

**NC State University**

**Department of Electrical and Computer Engineering**

**ECE 786: Spring 2023**

**Final Project**

**Profile based Cache Bypass logic using GP-GPU Sim**

**by**

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## TASK 1: Cache Efficiency Analysis

Configuration Used -> SM2\_GTX480

Assumptions ->

- In each of the kernel, if the % change in IPC between No cache-bypassing and cache-bypassing mode is
  - Greater than 2%, then it is assumed as Cache Unfriendly Kernel
  - Inbetween -2% and 2% then it is assumed as Cache Insensitive Kernel
  - Less than -2%, then it is assumed as Cache friendly Kernel
- If more than 50% of kernels in a benchmark is Cache Unfriendly, then the benchmark is considered as Cache Unfriendly Benchmark.
- Max. number of instructions executed to 100M by using below command in gpgpusim.config

-gpgpu\_max\_insn 100000000

| bench mark name | kernel name                              | kernel launch uid | IPC with no cache bypassing | IPC with cache bypassing | percentage change of comparing the IPC with/without cache bypassing | kernel category  | Benchmark Category |
|-----------------|--|-------------------|-----------------------------|--------------------------|---|--|--------------------|
| BFS             | _Z6KernelIP4NodePiPbS2_S1_S2_i           | 1                 | 217.5687                    | 167.9066                 | -22.82593958  | Cache Friendly (L1 cache bypassing will cause performance degradation)                             | Cache Unfriendly   |
|                 | _Z6KernelIP4NodePiPbS2_S1_S2_i           | 2                 | 206.0139                    | 146.9099                 | -28.6893263   | Cache Friendly (L1 cache bypassing will cause performance degradation)                             |                    |
|                 | _Z6KernelIP4NodePiPbS2_S1_S2_i           | 3                 | 165.9271                    | 112.0179                 | -32.48968975  | Cache Friendly (L1 cache bypassing will cause performance degradation)                             |                    |
|                 | _Z6KernelIP4NodePiPbS2_S1_S2_i           | 4                 | 76.2236                     | 61.3361                  | -19.53135249  | Cache Friendly (L1 cache bypassing will cause performance degradation)                             |                    |
|                 | _Z6KernelIP4NodePiPbS2_S1_S2_i           | 5                 | 21.3021                     | 36.1667                  | 69.77997474   | Cache Unfriendly (L1 cache bypassing can improve the IPC)  |                    |
|                 | _Z6KernelIP4NodePiPbS2_S1_S2_i           | 6                 | 22.5533                     | 44.4395                  | 97.042118   | Cache Unfriendly (L1 cache bypassing can improve the IPC)  |                    |
|                 | _Z6KernelIP4NodePiPbS2_S1_S2_i           | 7                 | 46.5675                     | 86.5094                  | 85.77205132   | Cache Unfriendly (L1 cache bypassing can improve the IPC)  |                    |
|                 | _Z6KernelIP4NodePiPbS2_S1_S2_i           | 8                 | 354.4445                    | 455.3303                 | 28.46307391   | Cache Unfriendly (L1 cache bypassing can improve the IPC)  |                    |
|                 | _Z6KernelIP4NodePiPbS2_S1_S2_i           | 9                 | 473.1056                    | 486.792                  | 2.892884802   | Cache Unfriendly (L1 cache bypassing can improve the IPC)  |                    |
| LPS             | _Z13GPU_laplace3diiiiiPfs_               | 1                 | 383.1095                    | 408.8568                 | 6.720611209   | Cache Unfriendly (L1 cache bypassing can improve the IPC)  | Cache Unfriendly   |
| NQU             | _Z24solve_nqueen_cuda_kernellipj_s_s_s_i | 1                 | 30.4185                     | 30.7699                  | 1.155218042   | Cache Insensitive (IPCs have no significant difference when enabling /disabling the bypass logic ) | Cache Insensitive  |
