

# 임베디드시스템설계 lab5

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## 1. 코드 설명

```
void ftl_read(u32 lba, u32 num_sectors, u32 *read_buffer)
{
    u32 spare;
    u32 read_buffer_sep[SECTORS_PER_PAGE];
    u32 num_sectors_to_read = 0;
    u32 sect_offset = lba % SECTORS_PER_PAGE;
    u32 lpn = lba/SECTORS_PER_PAGE;
    u32 sectors_remain = num_sectors;

    int i, j;
    while(sectors_remain != 0) {
        memset(read_buffer_sep, 0, DATA_SIZE);
        if (sect_offset + sectors_remain < SECTORS_PER_PAGE) {
            num_sectors_to_read = sectors_remain;
        }
        else {
            num_sectors_to_read = SECTORS_PER_PAGE - sect_offset;
        }
        for(i=0; i<N_BANKS; i++) {
            if(lpn % N_BANKS == i) {
                if(bitmapval[lpntable[lpn/N_BANKS][i]][i] == 0)          printf("no data\n");
                else if(bitmapval[lpntable[lpn/N_BANKS][i]][i] == 1)      printf("invalid data\n");
                else if(bitmapval[lpntable[lpn/N_BANKS][i]][i] == 2) {
                    nand_read(i, lpntable[lpn/N_BANKS][i] / PAGES_PER_BLK, lpntable[lpn/N_BANKS][i] % PAGES_PER_BLK, read_buffer_sep, &spare);
                }
            }
        }

        for(j=0; j<num_sectors_to_read; j++)    read_buffer[num_sectors - sectors_remain + j] = read_buffer_sep[j] + sect_offset;
        sect_offset = 0;
        sectors_remain -= num_sectors_to_read;
        lpn++;
    }
    return;
}
```

Ftl\_read 에서 읽는 sector 의 개수가 SECTORS\_PER\_PAGE 의 개수를 넘어갈 수 있으므로 while 을 돌면서 offset 이 있을 경우 띄어서 읽고 없는 경우 나머지를 읽던지 SECTORS\_PER\_PAGE 의 개수만큼 읽었다. 이 때 읽은 값은 read\_buffer\_sep 에 저장되고 최종적으로 read\_buffer 에 값을 붙여줘서 read\_buffer 의 값(실질적인 return 값)을 반환시켰다.

```
////////////////////////////////////
void ftl_write(u32 lba, u32 num_sectors, u32 *write_buffer)
{
    int i, j, r, k;
    u32 spare;
    u32 num_sectors_to_read;
    u32 lpn = lba / SECTORS_PER_PAGE;
    u32 sect_offset = lba % SECTORS_PER_PAGE;
    u32 sectors_remain = num_sectors;
    u32 write_buffer_sep[SECTORS_PER_PAGE];
    memset(write_buffer_sep, 0, DATA_SIZE);
    u32 read_buffer[SECTORS_PER_PAGE];
    memset(read_buffer, 0, DATA_SIZE);

    while (sectors_remain != 0)
    {
        //printf("lba : %d\n", lba);
        //printf("num_sectors : %d\n", num_sectors);
        //printf("remain sectors : %d\n", sectors_remain);
        if(sect_offset + sectors_remain < SECTORS_PER_PAGE)
        {
            num_sectors_to_read = sectors_remain;
            //printf("read_sector: %d\n", num_sectors_to_read);
        }
        else
        {
            num_sectors_to_read = SECTORS_PER_PAGE - sect_offset;
            //printf("read_sector: %d\n", num_sectors_to_read);
        }

        for(k = 0; k < num_sectors_to_read; k++) {
            //printf("%x\n", write_buffer[num_sectors - sectors_remain + k]);
            write_buffer_sep[k + sect_offset] = write_buffer[num_sectors - sectors_remain + k];
        }

        //printf("복제나옴\n");

        for(r=0; r<N_BANKS; r++) {
            if(lpn % N_BANKS == r) {
                //FREE BLOCK CHECK
                for(j=0; j < BLKS_PER_BANK; j++) {
                    if(j != fblk[r]) {
                        if(bitmapval[( (j+1) * PAGES_PER_BLK) - 1][r] == 0)    break;
                    }
                }
            }
        }
    }
}
```

Ftl\_write 에서 write\_buffer\_sep 을 두어 write\_buffer 를 각 페이지에서 읽을 양을 분할해서 넣어주었다.

