Improving DFTL(LRU to 2Q)

2024.08.28

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Motivation

bb.C코드에서 cmt히트 출력하는 부분 발견하여, femu 상에서 사용할 방법 찾아 봄
→ femu 내부에서 opcode, cmd 보내서 출력

```
nvme admin-passthru /dev/nvme0 --opcode=239 --cdw10=9
```

```
/*tpftl*/
if (st->access_cnt == 0) {
    st->cmt_hit_ratio = 0;
} else {
    st->cmt_hit_ratio = (double)st->cmt_hit_cnt / st->access_cnt;
}
// st->joule = st->read_joule + st->write_joule + st->erase_joule;

printf("CMT hit count: %lu\n", st->cmt_hit_cnt);
printf("CMT miss count: %lu\n", st->cmt_miss_cnt);
printf("CMT access count: %lu\n", st->access_cnt);
printf("CMT hit ratio: %lf\n", st->cmt_hit_ratio);
```

Motivation

- **기존의 DFTL cmt히트율**

실험환경: FIO 워크로드 4KB에서 1GB 60초 실행

```
CMT hit count: 40631
CMT miss count: 1422956
CMT access count: 1463587
CMT hit ratio: 0.027761
[FEMU] Log: vSSD0,Statistics print!
```

Fio random r/w 결과

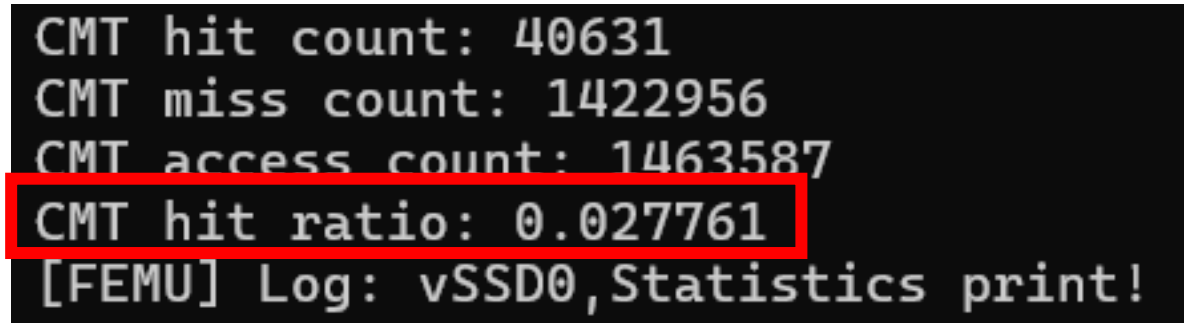
```
CMT hit count: 1265988
CMT miss count: 536411
CMT access count: 1802399
CMT hit ratio: 0.702391
[FEMU] Log: vSSD0,Statistics print!
```

