阿里云

PostgreSQL优化器浅析

康贤

阿里云

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优化器介绍

- 什么是优化器
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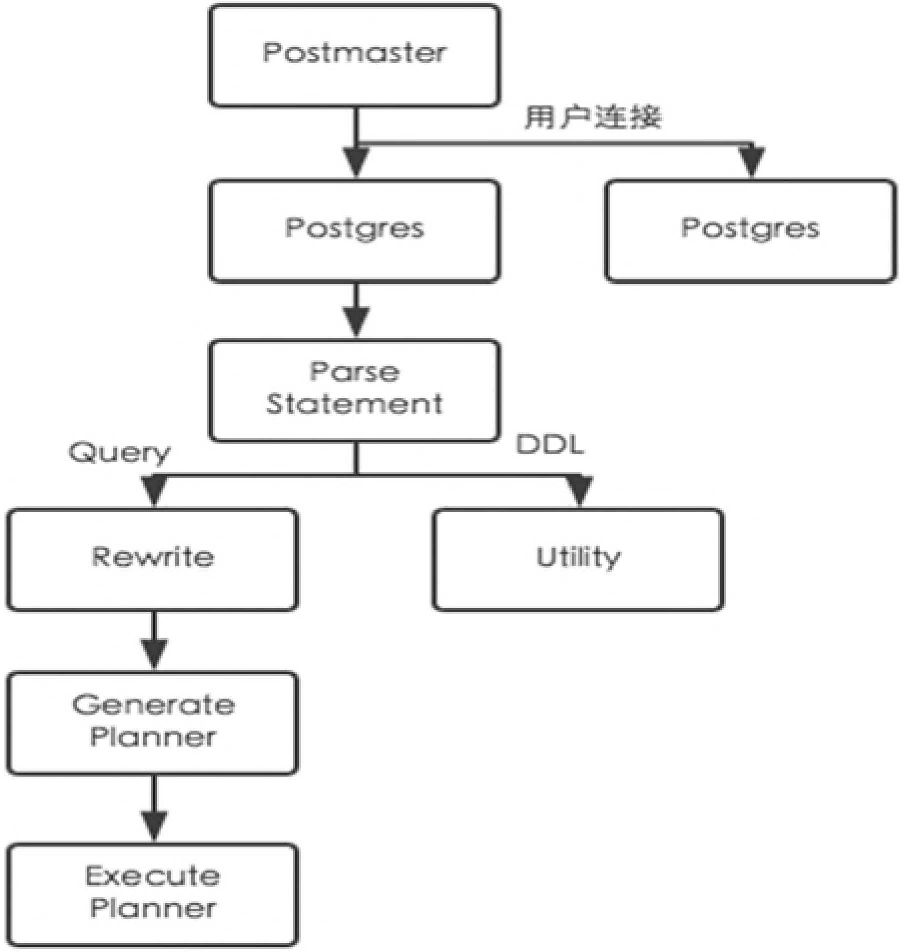
- SQL处理过程

优化器介绍



Postmaster
用户连接
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Postgres
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优化器介绍

- 查看优化器生成计划
  - explain query，如下

```
postgres=# explain select * from test where id = 10 limit 1;
                                 QUERY PLAN
------------------------------------------------------------------------------
 Limit  (cost=0.28..8.29 rows=1 width=4)
   ->  Index Only Scan using test11 on test  (cost=0.28..8.29 rows=1 width=4)
         Index Cond: (id = 10)
(3 rows)
```

优化器介绍

- Plan结构

```
{PLANNEDSTMT
:commandType 1
:queryId 0
:hasReturning false
:hasModifyingCTE false
:canSetTag true
:transientPlan false
:planTree
   {LIMIT
   :startup_cost 0.28
   :total_cost 8.29
   :plan_rows 1
   :plan_width 4
   :targetlist (
      {TARGETENTRY
      :expr
         {VAR
         :varno 65001
         :varattno 1
         :vartype 23
         :vartypmod -1
         :varcollid 0
         :varlevelsup 0
         :varnoold 1
         :varoattno 1
         :location -1
         }
      :resno 1
      :resname id
      :ressortgroupref 0
      :resorigtbl 16398
      :resorigcol 1
      :resjunk false
      }
   )
   :qual <>
   :lefttree
      {INDEXONLYSCAN
      :startup_cost 0.28
      :total_cost 8.29
      :plan_rows 1
      :plan_width 4
```

```
:targetlist (
   {TARGETENTRY
   :expr
      {VAR
      :varno 65002
      :varattno 1
      :vartype 23
      :vartypmod -1
      :varcollid 0
      :varlevelsup 0
      :varnoold 1
      :varoattno 1
      :location 7
      }
   :resno 1
   :resname id
   :ressortgroupref 0
   :resorigtbl 16398
   :resorigcol 1
   :resjunk false
   }
)
:qual <>
:lefttree <>
:righttree <>
:initPlan <>
:extParam (b)
:allParam (b)
:scanrelid 1
:indexid 24594
:indexqual (
   {OPEXPR
   :opno 96
   :opfuncid 65
   :opresulttype 16
   :opretset false
   :opcollid 0
   :inputcollid 0
   :args (
      {VAR
      :varno 65002
      :varattno 1
```

逻辑查询优化

- 什么是逻辑优化
  - 主要对SQL进行等价或者推倒变换，让其达到更好的执行计划

- 主要优化方向
  - 避免重复工作
  - 减少子集数据量

逻辑查询优化

- SQL组成

```
SELECT s.name                      target list
FROM score sc, student s           range table
WHERE s.no IN                      qualifiter
(SELECT st_no FROM class c         IN-clause subquery
WHERE c.name = '1101')
AND sc.st_no = s.no                Join predicate
ORDER BY sc.score DESC             sort order
LIMIT 1;                           limit expression
```

逻辑查询优化

- 查询重写
  - 消除view、rule等

```
create view v_t_1_2 as SELECT t1.a1, t1.b1, t2.a2, t2.b2 FROM t1, t2;

postgres=> explain select * from v_t_1_2, t1 where v_t_1_2.a1 = 10 and t1.b1 = 20;
QUERY PLAN
------------------------------------------------------------------------------------
 Nested Loop  (cost=0.55..41.59 rows=1000 width=24)
   -> Nested Loop  (cost=0.55..16.60 rows=1 width=16)
         -> Index Scan using t1_a1_key on t1 t1_1  (cost=0.28..8.29 rows=1 width=8)
               Index Cond: (a1 = 10)
         -> Index Scan using b1_1 on t1  (cost=0.28..8.29 rows=1 width=8)
               Index Cond: (b1 = 20)
   -> Seq Scan on t2  (cost=0.00..15.00 rows=1000 width=8)
(7 rows)
```

view又被重写回原来的query

- 提升子链
  - 将IN和exists子句递归提升

```
select * from t1 where t1.a1 in (select t2.a2 from t2 where t2.b2 = 10);
```
假设t2.a2为unique

转化为:

```
select t1.a1,t1,a2 from t1 join t2 where t1.a1=t2.a2 and t2.b2 = 10;
```

执行计划如下:

```
postgres=> explain select * from t1 where t1.a1 in (select t2.a2 from t2 where t2.b2 = 10);
                                QUERY PLAN
--------------------------------------------------------------------------
 Nested Loop  (cost=0.28..25.80 rows=1 width=8)
   ->  Seq Scan on t2  (cost=0.00..17.50 rows=1 width=4)
         Filter: (b2 = 10)
   ->  Index Scan using t1_a1_key on t1  (cost=0.28..8.29 rows=1 width=8)
         Index Cond: (a1 = t2.a2)
```

- # 提升子链

```
explain select * from t1 where exists  (select t2.a2 from t2 where t2.a2 = t1.a1) ; 假设t2.a2为unique
```
转化为:
```
select t1.a1, t1.b1 from t1, t2 where t1.a1=t2.a1;
```

执行计划如下:
```
postgres=> explain select * from t1 where exists  (select t2.a2 from t2 where t2.a2 = t1.a1) ;
                              QUERY PLAN
-----------------------------------------------------------------
 Hash Join  (cost=26.42..54.69 rows=952 width=8)
   Hash Cond: (t2.a2 = t1.a1)
   ->  Seq Scan on t2  (cost=0.00..15.00 rows=1000 width=4)
   ->  Hash  (cost=14.52..14.52 rows=952 width=8)
         ->  Seq Scan on t1  (cost=0.00..14.52 rows=952 width=8)
(5 rows)
```

- 提升子链
  - 部分IN和exists子句不能提升

```
postgres=> explain select * from t1 where t1.a1 in (select t2.a2 from t2 where t1.b1 = 10);
                             QUERY PLAN
---------------------------------------------------------------------
 Seq Scan on t1  (cost=0.00..8349.28 rows=476 width=8)
   Filter: (SubPlan 1)
   SubPlan 1
     ->  Result  (cost=0.00..15.00 rows=1000 width=4)
           One-Time Filter: (t1.b1 = 10)
           ->  Seq Scan on t2  (cost=0.00..15.00 rows=1000 width=4)
(6 rows)
```

这里也是可以优化的，把t1.b1移到父查询，但是PG没有支持

这里IN子句中使用了主查询的表字段，和主查询有相关性

- 提升子查询
  - 子查询和子链接区别：子查询是不在表达式中的子句，子链接在表达式中的子句

```
select * from t1, (select * from t2) as c  where  t1.a1 = c.a2;
转化为:
select * from t1, t2 where  t1.a1 = t2.a2;

postgres=> explain select * from t1, (select * from t2) as c  where  t1.a1 = c.a2;
                           QUERY PLAN
-----------------------------------------------------------------
 Hash Join  (cost=26.42..54.69 rows=952 width=16)
   Hash Cond: (t2.a2 = t1.a1)
   ->  Seq Scan on t2  (cost=0.00..15.00 rows=1000 width=8)
   ->  Hash  (cost=14.52..14.52 rows=952 width=8)
         ->  Seq Scan on t1  (cost=0.00..14.52 rows=952 width=8)
(5 rows)
```

