CSED211: Lab. 9

Cache Lab

(Part B: Efficient Matrix Transpose)

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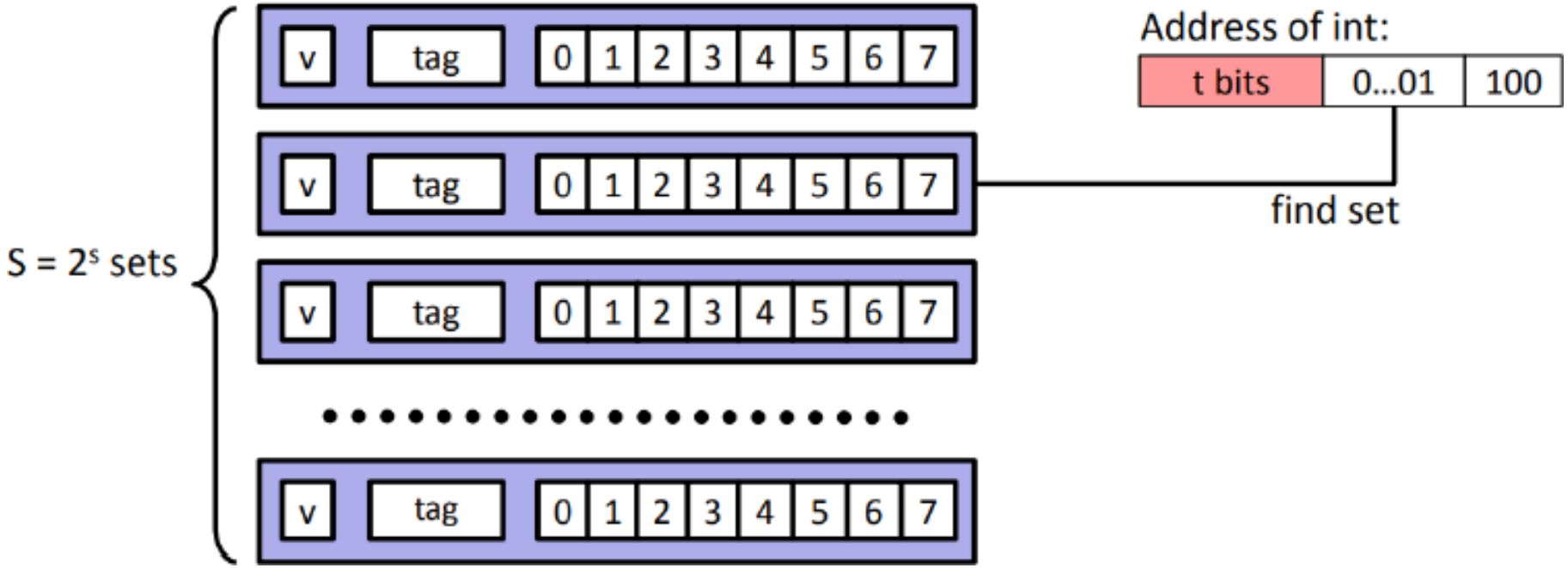
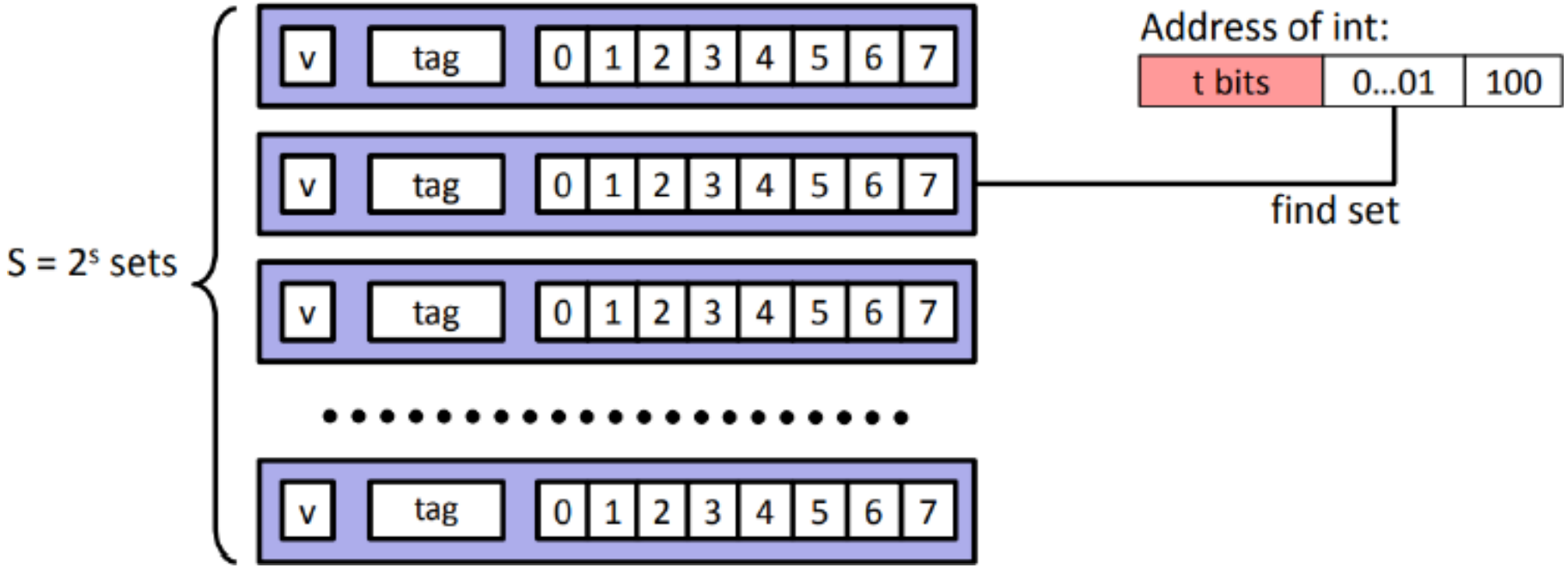
Review Previous Session