| NN              | _Z17executeFirstLayerPfs_S_              | 1                 | 345.3974                    | 144.1486                 | -58.26586998  | Cache Friendly (L1 cache bypassing will cause performance degradation)                             | Cache Friendly     |
|                 | _Z18executeSecondLayerPfs_S_             | 2                 | 211.7879                    | 97.8234                  | -53.81067568  | Cache Friendly (L1 cache bypassing will cause performance degradation)                             |                    |
|                 | _Z17executeThirdLayerPfs_S_              | 3                 | 9.449                       | 4.325                    | -54.22796063  | Cache Friendly (L1 cache bypassing will cause performance degradation)                             |                    |
|                 | _Z18executeFourthLayerPfs_S_             | 4                 | 6.8539                      | 3.2347                   | -52.80497235  | Cache Friendly (L1 cache bypassing will cause performance degradation)                             |                    |
| BP              | _Z22bpnn_layerforward_CUDAPfs_S_ii       | 1                 | 675.6067                    | 671.3728                 | -0.626681174  | Cache Insensitive (IPCs have no significant difference when cache bypassing )                      | Cache Insensitive  |
| HS              | _Z14calculate_tempiPfs_S_iiiiifffff      | 1                 | 701.3718                    | 707.6299                 | 0.8922657   | Cache Insensitive (IPCs have no significant difference when cache bypassing )                      | Cache Insensitive  |
|                 | _Z12lud_diagonalPfii                     | 1                 | 0.7026                      | 0.7176                   | 2.134927412   | Cache Unfriendly (L1 cache bypassing can improve the IPC)  |                    |
|                 | _Z13lud_perimeterPfii                    | 2                 | 9.2446                      | 9.1103                   | -1.452739978  | Cache Insensitive (IPCs have no significant difference when cache bypassing )                      |                    |
|                 | _Z12lud_internalPfii                     | 3                 | 501.2445                    | 567.1572                 | 13.14981012   | Cache Unfriendly (L1 cache bypassing can improve the IPC)  |                    |
|                 | _Z12lud_diagonalPfii                     | 4                 | 0.7558                      | 0.7742                   | 2.434506483   | Cache Unfriendly (L1 cache bypassing can improve the IPC)  |                    |
|                 | _Z13lud_perimeterPfii                    | 5                 | 10.9464                     | 11.8102                  | 7.891178835   | Cache Unfriendly (L1 cache bypassing can improve the IPC)  |                    |
|                 | _Z12lud_internalPfii                     | 6                 | 497.3745                    | 574.7466                 | 15.55610511   | Cache Unfriendly (L1 cache bypassing can improve the IPC)  |                    |
|                 | _Z12lud_diagonalPfii                     | 7                 | 0.7558                      | 0.7741                   | 2.42127547  | Cache Unfriendly (L1 cache bypassing can improve the IPC)  |                    |
|                 | _Z13lud_perimeterPfii                    | 8                 | 10.1697                     | 10.9718                  | 7.88715498  | Cache Unfriendly (L1 cache bypassing can improve the IPC)  |                    |
|                 | _Z12lud_internalPfii                     | 9                 | 473.0808                    | 557.2787                 | 17.79778423   | Cache Unfriendly (L1 cache bypassing can improve the IPC)  |                    |
|                 | _Z12lud_diagonalPfii                     | 10                | 0.7558                      | 0.7741                   | 2.42127547  | Cache Unfriendly (L1 cache bypassing can improve the IPC)  |                    |
|                 | _Z13lud_perimeterPfii                    | 11                | 9.3893                      | 10.1287                  | 7.874921453   | Cache Unfriendly (L1 cache bypassing can improve the IPC)  |                    |

