HARVARD
School of Engineering
and Applied Sciences

CS165
Data Systems

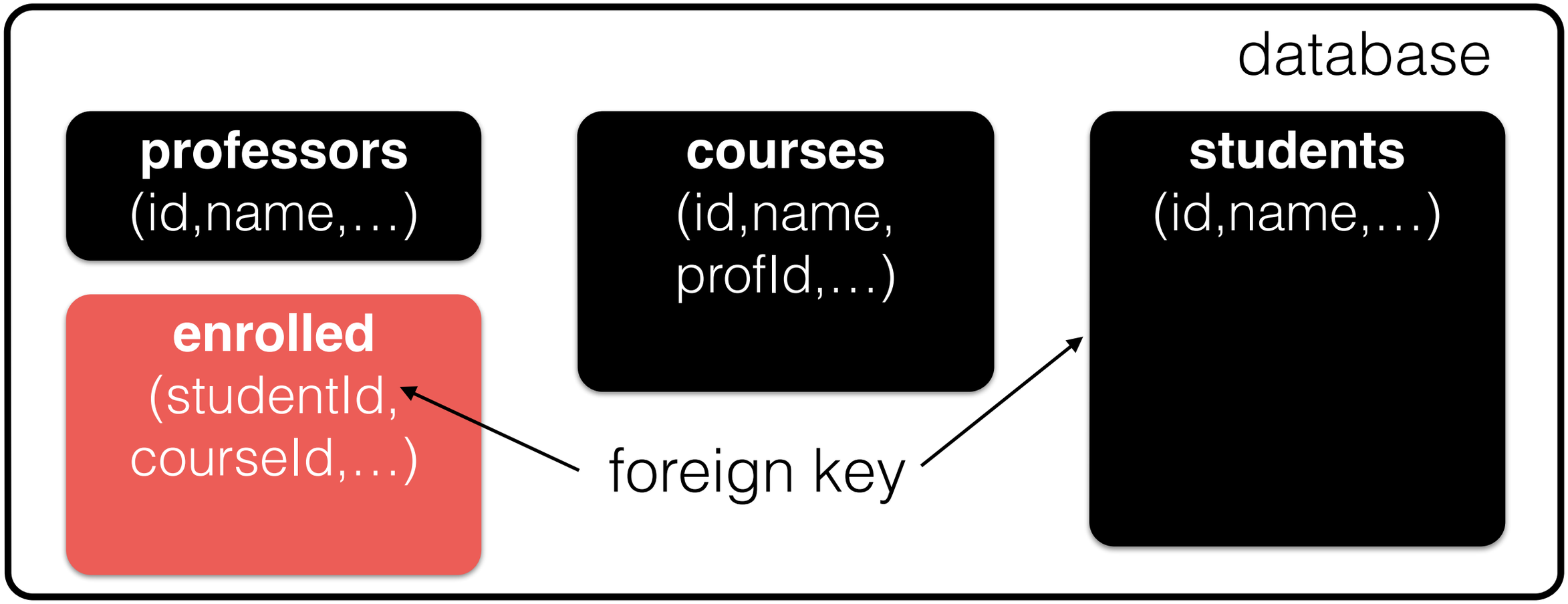
Have fun learning to design and build modern data systems

class 16

hash joins

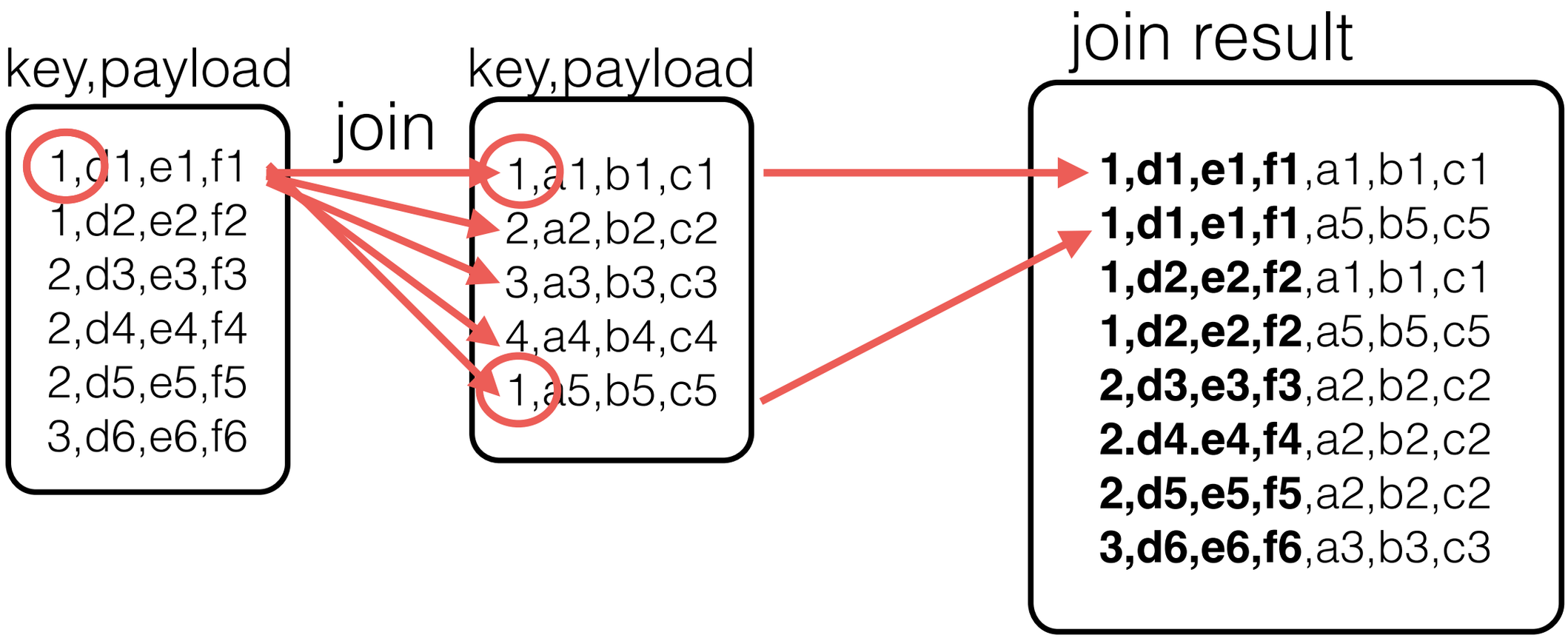
prof. Stratos Idreos

HTTP://DASLAB.SEAS.HARVARD.EDU/CLASSES/CS165/

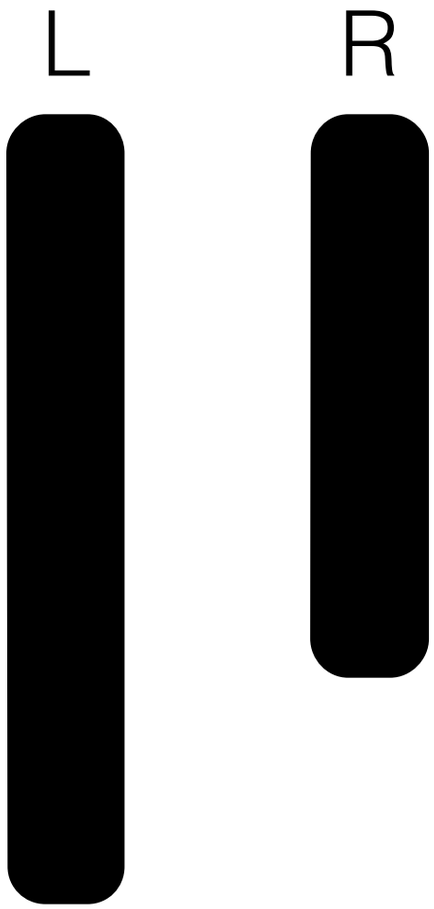


give me all students enrolled in cs165

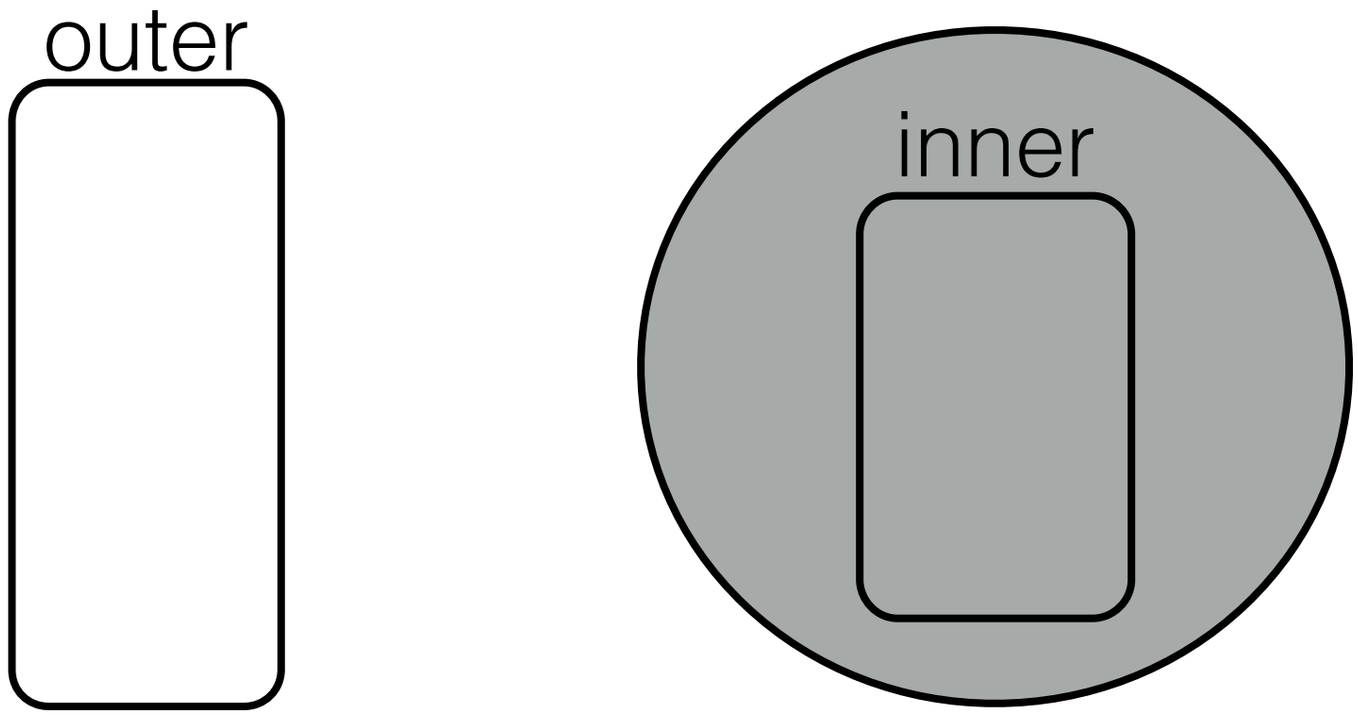
select *student.name* ***from*** *students, enrolled, courses* ***where*** *courses.name="cs165" and enrolled.courseId=course.id and student.id=enrolled.studentId* **join**