- 提升子查询
  - 同样子查询也有不支持的情况

```
postgres=> explain select t1.a1 from t1, (select a2 from t2 limit 1) as c where c.a2 = 10;
                              QUERY PLAN
------------------------------------------------------------------------
 Nested Loop  (cost=0.00..24.07 rows=952 width=4)
   -> Subquery Scan on c  (cost=0.00..0.03 rows=1 width=0)
        Filter: (c.a2 = 10)
        -> Limit  (cost=0.00..0.01 rows=1 width=4)
              -> Seq Scan on t2  (cost=0.00..15.00 rows=1000 width=4)
   -> Seq Scan on t1  (cost=0.00..14.52 rows=952 width=4)
(6 rows)
```

1. 没有集合操作
2. 没有聚合操作
3. 不包含sort/limit/with/group
4. 没有易失函数
5. from非空

……

- 化简条件

规则	化简前	化简后
常量传递	a1=a2 and a2=100	a1=100 and a2=100
表达式计算	a1=1+2	a1=3
去除多余括号	(a and b) and (c and d)	a and b and c and d
简化or	false or a > 1	a > 1

• 外连接消除(left/right/full join)

以left join为例，left join(左连接) 返回包括左表中的所有记录和右表中连接字段相等的记录 ，如果右表没有匹配的记录，那么右表将会以NULL值代替，例如：

A表 B表

ID1	ID2
1	1
2	

select * from A left join B on A.id1 = B.id2;

结果如下：

ID1	ID2
1	1
2	NULL

- 外连接消除(left/right/full join)

```
postgres=> explain select * from t1 left join t2 on true;
                              QUERY PLAN
-------------------------------------------------------------------
 Nested Loop Left Join  (cost=0.00..11932.02 rows=952000 width=16)
   ->  Seq Scan on t1  (cost=0.00..14.52 rows=952 width=8)
   ->  Materialize  (cost=0.00..20.00 rows=1000 width=8)
         ->  Seq Scan on t2  (cost=0.00..15.00 rows=1000 width=8)
(4 rows)
postgres=> explain select * from t1 left join t2 on true where t1.a1 = t2.a2;
                             QUERY PLAN
-----------------------------------------------------------------
 Hash Join  (cost=26.42..54.69 rows=952 width=16)
   Hash Cond: (t2.a2 = t1.a1)
   ->  Seq Scan on t2  (cost=0.00..15.00 rows=1000 width=8)
   ->  Hash  (cost=14.52..14.52 rows=952 width=8)
         ->  Seq Scan on t1  (cost=0.00..14.52 rows=952 width=8)
(5 rows)
```

- 外连接消除条件
  - where和join条件保证右表不会有NULL值的行产生

```
postgres=> explain select * from t1 left join t2 on t1.b1 = t2.b2 where t2.b2 is not NULL;
                              QUERY PLAN
---------------------------------------------------------------------
 Nested Loop  (cost=0.28..23.30 rows=1 width=16)
   ->  Seq Scan on t2  (cost=0.00..15.00 rows=1 width=8)
         Filter: (b2 IS NOT NULL)
   ->  Index Scan using b1_1 on t1  (cost=0.28..8.29 rows=1 width=8)
         Index Cond: (b1 = t2.b2)
(5 rows)
```

- 条件下推
  - 为了连接前，元组数组尽量少

```
postgres=> explain select * from t1,t2 where t1.a1 < 10 and t2.a2 > 900;
                                   QUERY PLAN
---------------------------------------------------------------------------------
 Nested Loop  (cost=0.55..31.20 rows=1000 width=16)
   ->  Index Scan using t2_a2_key on t2  (cost=0.28..10.03 rows=100 width=8)
         Index Cond: (a2 > 900)
   ->  Materialize  (cost=0.28..8.70 rows=10 width=8)
         ->  Index Scan using t1_a1_key on t1  (cost=0.28..8.65 rows=10 width=8)
               Index Cond: (a1 < 10)
```

- 语义优化
  - 约束优化

```
create table tt1(id int not null);
postgres=> explain select * from tt1 where id is null;
                       QUERY PLAN
--------------------------------------------------------
 Seq Scan on tt1  (cost=0.00..15407.02 rows=1 width=15)
   Filter: (id IS NULL)

set constraint_exclusion = on;

postgres=> explain select * from tt1 where id is null;
                QUERY PLAN
------------------------------------------
 Result  (cost=0.00..0.01 rows=1 width=0)
   One-Time Filter: false
```

默认未优化

• MIN/MAX

```
select min(a1) from t1;
转换为:
select a1 from t1 order by a1 limit 1;
如果a1没有索引，那么将会是全表扫描

postgres=> explain select min(a1) from t1;
                                        QUERY PLAN
------------------------------------------------------------------------------------------
 Result  (cost=0.32..0.33 rows=1 width=0)
   InitPlan 1 (returns $0)
     ->  Limit  (cost=0.28..0.32 rows=1 width=4)
           ->  Index Only Scan using t1_a1_key on t1  (cost=0.28..45.09 rows=952 width=4)
                 Index Cond: (a1 IS NOT NULL)
```

- group by优化

```
create index tt1_id_key on tt1 using btree ( id);
postgres=> explain select id from tt1 group by id;
                                          QUERY PLAN
-----------------------------------------------------------------------------------------------
 Group  (cost=0.42..33891.21 rows=1000102 width=4)
   Group Key: id
   ->  Index Only Scan using tt1_id_key on tt1  (cost=0.42..31390.96 rows=1000102 width=4)
(3 rows)
postgres=> explain select name from tt1 group by name;
                                  QUERY PLAN
---------------------------------------------------------------------------
 Group  (cost=132169.76..137170.27 rows=1000102 width=11)
   Group Key: name
   ->  Sort  (cost=132169.76..134670.02 rows=1000102 width=11)
         Sort Key: name
         ->  Seq Scan on tt1  (cost=0.00..15407.02 rows=1000102 width=11)
(5 rows)
```

order by优化

1. 利用索引消除order by

```
postgres=> explain select * from t1 order by a1;
                             QUERY PLAN
-----------------------------------------------------------------------
 Index Scan using t1_a1_key on t1  (cost=0.28..42.71 rows=952 width=8)
(1 row)
```

2. order by下推

```
postgres=> explain select * from t1,t2 where t1.b1=t2.b2 order by b1;
                            QUERY PLAN
------------------------------------------------------------------
 Merge Join  (cost=126.45..136.22 rows=1 width=16)
   Merge Cond: (t1.b1 = t2.b2)
   ->  Sort  (cost=61.62..64.00 rows=952 width=8)
         Sort Key: t1.b1
         ->  Seq Scan on t1  (cost=0.00..14.52 rows=952 width=8)
   ->  Sort  (cost=64.83..67.33 rows=1000 width=8)
         Sort Key: t2.b2
         ->  Seq Scan on t2  (cost=0.00..15.00 rows=1000 width=8)
(8 rows)
```

- distinct优化

```
postgres=> explain select distinct(a1) from t1;
                        QUERY PLAN
-----------------------------------------------------------
 HashAggregate  (cost=16.90..26.42 rows=952 width=4)
   Group Key: a1
   ->  Seq Scan on t1  (cost=0.00..14.52 rows=952 width=4)
(3 rows)
postgres=> explain select distinct(id) from tt1;
                                        QUERY PLAN
-------------------------------------------------------------------------------------------
 Unique  (cost=0.42..33891.21 rows=1000102 width=4)
   ->  Index Only Scan using tt1_id_key on tt1  (cost=0.42..31390.96 rows=1000102 width=4)
(2 rows)
postgres=> explain select distinct(name) from tt1;
                                  QUERY PLAN
-------------------------------------------------------------------------
 Unique  (cost=132169.76..137170.27 rows=1000102 width=11)
   ->  Sort  (cost=132169.76..134670.02 rows=1000102 width=11)
         Sort Key: name
         ->  Seq Scan on tt1  (cost=0.00..15407.02 rows=1000102 width=11)
(4 rows)
```

hash cost: cheapest_path + hashagg [+ fi
sort]

sort cost: sorted_path [+ sort] + group
final sort]

Hash VS Sort

- 集合操作优化

```
postgres=> explain select a1 from t1 where a1 < 10 union select a2 from t2;
                                 QUERY PLAN
------------------------------------------------------------------------------------
 HashAggregate  (cost=36.28..46.38 rows=1010 width=4)
   Group Key: t1.a1
   ->  Append  (cost=0.28..33.75 rows=1010 width=4)
         ->  Index Only Scan using t1_a1_key on t1  (cost=0.28..8.65 rows=10 width=4)
               Index Cond: (a1 < 10)
         ->  Seq Scan on t2  (cost=0.00..15.00 rows=1000 width=4)

postgres=> explain select a1 from t1 where a1 < 10 union all select a2 from t2;
                              QUERY PLAN
------------------------------------------------------------------------------
 Append  (cost=0.28..23.75 rows=1010 width=4)
   ->  Index Only Scan using t1_a1_key on t1  (cost=0.28..8.65 rows=10 width=4)
         Index Cond: (a1 < 10)
   ->  Seq Scan on t2  (cost=0.00..15.00 rows=1000 width=4)
```