Fio sequential r/w 결과

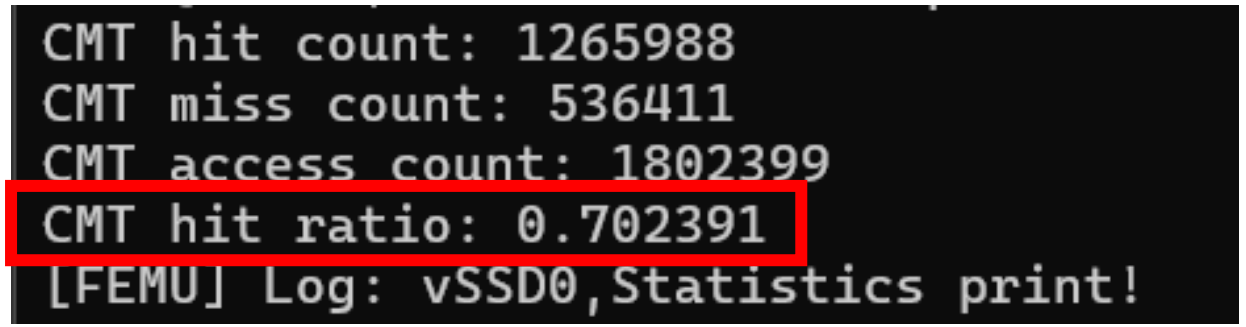
Motivation

- **기존의 DFTL cmt히트율**

실험환경: FIO 워크로드 4KB에서 총 1GB로 60초 실행



Fio random r/w 결과



Fio sequential r/w 결과

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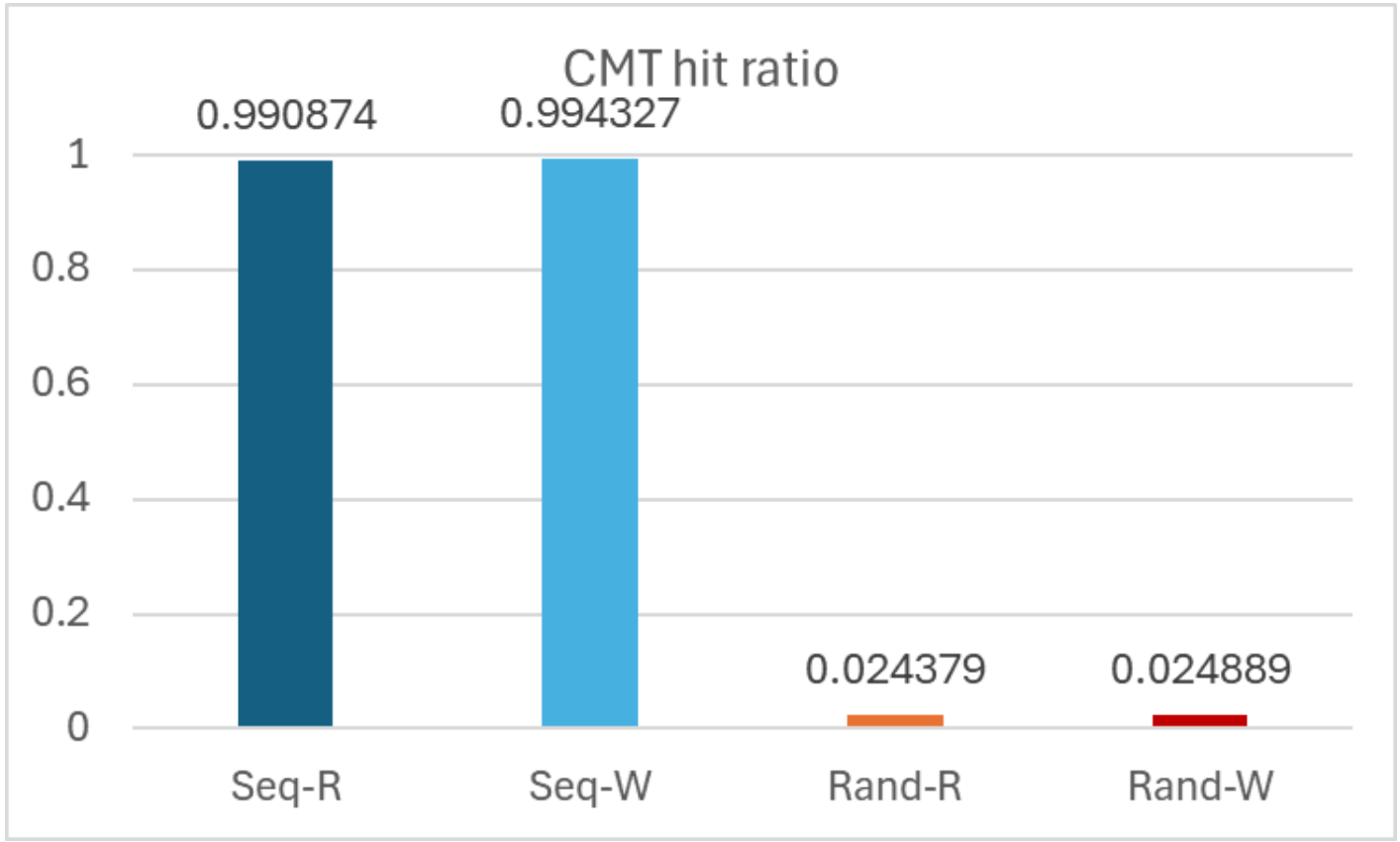
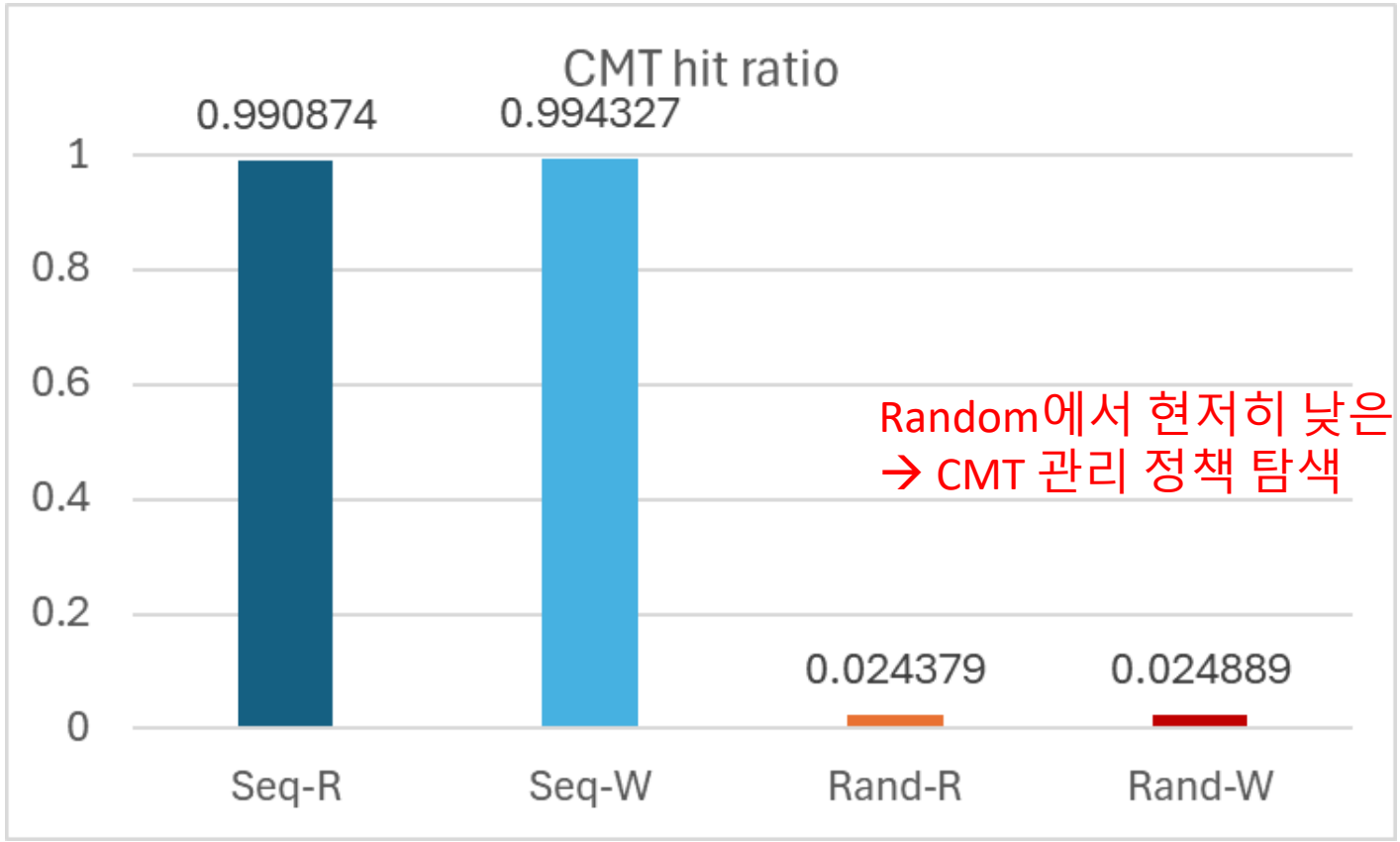
- 기존의 DFTL cmt히트율