key,payload
1,d1,e1,f1
1,d2,e2,f2
2,d3,e3,f3
2,d4,e4,f4
2,d5,e5,f5
3,d6,e6,f6
join
key,payload
1,a1,b1,c1
2,a2,b2,c2
3,a3,b3,c3
4,a4,b4,c4
1,a5,b5,c5
join result
1,d1,e1,f1,a1,b1,c1
1,d1,e1,f1,a5,b5,c5
1,d2,e2,f2,a1,b1,c1
1,d2,e2,f2,a5,b5,c5
2,d3,e3,f3,a2,b2,c2
2.d4.e4,f4,a2,b2,c2
2,d5,e5,f5,a2,b2,c2
3,d6,e6,f6,a3,b3,c3

nested loops



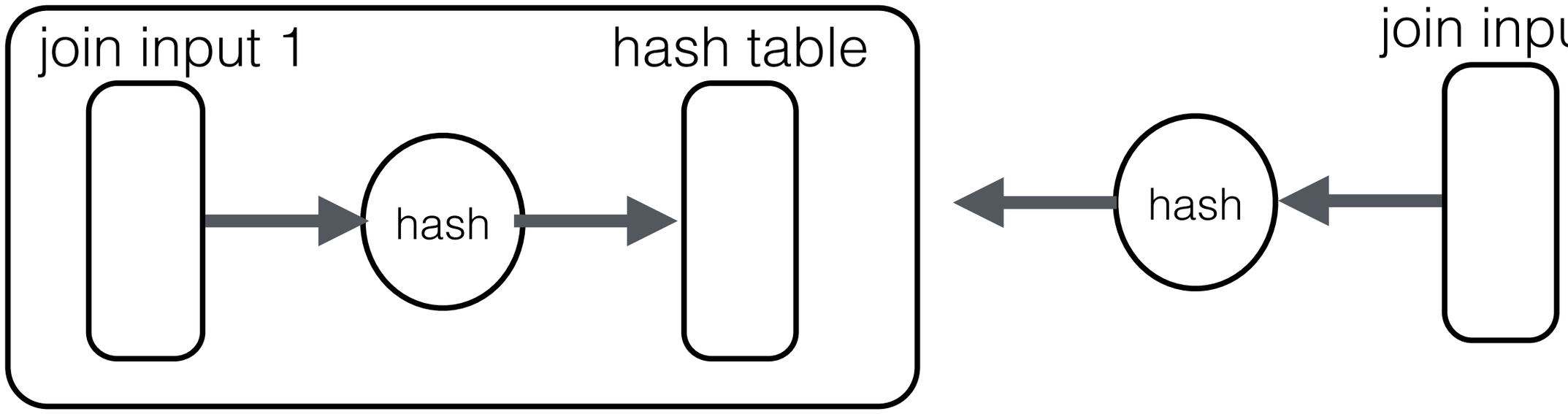

```
new resL[]; new resR[]; k=0
for (i=0;i<L.size;i=i++)
    for (j=0;j<R.size;j++)
        if L[i]==R[j]
            resL[k]=i
            resR[k++]=j
```

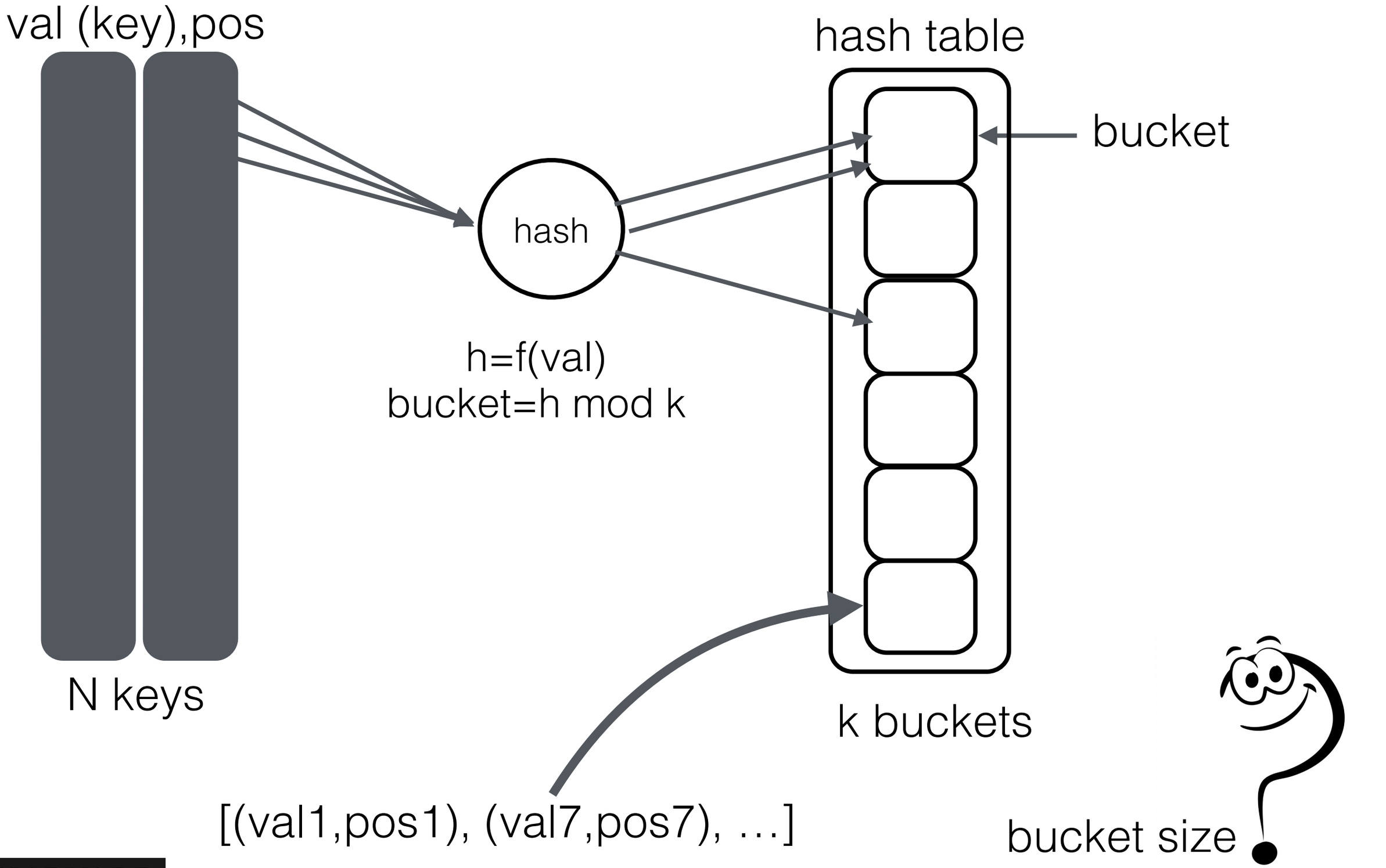


oracle

search in O(1)

hash join



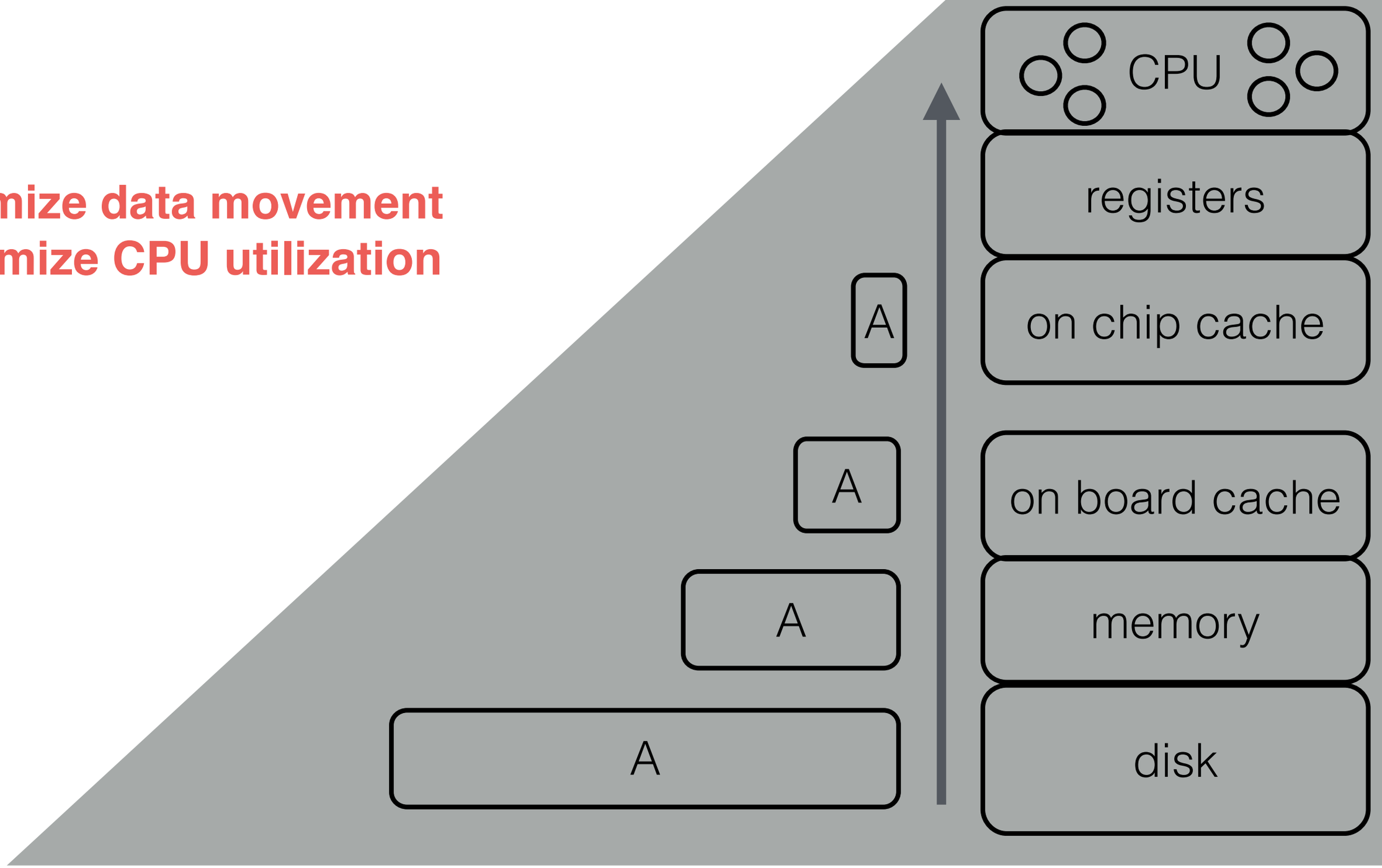

val (key),pos
N keys
hash
h=f(val)
bucket=h mod k
hash table
bucket
k buckets
[(val1,pos1), (val7,pos7), …]
bucket size

assumption for this class:

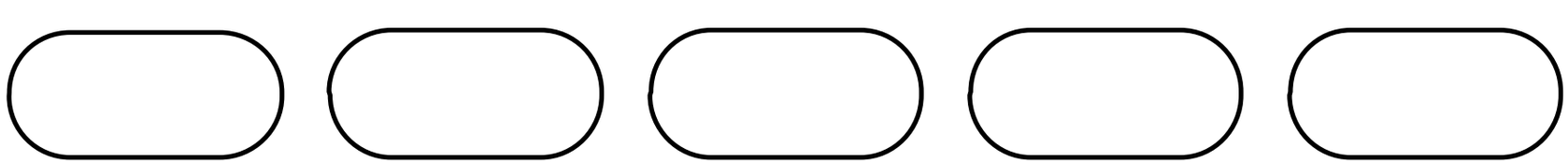
we know how many buckets we need

(more in next class about this)

minimize data movement
maximize CPU utilization



goal: join R(val,pos) and S(val,pos) = Res(posR,posS)



Level 1

5 blocks

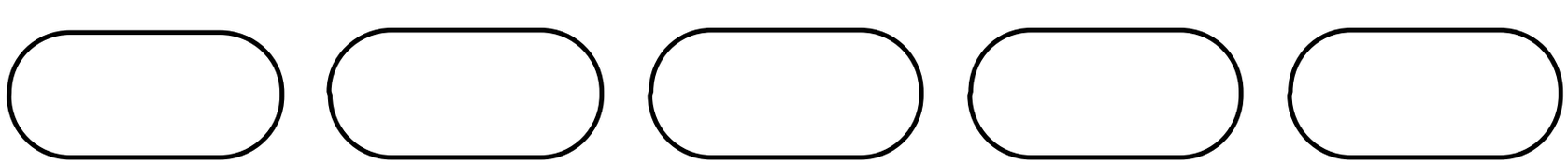
R

S

Level2

R+S<<L2

goal: join R(val,pos) and S(val,pos) = Res(posR,posS)



Level 1

5 blocks

R

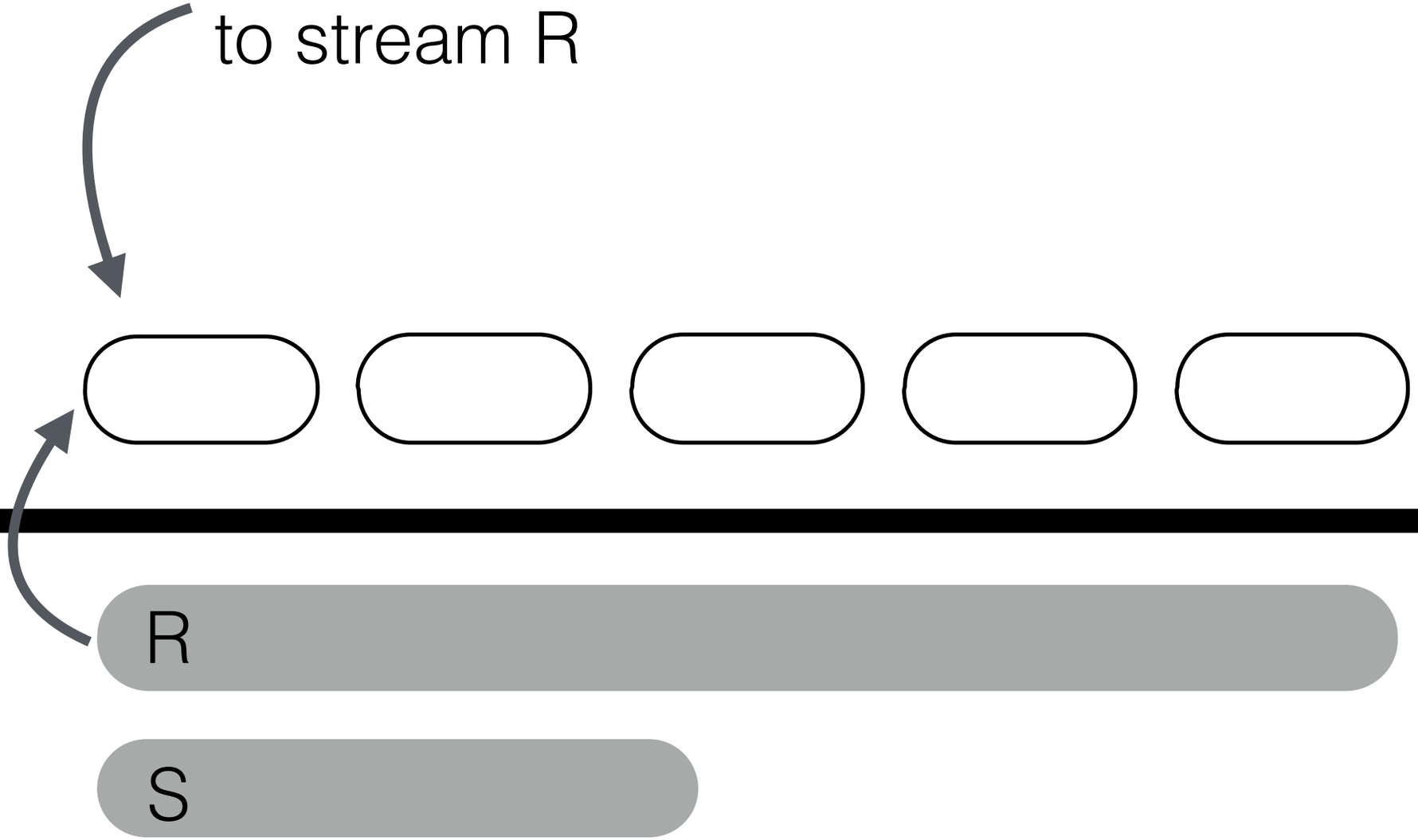
S

Level2

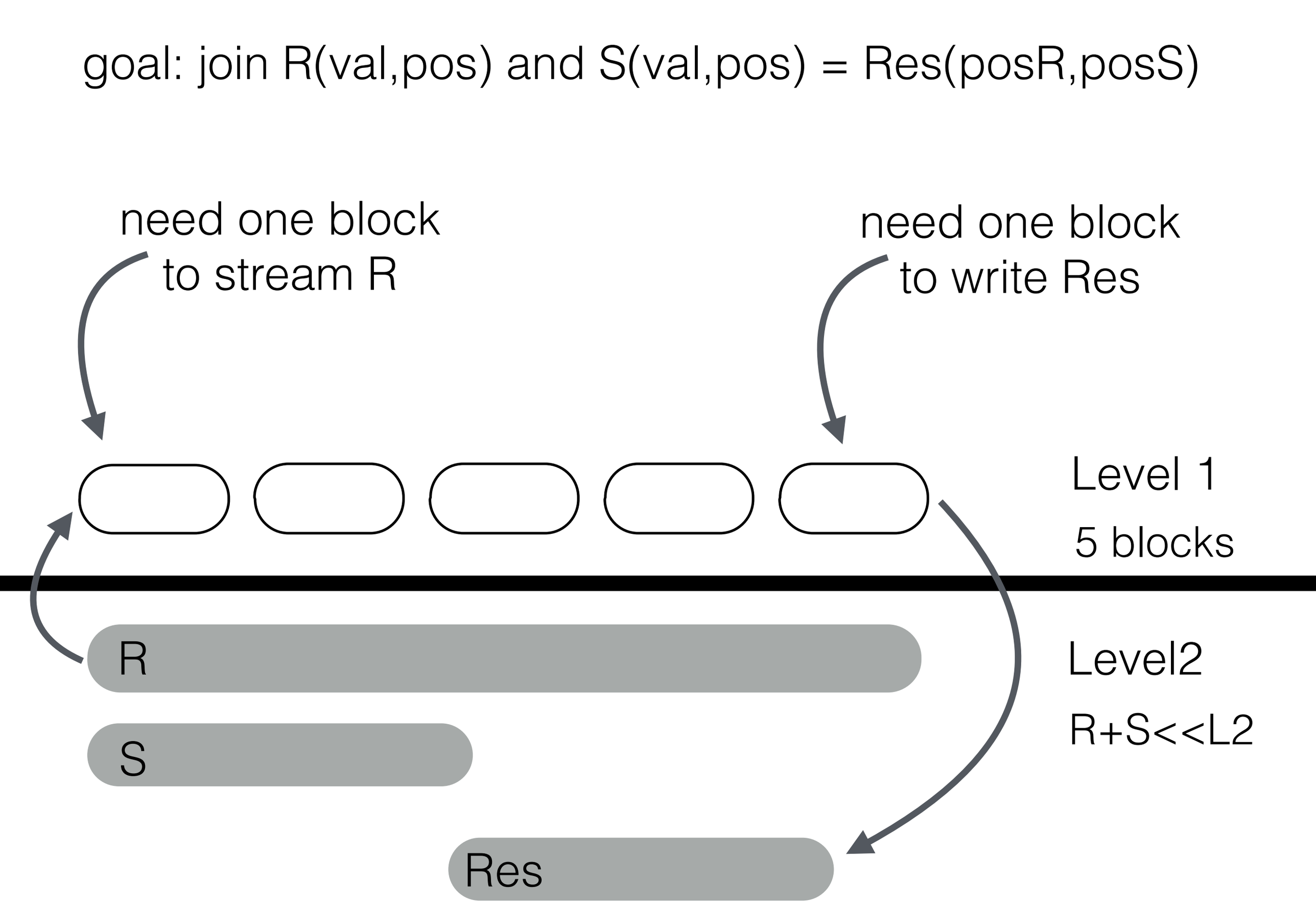
R+S<<L2

goal: join R(val,pos) and S(val,pos) = Res(posR,posS)

need one block
to stream R



goal: join R(val,pos) and S(val,pos) = Res(posR,posS)



goal: join R(val,pos) and S(val,pos) = Res(posR,posS)