物理查询优化

- 主要优化方向
  - 单表扫描方式
  - 多表组合方式
  - 多表组合顺序

- 表扫描方式
  - Seq scan, Index scan, Tid scan

```
postgres=> explain select * from t1 ;
                        QUERY PLAN
-----------------------------------------------------
 Seq Scan on t1  (cost=0.00..14.52 rows=952 width=8)

postgres=> explain select * from t1 where a1 = 10;
                                QUERY PLAN
--------------------------------------------------------------------
 Index Scan using t1_a1_key on t1  (cost=0.28..8.29 rows=1 width=8)
   Index Cond: (a1 = 10)

postgres=> explain select * from t1 where ctid='(1,10)';
                       QUERY PLAN
--------------------------------------------------
 Tid Scan on t1  (cost=0.00..4.01 rows=1 width=8)
   TID Cond: (ctid = '(1,10)'::tid)
```

顺序扫描物理数据页

先通过索引值获得物理数据的位置，再到物理页读取

通过page号和item号直接定位到物理数据

- 选择度计算
  - 无条件

```
EXPLAIN SELECT * FROM tenk1;

                         QUERY PLAN
-------------------------------------------------------------
 Seq Scan on tenk1  (cost=0.00..458.00 rows=10000 width=244)



 SELECT relpages, reltuples FROM pg_class WHERE relname = 'tenk1';

 relpages | reltuples
----------+-----------
      358 |     10000
```

- 选择度计算
  - 大于或者小于

```
EXPLAIN SELECT * FROM tenk1 WHERE unique1 < 1000;

                                   QUERY PLAN
--------------------------------------------------------------------------------
 Bitmap Heap Scan on tenk1  (cost=24.06..394.64 rows=1007 width=244)
   Recheck Cond: (unique1 < 1000)
   ->  Bitmap Index Scan on tenk1_unique1  (cost=0.00..23.80 rows=1007 width=0)
         Index Cond: (unique1 < 1000)
```

- # 计算公式

```
SELECT histogram_bounds FROM pg_stats
WHERE tablename='tenk1' AND attname='unique1';

                  histogram_bounds
------------------------------------------------------
 {0,993,1997,3050,4040,5036,5957,7057,8029,9016,9995}

selectivity = (1 + (1000 - bucket[2].min)/(bucket[2].max - bucket[2].min))/num_buckets
            = (1 + (1000 - 993)/(1997 - 993))/10
            = 0.100697

rows = rel_cardinality * selectivity
     = 10000 * 0.100697
     = 1007  (rounding off)
```

- 选择度计算
  - 等于计算

```
EXPLAIN SELECT * FROM tenk1 WHERE stringu1 = 'CRAAAA';

                        QUERY PLAN
----------------------------------------------------------
 Seq Scan on tenk1  (cost=0.00..483.00 rows=30 width=244)
   Filter: (stringu1 = 'CRAAAA'::name)
```

计算公式

```
SELECT null_frac, n_distinct, most_common_vals, most_common_freqs FROM pg_stats
WHERE tablename='tenk1' AND attname='stringu1';

null_frac          | 0
n_distinct         | 676
most_common_vals| {EJAAAA,BBAAAA,CRAAAA,FCAAAA,FEAAAA,GSAAAA,JOAAAA,MCAAAA,NAAAAA,WGAAAA}
most_common_freqs | {0.00333333,0.003,0.003,0.003,0.003,0.003,0.003,0.003,0.003,0.003}

selectivity = mcf[3]
            = 0.003

rows = 10000 * 0.003
     = 30
```

备注：如果值不在most_common_vals里面，计算公式为：

selectivity = (1 - sum(mvf))/(num_distinct - num_mcv)

pg_stats统计信息很重要！！！

- cost计算
  - 代价模型:总代价=CPU代价+IO代价+启动代价

```
postgres=> explain select * from t1 where a1 > 10;
                     QUERY PLAN
-----------------------------------------------------
 Seq Scan on t1  (cost=0.00..16.90 rows=942 width=8)
   Filter: (a1 > 10)
(2 rows)
```

Cost=16.90怎么计算出来的?

其中:

```
postgres=> select relpages, reltuples from pg_class where relname = 't1';
 relpages | reltuples
----------+-----------
        5 |       952
(1 row)
cpu_operator_cost=0.0025
cpu_tuple_cost=0.01
seq_page_cost=1
random_page_cost=4
```

cost计算

总cost = cpu_tuple_cost * 952 + seq_page_cost * 5 + cpu_operator_cost * 952
        = 16.90

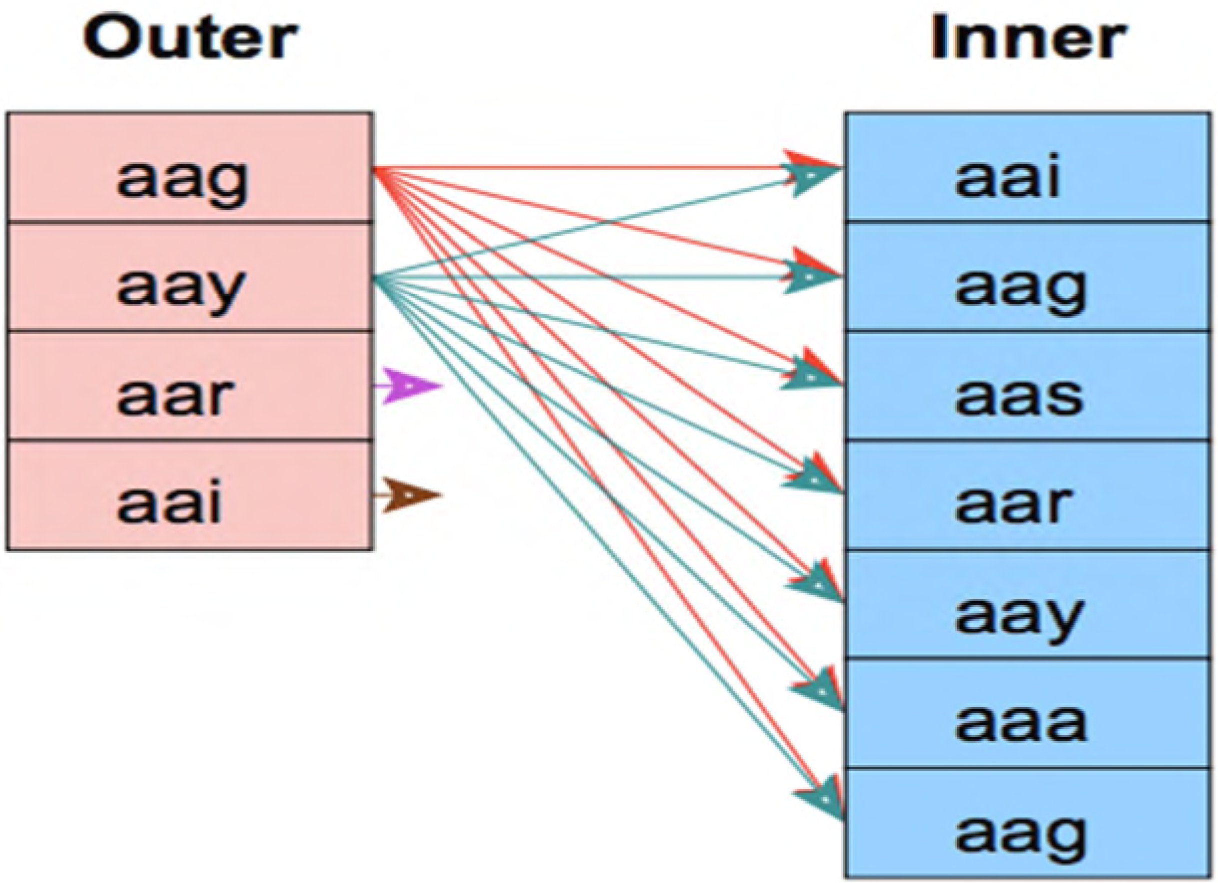
其他扫描方式cost计算可以参考如下函数：

```
postgres=> select amcostestimate,amname from pg_am ;
  amcostestimate   | amname
------------------+--------
 btcostestimate    | btree
 hashcostestimate | hash
 gistcostestimate | gist
 gincostestimate  | gin
 spgcostestimate  | spgist
(5 rows)
```

表组合方式

- Nest Loop
- Hash Join
- Merge Join

(Index)Nest Loop



简单连接代价估算

SELECT * FROM t1 L, t2 R WHERE L.id=R.id

假设：

M = 20000 pages in L, p_L = 40 rows per page,
N = 400 pages in R, p_R = 20 rows per page.

select relpages, reltuples from pg_class where relname= ‘t1’