Motivation

- 기존의 DFTL cmt히트율

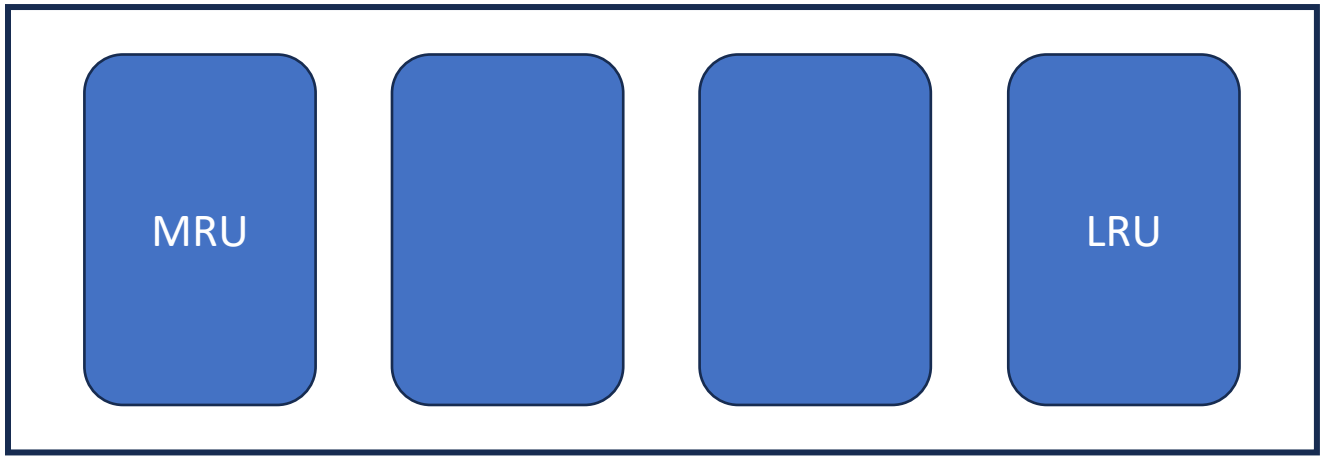


Random에서 현저히 낮은 히트율
→ CMT 관리 정책 탐색

Motivation

- 기존의 DFTL cmt관리 방식 → LRU 알고리즘

LRU_Q

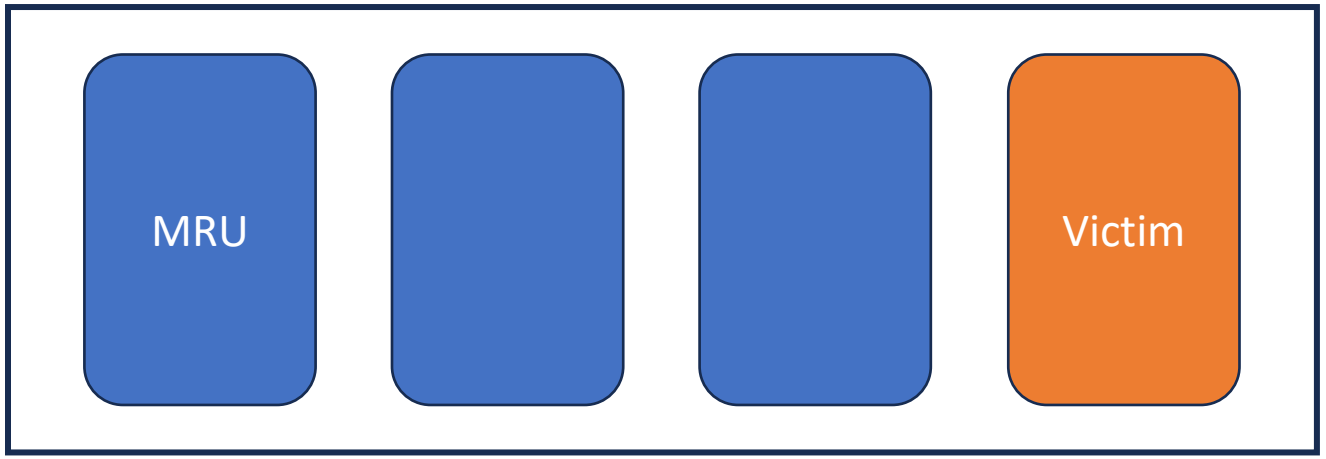


LFU 알고리즘을 함께 적용하면 다양한 워크로드에서 cmt히트율을 높일 수 있을 것이라 생각함

Motivation

- 기존의 DFTL cmt관리 방식 → LRU 알고리즘

LRU_Q



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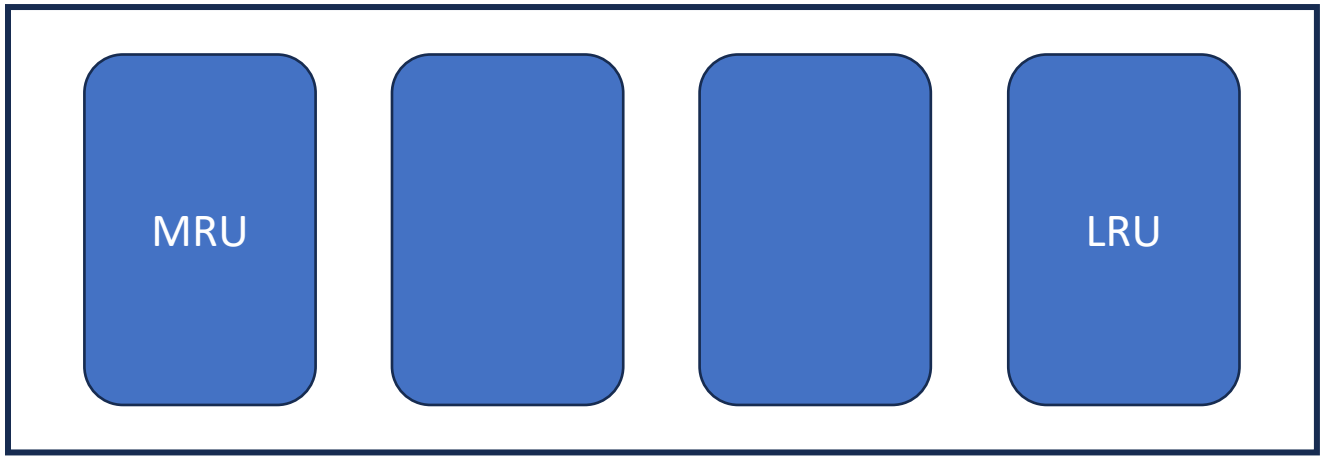
- 기존의 DFTL cmt관리 방식 → LRU 알고리즘