|     |                       |    |          |          |              |   |                  |
|-----|-----------------------|----|----------|----------|--------------|---|------------------|
| LUD | _Z12lud_internalPfii  | 12 | 462.4784 | 529.6388 | 14.52184578  | Cache Unfriendly (L1 cache bypassing can improve the IPC)                     | Cache Unfriendly |
|     | _Z12lud_diagonalPfii  | 13 | 0.7558   | 0.7741   | 2.42127547   | Cache Unfriendly (L1 cache bypassing can improve the IPC)                     |                  |
|     | _Z13lud_perimeterPfii | 14 | 8.6082   | 9.2874   | 7.890151251  | Cache Unfriendly (L1 cache bypassing can improve the IPC)                     |                  |
|     | _Z12lud_internalPfii  | 15 | 378.4012 | 504.6895 | 33.37418063  | Cache Unfriendly (L1 cache bypassing can improve the IPC)                     |                  |
|     | _Z12lud_diagonalPfii  | 16 | 0.7558   | 0.7742   | 2.434506483  | Cache Unfriendly (L1 cache bypassing can improve the IPC)                     |                  |
|     | _Z13lud_perimeterPfii | 17 | 7.8294   | 8.4467   | 7.884384499  | Cache Unfriendly (L1 cache bypassing can improve the IPC)                     |                  |
|     | _Z12lud_internalPfii  | 18 | 357.2093 | 493.737  | 38.22064543  | Cache Unfriendly (L1 cache bypassing can improve the IPC)                     |                  |
|     | _Z12lud_diagonalPfii  | 19 | 0.7558   | 0.7742   | 2.434506483  | Cache Unfriendly (L1 cache bypassing can improve the IPC)                     |                  |
|     | _Z13lud_perimeterPfii | 20 | 7.0473   | 7.604    | 7.899479233  | Cache Unfriendly (L1 cache bypassing can improve the IPC)                     |                  |
|     | _Z12lud_internalPfii  | 21 | 338.0277 | 453.3258 | 34.10906858  | Cache Unfriendly (L1 cache bypassing can improve the IPC)                     |                  |
|     | _Z12lud_diagonalPfii  | 22 | 0.7558   | 0.7741   | 2.42127547   | Cache Unfriendly (L1 cache bypassing can improve the IPC)                     |                  |
|     | _Z13lud_perimeterPfii | 23 | 6.264    | 6.7609   | 7.932630907  | Cache Unfriendly (L1 cache bypassing can improve the IPC)                     |                  |
|     | _Z12lud_internalPfii  | 24 | 324.1251 | 467.1097 | 44.11401647  | Cache Unfriendly (L1 cache bypassing can improve the IPC)                     |                  |
|     | _Z12lud_diagonalPfii  | 25 | 0.7558   | 0.7741   | 2.42127547   | Cache Unfriendly (L1 cache bypassing can improve the IPC)                     |                  |
|     | _Z13lud_perimeterPfii | 26 | 5.4832   | 5.9163   | 7.898672308  | Cache Unfriendly (L1 cache bypassing can improve the IPC)                     |                  |
|     | _Z12lud_internalPfii  | 27 | 290.9933 | 405.2074 | 39.2497353   | Cache Unfriendly (L1 cache bypassing can improve the IPC)                     |                  |
|     | _Z12lud_diagonalPfii  | 28 | 0.7558   | 0.7741   | 2.42127547   | Cache Unfriendly (L1 cache bypassing can improve the IPC)                     |                  |
|     | _Z13lud_perimeterPfii | 29 | 4.7006   | 5.0733   | 7.92877505   | Cache Unfriendly (L1 cache bypassing can improve the IPC)                     |                  |
|     | _Z12lud_internalPfii  | 30 | 246.8571 | 344.3503 | 39.49378     | Cache Unfriendly (L1 cache bypassing can improve the IPC)                     |                  |
|     | _Z12lud_diagonalPfii  | 31 | 0.7558   | 0.7741   | 2.42127547   | Cache Unfriendly (L1 cache bypassing can improve the IPC)                     |                  |
|     | _Z13lud_perimeterPfii | 32 | 3.9172   | 4.2288   | 7.954661493  | Cache Unfriendly (L1 cache bypassing can improve the IPC)                     |                  |
|     | _Z12lud_internalPfii  | 33 | 208.6225 | 253.2766 | 21.40425889  | Cache Unfriendly (L1 cache bypassing can improve the IPC)                     |                  |
|     | _Z12lud_diagonalPfii  | 34 | 0.7558   | 0.7741   | 2.42127547   | Cache Unfriendly (L1 cache bypassing can improve the IPC)                     |                  |
|     | _Z13lud_perimeterPfii | 35 | 3.1348   | 3.3833   | 7.927140487  | Cache Unfriendly (L1 cache bypassing can improve the IPC)                     |                  |
|     | _Z12lud_internalPfii  | 36 | 142.2966 | 172.1319 | 20.96698024  | Cache Unfriendly (L1 cache bypassing can improve the IPC)                     |                  |
|     | _Z12lud_diagonalPfii  | 37 | 0.7558   | 0.7741   | 2.42127547   | Cache Unfriendly (L1 cache bypassing can improve the IPC)                     |                  |
|     | _Z13lud_perimeterPfii | 38 | 2.3514   | 2.5387   | 7.965467381  | Cache Unfriendly (L1 cache bypassing can improve the IPC)                     |                  |
|     | _Z12lud_internalPfii  | 39 | 111.9498 | 134.8471 | 20.45318527  | Cache Unfriendly (L1 cache bypassing can improve the IPC)                     |                  |
|     | _Z12lud_diagonalPfii  | 40 | 0.7558   | 0.7741   | 2.42127547   | Cache Unfriendly (L1 cache bypassing can improve the IPC)                     |                  |
|     | _Z13lud_perimeterPfii | 41 | 1.5679   | 1.6926   | 7.953313349  | Cache Unfriendly (L1 cache bypassing can improve the IPC)                     |                  |
|     | _Z12lud_internalPfii  | 42 | 39.4499  | 44.9208  | 13.86796925  | Cache Unfriendly (L1 cache bypassing can improve the IPC)                     |                  |
|     | _Z12lud_diagonalPfii  | 43 | 0.7558   | 0.7741   | 2.42127547   | Cache Unfriendly (L1 cache bypassing can improve the IPC)                     |                  |
|     | _Z13lud_perimeterPfii | 44 | 0.8583   | 0.8467   | -1.351508796 | Cache Insensitive (IPCs have no significant difference when cache bypassing ) |                  |
|     | _Z12lud_internalPfii  | 45 | 16.2623  | 16.6957  | 2.665059678  | Cache Unfriendly (L1 cache bypassing can improve the IPC)                     |                  |
|     | _Z12lud_diagonalPfii  | 46 | 0.7558   | 0.7741   | 2.42127547   | Cache Unfriendly (L1 cache bypassing can improve the IPC)                     |                  |