```

for(r=0;r<N_BANKS;r++) {
    if(lpnr % N_BANKS == r) {
        //FREE BLOCK CHECK
        for(j=0; j < BLKS_PER_BANK; j++) {
            if(j != fblk[r]) {
                if(bitmapval[( (j+1) * PAGES_PER_BLK) - 1][r] == 0) break;
            }
        }
        if(j == BLKS_PER_BANK) garbage_collection(r);

        //SAME LPN
        if(lpntable[lpnr/N_BANKS][r] != -1) {
            bitmap[lpntable[lpnr/N_BANKS][r] / PAGES_PER_BLK][r] = s.ftl_write + s.gc_write;
            bitmapval[lpntable[lpnr/N_BANKS][r]][r] = 1;
            validpage[lpntable[lpnr/N_BANKS][r]/PAGES_PER_BLK][r]--;

            nand_read(r, lpntable[lpnr/N_BANKS][r] / PAGES_PER_BLK, lpntable[lpnr/N_BANKS][r] % PAGES_PER_BLK, read_buffer, &spare);
            for(k = 0; k < sect_offset; k++) write_buffer_sep[k] = read_buffer[k];
            for(k = sect_offset + num_sectors_to_read; k < SECTORS_PER_PAGE; k++) write_buffer_sep[k] = read_buffer[k];
        }

        //NO DATA
        for(i=0; i < BLKS_PER_BANK * PAGES_PER_BLK; i++) {
            if((i/PAGES_PER_BLK) != fblk[r]) {
                if(bitmapval[i][r] == 0) break;
            }
        }
        if(i == BLKS_PER_BANK * PAGES_PER_BLK) return;

        lpntable[lpnr/N_BANKS][r] = i;
        validpage[i / PAGES_PER_BLK][r]++;
        bitmapval[i][r] = 2;
        nand_write(r, i / PAGES_PER_BLK, i % PAGES_PER_BLK, write_buffer_sep, lpnr);
        s.ftl_write = s.ftl_write + SECTORS_PER_PAGE;
    }
}

memset(read_buffer, 0, DATA_SIZE);
memset(write_buffer_sep, 0, DATA_SIZE);
sect_offset = 0;
sectors_remain -= num_sectors_to_read;

```

Write 도 마찬가지로 sector 의 개수가 SECTORS\_PER\_PAGE 의 개수를 넘어갈 수 있으므로 while 을 돌면서 offset 이 있을 경우 띄어서 읽고 없는 경우 나머지를 읽던지 SECTORS\_PER\_PAGE 의 개수만큼 읽었다. 만약 lpntable 에 값이 존재하고 valid 할 경우에는 read 를 하여 값을 확인한 후 앞에서 write\_buffer\_sep 에서 쓴 부분을 제외한 곳에 넣어주었다. 그후 nand\_write 를 해주고 s.ftl\_write 에 SECTORS\_PER\_PAGE 를 더하였다.

## 2. WAF

- Random greedy

```
Bank: 2
Blocks / Bank: 32 blocks
Pages / Block: 32 pages
OP ratio: 7%
Physical Blocks: 64
User Blocks: 56
OP Blocks: 8
PPNs: 2048
LPNs: 1792
Workload: Random
FTL: Greedy policy
Max Sectors: 32

[Run 1] host 29505, ftl 42040, valid page copy 4441, GC# 241, WAF 2.63
[Run 2] host 58945, ftl 83952, valid page copy 21312, GC# 932, WAF 4.32
[Run 3] host 88378, ftl 126024, valid page copy 41078, GC# 1714, WAF 5.14
[Run 4] host 118058, ftl 168224, valid page copy 60633, GC# 2490, WAF 5.53
[Run 5] host 147609, ftl 210072, valid page copy 80393, GC# 3271, WAF 5.78
[Run 6] host 176615, ftl 251544, valid page copy 99780, GC# 4039, WAF 5.94
[Run 7] host 206005, ftl 293704, valid page copy 119539, GC# 4821, WAF 6.07
[Run 8] host 235649, ftl 335920, valid page copy 139381, GC# 5606, WAF 6.16
[Run 9] host 265513, ftl 378256, valid page copy 159337, GC# 6395, WAF 6.23
[Run 10] host 295240, ftl 420568, valid page copy 179100, GC# 7178, WAF 6.28
[Run 11] host 324989, ftl 462912, valid page copy 198929, GC# 7963, WAF 6.32
[Run 12] host 354668, ftl 505184, valid page copy 218703, GC# 8746, WAF 6.36
[Run 13] host 384690, ftl 547552, valid page copy 238463, GC# 9529, WAF 6.38
[Run 14] host 414532, ftl 589728, valid page copy 258087, GC# 10307, WAF 6.40
[Run 15] host 443878, ftl 631792, valid page copy 278044, GC# 11095, WAF 6.43
[Run 16] host 473817, ftl 674272, valid page copy 298016, GC# 11885, WAF 6.45
[Run 17] host 503411, ftl 716528, valid page copy 317723, GC# 12666, WAF 6.47
[Run 18] host 532894, ftl 758728, valid page copy 337694, GC# 13455, WAF 6.49
[Run 19] host 562627, ftl 801864, valid page copy 357907, GC# 14252, WAF 6.51
[Run 20] host 592428, ftl 843352, valid page copy 377584, GC# 15032, WAF 6.52