need one block
to stream R

need one block
to write Res

hash table, S<=L1-2

Level 1

5 blocks

R

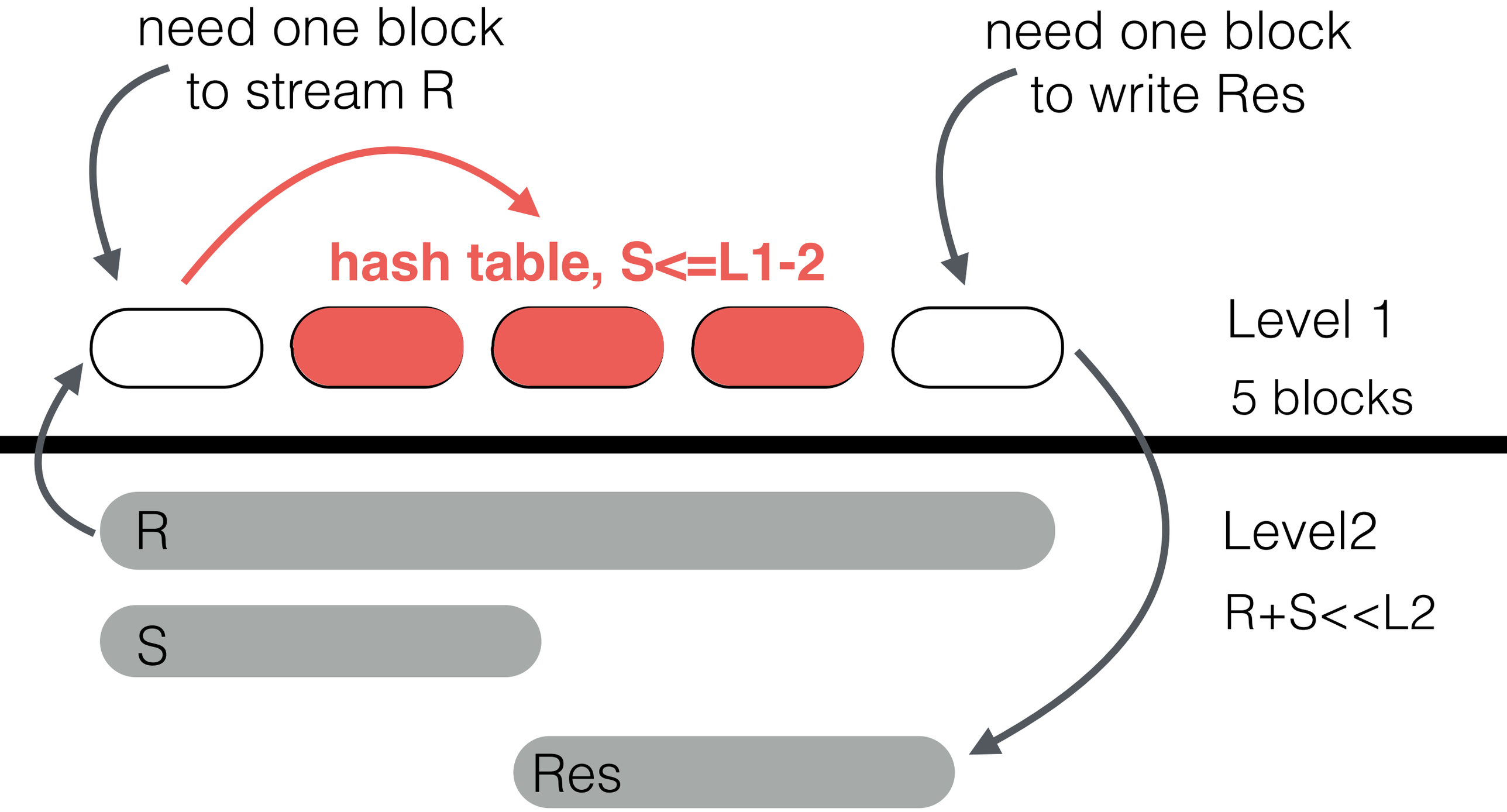
S

Res

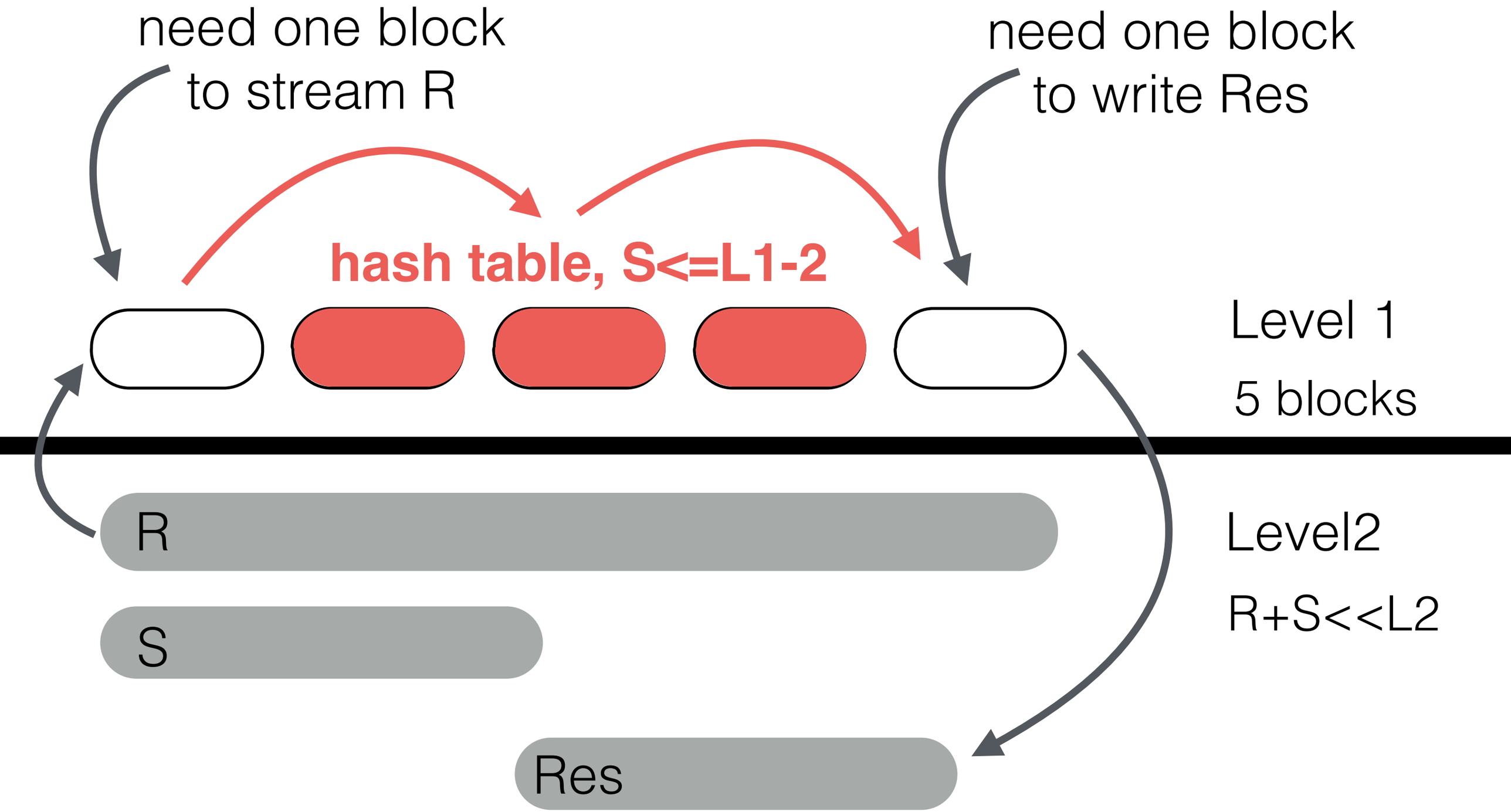
Level2

R+S<<L2

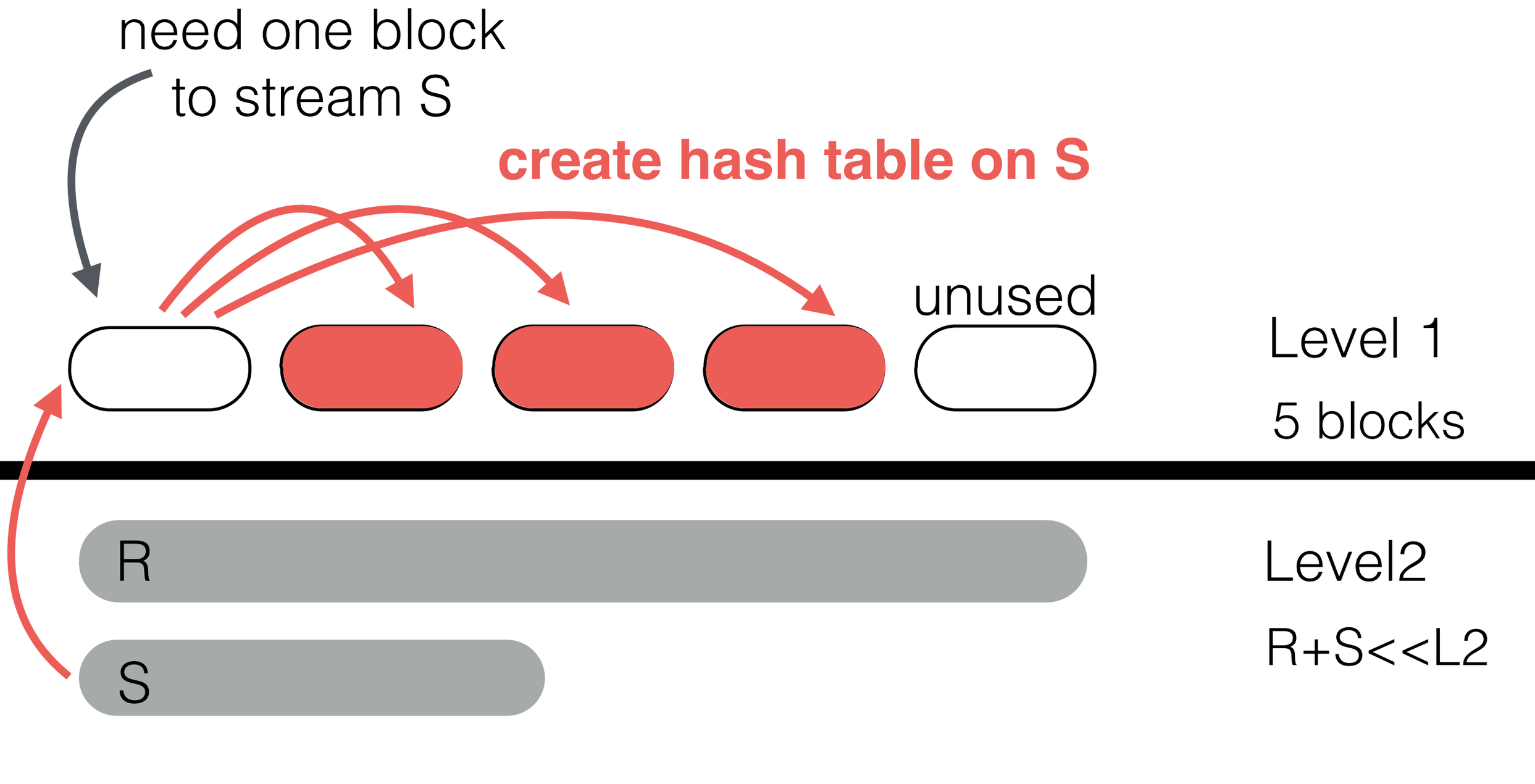
goal: join R(val,pos) and S(val,pos) = Res(posR,posS)