From the above table,

- BFS, LPS, LUD benchmarks -> Cache Unfriendly benchmarks
- NQU, BP, HS benchmarks -> Cache Insensitive benchmarks
- NN -> Cache Friendly Benchmark

## TASK 2: Profile-based Cache Bypassing

Configuration Used -> **SM7\_QV100**

Benchmarks Used -> BFS, LPS, LUD (Cache Unfriendly Benchmarks from Task 1)

### **Implimentation:**

- The simulation runs in two modes depending on the existence of "ProfileDump.txt" file in the run directory.
  - Profiling Mode (when "ProfileDump.txt" is not present)
  - Profile Based Bypassed Mode (when "ProfileDump.txt" is present)
- The mode is maintained using an enum variable **profiling\_mode**
- A hash table **cache\_bypass\_profiling\_data** with three nested keys (SM, Kernel, Address) are created to store the reference counters for each of the memory access addresses without any duplicate entry.

### Profiling Mode:

- The reference counters with appropriate keys are incremented for each memory access in `ldst_unit::memory_cycle()`.
- At the end of simulation, all the keys are stored in "ProfileDump.txt" which can be used as reference for subsequent simulation to run in Profile based Bypass mode.

### Profile Based Bypassed Mode:

- The reference counters with appropriate keys are updated with the datum present in "ProfileDump.txt" file.
- These counters are checked everytime, when accessing a memory. If the counter value is less than 3, bypassing logic enabled (Similar to PA3a) in `ldst_unit::memory_cycle()` and `ldst_unit::cycle()`

### **Modifications made in the code:**

#### Shadder.h file

- Hash Table, Profile\_mode\_enum and DumpFileName are defined in shadder.h
- These files are defined using **extern** to avoid multiple declaration when shader.h is called by may .cc files.

```
71 #define WRITE_PACKET_SIZE 8
72
73 #define WRITE_MASK_SIZE 8
74
75 extern std::map<unsigned, std::map<unsigned, std::map<unsigned, unsigned>>> Cache_bypass_Profiling_data;
76 enum profiling_mode_enum
77 {
78     PROFILING = 0,
79     BYPASSING = 1
80 };
81 extern profiling_mode_enum profiling_mode;
82 extern std::string DumpFileName;
83
84
85 class gpgpu_context;
86
87 enum exec_unit_type_t
88 {
```