[Run 21] host 621911, ftl 885224, valid page copy 397120, GC# 15806, WAF 6.53
[Run 22] host 650780, ftl 926528, valid page copy 416307, GC# 16567, WAF 6.54
[Run 23] host 680436, ftl 968624, valid page copy 436233, GC# 17354, WAF 6.55
[Run 24] host 710169, ftl 101008, valid page copy 456118, GC# 18141, WAF 6.56
[Run 25] host 739758, ftl 1053168, valid page copy 475898, GC# 18924, WAF 6.57
[Run 26] host 769608, ftl 1095704, valid page copy 495958, GC# 19717, WAF 6.58
[Run 27] host 799781, ftl 1138320, valid page copy 515970, GC# 20509, WAF 6.58
[Run 28] host 829886, ftl 1181064, valid page copy 535755, GC# 21294, WAF 6.59
[Run 29] host 859368, ftl 1222880, valid page copy 555674, GC# 22080, WAF 6.60
[Run 30] host 888388, ftl 1264456, valid page copy 574926, GC# 22844, WAF 6.60
[Run 31] host 917713, ftl 1306064, valid page copy 594366, GC# 23614, WAF 6.60
[Run 32] host 947768, ftl 1348592, valid page copy 614107, GC# 24397, WAF 6.61

[Run 64] host 1891730, ftl 2692880, valid page copy 1241753, GC# 49262, WAF 6.67
[Run 65] host 1921009, ftl 2734848, valid page copy 1261592, GC# 50046, WAF 6.68
[Run 66] host 1950379, ftl 2776920, valid page copy 1281522, GC# 50833, WAF 6.68
[Run 67] host 1980499, ftl 2819456, valid page copy 1301227, GC# 51615, WAF 6.68
[Run 68] host 2010274, ftl 2861912, valid page copy 1320917, GC# 52396, WAF 6.68
[Run 69] host 2039896, ftl 2904200, valid page copy 1340716, GC# 53180, WAF 6.68
[Run 70] host 2069241, ftl 2946160, valid page copy 1360428, GC# 53960, WAF 6.68
[Run 71] host 2097919, ftl 2987264, valid page copy 1379542, GC# 54718, WAF 6.68
[Run 72] host 2127255, ftl 3029008, valid page copy 1399416, GC# 55502, WAF 6.69
[Run 73] host 2157069, ftl 3071424, valid page copy 1419072, GC# 56282, WAF 6.69
[Run 74] host 2186740, ftl 3113488, valid page copy 1438773, GC# 57062, WAF 6.69
[Run 75] host 2216049, ftl 3155400, valid page copy 1458398, GC# 57839, WAF 6.69
[Run 76] host 2245465, ftl 3197128, valid page copy 1477698, GC# 58605, WAF 6.69
[Run 77] host 2274918, ftl 3239184, valid page copy 1497402, GC# 59385, WAF 6.69
[Run 78] host 2304098, ftl 3280640, valid page copy 1516762, GC# 60152, WAF 6.69
[Run 79] host 2334208, ftl 3323568, valid page copy 1536744, GC# 60944, WAF 6.69
[Run 80] host 2362733, ftl 3364488, valid page copy 1555785, GC# 61699, WAF 6.69
[Run 81] host 2391778, ftl 3406056, valid page copy 1575452, GC# 62476, WAF 6.69
[Run 82] host 2421187, ftl 3448128, valid page copy 1594930, GC# 63249, WAF 6.69
[Run 83] host 2451009, ftl 3490504, valid page copy 1614497, GC# 64026, WAF 6.69
[Run 84] host 2480936, ftl 3533160, valid page copy 1634735, GC# 64825, WAF 6.70
[Run 85] host 2511005, ftl 3575648, valid page copy 1654451, GC# 65607, WAF 6.70
[Run 86] host 2541065, ftl 3618264, valid page copy 1674147, GC# 66389, WAF 6.69
[Run 87] host 2570491, ftl 3660312, valid page copy 1693879, GC# 67170, WAF 6.70
[Run 88] host 2600009, ftl 3702416, valid page copy 1713767, GC# 67956, WAF 6.70
[Run 89] host 2629770, ftl 3743736, valid page copy 1732893, GC# 68717, WAF 6.70
[Run 90] host 2658322, ftl 3785096, valid page copy 1753074, GC# 69509, WAF 6.70
[Run 91] host 2687874, ftl 3827032, valid page copy 1772718, GC# 70288, WAF 6.70
[Run 92] host 2717383, ftl 3869048, valid page copy 1792711, GC# 71077, WAF 6.70
[Run 93] host 2746829, ftl 3911880, valid page copy 1812416, GC# 71857, WAF 6.70
[Run 94] host 2777146, ftl 3954680, valid page copy 1832250, GC# 72644, WAF 6.70
[Run 95] host 2806583, ftl 3996776, valid page copy 1851887, GC# 73422, WAF 6.70
[Run 96] host 2836397, ftl 4039136, valid page copy 1871516, GC# 74201, WAF 6.70
[Run 97] host 2865417, ftl 4080864, valid page copy 1891196, GC# 74979, WAF 6.70