Nest Loop IO代价计算

L和R进行join

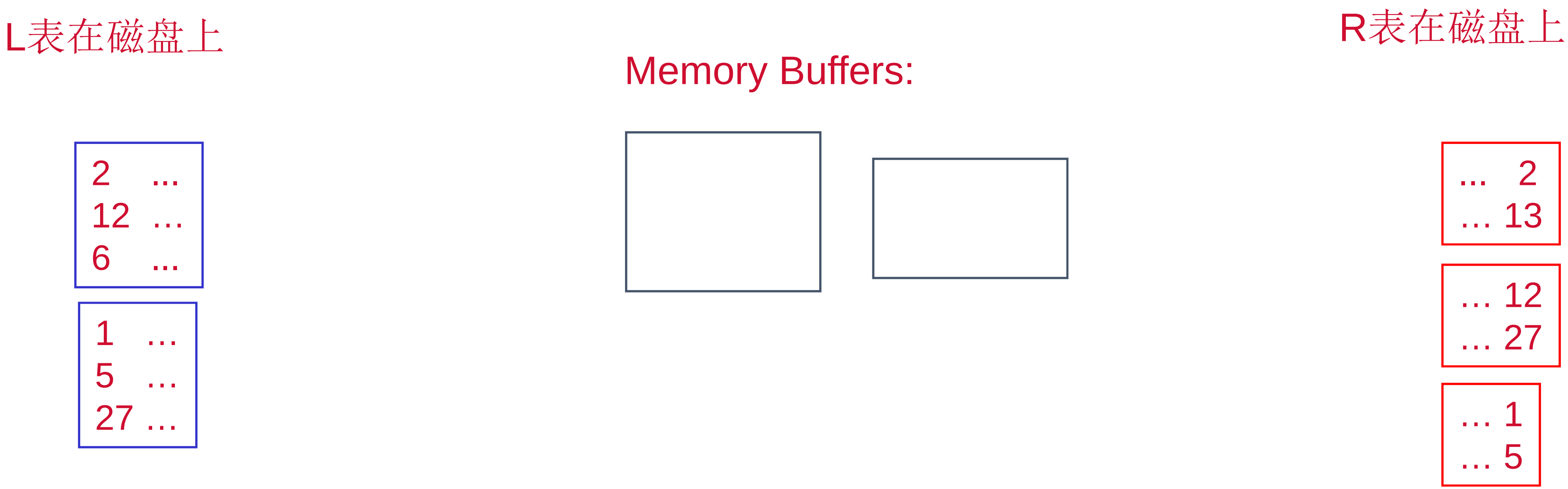
```
for l in L do
  for r in R do
    if r_id == l_id  then ret += (r, s)
```

对于外表L每一个元组扫描内表R所有的元组

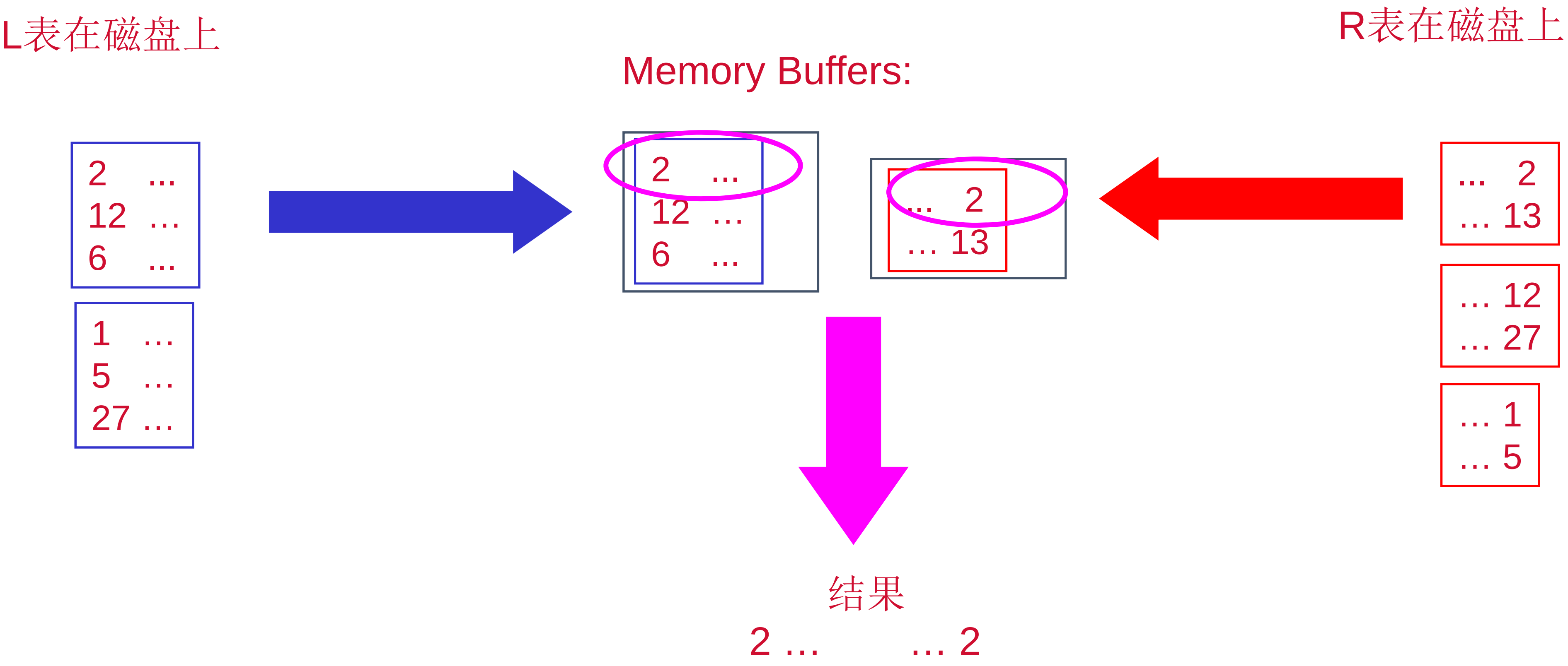
总IO代价： $M + (p_L * M) * N = 20000 + (40*20000)*400$