#### Shadder.cc file

- Hash Table, Profile\_mode\_enum and DumpFileName are initialized in shadder.cc

```
53 #define MIN(a, b) (((a) < (b)) ? (a) : (b))
54
55 std::map<unsigned, std::map<unsigned, std::map<unsigned, unsigned>>> Cache_bypass_Profiling_data;
56 profiling_mode_enum profiling_mode;
57 std::string DumpFileName = "ProfileDump.txt";
58
59 mem_fetch *shader_core_mem_fetch_allocator::alloc(
```

- In `ldst_unit::memory_Cycle()`, the hash table `cache_bypass_profiling_data` is
  - incremented if the simulator is in profiling mode
  - read used to bypass L1D if the ref. counter is less than 3. (in bypassing mode)

```
2384 if (profiling_mode == profiling_mode_enum::PROFILING)
2385 {
2386     Cache_bypass_Profiling_data[m_core->get_sid()][m_core->get_kernel()->get_uid()][access.get_addr()] += 1;
2387 }
2388 else if (profiling_mode == profiling_mode_enum::BYPASSING)
2389 {
2390     if (Cache_bypass_Profiling_data[m_core->get_sid()][m_core->get_kernel()->get_uid()][access.get_addr()] < 3)
2391         bypassL1D = true;
2392 }
2393
```

- In `ldst_unit::cycle()`, if the simulator is in Bypassing mode, `bypassL1D` is set to true if the ref. counter in `cache_bypass_profiling_data` is less than 3.

```

3032         if (profiling_mode == profiling_mode_enum::BYPASSING)
3033         {
3034             if (Cache_bypass_Profiling_data[m_core->get_sid()][m_core->get_kernel()->get_uid()][mf->get_addr()] < 3)
3035                 bypassL1D = true;
3036         }

```

### Gpgpusim\_entrypoint.cc file

- In `gpgpu_context::gpgpu_ptpx_sim_init_perf()`, enum variable `profile_mode` assigned depending on the presence of "ProfileDump.txt".
- If "ProfileDump.txt" is present, all the datum read, parsed and reference counters with keys are stored in `cache_bypass_profiling_data` table.

```

259     ifstream DumpFileHandler;
260     DumpFileHandler.open(DumpFileName);
261     if (!DumpFileHandler.is_open())
262     {
263         profiling_mode = profiling_mode_enum::PROFILING;
264         cout << "****ProfileDump.txt not found. Entering PROFILING Mode****" << '\n';
265     }
266     else
267     {
268         profiling_mode = profiling_mode_enum::BYPASSING;
269         cout << "****ProfileDump.txt found. Entering BYPASSING Mode****" << '\n';
270
271         string FileLine;
272         int File_SM, File_Kernel, File_Address, File_Counter;
273         while (getline(DumpFileHandler, FileLine))
274         {
275             if (!FileLine.empty())
276             {
277                 string SubFileLine = FileLine.substr(0, 1);
278                 if (SubFileLine == "1_")
279                 {
280                     File_SM = stoi(FileLine.substr(5)); // 1_SM
281                 }
282                 else if (SubFileLine == "2_")
283                 {
284                     File_Kernel = stoi(FileLine.substr(9)); // 2_KERNEL
285                 }
286                 else if (SubFileLine == "3_")
287                 {
288                     string SecondPartFileLine = FileLine.substr(FileLine.find(";") + 1);
289                     FileLine = FileLine.substr(0, FileLine.find(";"));
290                     File_Address = stoi(FileLine.substr(10)); // 3_ADDRESS
291                     File_Counter = stoi(SecondPartFileLine.substr(10)); // 4_COUNTER
292
293                     Cache_bypass_Profiling_data[File_SM][File_Kernel][File_Address] = File_Counter;
294                 }
295             }
296         }
297     }
298
299     return the_gpgpusim->g_the_gpu;
300 }