LRU_Q



2Q 알고리즘 적용 시도

LFU 알고리즘을 함께 적용하면 다양한 워크로드에서 cmt히트율을 높일 수 있을 것이라 생각함

Motivation

버퍼 크기가 늘어날 때 2Q에서 더 큰 히트율 향상

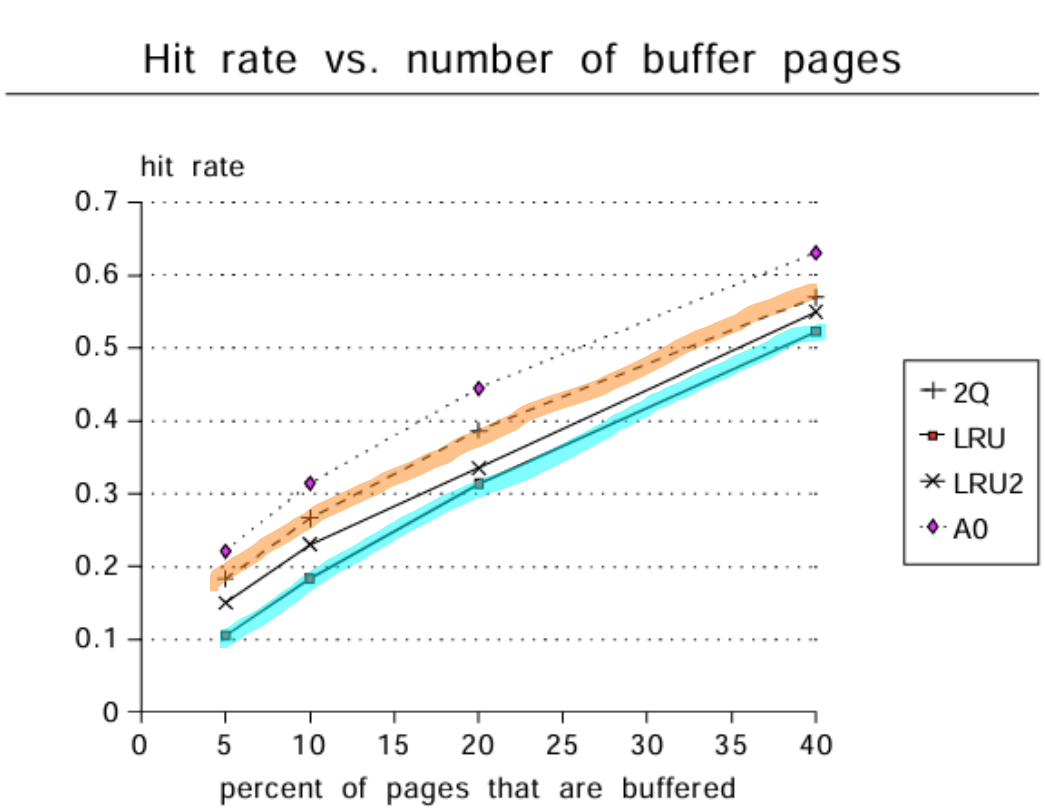


Figure 1: Zipf input comparison with parameter 0.5

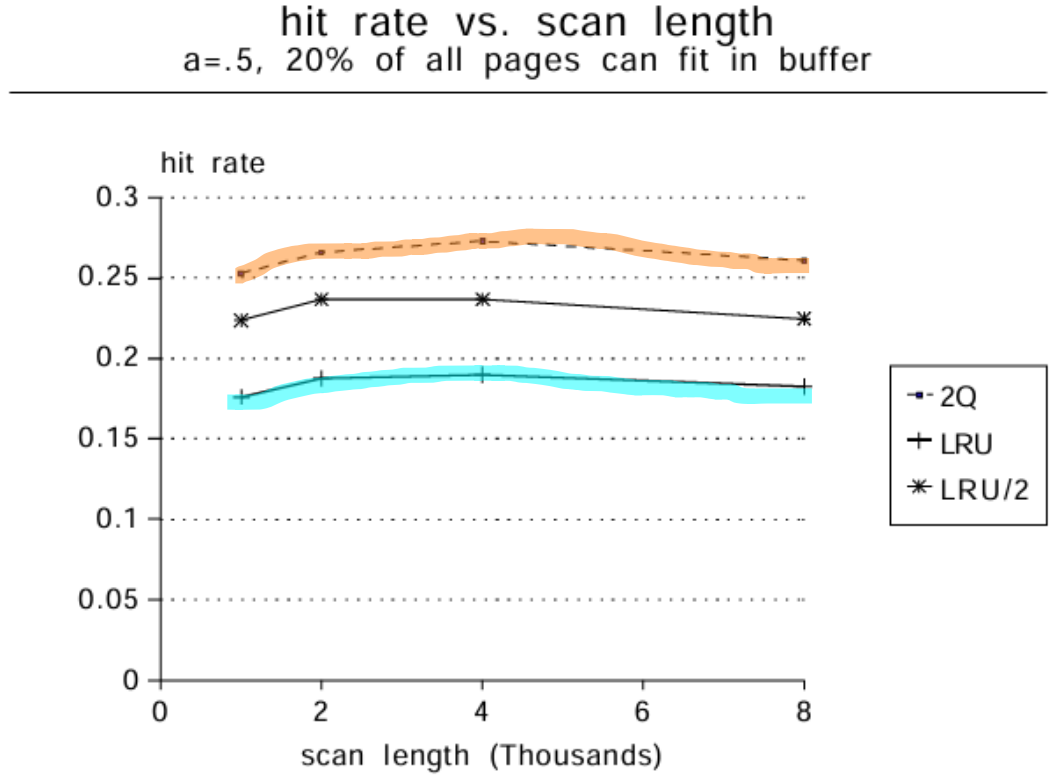


Figure 3: 1/3 Scan Input Mixed with Zipf Input Having Parameter 0.5

Motivation

버퍼 크기가 늘어날 때 2Q에서 더 큰 히트율 향상

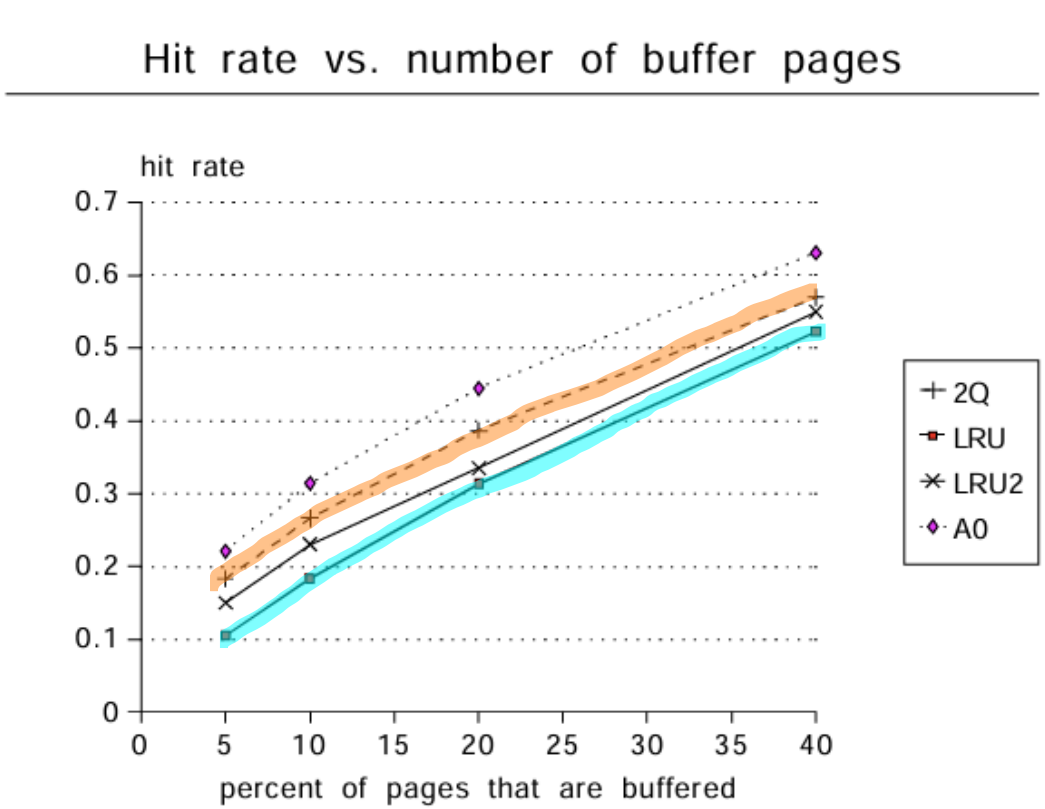


Figure 1: Zipf input comparison with parameter 0.5

Scan 방식 접근: 지나온 것에 다시 접근하지 않기 때문에 최근 entry를 유지하는 LRU는 비효율적

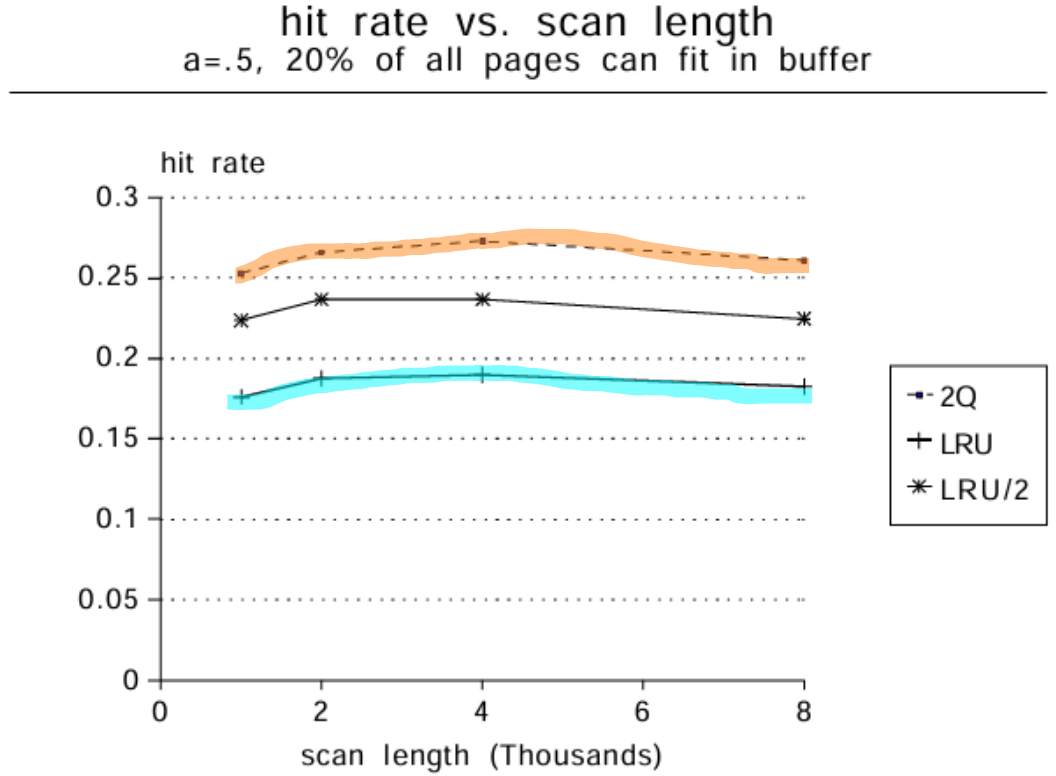
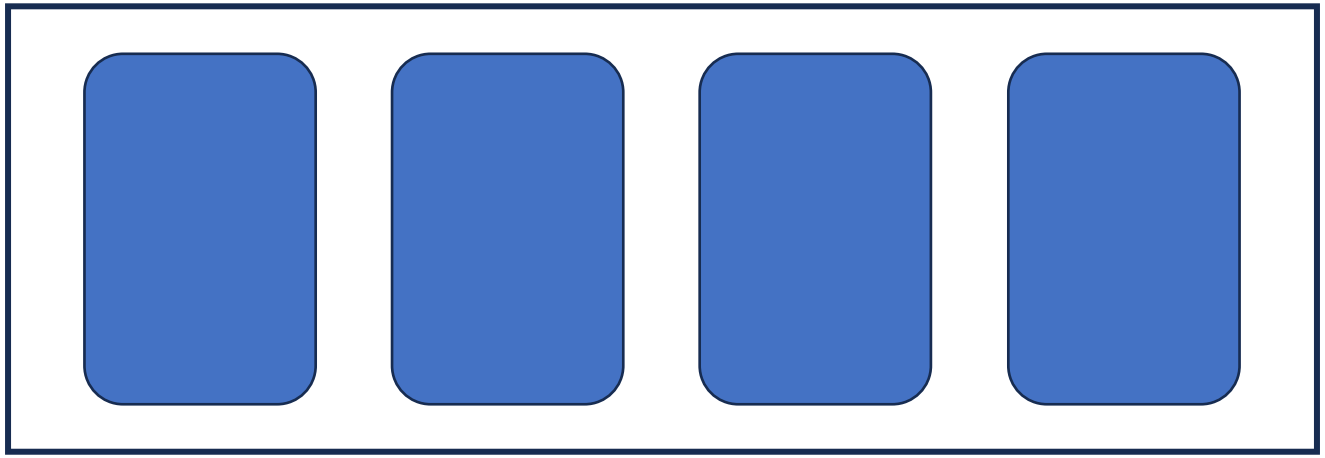