- Directed Mapped Cache
  - One line per set



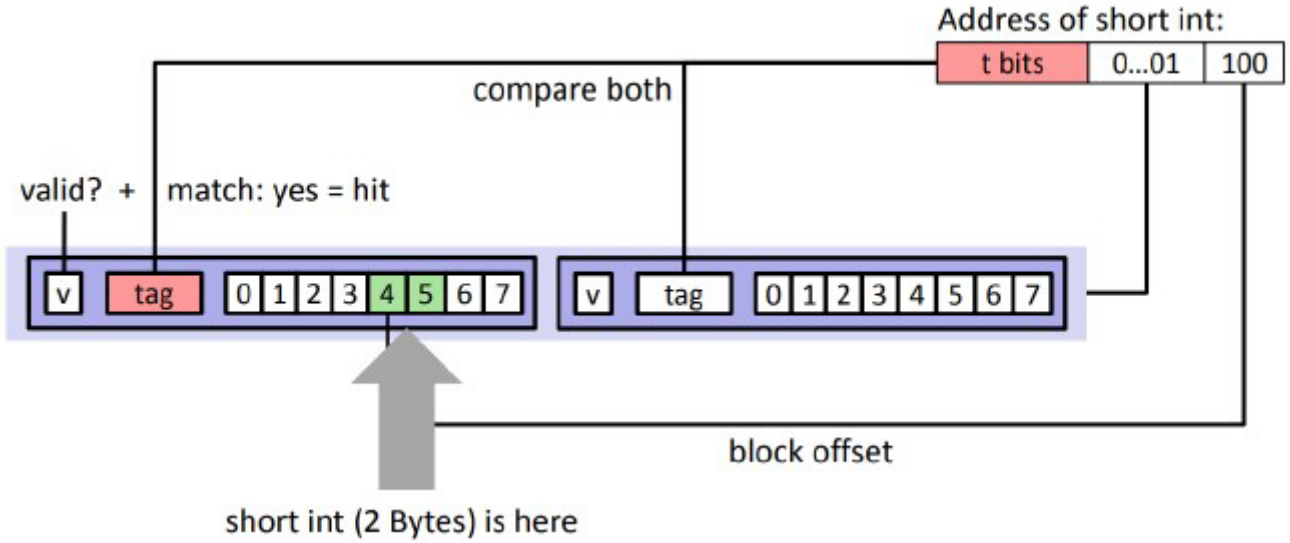
Review Previous Session

- 2-way Set Associative Cache
  - Two lines per set



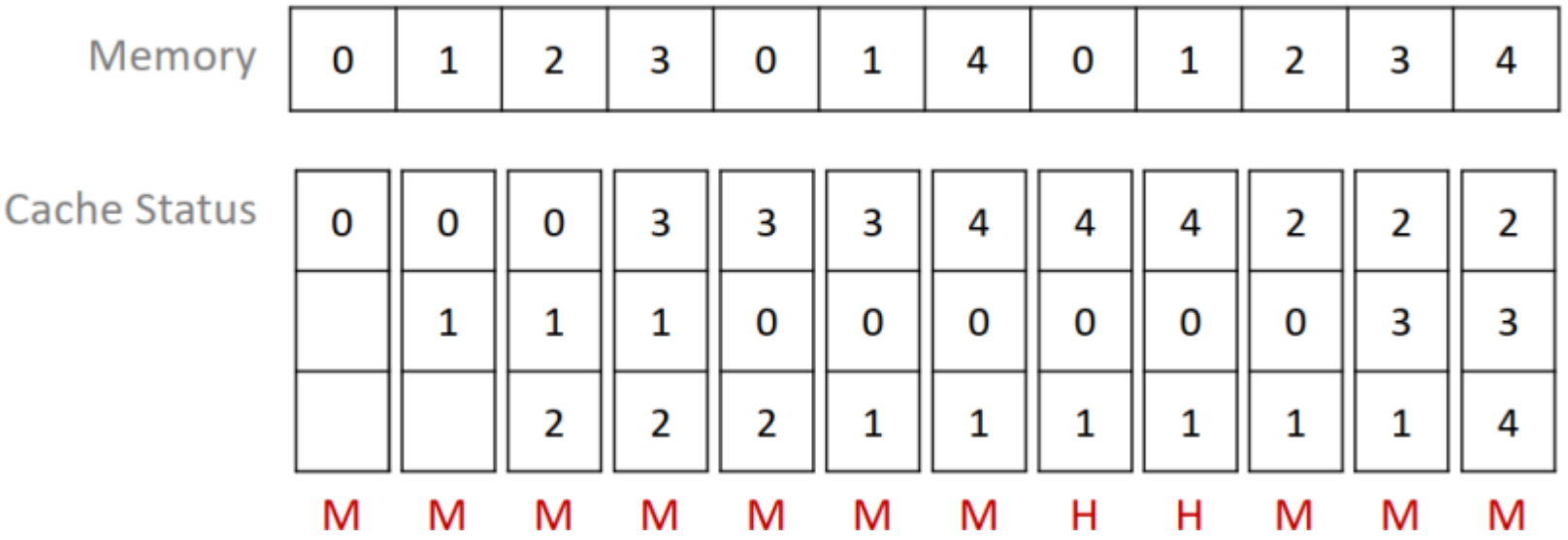
Review Previous Session

- When the cache is full,
  - Directed mapped Cache
    - Old line is evicted and replaced
  - E-way Set Associative Cache
    - One line in set is selected for eviction and replaced
    - Replacement Policy: Least Recently Used (LRU)



Review Previous Session

- Least Recently Used (LRU)
  - Replace the cache block which was used least recently