[Run 98] host 2894179, ftl 4122264, valid page copy 1910568, GC# 75746, WAF 6.71
[Run 99] host 2923674, ftl 4164376, valid page copy 1929944, GC# 76516, WAF 6.71
[Run 100] host 2953017, ftl 4206352, valid page copy 1949653, GC# 77296, WAF 6.71

Results -----
Host write sectors: 2953017
FTL write sectors: 4206352
GC write sectors: 15597224
Number of GCs: 77296
Valid pages per GC: 25.22 pages
WAF: 6.71
```

- Random cost benefit

```
Bank: 2
Blocks / Bank: 32 blocks
Pages / Block: 32 pages
OP ratio: 7%
Physical Blocks: 64
User Blocks: 56
OP Blocks: 8
PPNs: 2048
LPNs: 1792
Workload: Random
FTL: Cost-Benefit policy
Max Sectors: 32

[Run 1] host 29505, ftl 42040, valid page copy 4911, GC# 256, WAF 2.76
[Run 2] host 58945, ftl 83952, valid page copy 23870, GC# 1012, WAF 4.66
[Run 3] host 88378, ftl 126024, valid page copy 46549, GC# 1885, WAF 5.64
[Run 4] host 118058, ftl 168224, valid page copy 69208, GC# 2758, WAF 6.11
[Run 5] host 147609, ftl 210072, valid page copy 91942, GC# 3632, WAF 6.41
[Run 6] host 176615, ftl 251544, valid page copy 113863, GC# 4479, WAF 6.58
[Run 7] host 206005, ftl 293704, valid page copy 136690, GC# 5357, WAF 6.73
[Run 8] host 235649, ftl 335920, valid page copy 159669, GC# 6240, WAF 6.85
[Run 9] host 265513, ftl 378256, valid page copy 182601, GC# 7122, WAF 6.93
[Run 10] host 295240, ftl 420568, valid page copy 205283, GC# 7996, WAF 6.99
[Run 11] host 324989, ftl 462912, valid page copy 228243, GC# 8879, WAF 7.04
[Run 12] host 354668, ftl 505184, valid page copy 250928, GC# 9753, WAF 7.08
[Run 13] host 384690, ftl 547552, valid page copy 273859, GC# 10635, WAF 7.12
[Run 14] host 414532, ftl 589728, valid page copy 296678, GC# 11513, WAF 7.15
[Run 15] host 443878, ftl 631792, valid page copy 319357, GC# 12386, WAF 7.18
[Run 16] host 473817, ftl 674272, valid page copy 342240, GC# 13267, WAF 7.20
[Run 17] host 503411, ftl 716528, valid page copy 365502, GC# 14159, WAF 7.23
[Run 18] host 532894, ftl 758728, valid page copy 388482, GC# 15042, WAF 7.26
[Run 19] host 562627, ftl 801064, valid page copy 411162, GC# 15916, WAF 7.27
[Run 20] host 592428, ftl 843352, valid page copy 434414, GC# 16808, WAF 7.29
[Run 21] host 621911, ftl 885224, valid page copy 456991, GC# 17677, WAF 7.30
[Run 22] host 650780, ftl 926528, valid page copy 478899, GC# 18523, WAF 7.31
[Run 23] host 680436, ftl 968624, valid page copy 501799, GC# 19403, WAF 7.32
[Run 24] host 710169, ftl 1011008, valid page copy 524654, GC# 20283, WAF 7.33
[Run 25] host 739758, ftl 1053168, valid page copy 547168, GC# 21151, WAF 7.34
[Run 26] host 769608, ftl 1095704, valid page copy 569717, GC# 22022, WAF 7.35
[Run 27] host 799781, ftl 1138320, valid page copy 592873, GC# 22912, WAF 7.35
[Run 28] host 829886, ftl 1181064, valid page copy 615849, GC# 23797, WAF 7.36
[Run 29] host 859368, ftl 1222880, valid page copy 638620, GC# 24672, WAF 7.37
[Run 30] host 888388, ftl 1264456, valid page copy 660724, GC# 25525, WAF 7.37
[Run 31] host 917713, ftl 1306064, valid page copy 682976, GC# 26383, WAF 7.38
[Run 32] host 947768, ftl 1348592, valid page copy 705662, GC# 27258, WAF 7.38

[Run 64] host 1891730, ftl 2692880, valid page copy 1432185, GC# 55213, WAF 7.48
[Run 65] host 1921009, ftl 2734848, valid page copy 1455230, GC# 56097, WAF 7.48
[Run 66] host 1950379, ftl 2776920, valid page copy 1477937, GC# 56971, WAF 7.49
[Run 67] host 1980499, ftl 2819456, valid page copy 1500005, GC# 57855, WAF 7.49
[Run 68] host 2010274, ftl 2861912, valid page copy 1523082, GC# 58742, WAF 7.49
[Run 69] host 2039896, ftl 2904200, valid page copy 1546762, GC# 59619, WAF 7.49
[Run 70] host 2069241, ftl 2946160, valid page copy 1569328, GC# 60488, WAF 7.49