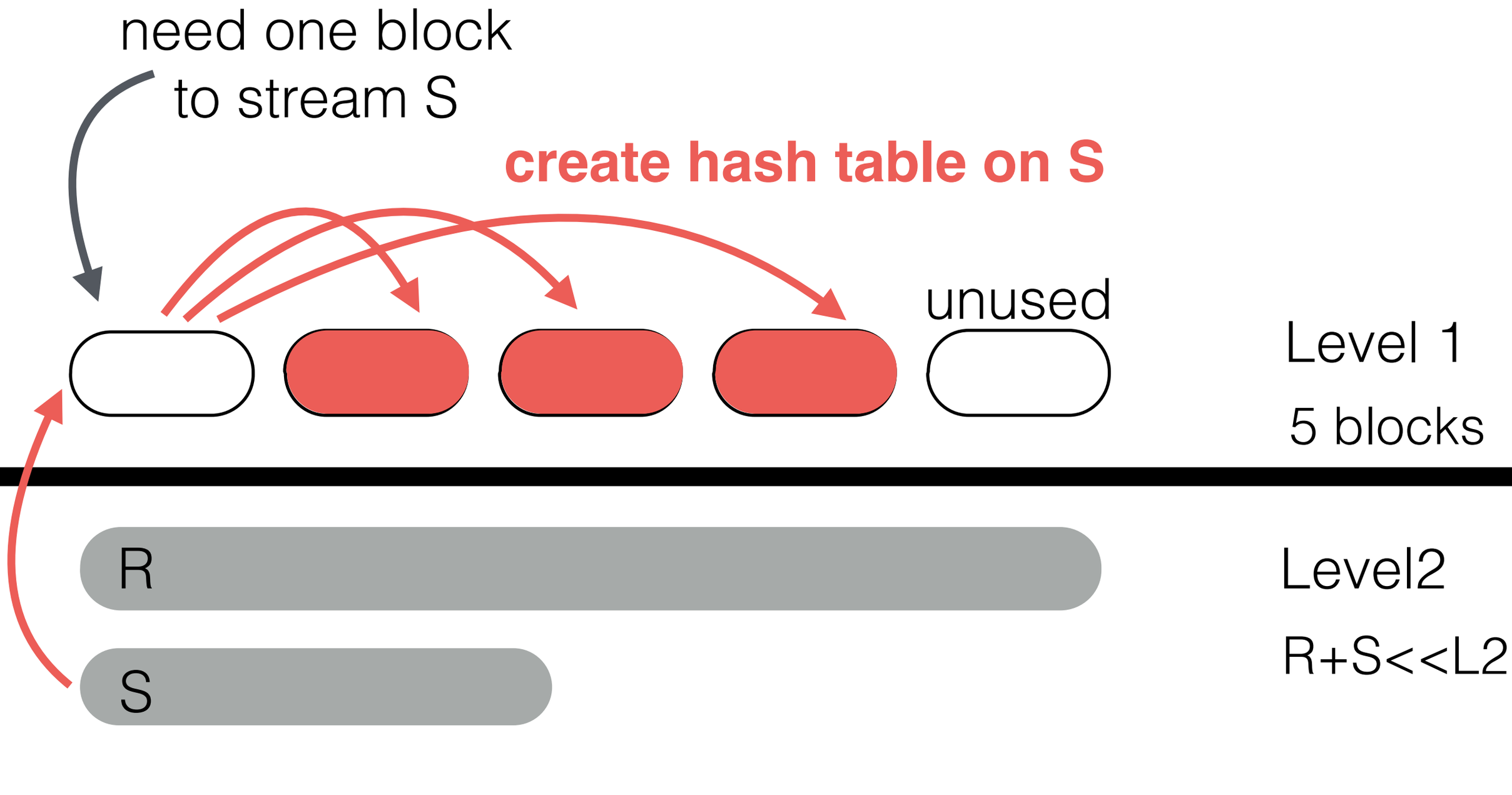
goal: join R(val,pos) and S(val,pos) = Res(posR,posS)



goal: join R(val,pos) and S(val,pos) = Res(posR,posS)



goal: join R(val,pos) and S(val,pos) = Res(posR,posS)



Total Cost=R+S+Res (blocks)

what if R>L1-2 & S>L1-2?

```
new resL; new resS; k=0;r=0;
for (i=0,i<S.size;i++,k++)
        addToHash(ht,S[i], S[i].val mod L1-2)
         if (k==L1-2 || i==S.size-1)
             k=0
             for (j=0;j<R.size;j++)
                  res=probe(ht,R[i].val);
     if (res!=null)
          resR[r]=R[j].[pos]
          resS[r++]=res.pos
empty(ht);
```

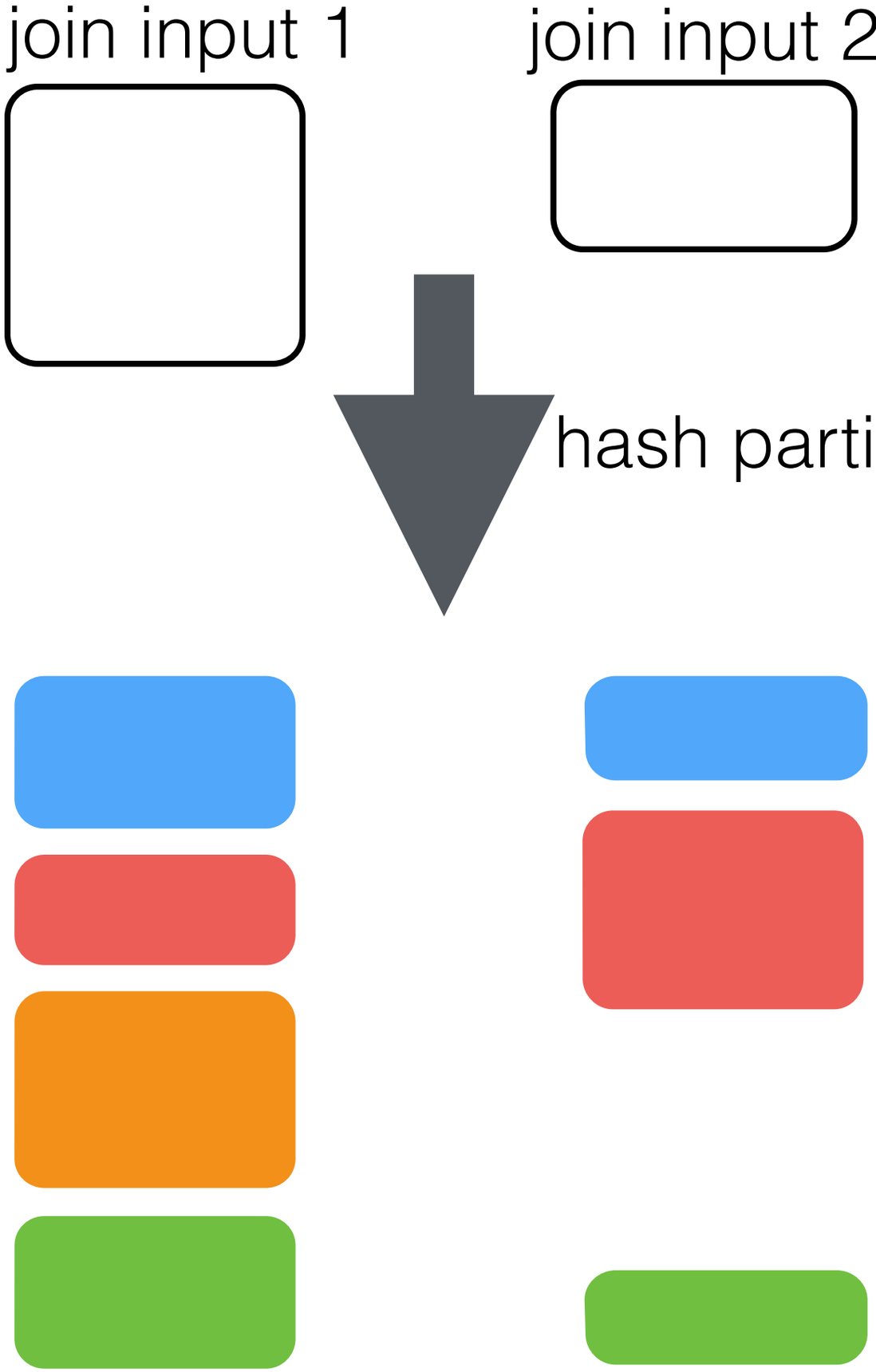
hash first L1-2 values from S

scan all R and probe

repeat until we hash everything in S

Total Cost=R*S/(L1-2)+S+Res (blocks)

grace hash join

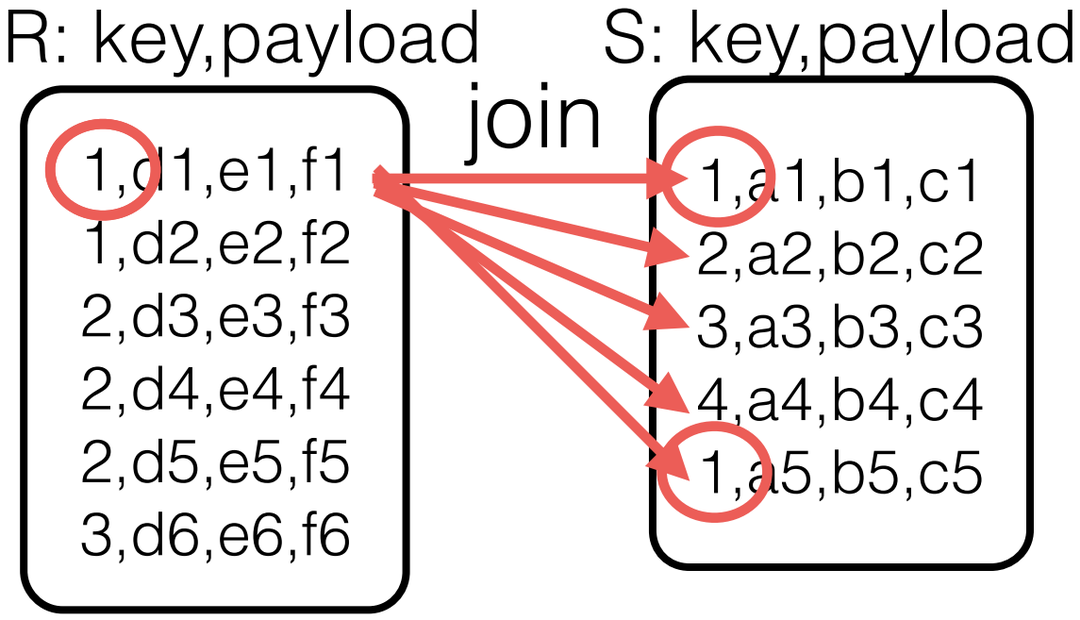


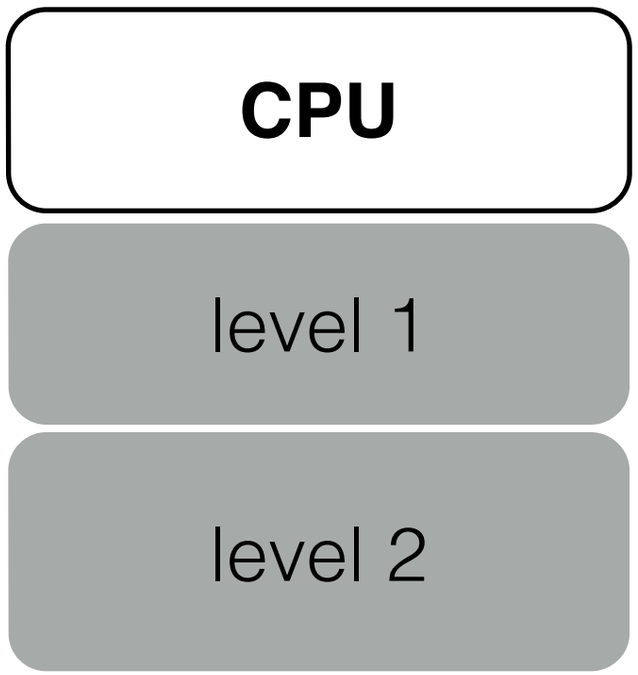
one pass to partition

then one pass to
join each pair of partitions independently in memory

for every
L.key = R.key pair
return [L.pos,R.pos]