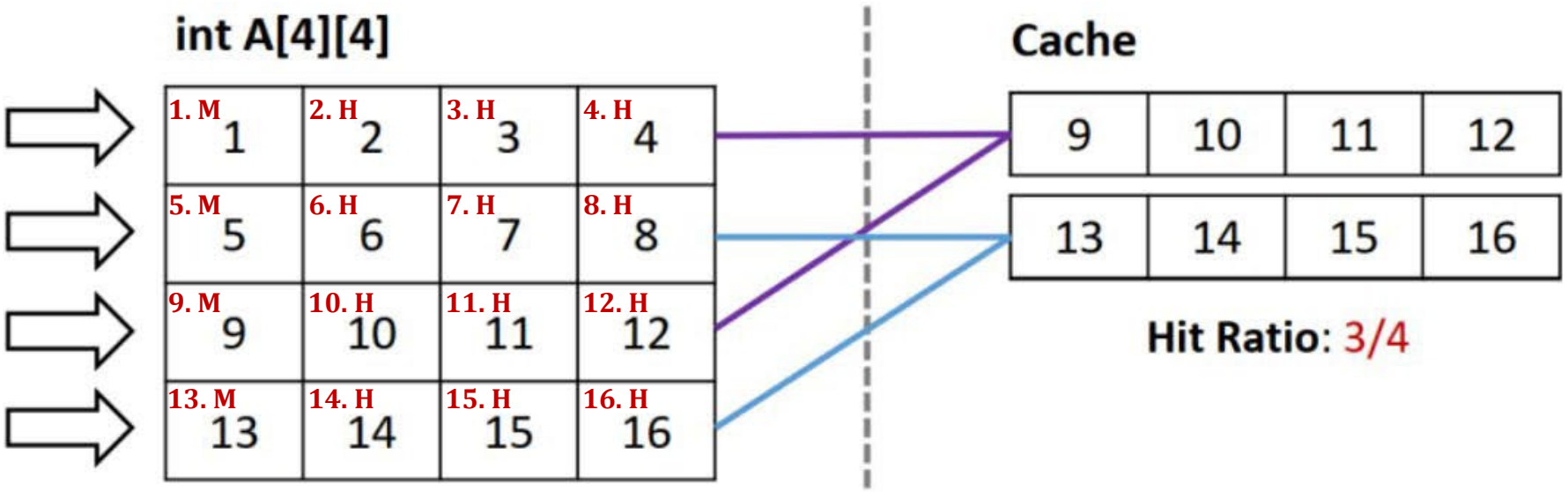


Cache Lab

Part B. Efficient Matrix Transpose

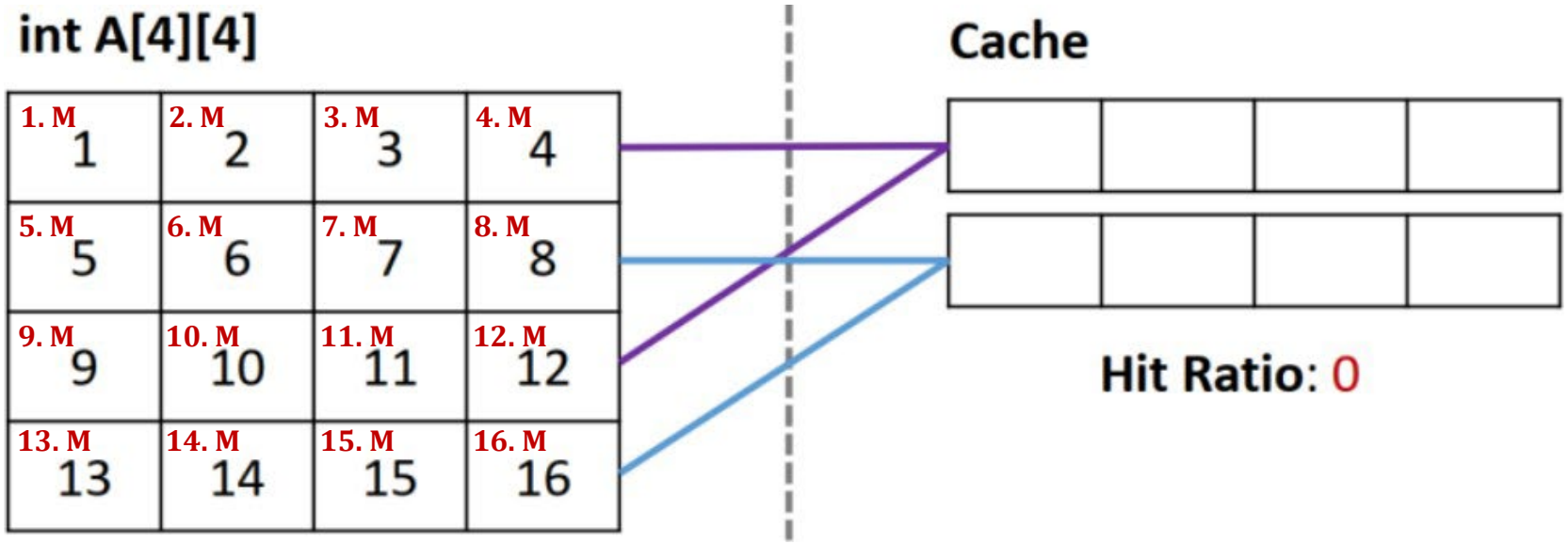
Hit Ratio

- The percentage of accesses that result in cache hits
- e.g.
  - For 32 bytes directed mapped cache with a block size of 16 bytes,
  - Accessing elements in **row-major** order:



Hit Ratio

- The percentage of accesses that result in cache hits
- e.g.
  - For 32 bytes directed mapped cache with a block size of 16 bytes,
  - Accessing elements in **column-major** order:

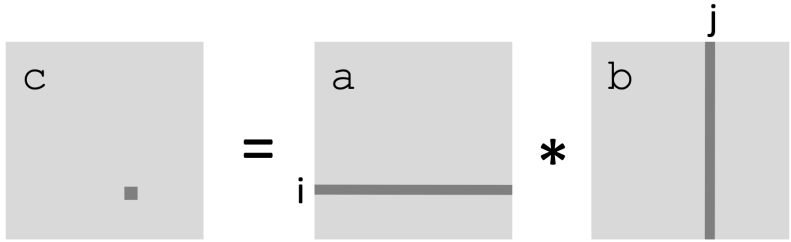


Matrix Multiplication w/o Blocking

- Assume: 1. Matrix elements are doubles
  2. Cache blocks = 8 doubles
  3. Cache size C << n

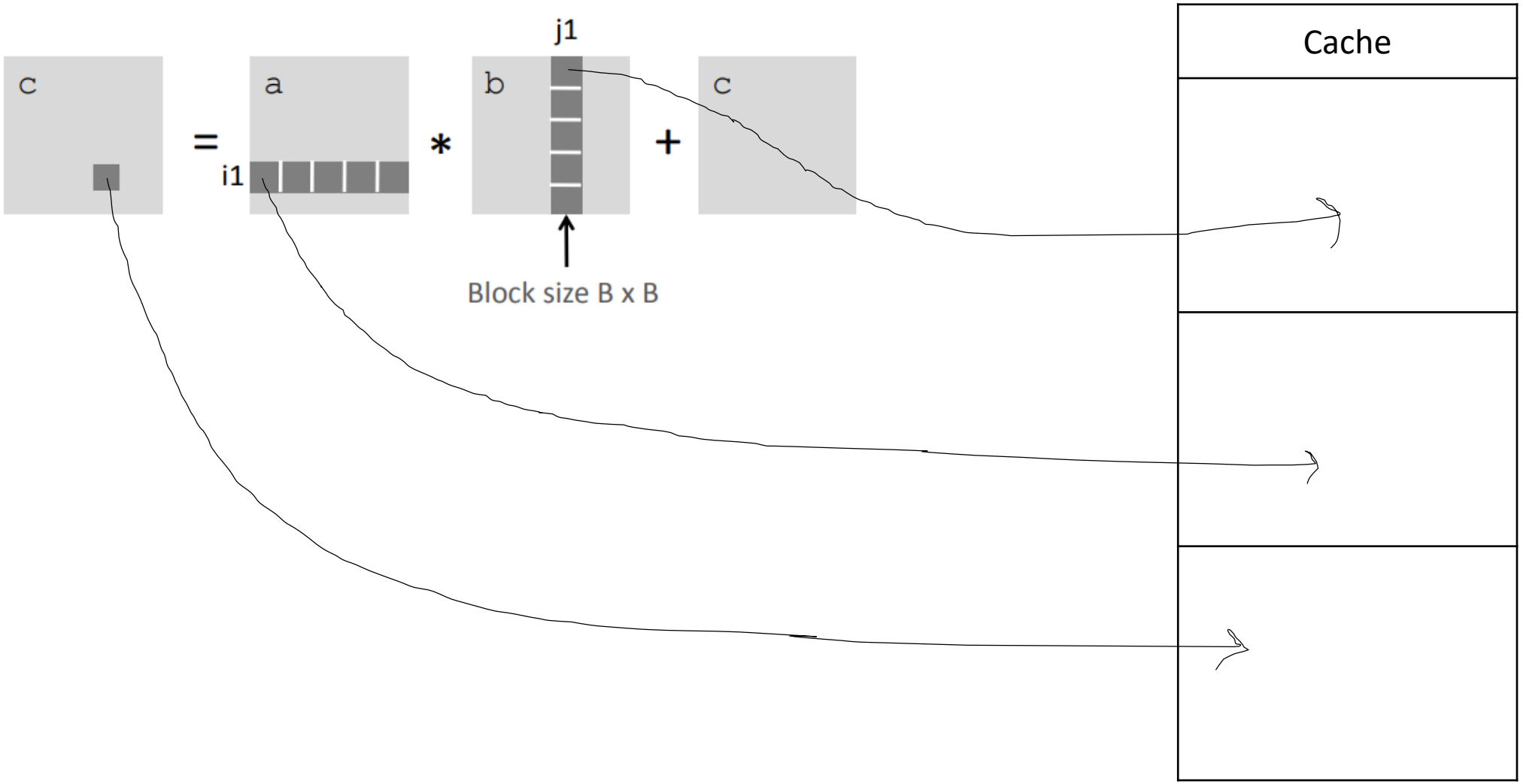
```
c = (double *) calloc(sizeof(double), n * n);

/* Multiply n x n matrices a and b */
void mmm(double *a, double *b, double *c, int n) {
    int i, j, k;
    for (i = 0; i < n; i++) {
        for (j = 0; j < n; j++) {
            for (k = 0; k < n; k++)
                c[i * n + j] += a[i * n + k] * b[k * n + j];
        }
    }
}
```