[Run 71] host 2097919, ftl 2987264, valid page copy 1591160, GC# 61331, WAF 7.49
[Run 72] host 2127255, ftl 3029008, valid page copy 1613944, GC# 62206, WAF 7.49
[Run 73] host 2157069, ftl 3071424, valid page copy 1636707, GC# 63083, WAF 7.49
[Run 74] host 2186740, ftl 3113488, valid page copy 1659479, GC# 63959, WAF 7.49
[Run 75] host 2216049, ftl 3155400, valid page copy 1682852, GC# 64853, WAF 7.50
[Run 76] host 2245465, ftl 3197128, valid page copy 1705702, GC# 65730, WAF 7.50
[Run 77] host 2274918, ftl 3239184, valid page copy 1728466, GC# 66606, WAF 7.50
[Run 78] host 2304098, ftl 3280640, valid page copy 1751134, GC# 67476, WAF 7.50
[Run 79] host 2334208, ftl 3323568, valid page copy 1774214, GC# 68365, WAF 7.50
[Run 80] host 2362733, ftl 3364488, valid page copy 1796621, GC# 69225, WAF 7.51
[Run 81] host 2391778, ftl 3406056, valid page copy 1819386, GC# 70099, WAF 7.51
[Run 82] host 2421387, ftl 3448128, valid page copy 1841905, GC# 70967, WAF 7.51
[Run 83] host 2451009, ftl 3490504, valid page copy 1864960, GC# 71853, WAF 7.51
[Run 84] host 2480936, ftl 3533160, valid page copy 1887695, GC# 72730, WAF 7.51
[Run 85] host 2511005, ftl 3575648, valid page copy 1910546, GC# 73610, WAF 7.51
[Run 86] host 2541065, ftl 3618264, valid page copy 1933630, GC# 74498, WAF 7.51
[Run 87] host 2570491, ftl 3660312, valid page copy 1956665, GC# 75382, WAF 7.51
[Run 88] host 2600009, ftl 3702416, valid page copy 1979142, GC# 76249, WAF 7.51
[Run 89] host 2628770, ftl 3743736, valid page copy 2001597, GC# 77112, WAF 7.52
[Run 90] host 2658322, ftl 3785896, valid page copy 2024102, GC# 77980, WAF 7.52
[Run 91] host 2687874, ftl 3827832, valid page copy 2046700, GC# 78850, WAF 7.52
[Run 92] host 2717383, ftl 3869848, valid page copy 2069474, GC# 79726, WAF 7.52
[Run 93] host 2746829, ftl 3911880, valid page copy 2092608, GC# 80613, WAF 7.52
[Run 94] host 2777146, ftl 3954680, valid page copy 2116024, GC# 81512, WAF 7.52
[Run 95] host 2806583, ftl 3996776, valid page copy 2138762, GC# 82387, WAF 7.52
[Run 96] host 2836397, ftl 4039136, valid page copy 2161205, GC# 83254, WAF 7.52
[Run 97] host 2865417, ftl 4080864, valid page copy 2183874, GC# 84125, WAF 7.52
[Run 98] host 2894179, ftl 4122264, valid page copy 2206246, GC# 84986, WAF 7.52
[Run 99] host 2923674, ftl 4164376, valid page copy 2229172, GC# 85867, WAF 7.52
[Run 100] host 2953017, ftl 4206352, valid page copy 2252248, GC# 86752, WAF 7.53

Results -----
Host write sectors: 2953017
FTL write sectors: 4206352
GC write sectors: 18017984
Number of GCs: 86752
Valid pages per GC: 25.96 pages
WAF: 7.53
```

C

- Hot cold greedy

```
Bank: 2
Blocks / Bank: 32 blocks
Pages / Block: 32 pages
OP ratio: 7%
Physical Blocks: 64
User Blocks: 56
OP Blocks: 8
PPNs: 2048
LPNs: 1792
Workload: Hot 96 / Cold 4
FTL: Greedy policy
Max Sectors: 32

[Run 1] host 29695, ftl 42384, valid page copy 127, GC# 108, WAF 1.46
[Run 2] host 59446, ftl 84864, valid page copy 849, GC# 297, WAF 1.54
[Run 3] host 89222, ftl 127160, valid page copy 2135, GC# 502, WAF 1.62
[Run 4] host 118726, ftl 169256, valid page copy 4104, GC# 728, WAF 1.70
[Run 5] host 148722, ftl 211728, valid page copy 6859, GC# 980, WAF 1.79
[Run 6] host 178811, ftl 254216, valid page copy 10510, GC# 1260, WAF 1.89
[Run 7] host 208126, ftl 295904, valid page copy 14994, GC# 1563, WAF 2.00
[Run 8] host 238032, ftl 338280, valid page copy 20445, GC# 1899, WAF 2.11
[Run 9] host 268037, ftl 380776, valid page copy 26952, GC# 2268, WAF 2.23
[Run 10] host 297668, ftl 423104, valid page copy 34233, GC# 2661, WAF 2.34
[Run 11] host 328040, ftl 466024, valid page copy 42339, GC# 3082, WAF 2.45