Figure 3: 1/3 Scan Input Mixed with Zipf Input Having Parameter 0.5

Structure

Queue1
(LRU)

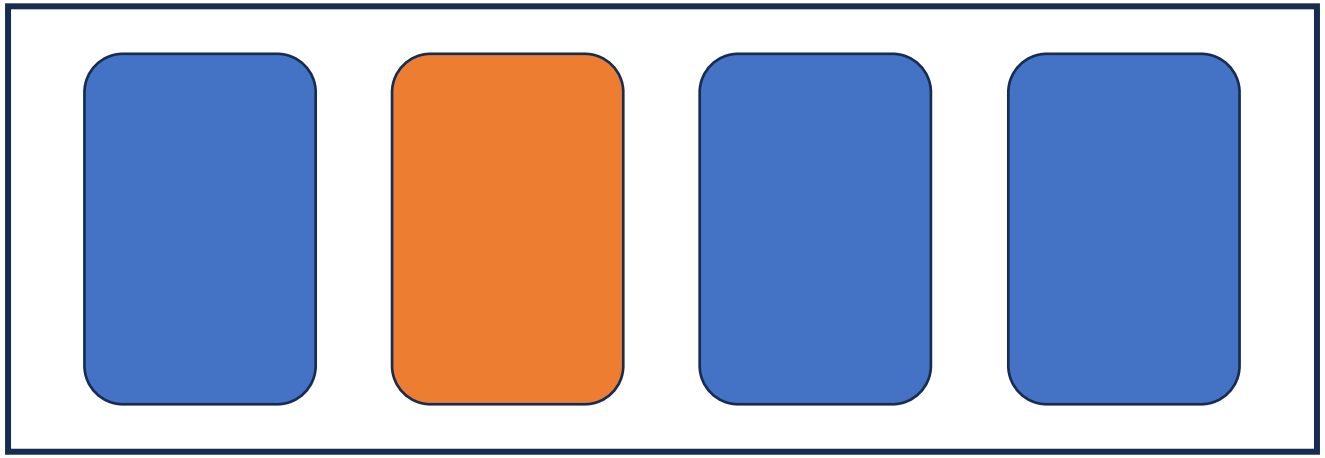


: 최근에 접근한 entry 관리

Queue2
(LFU)

Structure

Queue1
(LRU)



: 최근에 접근한 entry 관리

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Q1에서 다시 접근된 데이터는
Q2로 이동

Structure

Queue1
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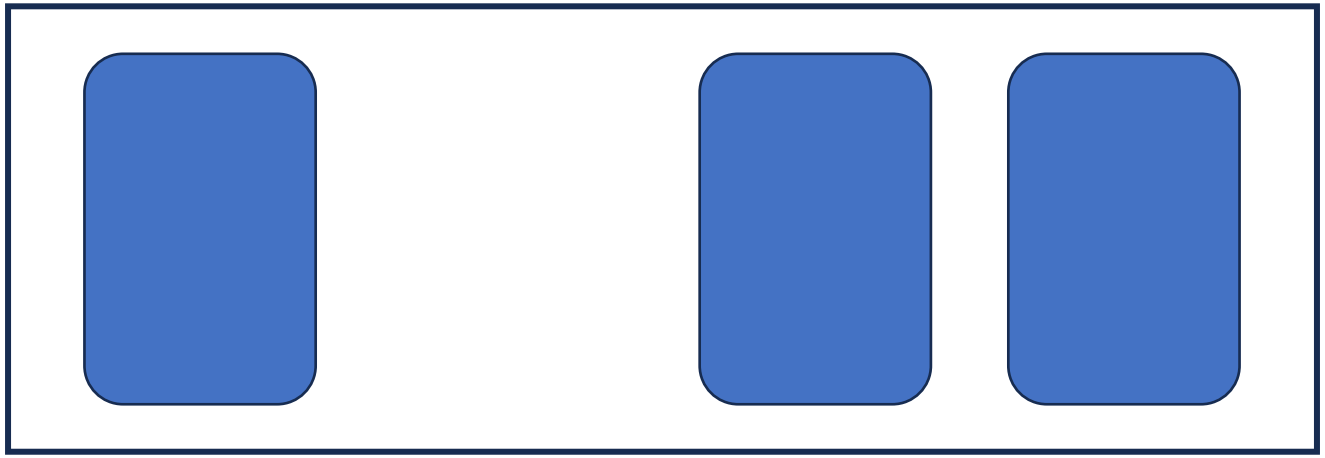