$= 320020000$

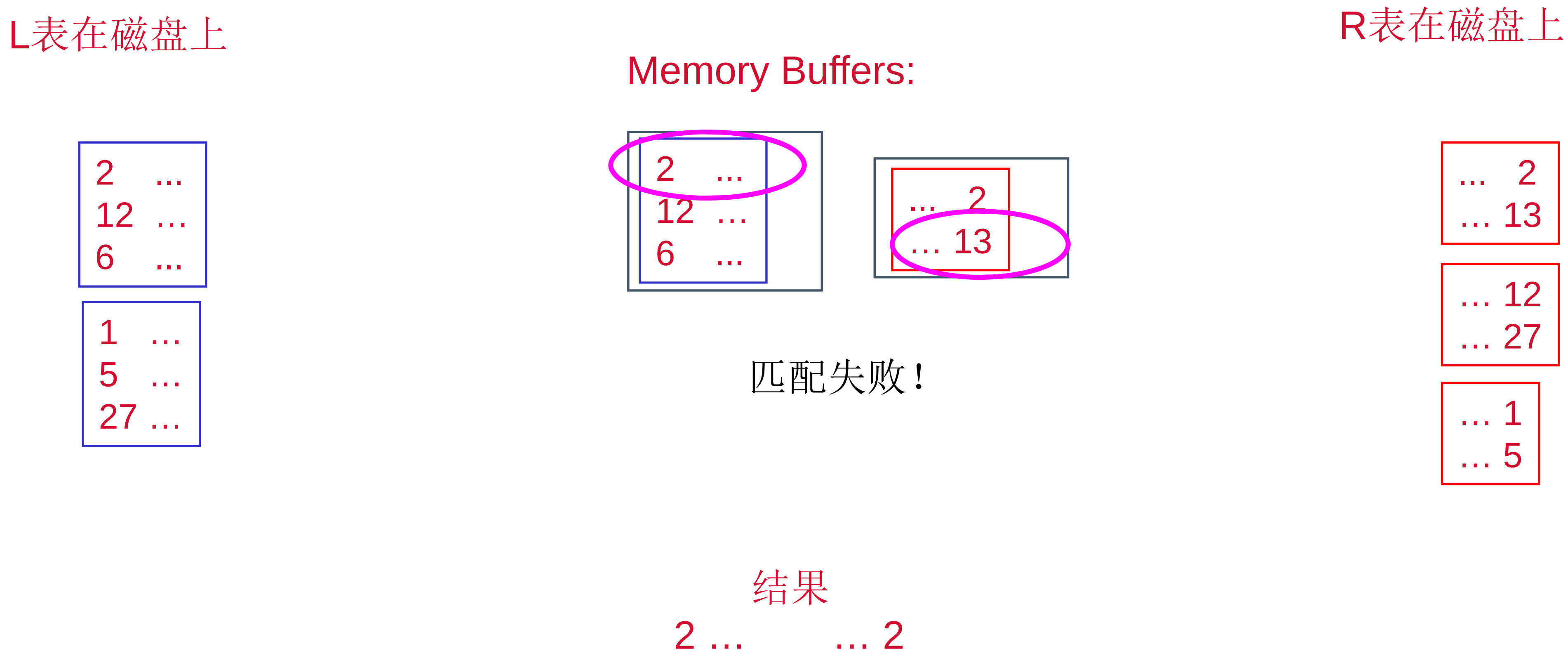
Nest Loop Join



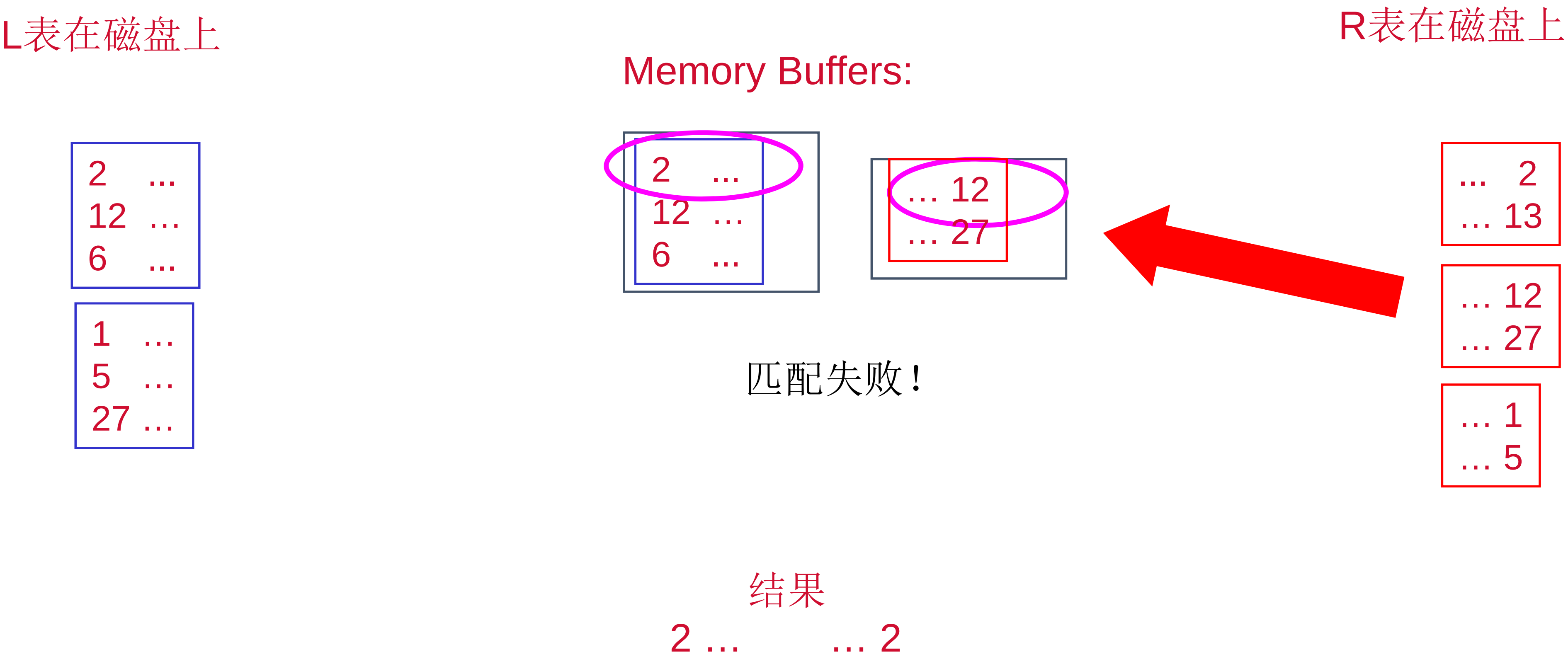
Nest Loop Join



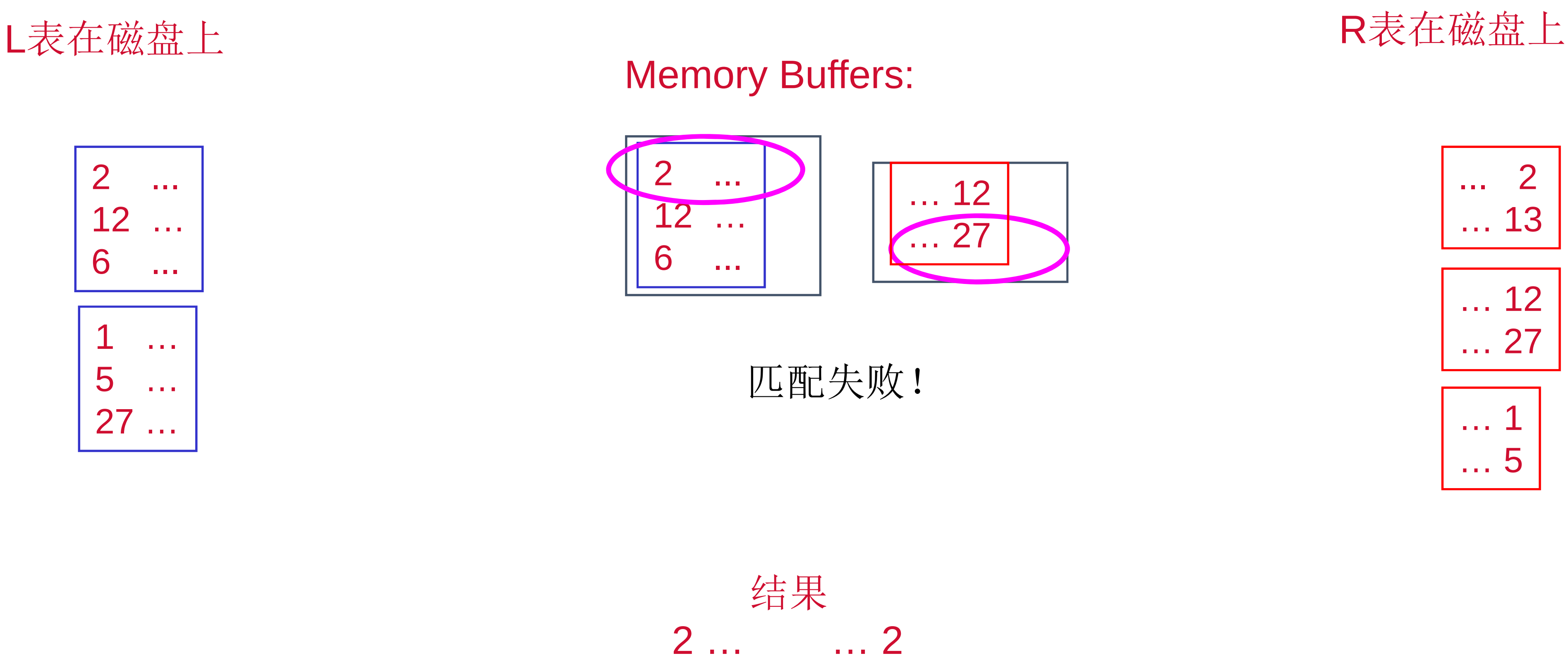
Nest Loop Join



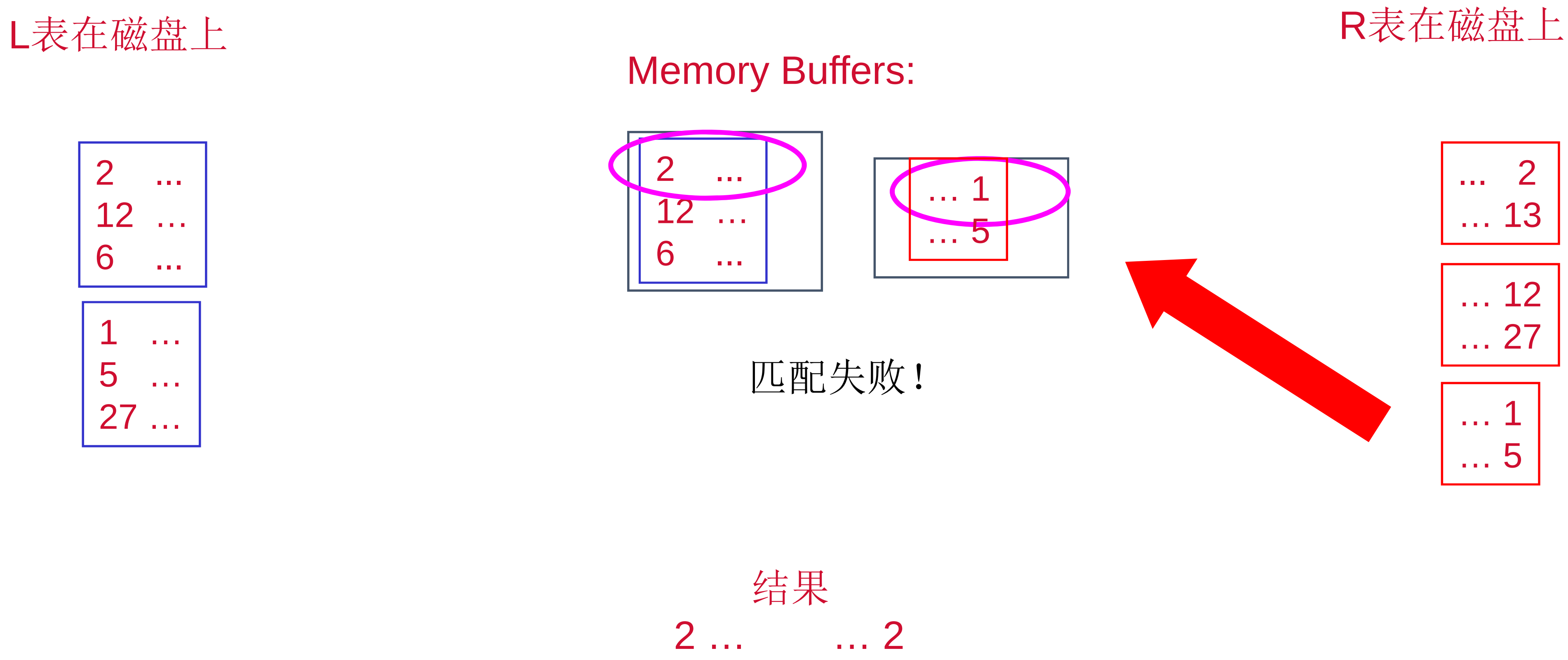
Nest Loop Join



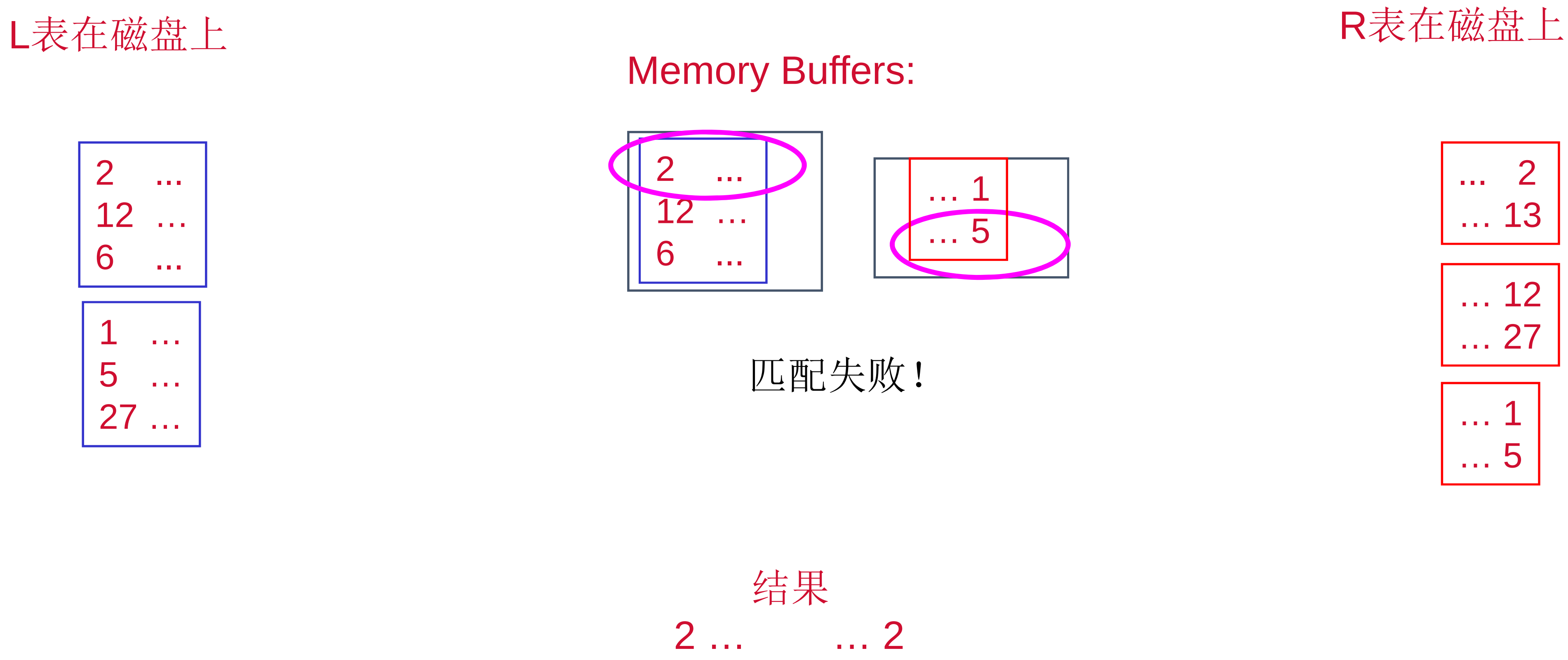
Nest Loop Join