[Run 12] host 357495, ftl 508120, valid page copy 51032, GC# 3518, WAF 2.56
[Run 13] host 386260, ftl 549448, valid page copy 60332, GC# 3970, WAF 2.67
[Run 14] host 415493, ftl 591224, valid page copy 71016, GC# 4467, WAF 2.79
[Run 15] host 444905, ftl 632968, valid page copy 82921, GC# 5002, WAF 2.91
[Run 16] host 474200, ftl 674792, valid page copy 95803, GC# 5568, WAF 3.04
[Run 17] host 504004, ftl 717264, valid page copy 110043, GC# 6179, WAF 3.17
[Run 18] host 533648, ftl 759480, valid page copy 124931, GC# 6809, WAF 3.30
[Run 19] host 563721, ftl 802032, valid page copy 141053, GC# 7479, WAF 3.42
[Run 20] host 592631, ftl 843512, valid page copy 158424, GC# 8184, WAF 3.56
[Run 21] host 621496, ftl 885192, valid page copy 176389, GC# 8908, WAF 3.69
[Run 22] host 651177, ftl 927520, valid page copy 195638, GC# 9675, WAF 3.83
[Run 23] host 680413, ftl 969248, valid page copy 216058, GC# 10476, WAF 3.96
[Run 24] host 709481, ftl 1010576, valid page copy 236804, GC# 11286, WAF 4.09
[Run 25] host 738825, ftl 1052328, valid page copy 258498, GC# 12127, WAF 4.22
[Run 26] host 768528, ftl 1094336, valid page copy 280994, GC# 12994, WAF 4.35
[Run 27] host 798358, ftl 1136672, valid page copy 304855, GC# 13905, WAF 4.48
[Run 28] host 827478, ftl 1178112, valid page copy 328378, GC# 14802, WAF 4.60
[Run 29] host 857156, ftl 1220392, valid page copy 352885, GC# 15733, WAF 4.72
[Run 30] host 886899, ftl 1262752, valid page copy 378603, GC# 16702, WAF 4.84
[Run 31] host 916351, ftl 1304856, valid page copy 404186, GC# 17666, WAF 4.95
[Run 32] host 946153, ftl 1347376, valid page copy 430325, GC# 18649, WAF 5.06

[Run 64] host 1891716, ftl 2694160, valid page copy 1368825, GC# 53238, WAF 7.21
[Run 65] host 1920594, ftl 2735176, valid page copy 1398230, GC# 54317, WAF 7.25
[Run 66] host 1949960, ftl 2777040, valid page copy 1428960, GC# 55441, WAF 7.29
[Run 67] host 1979572, ftl 2819320, valid page copy 1460091, GC# 56579, WAF 7.32
[Run 68] host 2009080, ftl 2861464, valid page copy 1489515, GC# 57663, WAF 7.36
[Run 69] host 2038772, ftl 2903648, valid page copy 1519629, GC# 58769, WAF 7.39
[Run 70] host 2068424, ftl 2945504, valid page copy 1549348, GC# 59861, WAF 7.42
[Run 71] host 2097781, ftl 2987504, valid page copy 1579135, GC# 60956, WAF 7.45
[Run 72] host 2126660, ftl 3028728, valid page copy 1608860, GC# 62046, WAF 7.48
[Run 73] host 2155972, ftl 3070456, valid page copy 1639418, GC# 63164, WAF 7.51
[Run 74] host 2185160, ftl 3112224, valid page copy 1669368, GC# 64263, WAF 7.54
[Run 75] host 2214279, ftl 3153848, valid page copy 1699558, GC# 65369, WAF 7.56
[Run 76] host 2243226, ftl 3195336, valid page copy 1729542, GC# 66468, WAF 7.59
[Run 77] host 2273218, ftl 3238048, valid page copy 1760807, GC# 67612, WAF 7.62
[Run 78] host 2303429, ftl 3280920, valid page copy 1791446, GC# 68737, WAF 7.65
[Run 79] host 2332585, ftl 3322752, valid page copy 1821323, GC# 69834, WAF 7.67
[Run 80] host 2362097, ftl 3364904, valid page copy 1850995, GC# 70926, WAF 7.69
[Run 81] host 2391095, ftl 3406536, valid page copy 1880003, GC# 71995, WAF 7.71
[Run 82] host 2421058, ftl 3449056, valid page copy 1910398, GC# 73111, WAF 7.74
[Run 83] host 2450829, ftl 3491288, valid page copy 1942176, GC# 74269, WAF 7.76
[Run 84] host 2480073, ftl 3533024, valid page copy 1971713, GC# 75355, WAF 7.78
[Run 85] host 2508904, ftl 3574584, valid page copy 2001938, GC# 76462, WAF 7.81
[Run 86] host 2538121, ftl 3616384, valid page copy 2031981, GC# 77564, WAF 7.83
[Run 87] host 2567161, ftl 3657824, valid page copy 2061135, GC# 78637, WAF 7.85
[Run 88] host 2596269, ftl 3699408, valid page copy 2090466, GC# 79716, WAF 7.87