: 최근에 접근한 entry 관리

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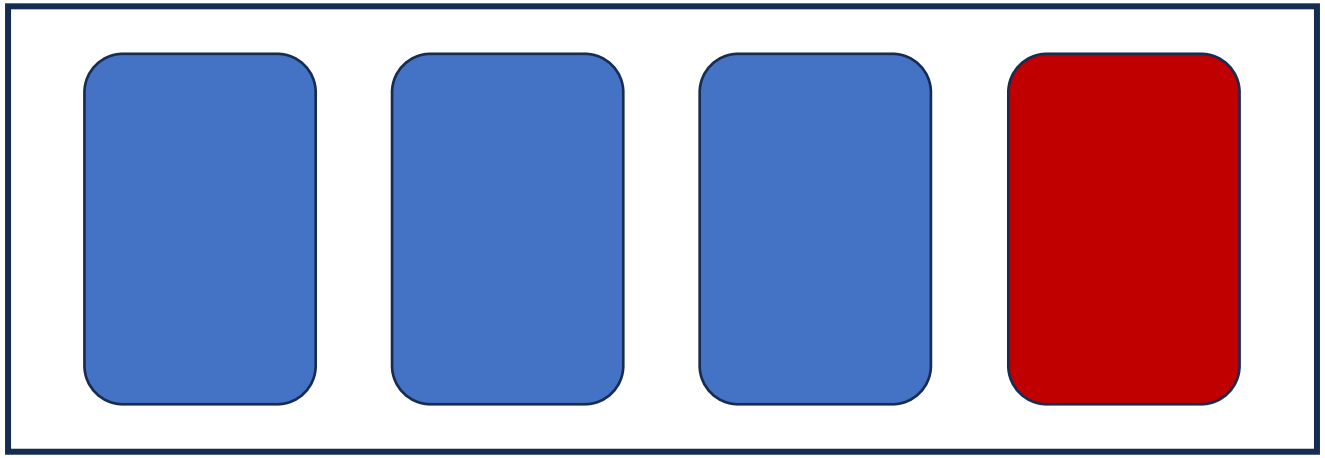
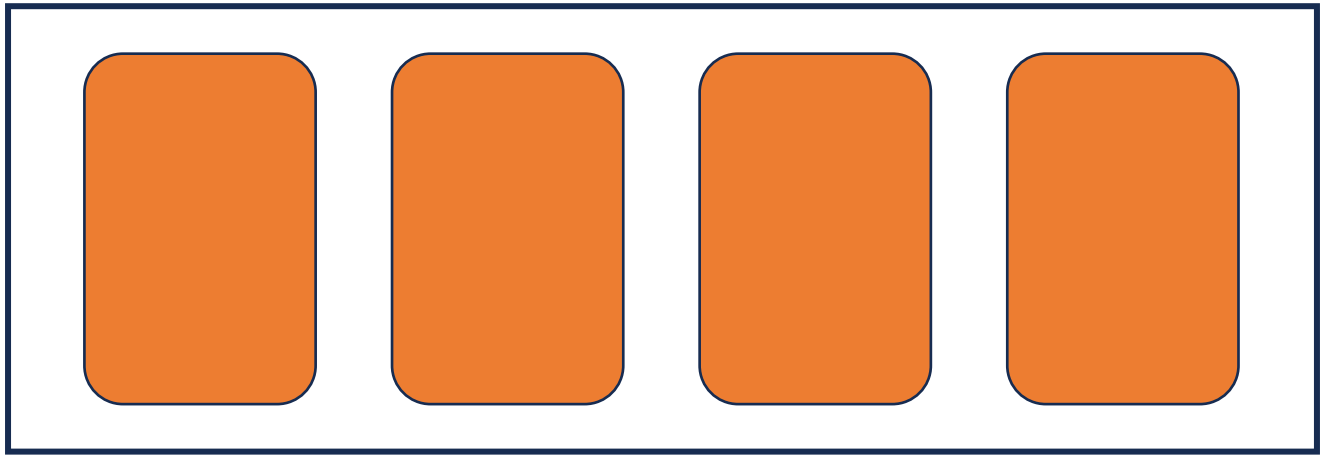


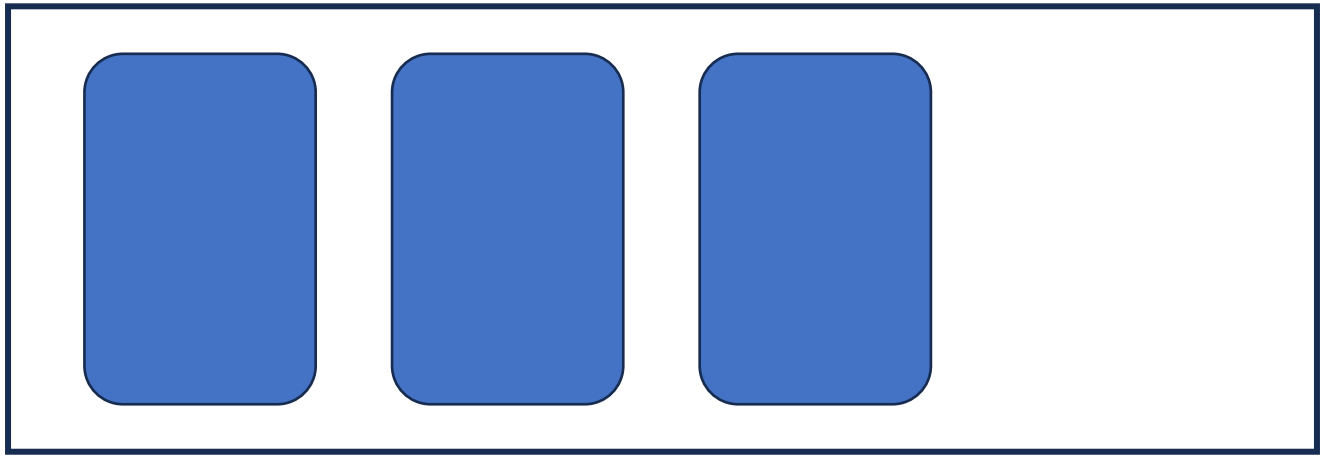
Queue2
(LFU)



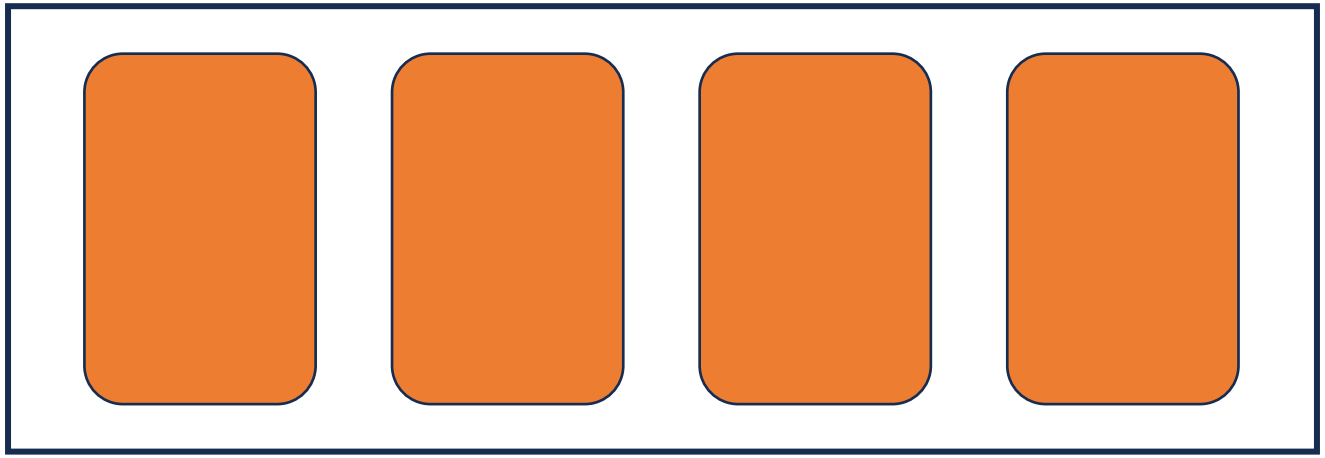
Entry evict시 Q1 우선 선택
(자주 접근한 데이터 유지)

Structure

Queue1
(LRU)



Queue2
(LFU)



