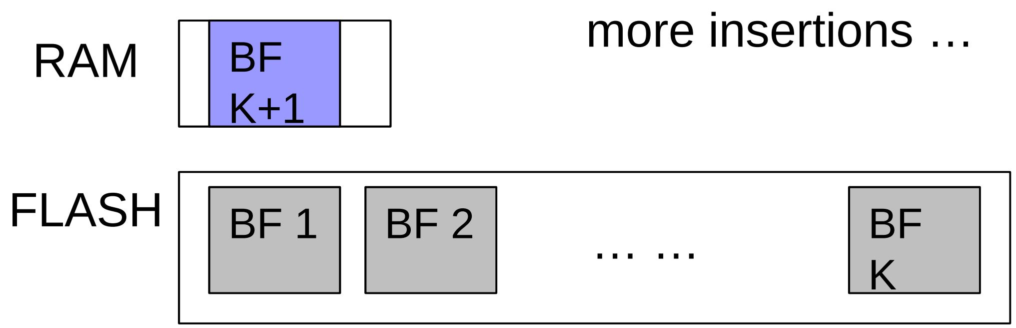

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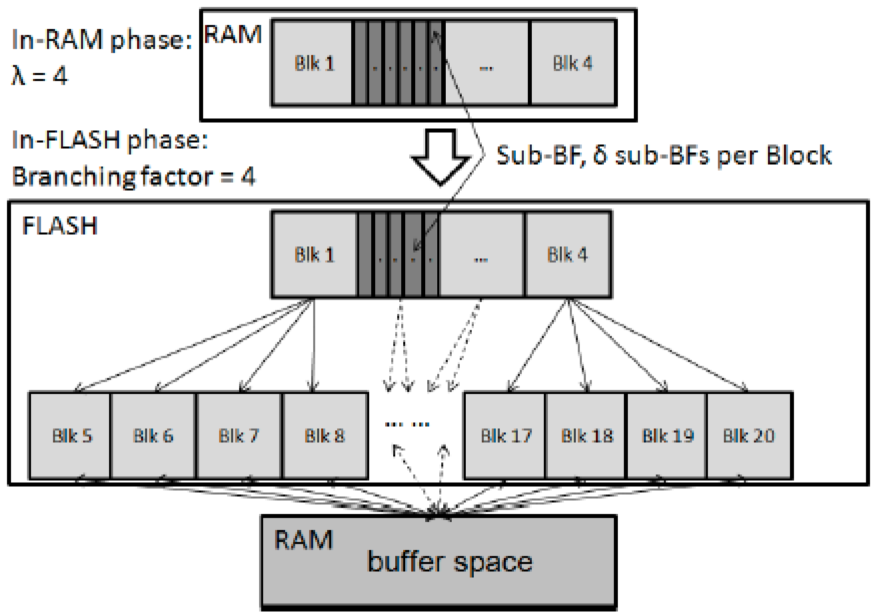
Proposed Forest-structured BF(FBF) Design

- Goal: To strike a balance between key query and insert performance
- Partition flash … of flash-page sized and org… .
- Key features
  - Overall BF … ayer of forest
  - Each key c… ls equal to forest heig…
  - Key inserti… uffer, which is designed t… d in next page).

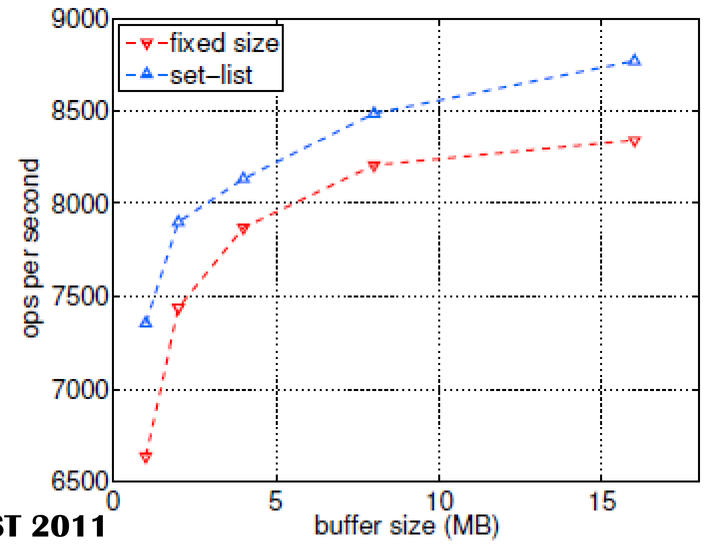


Proposed Buffer Space Management Scheme for FBF Design

- FBF inserts new keys into the lowest-layer of the forest only, which optimizes for
  - allowing larger buffer space per sub-BF
  - Minimize the target address range for flash writes
- FBF manages buffer space by
  - grouping consecutive sub-BFs into blocks
  - buffering key insertions per block in a in-RAM set data structure
  - keeping all sets into a linked-list
  - selecting the block corresponding to the set containing most insertions to update when the entire buffer space is used up.