[Run 89] host 2625906, ftl 3741632, valid page copy 2120164, GC# 80809, WAF 7.88
[Run 90] host 2655578, ftl 3783696, valid page copy 2149756, GC# 81898, WAF 7.90
[Run 91] host 2685011, ftl 3825704, valid page copy 2179415, GC# 82989, WAF 7.92
[Run 92] host 2714491, ftl 3867568, valid page copy 2209188, GC# 84083, WAF 7.94
[Run 93] host 2743841, ftl 3909672, valid page copy 2238964, GC# 85178, WAF 7.95
[Run 94] host 2774021, ftl 3952632, valid page copy 2269182, GC# 86290, WAF 7.97
[Run 95] host 2803384, ftl 3994512, valid page copy 2299368, GC# 87397, WAF 7.99
[Run 96] host 2832794, ftl 4036392, valid page copy 2328889, GC# 88483, WAF 8.00
[Run 97] host 2862090, ftl 4078328, valid page copy 2358333, GC# 89567, WAF 8.02
[Run 98] host 2891681, ftl 4120488, valid page copy 2388422, GC# 90672, WAF 8.03
[Run 99] host 2921229, ftl 4162456, valid page copy 2419081, GC# 91794, WAF 8.05
[Run 100] host 2950614, ftl 4204192, valid page copy 2448968, GC# 92891, WAF 8.06

Results -----
Host write sectors: 2950614
FTL write sectors: 4204192
GC write sectors: 19591744
Number of GCs: 92891
Valid pages per GC: 26.36 pages
WAF: 8.06
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- hot cold cost benefit

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Bank: 2
Blocks / Bank: 32 blocks
Pages / Block: 32 pages
OP ratio: 7%
Physical Blocks: 64
User Blocks: 56
OP Blocks: 8
PPNs: 2048
LPNs: 1792
Workload: Hot 96 / Cold 4
FTL: Cost-Benefit policy
Max Sectors: 32

[Run 1] host 29695, ftl 42384, valid page copy 159, GC# 110, WAF 1.47
[Run 2] host 59446, ftl 84864, valid page copy 912, GC# 299, WAF 1.55
[Run 3] host 89222, ftl 127160, valid page copy 2301, GC# 507, WAF 1.63
[Run 4] host 118726, ftl 169256, valid page copy 4365, GC# 736, WAF 1.72
[Run 5] host 148722, ftl 211728, valid page copy 7214, GC# 991, WAF 1.81
[Run 6] host 178811, ftl 254216, valid page copy 10948, GC# 1274, WAF 1.91
[Run 7] host 208126, ftl 295904, valid page copy 15537, GC# 1580, WAF 2.02
[Run 8] host 238032, ftl 338280, valid page copy 21250, GC# 1924, WAF 2.14
[Run 9] host 268037, ftl 380776, valid page copy 28005, GC# 2301, WAF 2.26
[Run 10] host 297668, ftl 423104, valid page copy 35647, GC# 2705, WAF 2.38
[Run 11] host 328040, ftl 466024, valid page copy 44130, GC# 3138, WAF 2.50
[Run 12] host 357495, ftl 508120, valid page copy 53248, GC# 3587, WAF 2.61
[Run 13] host 386260, ftl 549448, valid page copy 62829, GC# 4048, WAF 2.72
[Run 14] host 415493, ftl 591224, valid page copy 74143, GC# 4565, WAF 2.85
[Run 15] host 444905, ftl 632968, valid page copy 86444, GC# 5112, WAF 2.98
[Run 16] host 474200, ftl 674792, valid page copy 99798, GC# 5693, WAF 3.11
[Run 17] host 504004, ftl 717264, valid page copy 114588, GC# 6321, WAF 3.24
[Run 18] host 533648, ftl 759480, valid page copy 130499, GC# 6983, WAF 3.38
[Run 19] host 563721, ftl 802032, valid page copy 147638, GC# 7685, WAF 3.52
[Run 20] host 592631, ftl 843512, valid page copy 165745, GC# 8413, WAF 3.66
[Run 21] host 621496, ftl 885192, valid page copy 184447, GC# 9160, WAF 3.80
[Run 22] host 651177, ftl 927520, valid page copy 204467, GC# 9951, WAF 3.94
[Run 23] host 680413, ftl 969248, valid page copy 225205, GC# 10762, WAF 4.07
[Run 24] host 709481, ftl 1010576, valid page copy 246632, GC# 11593, WAF 4.21
[Run 25] host 738825, ftl 1052328, valid page copy 268737, GC# 12447, WAF 4.33
[Run 26] host 768528, ftl 1094336, valid page copy 292221, GC# 13345, WAF 4.47
[Run 27] host 798358, ftl 1136672, valid page copy 316023, GC# 14254, WAF 4.59
[Run 28] host 827478, ftl 1178112, valid page copy 340445, GC# 15179, WAF 4.72
[Run 29] host 857156, ftl 1220392, valid page copy 365622, GC# 16131, WAF 4.84