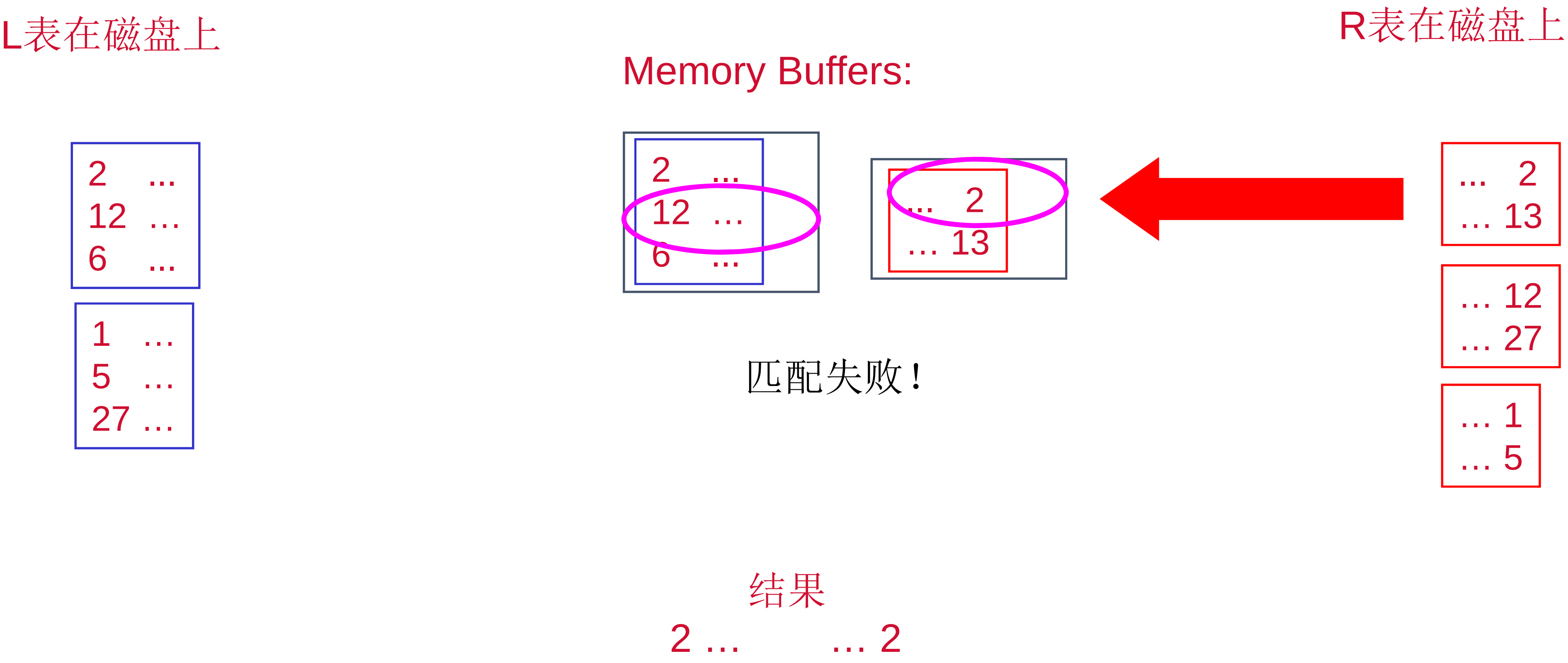
Nest Loop Join



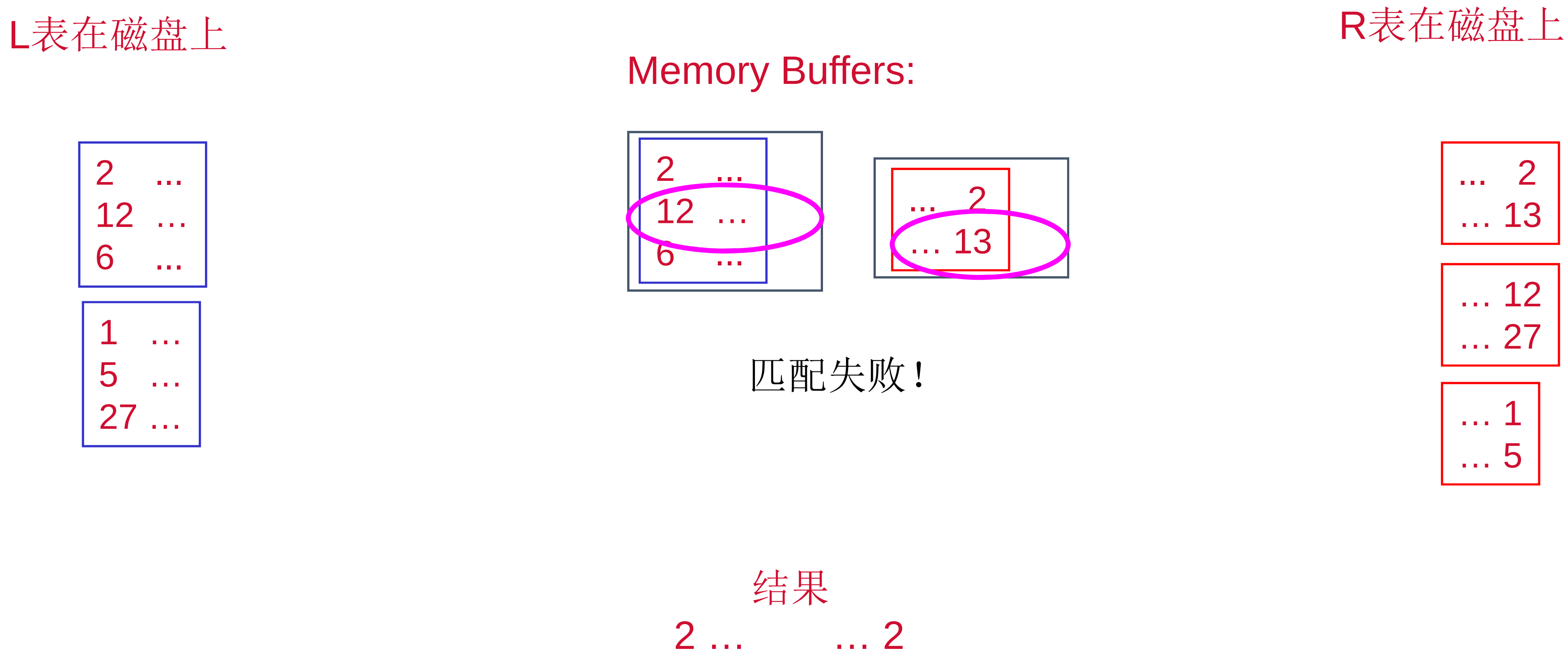
Nest Loop Join



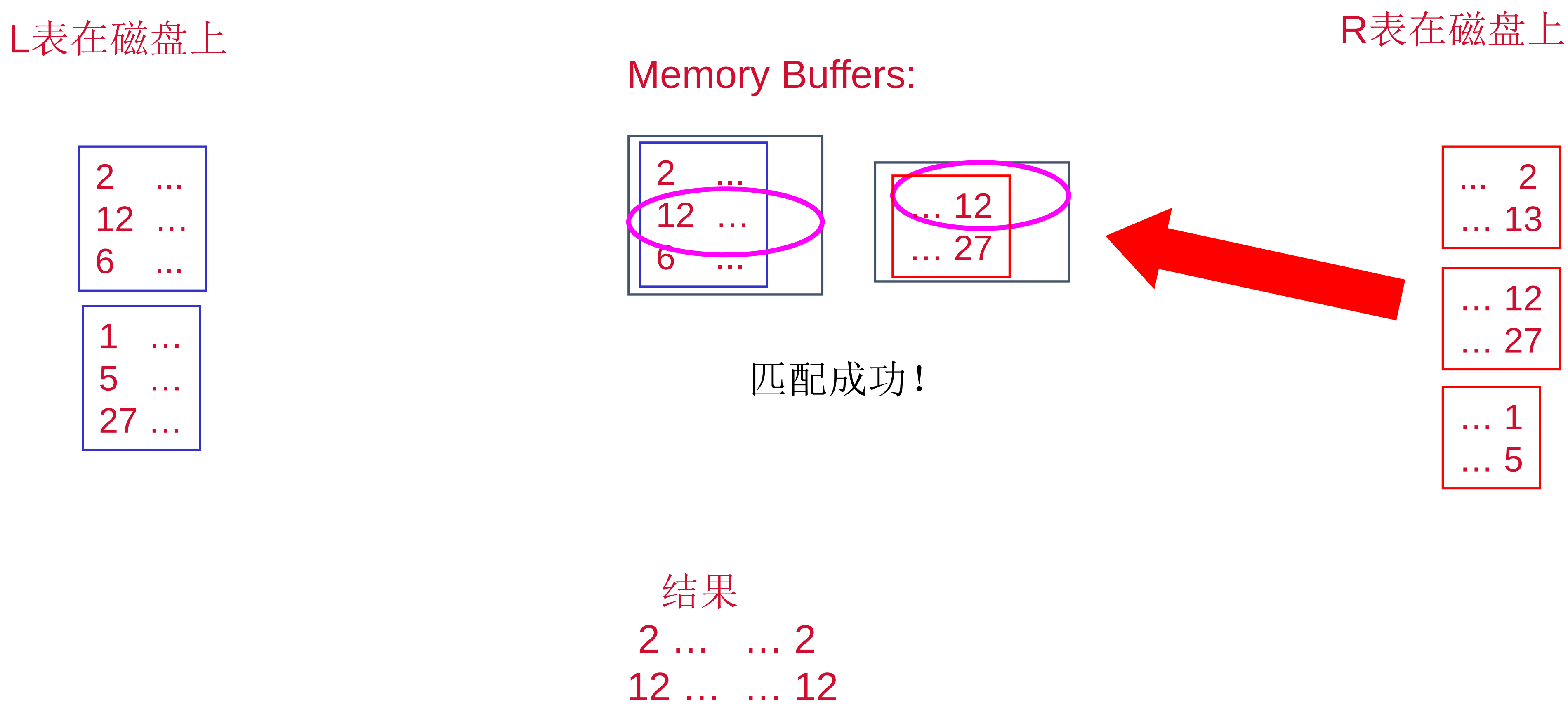
Nest Loop Join



Nest Loop Join



Nest Loop Join



Index Nest Loop IO代价

SELECT * FROM t1 L, t2 R WHERE L.id=R.id

假设在表R.id上创建了索引

for l in L do

