Query Processing 4: Hash Join

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This lecture will introduce the **hash join** algorithm for computing a natural join involving two relations.

The Binary Join Problem

$R_1(X, Y)$: A relation with attributes X and Y.
$R_2(X, Z)$: A relation with attributes X and Z.
B_1 = the number of disk blocks that R_1 occupies.
B_2 = the number of disk blocks that R_2 occupies.
M = the number of memory blocks (a.k.a., the buffer blocks).

- We assume that $M \geq 7$ and $M - 1$ is a multiple of 3.

Goal: Compute the join result $R_1 \bowtie R_2$.

Recall that the **block-based nested loop** (BNL) algorithm can compute the join result in $B_1 + \lceil \frac{B_1}{M-1} \rceil B_2$ I/Os. In particular, if R_1 fits in $M - 1$ memory blocks, then the I/O cost of BNL is $B_1 + B_2$.

Hashing

Let $\mathbb{D}$ be the domain of the "join attribute" X. Set

$$U = (M - 1)/3$$

We are given a **hash function** H, which is a function mapping $\mathbb{D}$ to the set of integers $\{1, 2, ..., U\}$.

Given a tuple t_1 of R_1, we refer to $H(t_1.X)$ as the **hash value** of t_1.
Given a tuple t_2 of R_2, we refer to $H(t_2.X)$ as the **hash value** of t_2.

We will carry out our discussion under the following assumption:

> **Good hashing assumption:** For any $h \in [1, U]$, the tuples of R_1 with hash value h can fit in U blocks.

No such requirements are placed on R_2.

Buckets

Given a value $h \in [1, U]$, define

$$\begin{aligned} R_1(h) &= \{\text{tuple } t \in R_1 \mid H(t_1.X) = h\} \\ R_2(h) &= \{\text{tuple } t \in R_2 \mid H(t_2.X) = h\} \end{aligned}$$

We will refer to $R_1(h)$ and $R_2(h)$ as **buckets**. Clearly, each relation has U buckets.

Fact: $R_1 \bowtie R_2 = \bigcup_{h=1}^{U} R_1(h) \bowtie R_2(h)$.

In other words, once we have obtained all buckets, we can focus on joining each $R_1(h)$ with the **corresponding** $R_2(h)$.

Hash Join

Step 1: Create the U buckets of R_1 and R_2, respectively.
Step 2: For each $h \in [1, U]$, compute $R_1(h) \bowtie R_2(h)$.

We will discuss each step in turn.

Hash Join: Step 1

We will explain how to create the U buckets of R_1.

Use one memory block as the **output buffer** for each bucket $R_1(h)$, where $h \in [1, U]$.

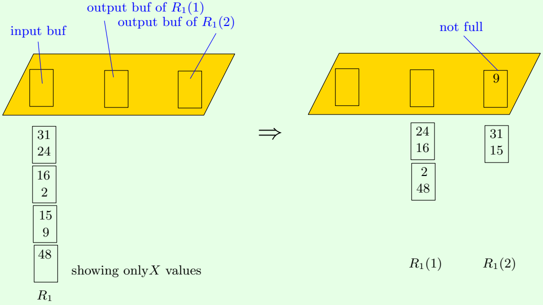
Use one memory block as the **input buffer** for reading R_1.

Hash Join: Step 1

For each tuple t read from R_1, add it to the output buffer of $R_1(H(t.X))$.

When an output buffer — say for bucket $R_1(h)$ of some $h \in [1, U]$ — is **full**, append it to the file of $R_1(h)$ on disk.

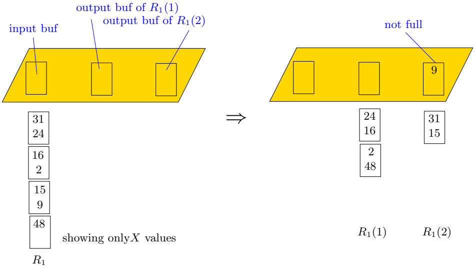
Example: $U = 2$ and $H(x) = 1 + (x \bmod 2)$.



Hash Join: Step 1

The I/O cost is bounded by $2B_1$ because

- every block of R_1 is read once;
- the number of full blocks flushed to the disk is at most B_1.



Remark: Each bucket can have **at most one non-full block**, and this block **must reside in memory**. We do not write those blocks to disk; otherwise, the I/O cost can increase to $2B_1 + U$ in the worst case (**think:** why?).

Hash Join: Step 1

Create the U buckets of R_2 in the same way, while keeping the non-full bucket blocks of R_1 in memory.

The I/O cost is bounded by $2B_2$

At this moment, we have used $2U$ memory blocks:

- U blocks for R_1 (each may be the non-full block of a bucket);
- U blocks for R_2 (each may be the non-full block of a bucket).

Hash Join: Step 2

Step 2: For each $h \in [1, U]$, compute $R_1(h) \bowtie R_2(h)$.

Apply BNL to compute $R_1(h) \bowtie R_2(h)$. By the good hashing assumption, $R_1(h)$ can be loaded into U memory blocks. Then, use one memory block to scan $R_2(h)$.

- In total, we use at most $3U + 1 = M$ memory blocks.

The I/O cost is bounded by $B_1 + B_2$ because every disk-resident block of the $2U$ buckets is read exactly once.

Overall, the hash join algorithm performs $3(B_1 + B_2)$ I/Os.