```

- In `gpgpu_context::print_simulation_time()` , if the sim is in profiling mode, the reference counters are dumped to “ProfileDump.txt” files in appropriate format.

```

320 void gpgpu_context::print_simulation_time()
321 {
322     if (profiling_mode == PROFILING)
323     {
324         ofstream DumpFileHandler;
325         DumpFileHandler.open(DumpFileName);
326         for (auto SmIndex = Cache_bypass_Profiling_data.begin(); SmIndex != Cache_bypass_Profiling_data.end(); SmIndex++)
327         {
328             DumpFileHandler << "1_SM " << SmIndex->first << '\n';
329             for (auto KernelIndex = SmIndex->second.begin(); KernelIndex != SmIndex->second.end(); KernelIndex++)
330             {
331                 DumpFileHandler << "2_KERNEL " << KernelIndex->first << '\n';
332                 for (auto AddressIndex = KernelIndex->second.begin(); AddressIndex != KernelIndex->second.end(); AddressIndex++)
333                 {
334                     DumpFileHandler << "3_ADDRESS " << AddressIndex->first << ";4_COUNTER " << AddressIndex->second << '\n';
335                 }
336             }
337         }
338     }
339
340     time_t current_time, difference, d, h, m, s;
341     current_time = time((time_t *)NULL);
342     difference = MAX(current_time - the_gpgpusim->g_simulation_starttime, 1);

```

### Steps to be followed to run in no-bypass / profile based bypass mode:

- In the run directory, if the “profiledump.txt” file is not present, then the GPGPUsim will run in Profiling mode to get the reference counter values and dump it in “profiledump.txt” file, so that on subsequent runs, the GPGPUsim used this dump file to run in profile based bypassing mode.
- In the run directory, if the “profiledump.txt” file is present, then the GPGPUsim will run in Profile based bypassing mode by reading the reference counters from this file.
- One main advantage of this method is we don’t have to recompile the GPGPUsim for switching between the two modes.

### Benchmark results – Without Bypassing vs Profile based bypassing

| benchmark name | kernel name                   | kernel_launch_uid | IPC -> Without Bypassing | IPC -> Profile based bypassing |
|----------------|-------------------------------|-------------------|--------------------------|--------------------------------|
| BFS            | _Z6KernelP4NodePiPbS2_S1_S2_i | 1                 | 139.74                   | 104.468                        |
|                | _Z6KernelP4NodePiPbS2_S1_S2_i | 2                 | 124.5014                 | 90.2066                        |
|                | _Z6KernelP4NodePiPbS2_S1_S2_i | 3                 | 115.862                  | 77.9455                        |
|                | _Z6KernelP4NodePiPbS2_S1_S2_i | 4                 | 109.4502                 | 72.6998                        |
|                | _Z6KernelP4NodePiPbS2_S1_S2_i | 5                 | 87.2392                  | 66.722                         |
|                | _Z6KernelP4NodePiPbS2_S1_S2_i | 6                 | 86.6631                  | 66.8945                        |
|                | _Z6KernelP4NodePiPbS2_S1_S2_i | 7                 | 145.4857                 | 111.03                         |
|                | _Z6KernelP4NodePiPbS2_S1_S2_i | 8                 | 229.1067                 | 175.9334                       |
|                | _Z6KernelP4NodePiPbS2_S1_S2_i | 9                 | 161.7932                 | 149.3736                       |
|                | _Z6KernelP4NodePiPbS2_S1_S2_i | 10                | 193.9836                 | 188.3223                       |
| LPS            | _Z13GPU_laplace3diiipfs_      | 1                 | 638.116                  | 667.4357                       |
| LUD            | _Z12lud_diagonalPfii          | 1                 | 0.7678                   | 0.7782                         |
|                | _Z13lud_perimeterPfii         | 2                 | 14.5785                  | 15.359                         |
|                | _Z12lud_internalPfii          | 3                 | 712.5299                 | 721.2603                       |
|                | _Z12lud_diagonalPfii          | 4                 | 0.7678                   | 0.7782                         |
|                | _Z13lud_perimeterPfii         | 5                 | 13.6126                  | 14.3418                        |
|                | _Z12lud_internalPfii          | 6                 | 637.3949                 | 642.5734                       |
|                | _Z12lud_diagonalPfii          | 7                 | 0.7678                   | 0.7782                         |
|                | _Z13lud_perimeterPfii         | 8                 | 12.6459                  | 13.3236                        |
|                | _Z12lud_internalPfii          | 9                 | 556.1233                 | 557.6649                       |
|                | _Z12lud_diagonalPfii          | 10                | 0.7678                   | 0.7782                         |
|                | _Z13lud_perimeterPfii         | 11                | 11.6784                  | 12.3045                        |
|                | _Z12lud_internalPfii          | 12                | 502.3962                 | 506.7778                       |
|                | _Z12lud_diagonalPfii          | 13                | 0.7678                   | 0.7782                         |
|                | _Z13lud_perimeterPfii         | 14                | 10.7269                  | 11.3033                        |
|                | _Z12lud_internalPfii          | 15                | 423.2689                 | 429.6447                       |
|                | _Z12lud_diagonalPfii          | 16                | 0.7678                   | 0.7782                         |
|                | _Z13lud_perimeterPfii         | 17                | 9.7561                   | 10.2805                        |
|                | _Z12lud_internalPfii          | 18                | 352.6066                 | 357.2629                       |
|                | _Z12lud_diagonalPfii          | 19                | 0.7678                   | 0.7782                         |
|                | _Z13lud_perimeterPfii         | 20                | 8.7844                   | 9.2568                         |
|                | _Z12lud_internalPfii          | 21                | 290.0794                 | 293.3001                       |
|                | _Z12lud_diagonalPfii          | 22                | 0.7678                   | 0.7782                         |
|                | _Z13lud_perimeterPfii         | 23                | 7.8118                   | 8.2322                         |
|                | _Z12lud_internalPfii          | 24                | 232.6988                 | 235.2133                       |