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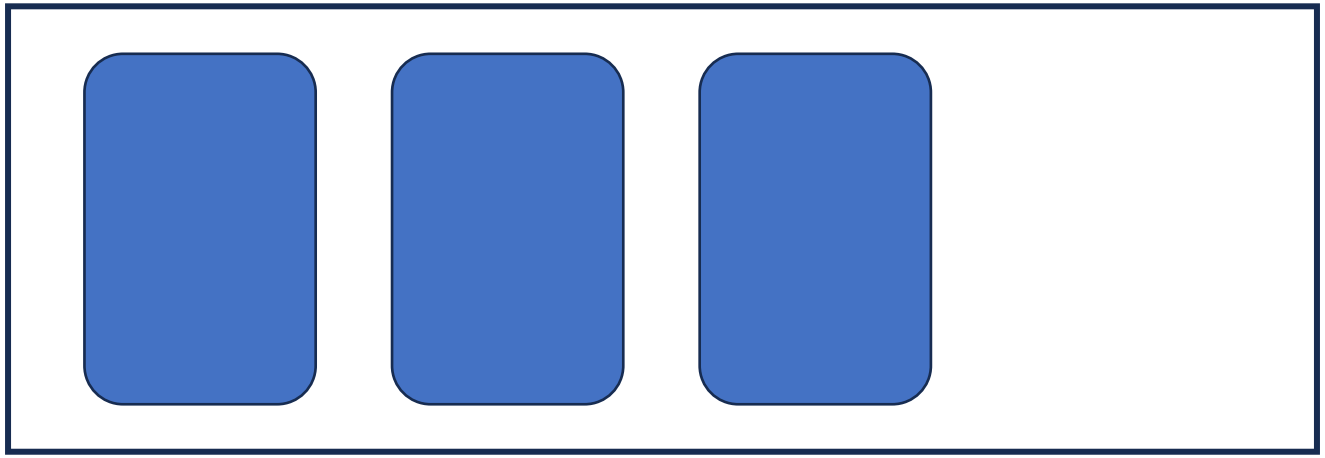

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Queue2
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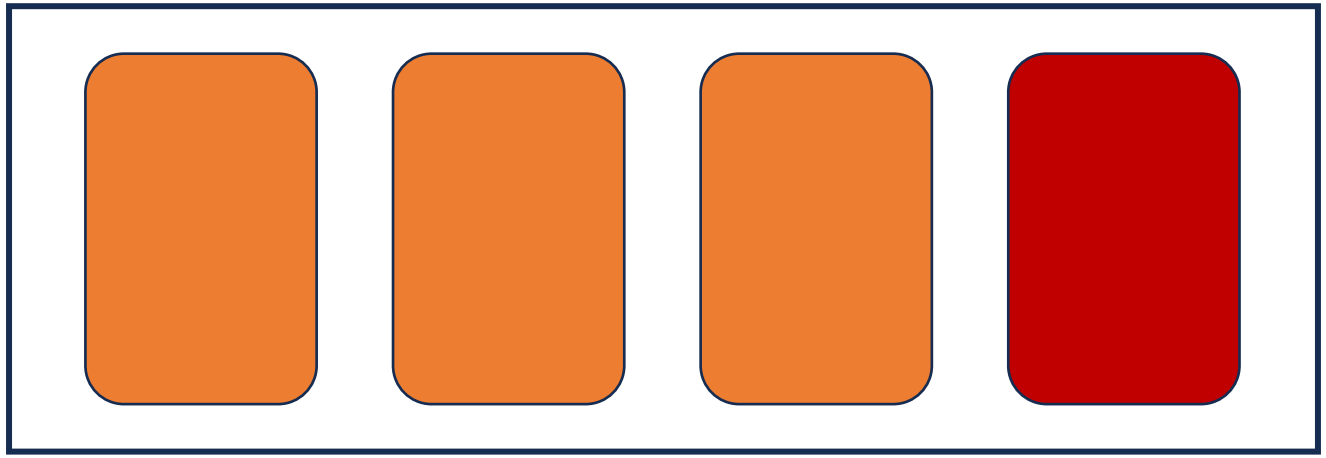
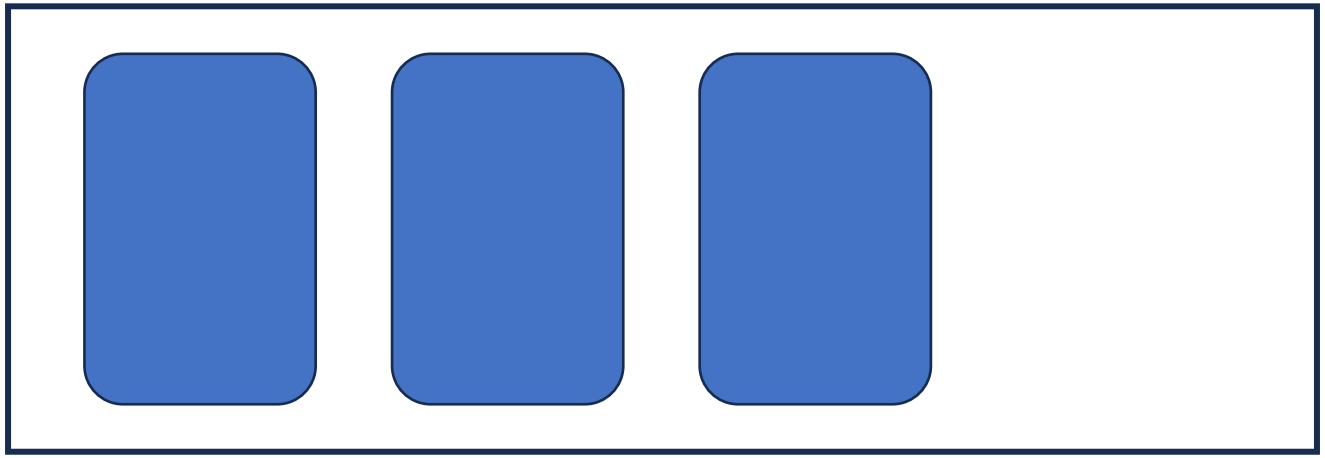


Q2 꽉 차면 LRU 방식으로 제거

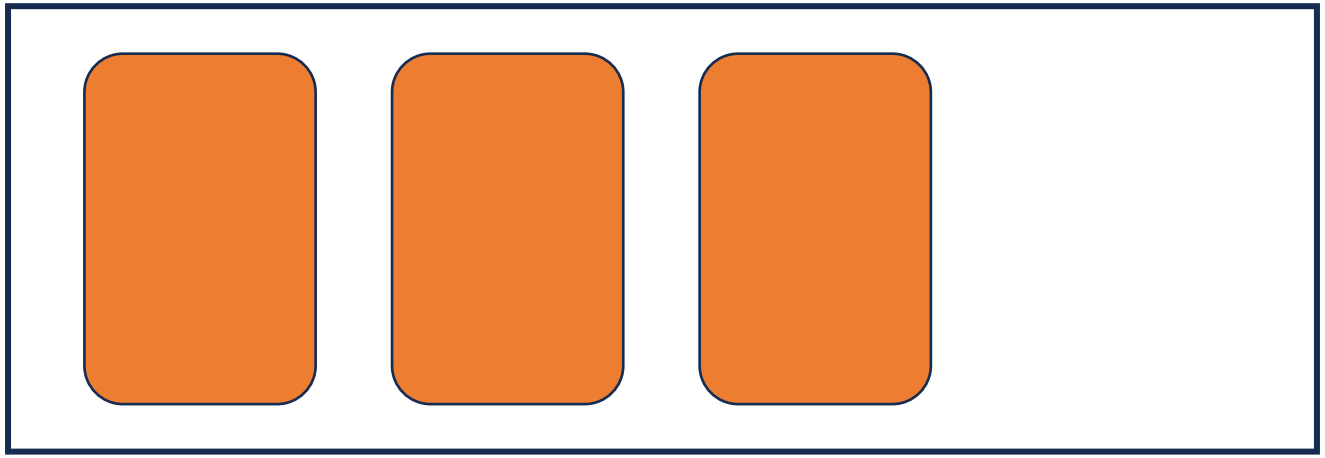
Structure

Queue1
(LRU)



Entry evict시 Q1 우선 선택
(자주 접근한 데이터 유지)

Queue2
(LFU)