data/results
one column-at-a-time

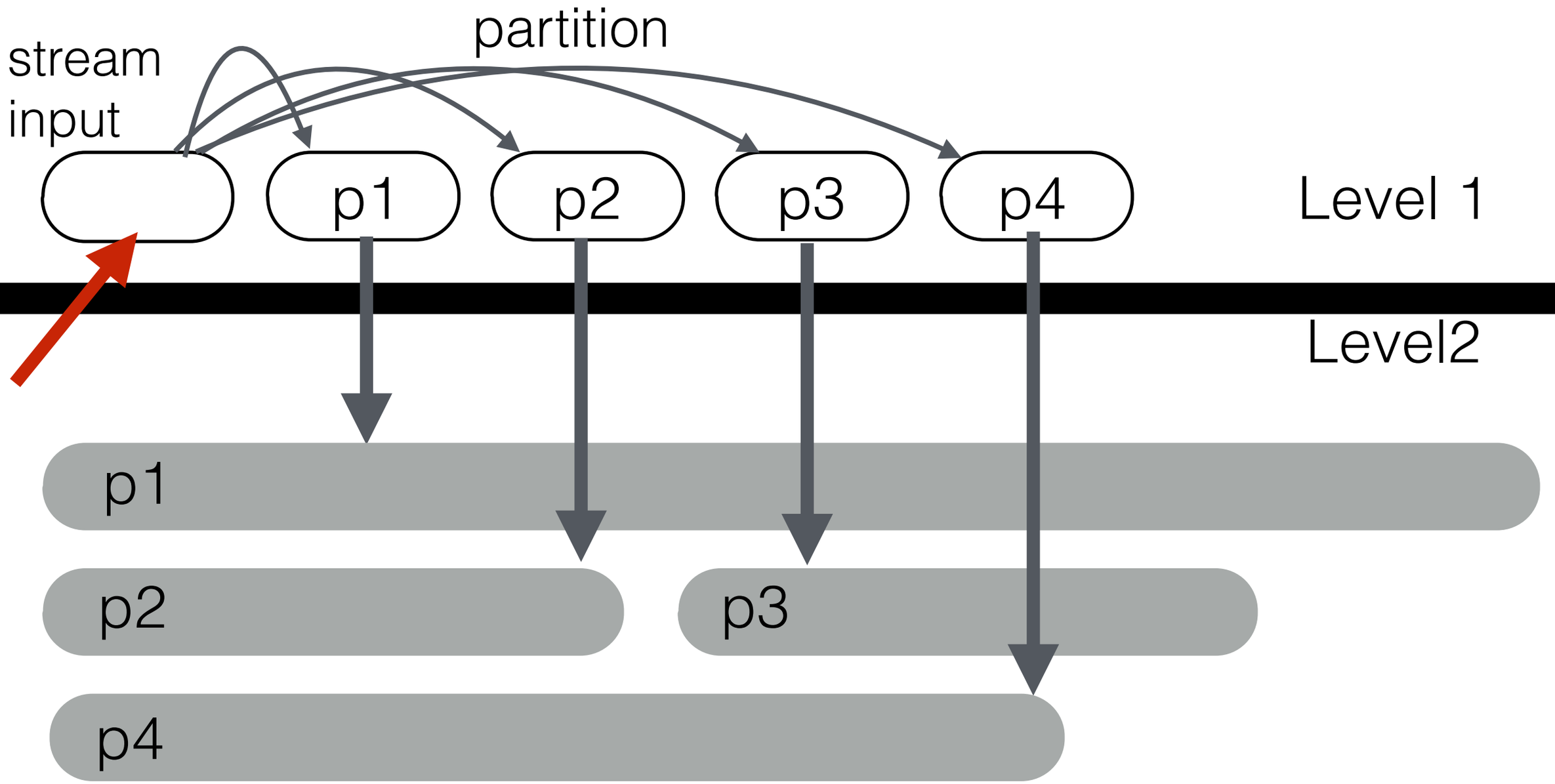




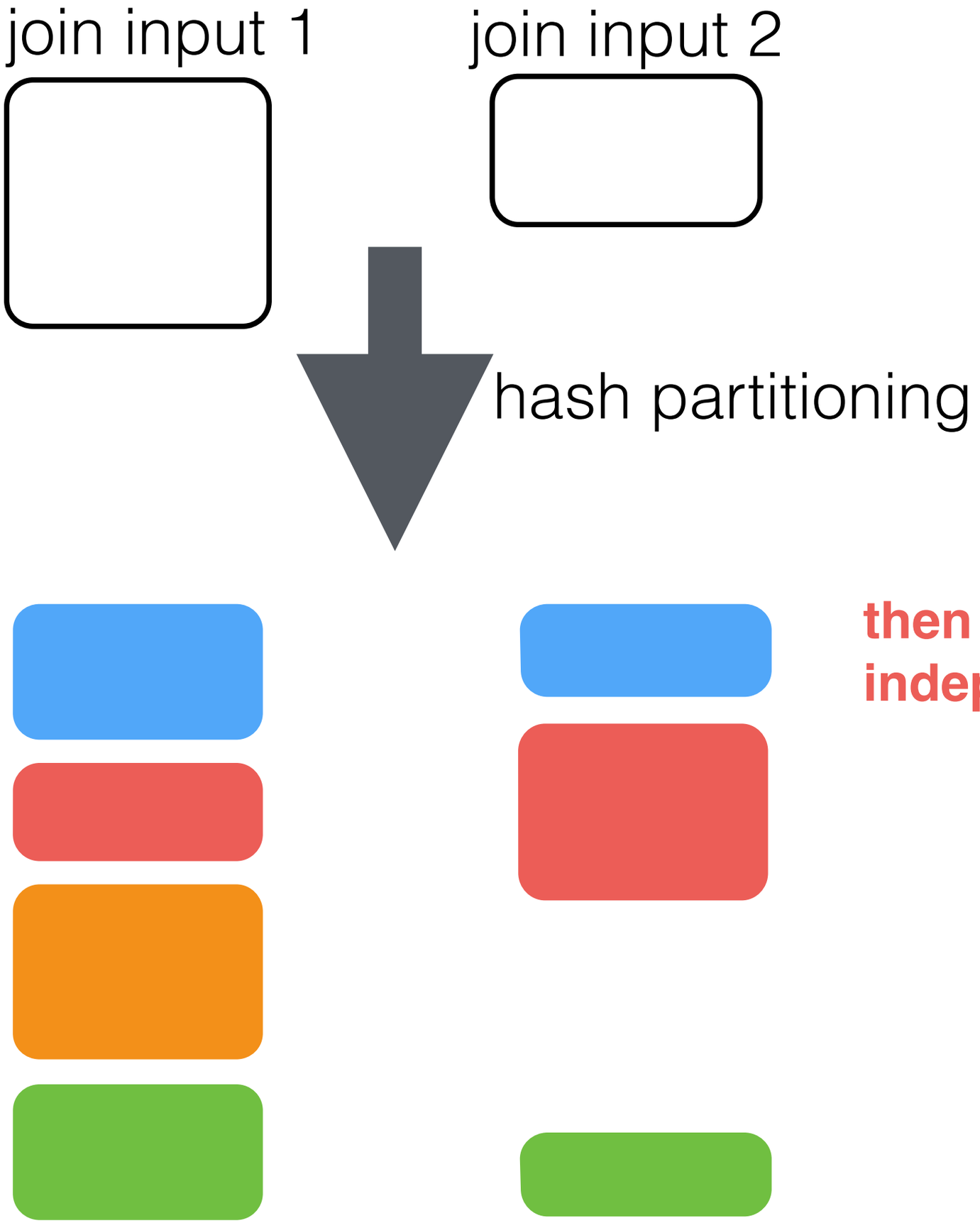
1) design a grace join algorithm and give its cost
2) which table do we start from?
3) what if partitions end up being >L1-2?
4) when can we do grace join in 2 passes max?

5) utilize multi-cores
6) can you keep all cores at 100% all the time?

1. read input into stream buffer, hash and write to respective partition buffer
2. when input buffer is consumed, bring the next one
3. when a partition buffer is full, write to L2
we can partition into L1-1 pieces in one pass