| LUD |                       |    |          |          |
|-----|-----------------------|----|----------|----------|
|     | _Z12lud_internalPfii  | 24 | 232.6988 | 235.2133 |
|     | _Z12lud_diagonalPfii  | 25 | 0.7678   | 0.7782   |
|     | _Z13lud_perimeterPfii | 26 | 6.8493   | 7.2186   |
|     | _Z12lud_internalPfii  | 27 | 178.1328 | 180.4473 |
|     | _Z12lud_diagonalPfii  | 28 | 0.7678   | 0.7782   |
|     | _Z13lud_perimeterPfii | 29 | 5.8735   | 6.1903   |
|     | _Z12lud_internalPfii  | 30 | 131.4149 | 132.7995 |
|     | _Z12lud_diagonalPfii  | 31 | 0.7678   | 0.7782   |
|     | _Z13lud_perimeterPfii | 32 | 4.8967   | 5.161    |
|     | _Z12lud_internalPfii  | 33 | 91.527   | 92.7536  |
|     | _Z12lud_diagonalPfii  | 34 | 0.7678   | 0.7782   |
|     | _Z13lud_perimeterPfii | 35 | 3.9191   | 4.1308   |
|     | _Z12lud_internalPfii  | 36 | 58.4963  | 59.3623  |
|     | _Z12lud_diagonalPfii  | 37 | 0.7678   | 0.7782   |
|     | _Z13lud_perimeterPfii | 38 | 2.9442   | 3.1034   |
|     | _Z12lud_internalPfii  | 39 | 33.1178  | 33.585   |
|     | _Z12lud_diagonalPfii  | 40 | 0.7678   | 0.7782   |
|     | _Z13lud_perimeterPfii | 41 | 1.966    | 2.0726   |
|     | _Z12lud_internalPfii  | 42 | 14.7418  | 14.943   |
|     | _Z12lud_diagonalPfii  | 43 | 0.7678   | 0.7782   |
|     | _Z13lud_perimeterPfii | 44 | 0.9846   | 1.0381   |
|     | _Z12lud_internalPfii  | 45 | 3.6923   | 3.7422   |
|     | _Z12lud_diagonalPfii  | 46 | 0.7678   | 0.7782   |

From the above table,

- In LUD and LPS benchamrks, as expected IPCs increased when GPGPUsim is run in profile based bypass mode.
- But in case of BFS benchmark, there is decrease in IPC when rin in profile based bypass mode. This may be because there are some cache friendly kernels in BFS.