- # of miss in every inner iteration: $\frac{n}{8} + n = \frac{9n}{8}$
- # of total miss: $\frac{9n}{8} * n^2 = \frac{9n^3}{8}$

Blocking

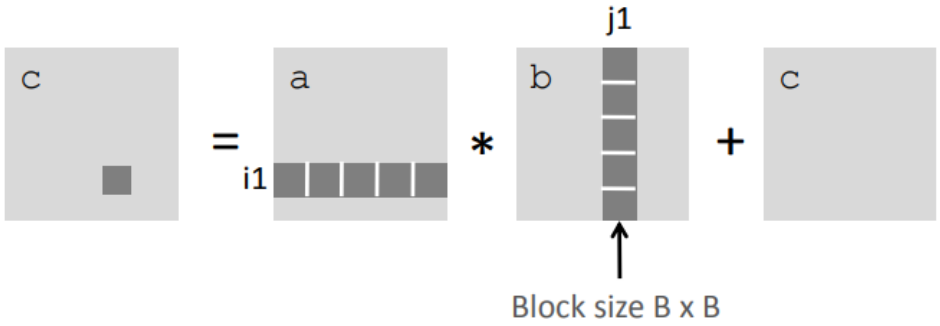


Matrix Multiplication w/ Blocking

- Assume: 1. Matrix elements are doubles 3. Cache size $C \ll n$
  2. Cache blocks = 8 doubles 4. $3B^2 < C$

```
c = (double *) calloc(sizeof(double), n * n);

/* Multiply n x n matrices a and b */
void mmm(double *a, double *b, double *c, int n) {
    int i, j, k, i1, j1, k1;
    for (i = 0; i < n; i += B)
        for (j = 0; j < n; j += B)
            for (k = 0; k < n; k += B)
                /* B x B mini matrix multiplication */
                for (i1 = i; i1 < i + B; i1++)
                    for (j1 = j; j1 < j + B; j1++)
                        for (k1 = k; k1 < k + B; k1++)
                            c[i1 * n + j1] += a[i1 * n + k1] * b[k1 * n + j1];
}
```



- # of miss in every inner iteration: $\frac{B^2}{8} * \frac{2n}{B} = \frac{nB}{4}$
- # of total miss: $\frac{nB}{4} * \left(\frac{n}{B}\right)^2 = \frac{n^3}{4B}$

Blocking Summary

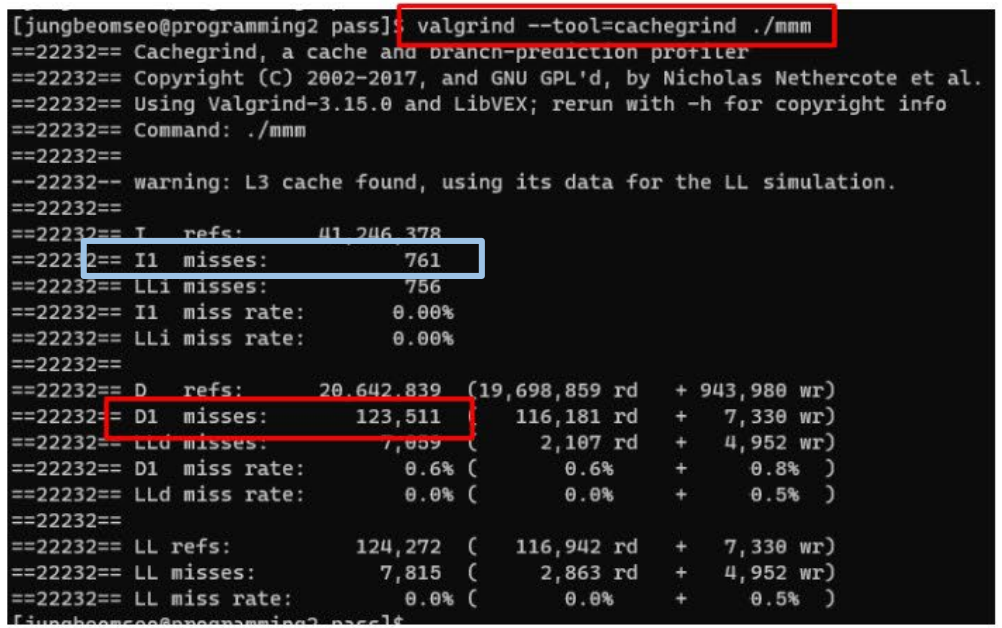
- Matrix multiplication w/o blocking: $\frac{9n^3}{8}$
- Matrix multiplication w/ blocking: $\frac{n^3}{4B}$