grace hash join



then join each pair of partitions independently in memory

as long as at least one of the pieces <=L1-2

stream input left

probe

L1-2

p1 right hash table

result

Level 1

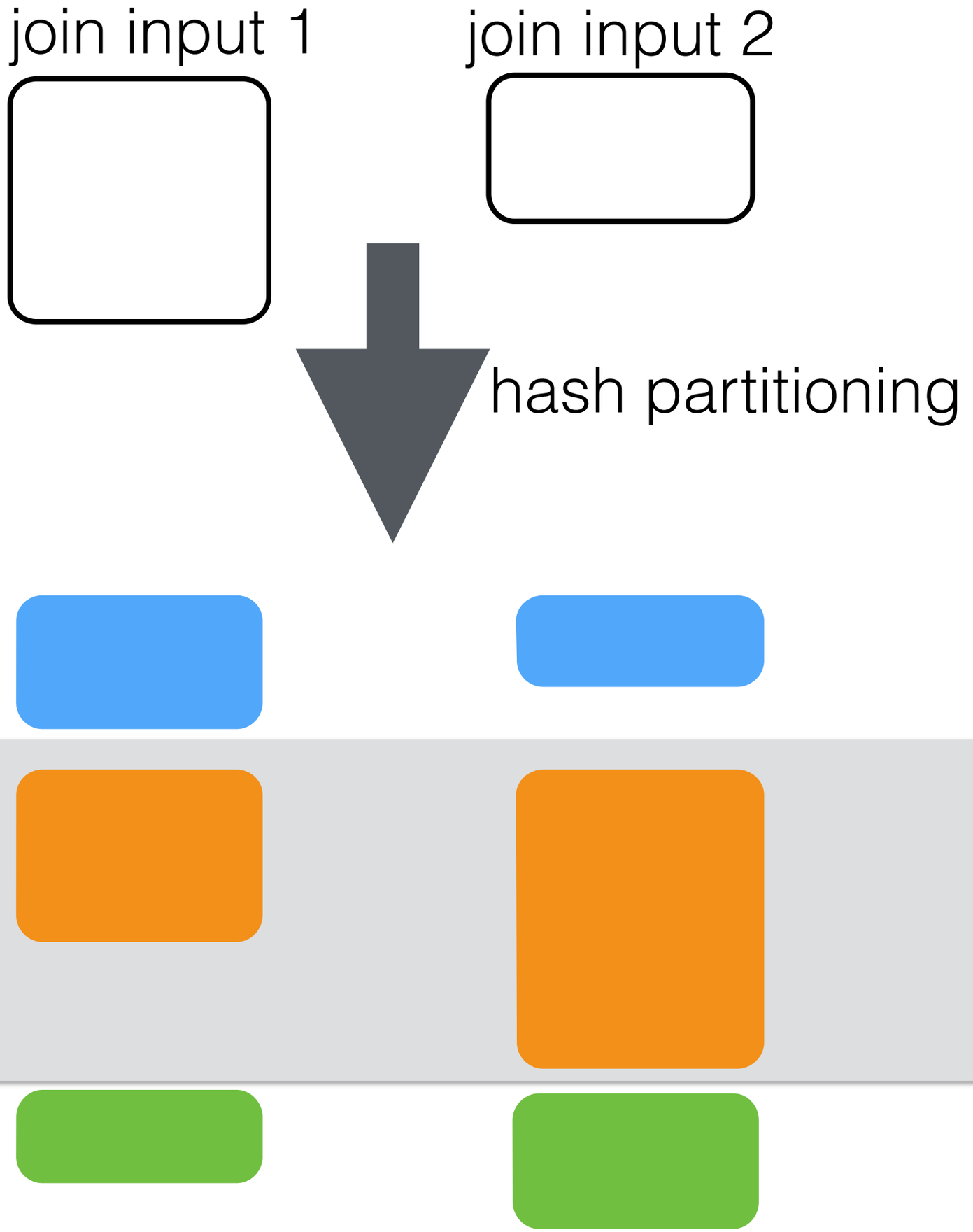
Level2

p1 left

p1 right

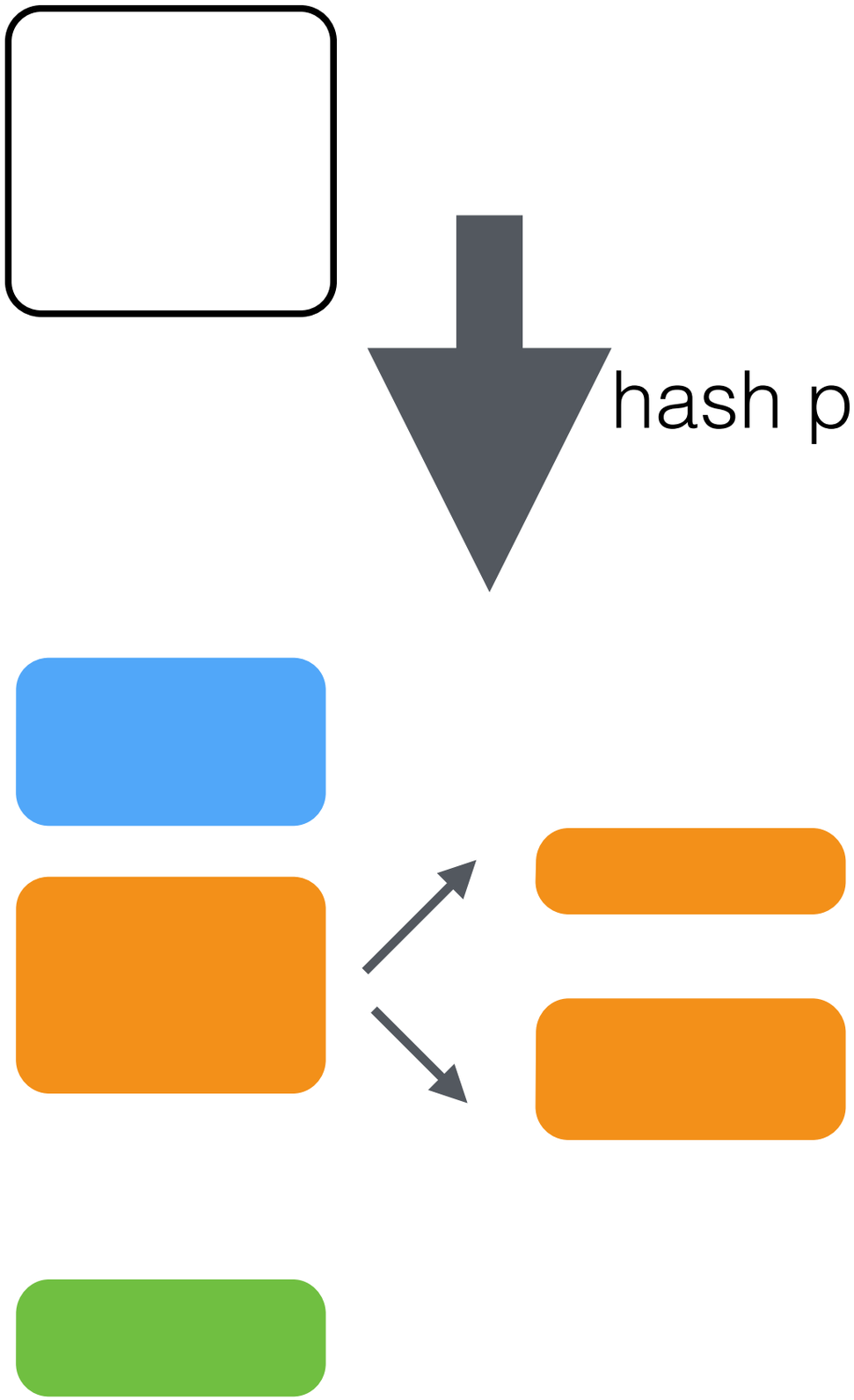
result

grace hash join



both left and right side >L1-2

grace hash join



apply recursively if a partition does not fit in memory

when can we do grace join in exactly 2 passes

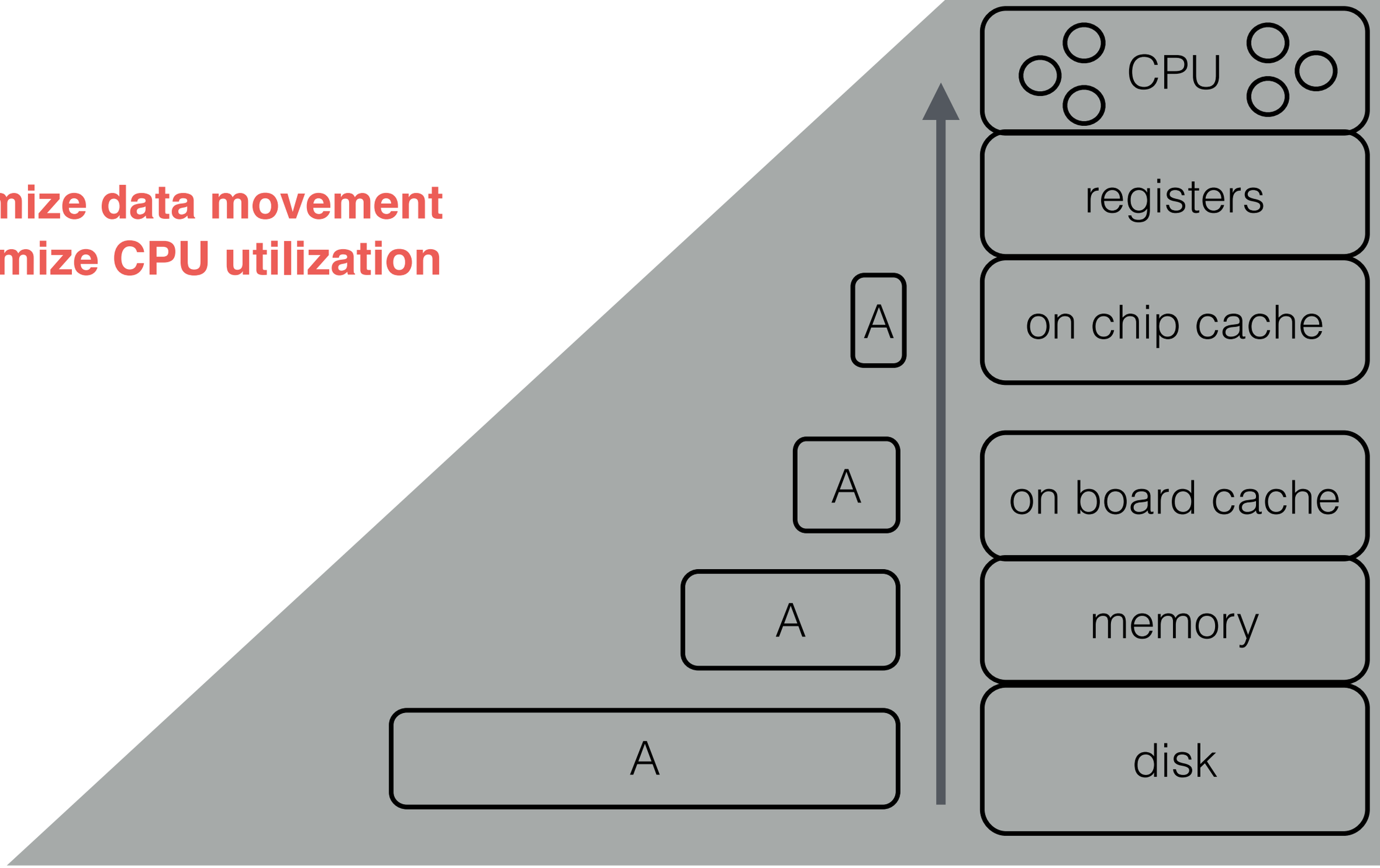
1) at least one side should fit in L1-2

2) simplify problem by considering one side only:
if all partitions we create fit in L1-2 we are ok

3) the maximum number of partitions we can create in one pass is L1-1

4) so if R/L1-1<=L1-2 -> R<=(L1-1)(L1-2)
we will not need to repartition any pieces

minimize data movement
maximize CPU utilization



how to partition in parallel?