Q2 꽉 차면 LRU 방식으로 제거

Structure

Queue1
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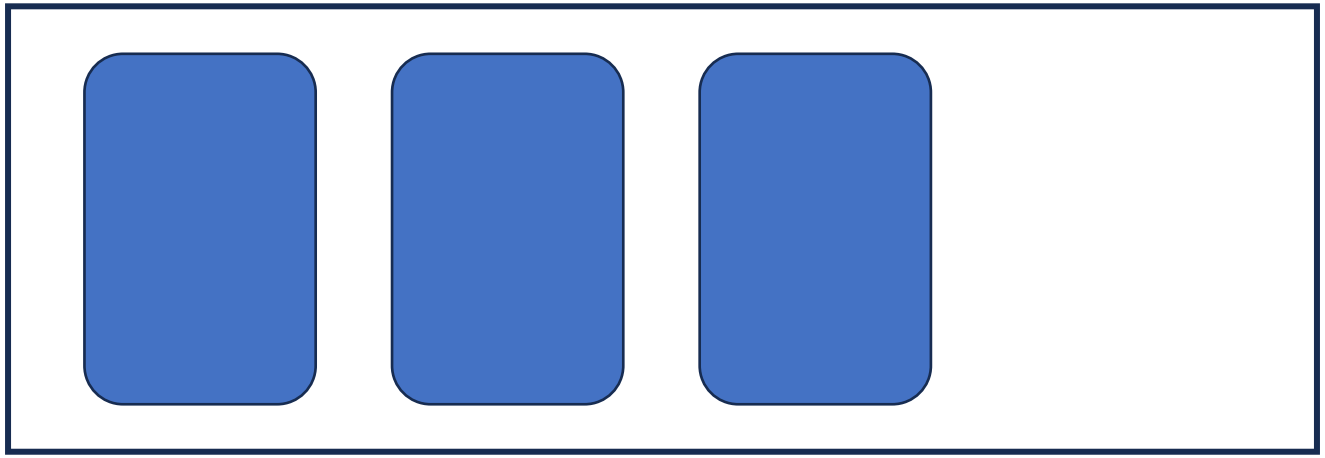
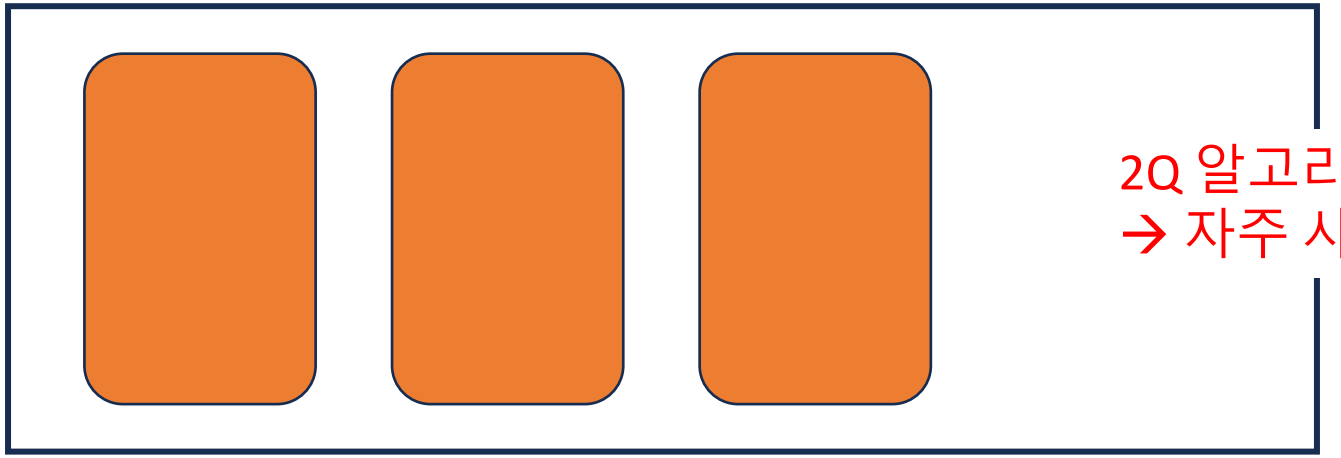


Queue2
(LFU)



2Q 알고리즘
→ 자주 사용하는 entry를 cmt에 더 유지시킴

Code

cmt_mgmt: 구조체에 Q1, 2 추가

```
struct cmt_mgmt {
    struct cmt_entry *cmt_entries;
    struct hash_table ht;
    QTAILQ_HEAD(, cmt_entry) free_cmt_entry_list;
    QTAILQ_HEAD(, cmt_entry) A1_list;
    QTAILQ_HEAD(, cmt_entry) Am_list;
    QTAILQ_HEAD(, TPnode) TPnode_list;
    uint64_t tt_entries;
    uint64_t tt_TPnodes;
    int free_cmt_entry_cnt;
    int used_cmt_entry_cnt;
    int counter;
};
```

cmt_entry: 구조체에 frequency 추가

```
typedef struct cmt_entry {
    uint64_t lpn;
    uint64_t ppn;
    int dirty;
    // int hotness;
    QTAILQ_ENTRY(cmt_entry) entry;
    bool prefetch;
    uint64_t next_avail_time;
    struct cmt_entry *next;     /* for hash */
    int frequency;  // LFU에 사용
    time_t last_access_time;  // LRU에 사용
} cmt_entry;
```

Code

Insert_entry_to_cmt함수: 먼저 Q1에 넣음

```
QTAILQ_INSERT_HEAD(&cm->A1_list, cmt_entry, entry);
```

Evict_entry_from_cmt함수: Q1 마지막에 엔트리 없으면 Q2의 마지막에서 선택함

```
cmt_entry = QTAILQ_LAST(&cm->A1_list);
if (cmt_entry == NULL) {
    cmt_entry = QTAILQ_LAST(&cm->Am_list);
}
if (cmt_entry == NULL) {
    ftl_err("no entry to evict");
}
```

Code

*cmt_hit: Q1에서 히트 시 Q2로 옮김

```
if (cmt_entry != NULL) {
    if (QTAILQ_FIRST(&curTP->cmt_entry_list) != cmt_entry) {
        QTAILQ_REMOVE(&curTP->cmt_entry_list, cmt_entry, entry);
        QTAILQ_INSERT_HEAD(&curTP->cmt_entry_list, cmt_entry, entry);
    }
    QTAILQ_REMOVE(&cm->A1_list, cmt_entry, entry);
    QTAILQ_INSERT_TAIL(&cm->Am_list, cmt_entry, entry);
}

return cmt_entry;
```

Code

*cmt_hit: Q1에서 히트 시 Q2로 옮김

```
if (cmt_entry != NULL) {
    if (QTAILQ_FIRST(&curTP->cmt_entry_list) != cmt_entry) {
        QTAILQ_REMOVE(&curTP->cmt_entry_list, cmt_entry, entry);
        QTAILQ_INSERT_HEAD(&curTP->cmt_entry_list, cmt_entry, entry);
    }
    QTAILQ_REMOVE(&cm->A1_list, cmt_entry, entry);
    QTAILQ_INSERT_TAIL(&cm->Am_list, cmt_entry, entry);
}

return cmt_entry;
```

- 구현 문제로 인한 segmentation falut 발생

Plan

- 코드 문제 해결하여 cmt히트 측정
- 실시간 random/sequential 워크로드 판단 알고리즘 탐색
  - Markov-based technique(전이 확률 기반)
  - Dynamic Time Warping(이상 감지 기법)
  - 가중 표준 편차 사용한 변화 감지
- Random 처리하는 방법 구상

Thank you!
Q & A ?

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