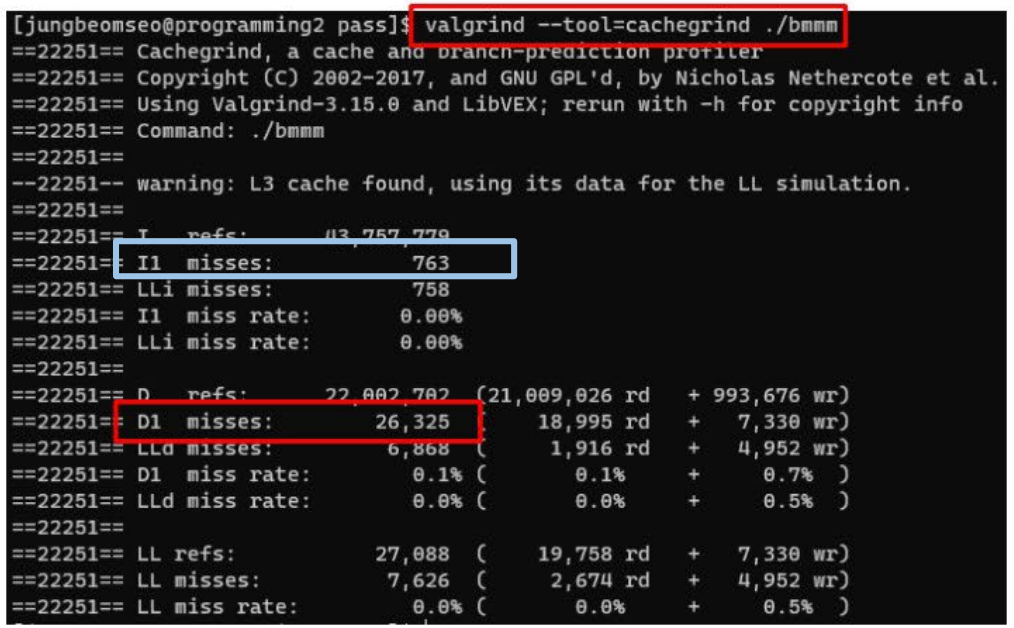
→ Suggest largest possible block size B, but limits $3B^2 < C$!

- For a detailed discussion of blocking:
  http://csapp.cs.cmu.edu/public/waside.html

Cachegrind

- Simulating how your program interacts with a machine's cache hierarchy and branch predictor
- For modern machines that have three or four levels of caches, Cachegrind simulates the first-level and last level caches
  - Instruction Cache: I1, Lli
  - Data Cache: D1, LLd





Homework (Part B)

- Optimize matrix transpose ($A \rightarrow A^T$)
  - Write the efficient code for the highest hit ratio
    (i.e. minimize the cache miss)

- Cache:
  - You get 1 kilobytes of cache
  - Directly mapped (E=1)
  - Block size is 32 bytes (b=5)
  - There are 32 sets (s=5)

- Read **Programming Rules** in **writeup_cachelab.pdf** over and over!

Homework (Report)

- Deadline: 11/27 (Mon) 23:59
- You need to
  - Explain how did you optimize your matrix transpose in the report.
  - For the report, follow the format [student#].pdf
    - For example, 20170354.pdf (No square brackets in the file name).
  - For the code, follow the format [student#].tar
    - For example, 20170354.tar (No square brackets in the file name).
    - Combining Part A(csim.c) and Part B(trans.c) together.
    - **No zip, No tar.gz!**
- You can find more details in writeup_cachelab.pdf

Quiz