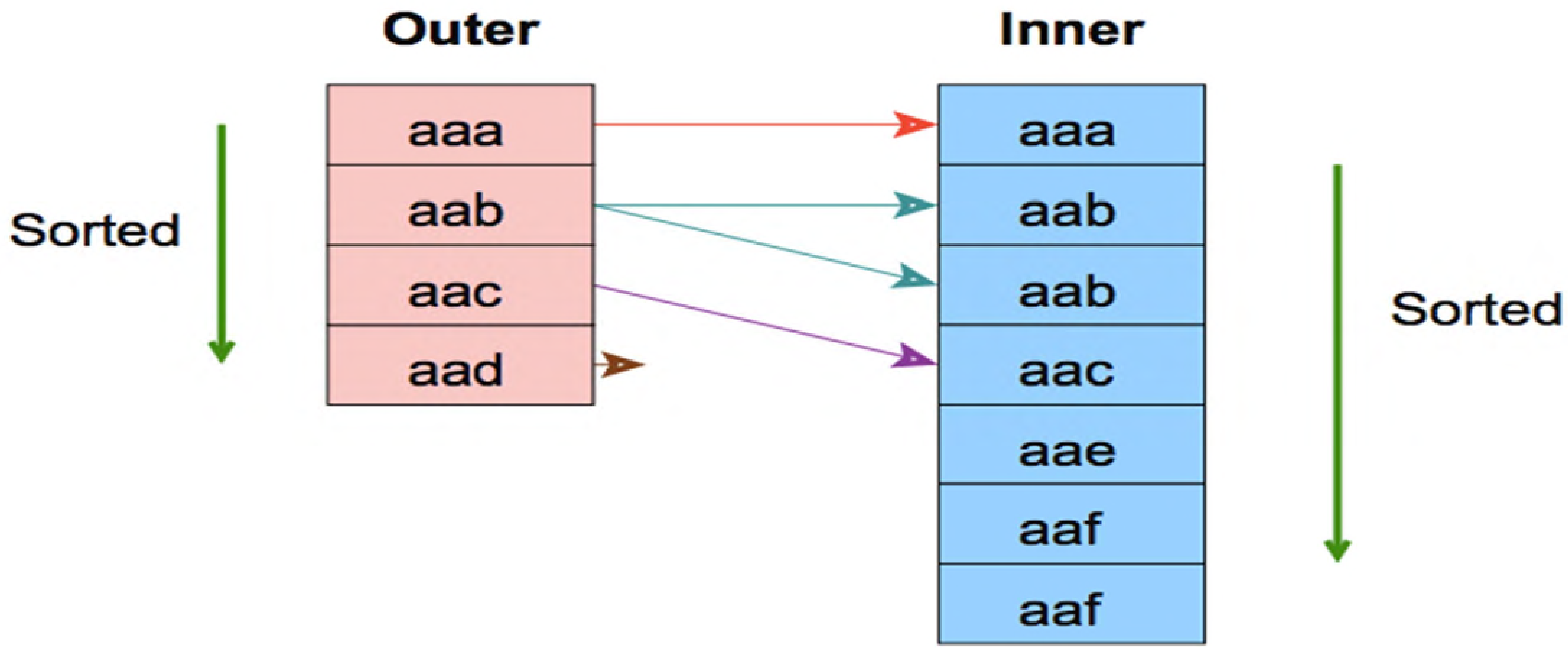
Index Scan r in R where $l_{id} = r_{id}$

ret += (l, r)

总IO: M + ($(M*p_L)$ * cost of finding matching R rows)

= 20000 + ((20000*40)*3) =2420000

Merge Join

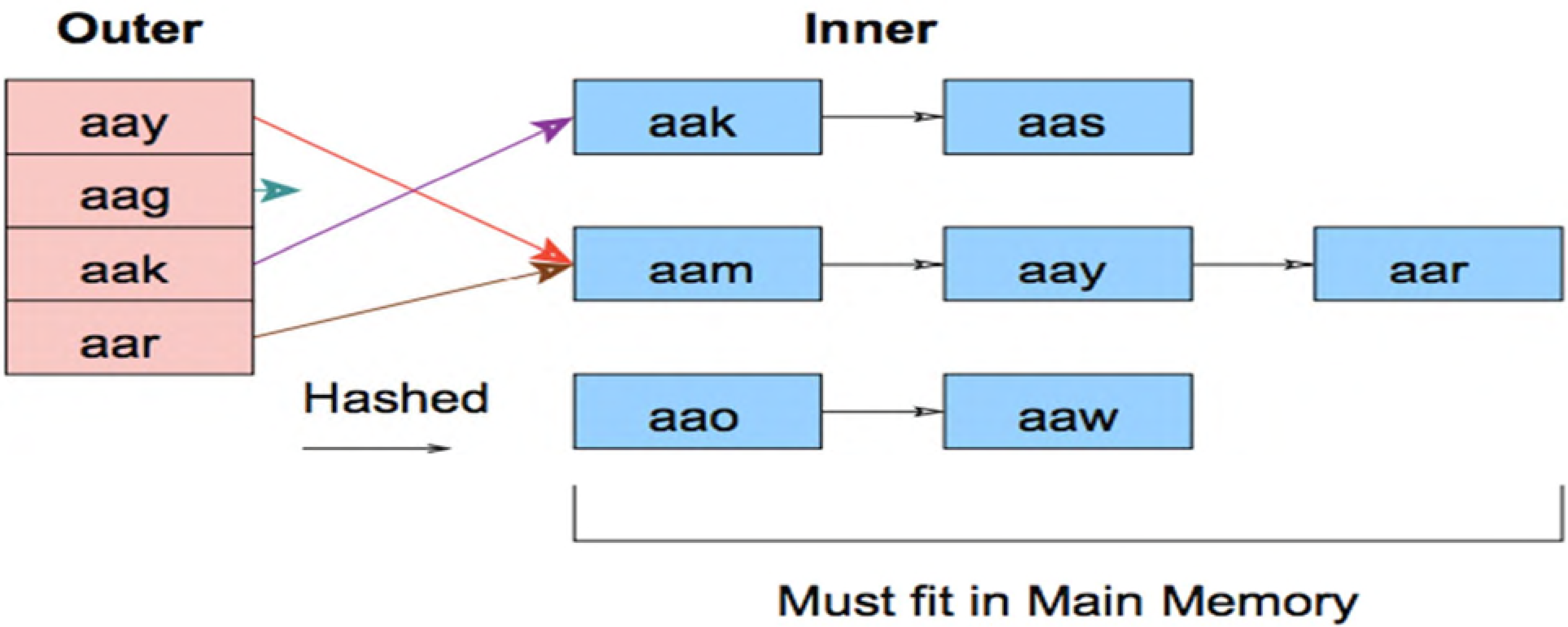

Outer
Inner
Sorted
aaa
aab
aac
aad
aaa
aab
aab
aac
aae
aaf
aaf
Sorted

Merge Join

主要分为3步:

1. Sort L on l_{id} 代价MlogM
2. Sort R on r_{id} 代价NlogN
3. Merge the sorted L and R on l_{id} and r_{id} 代价M+N

Hash Join


Outer
Inner
aay
aag
aak
aar
aak
aas
aam
aay
aar
aao
aaw
Hashed
Must fit in Main Memory

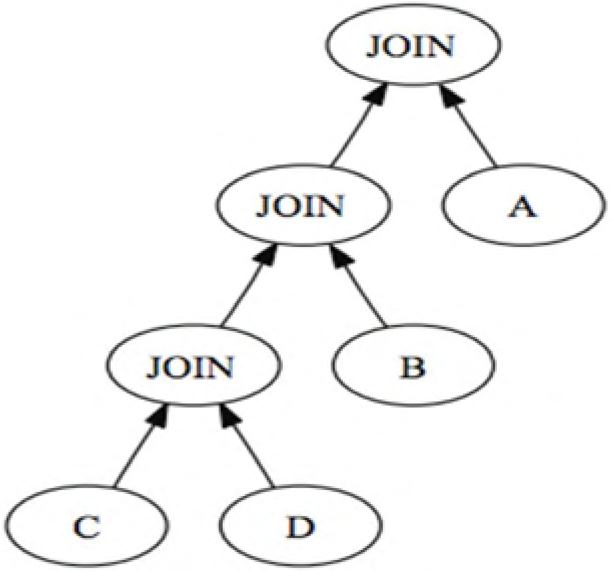
多表连接算法

- 动态规划

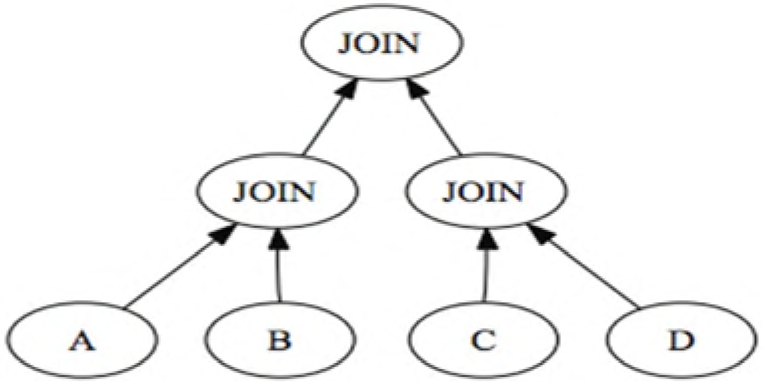
- 遗传算法：适用于join特别多情况

多表连接算法

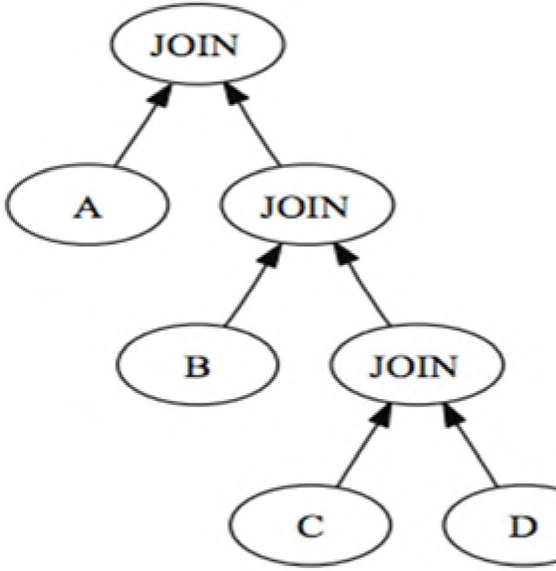
- 连接树



左深树

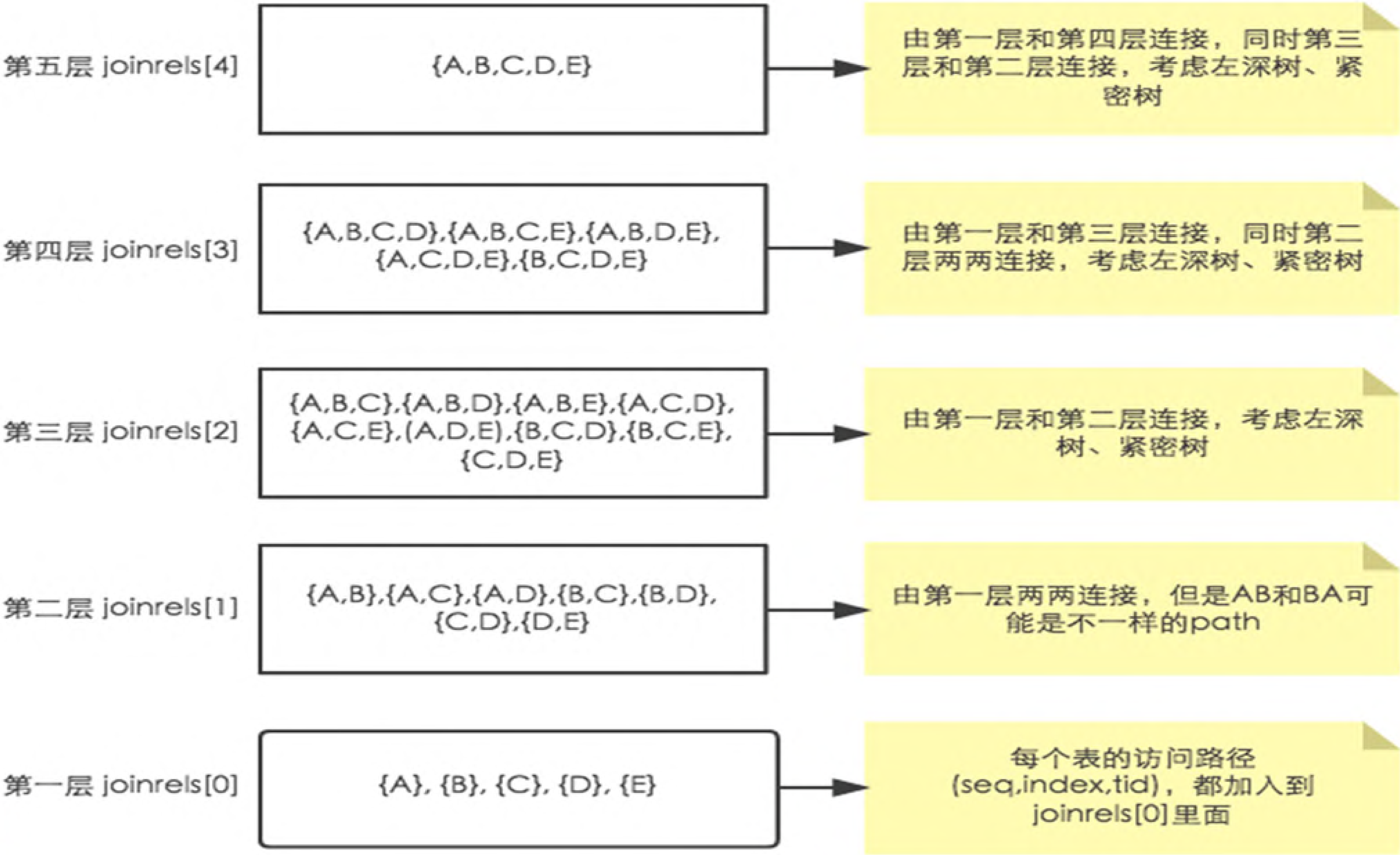


紧密型树



右深树

动态规划求解过程


第五层 joinrels[4]
{A,B,C,D,E}
由第一层和第四层连接，同时第三层和第二层连接，考虑左深树、紧密树
第四层 joinrels[3]
{A,B,C,D},{A,B,C,E},{A,B,D,E},
{A,C,D,E},{B,C,D,E}
由第一层和第三层连接，同时第二层两两连接，考虑左深树、紧密树
第三层 joinrels[2]
{A,B,C},{A,B,D},{A,B,E},{A,C,D},
{A,C,E},(A,D,E),{B,C,D},{B,C,E},
{C,D,E}
由第一层和第二层连接，考虑左深树、紧密树
第二层 joinrels[1]
{A,B},{A,C},{A,D},{B,C},{B,D},
{C,D},{D,E}
由第一层两两连接，但是AB和BA可能是不一样的path
第一层 joinrels[0]
{A}, {B}, {C}, {D}, {E}
每个表的访问路径(seq,index,tid)，都加入到joinrels[0]里面

动态规划

- 每个中间结果都保留三个路径
  - 1. 最小启动代价
  - 2. 代价最小路径
  - 3. 代价最小排序路径

Thanks!

Q & A