[Run 30] host 886809, ftl 1262752, valid page copy 391910, GC# 17118, WAF 4.96
[Run 31] host 916351, ftl 1304856, valid page copy 417852, GC# 18093, WAF 5.07
[Run 32] host 946153, ftl 1347376, valid page copy 444852, GC# 19103, WAF 5.19

[Run 64] host 1891716, ftl 2694160, valid page copy 1403449, GC# 54320, WAF 7.36
[Run 65] host 1920594, ftl 2735176, valid page copy 1433589, GC# 55422, WAF 7.40
[Run 66] host 1949960, ftl 2777040, valid page copy 1463997, GC# 56536, WAF 7.43
[Run 67] host 1979572, ftl 2819320, valid page copy 1494365, GC# 57650, WAF 7.46
[Run 68] host 2009080, ftl 2861464, valid page copy 1525162, GC# 58777, WAF 7.50
[Run 69] host 2038772, ftl 2903648, valid page copy 1556429, GC# 59919, WAF 7.53
[Run 70] host 2068424, ftl 2945504, valid page copy 1587326, GC# 61048, WAF 7.56
[Run 71] host 2097781, ftl 2987504, valid page copy 1618270, GC# 62179, WAF 7.60
[Run 72] host 2126660, ftl 3028728, valid page copy 1647963, GC# 63268, WAF 7.62
[Run 73] host 2155972, ftl 3070456, valid page copy 1679227, GC# 64408, WAF 7.66
[Run 74] host 2185160, ftl 3112224, valid page copy 1709659, GC# 65522, WAF 7.68
[Run 75] host 2214279, ftl 3153848, valid page copy 1740423, GC# 66646, WAF 7.71
[Run 76] host 2243226, ftl 3195336, valid page copy 1772035, GC# 67796, WAF 7.74
[Run 77] host 2273218, ftl 3238048, valid page copy 1804616, GC# 68981, WAF 7.78
[Run 78] host 2303429, ftl 3280920, valid page copy 1836282, GC# 70138, WAF 7.80
[Run 79] host 2332585, ftl 3322752, valid page copy 1867819, GC# 71287, WAF 7.83
[Run 80] host 2362097, ftl 3364904, valid page copy 1899255, GC# 72434, WAF 7.86
[Run 81] host 2391095, ftl 3406536, valid page copy 1929604, GC# 73545, WAF 7.88
[Run 82] host 2421058, ftl 3449056, valid page copy 1959136, GC# 74634, WAF 7.90
[Run 83] host 2450829, ftl 3491288, valid page copy 1990207, GC# 75770, WAF 7.92
[Run 84] host 2480073, ftl 3533024, valid page copy 2020897, GC# 76892, WAF 7.94
[Run 85] host 2509004, ftl 3574584, valid page copy 2051703, GC# 78017, WAF 7.97
[Run 86] host 2538124, ftl 3616384, valid page copy 2082312, GC# 79137, WAF 7.99
[Run 87] host 2567161, ftl 3657824, valid page copy 2112108, GC# 80230, WAF 8.01
[Run 88] host 2596269, ftl 3699408, valid page copy 2141442, GC# 81309, WAF 8.02
[Run 89] host 2625906, ftl 3741632, valid page copy 2172232, GC# 82436, WAF 8.04
[Run 90] host 2655578, ftl 3783696, valid page copy 2202426, GC# 83544, WAF 8.06
[Run 91] host 2685011, ftl 3825704, valid page copy 2233529, GC# 84680, WAF 8.08
[Run 92] host 2714491, ftl 3867568, valid page copy 2264290, GC# 85805, WAF 8.10
[Run 93] host 2743841, ftl 3909672, valid page copy 2294966, GC# 86928, WAF 8.12
[Run 94] host 2774021, ftl 3952632, valid page copy 2327617, GC# 88116, WAF 8.14
[Run 95] host 2803384, ftl 3994512, valid page copy 2358955, GC# 89259, WAF 8.16
[Run 96] host 2832794, ftl 4036392, valid page copy 2389493, GC# 90377, WAF 8.17
[Run 97] host 2862090, ftl 4078328, valid page copy 2420185, GC# 91500, WAF 8.19
[Run 98] host 2891681, ftl 4120488, valid page copy 2450347, GC# 92607, WAF 8.20
[Run 99] host 2921229, ftl 4162456, valid page copy 2481644, GC# 93749, WAF 8.22
[Run 100] host 2950614, ftl 4204192, valid page copy 2512393, GC# 94873, WAF 8.24

Results -----
Host write sectors: 2950614
FTL write sectors: 4204192
GC write sectors: 20099144
Number of GCs: 94873
Valid pages per GC: 26.48 pages
WAF: 8.24

```

Hot cold는 waf값이 점진적으로 증가하는 반면 random은 waf값이 처음에 증가했다가 점점 증가 폭이 감소하는 경향을 보였다. 이는 hot부분과 cold부분을 나누어서 보았을 때 hot부분은 waf값이 빠르게 증가하지만, cold부분이 천천히 증가하여 cold부분이 천천히 반영됨으로 인하여 점진적으로 증가하는 것처럼 보였을 것이다. 또한 greedy보다 cost\_benefit의 waf값이 조금 더 높게 측정되었다. 이는 특수한 경우만 보았기 때문에 이런 양상을 보인다고 생각한다.