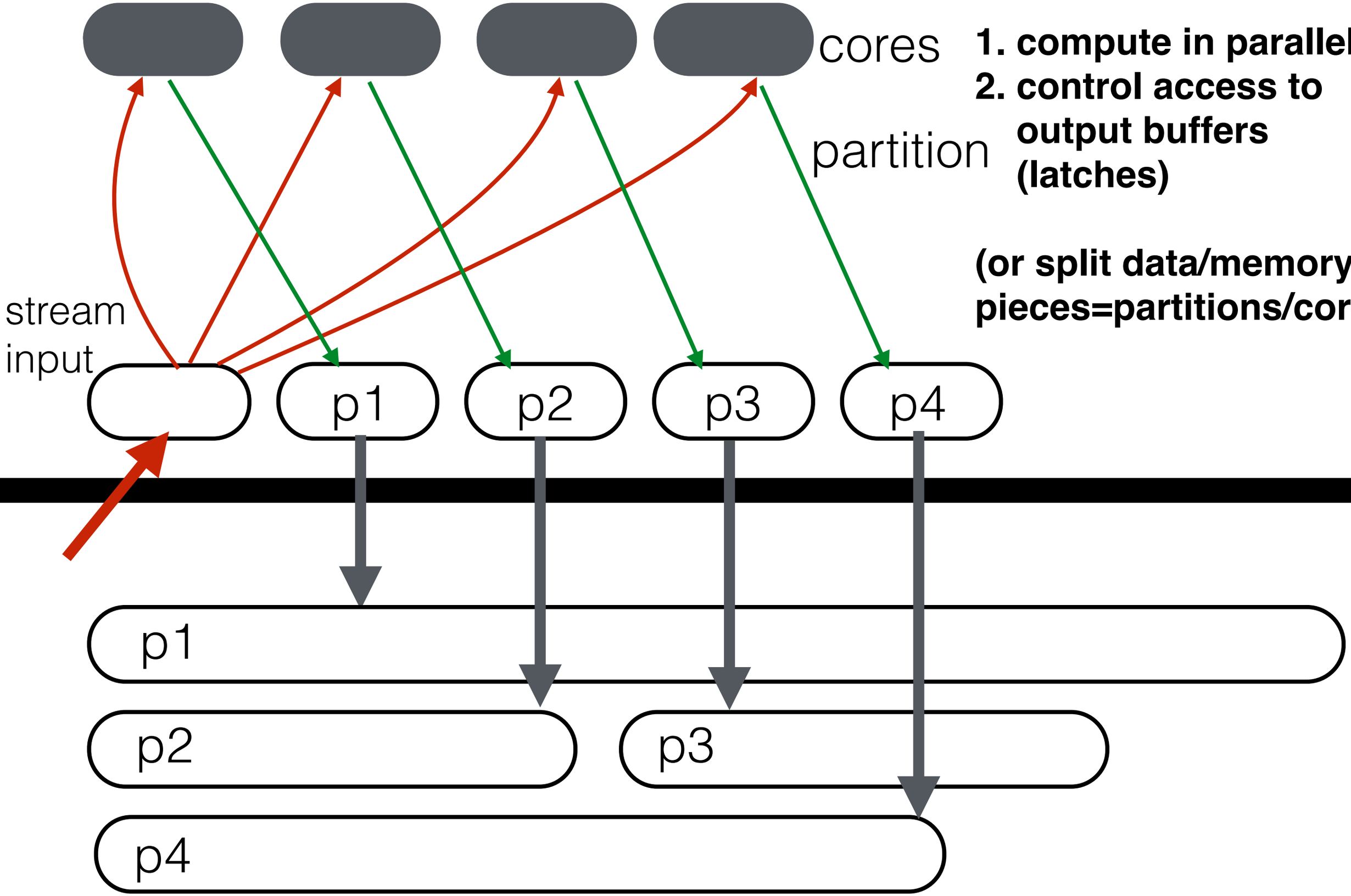
join

partition each input

for each pair of partitions
create hash table
probe hash table

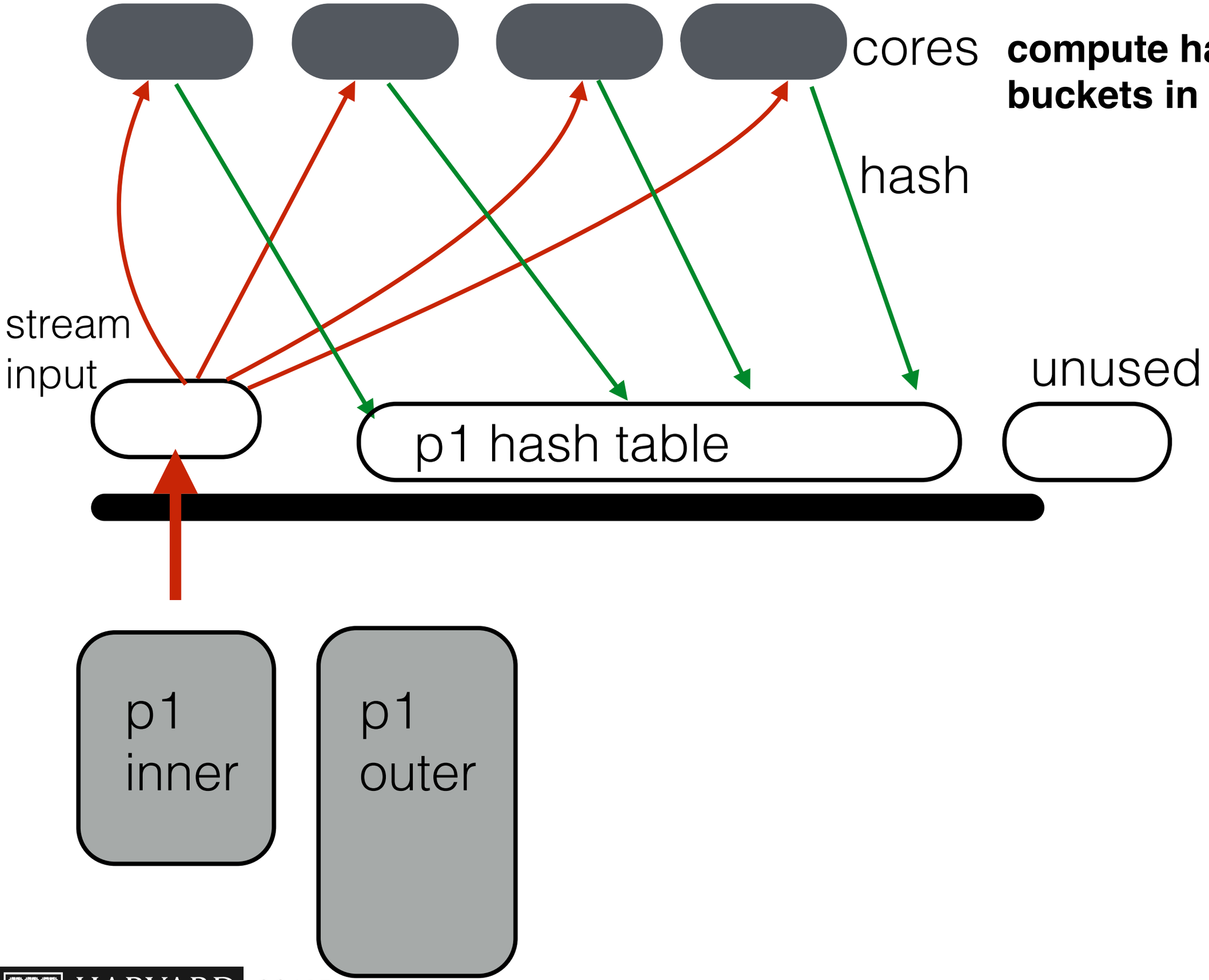
how to create HT in parallel?

how to probe HT in parallel?



1. compute in parallel
2. control access to output buffers (latches)

(or split data/memory pieces=partitions/cores)


cores
compute hash values &
buckets in parallel
hash
stream
input
unused
p1 hash table
p1
inner
p1
outer

cores

compute hash values & buckets in parallel

hash

control

stream input

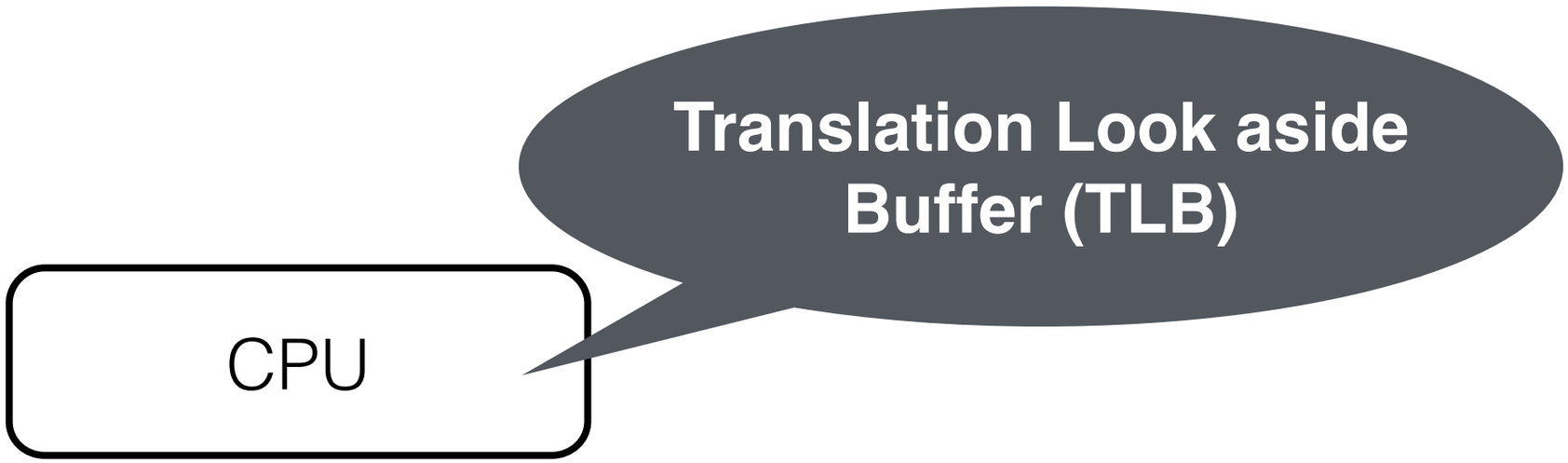
p1 hash table

result

p1 inner

p1 outer

p1 result



we need to translate virtual memory addresses to physical memory

cache conscious grace join

CPU

L1

L2

L3

memory

disk

partition R such as each hash table fits in L3 (L3-2)
as much as K=L3-1 partitions in one pass

every time a buffer/cache line is full spill to memory
we may be writing to K memory areas

if K>TLB then we incur TLB misses

radix join

recursively partition with maximum **outputs<=TLB**

may do more passes but sequential access for reads
and random access for writes < TLB

no TLB misses

joins

(project=m4)

what to do in m4?

nested loops and hash joins

cache conscious and multi-core (within reason)

Join Processing in Databases with Large Main Memories
L. Shapiro
ACM Transactions on Database Systems. 11(3), 1986

Cache Conscious Algorithms for Relational Query Processing
A. Shatdal, C. Kant and J. Naughton
Very Large Databases Conference, 1984

Database Architecture Optimized for the new Bottleneck: Memory Access
P. Boncz, S. Manegold and M. Kersten
Very Large Databases Conference, 1999

Sort vs. Hash Revisited: Fast Join Implementation on Modern Multi-Core CPUs
Changkyu Kim, et all.
International Conference on Very Large Databases, 2009

hash joins

DATA SYSTEMS

prof. Stratos Idreos