Experimental Evaluation Results

- Workload description:
  - A sequence (20 millions) of SHA1 hash value of 160-bit length. Each of which represents a chunk-id produced by standard content-defined chunking algorithm; 57% are unique chunk-ids
  - BF access pattern: Key query & insert are interleaved
- TR vs. buffer size for both cache managing schemes:

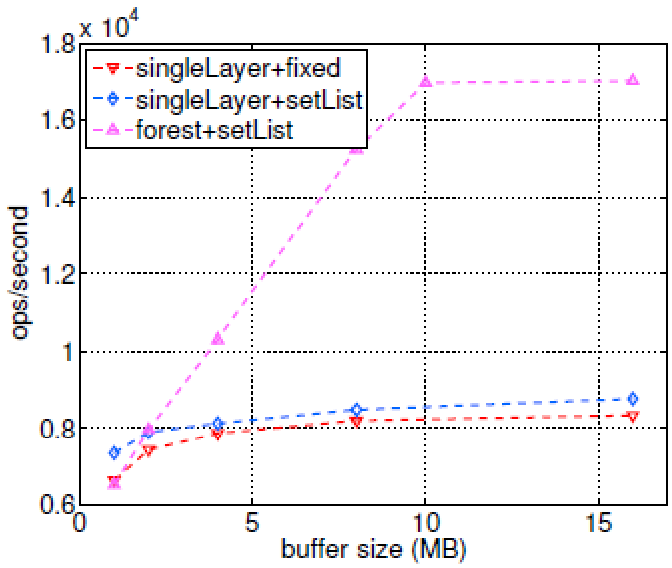


COMPARTMENT VS. SET-LIST SCHEMES ON *vx-20m*

buffer schemes	fixed-size compartment	set-list
number of flash writes	2,024	1,053
ops/sec	8,405	8,657

Experimental Evaluation Results

- Throughput Rate (TR) vs. buffer sizes for forest-structure BF and single-layer BF



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Summary of Contributions

- We present a novel BF design (FBF) with flash memory that
  - strikes a balance between key query and key insert performance
  - achieves a significantly higher TR with the same buffer size compared with existing designs.
- Furthermore, our proposed buffer space managing scheme reduces the number of flash writes remarkably (e.g., 50% less), even with the same existing BF design.

Thank you!

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Background Works

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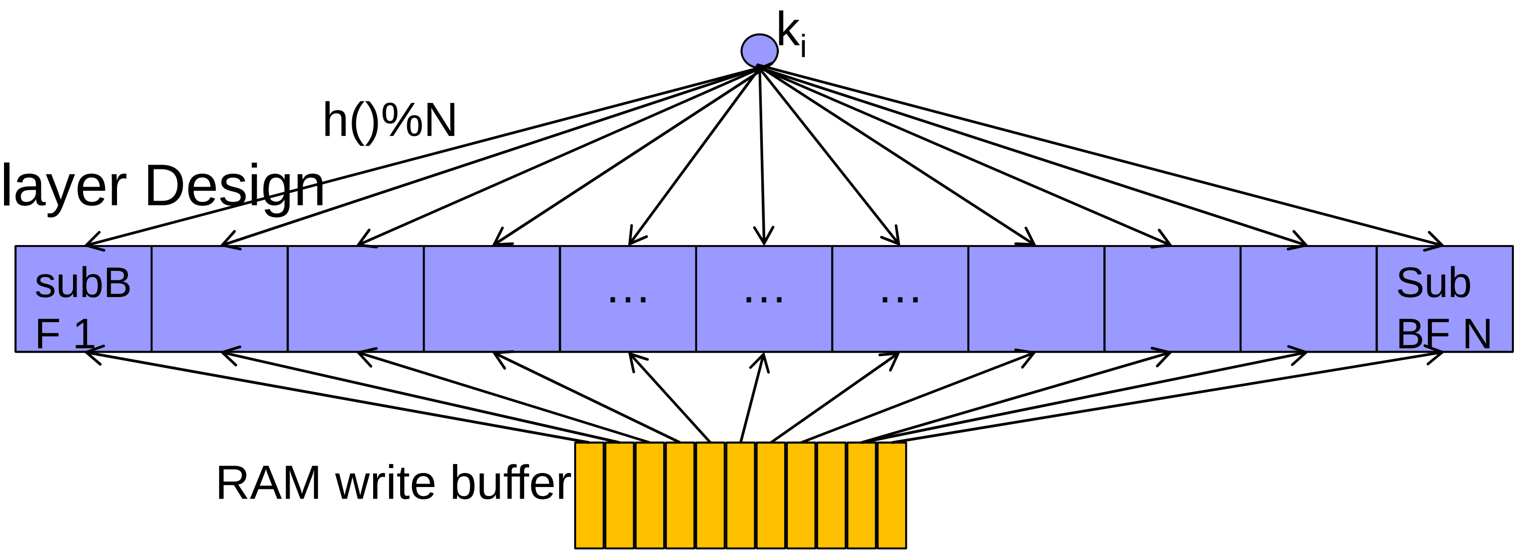

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