f\_par\_pro\_WiSe 2024/25;

2. Aufgabe: Matrix-Matrix Multiplikation;

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Verwendete Hardware:

* HP Victus TG02-2301ng
* NVIDIA® GeForce RTX™ 4060 (8 GB GDDR6 dediziert)

Verwendete Programmierung-Umgebung: Microsoft Visual Studio auf Windows 11 Home

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# 1. Problemlösungsansatz

Es sind insgesamt vier Programmvarianten zu erstellen, eine einfache Version ohne und eine mit Shared Memory und jeweils eine Version für die Ergebnismatrix mit malloc und mit cudaMallocHost. Der einfache Kernel ohne Shared Memory stellt sich wie folgt dar

\_\_global\_\_ void dgemm\_gpu\_simple(const float\* a, const float\* b, float\* c, const int n) {

int x = threadIdx.x + blockIdx.x \* blockDim.x;  
 int y = threadIdx.y + blockIdx.y \* blockDim.y;  
 int id = x + y \* blockDim.x \* gridDim.x;

int vx = id % n; // Spalte  
 int vy = id - vx; // Zeile

int i;

float s = 0.0;   
for(i=0;i<n;++i)  
 s += a[vy+i] \* b[vx+i\*n];

c[id] = s;  
}

Jeder Thread berechnet ein Element der Matrix. Die Matrixspalte ergibt sich aus der Modulooperation, die Zeile durch Abzug der Spaltennummer von dem jeweiligen gewählten Matrixelement.

Der Kernel mit Shared Memory baut auf der zweidimensionalen Threadnutzung auf, indem zweidimensionale Arrays für das Shared Memory verwendet werden, für die Zeilen die Y-Dimension und für die Spalten die X-Dimension:

\_global\_\_ void dgemm\_gpu\_shared(const float\* a, const float\* b, float\* c, const int n) {

\_\_shared\_\_ float sA[BLOCK\_SIZE][BLOCK\_SIZE]; // Tile size of 32x32  
 \_\_shared\_\_ float sB[BLOCK\_SIZE][BLOCK\_SIZE];

int Row = blockDim.y \* blockIdx.y + threadIdx.y;  
 int Col = blockDim.x \* blockIdx.x + threadIdx.x;

float Cvalue = 0.0;  
 sA[threadIdx.y][threadIdx.x] = 0.0;  
 sB[threadIdx.y][threadIdx.x] = 0.0;

int Row\_n = Row \* n;  
 int anz\_BL = (n + BLOCK\_SIZE - 1) / BLOCK\_SIZE; // Number of Blocks in Matrix  
 int ph, j;

for (ph = 0; ph < anz\_BL; ph++) {

// Load  
int ph\_BLOCK\_SIZE = ph \* BLOCK\_SIZE;  
sA[threadIdx.y][threadIdx.x] = a[Row\_n + threadIdx.x + ph\_BLOCK\_SIZE];  
sB[threadIdx.y][threadIdx.x] = b[(threadIdx.y + ph\_BLOCK\_SIZE) \* n + Col];  
\_\_syncthreads();

// Calc  
 for (j = 0; j < BLOCK\_SIZE; ++j) {  
 Cvalue += sA[threadIdx.y][j] \* sB[j][threadIdx.x];  
 }  
 }

//Store   
 c[Row\_n + Col] = Cvalue;  
}

Es folgen dann die Lade- sowie die Rechenphase innerhalb der äußeren Schleife. Die Schleifendurchlaufanzahl ergibt sich aufgerundet aus der Anzahl der Elemente durch die Blockgröße. Im ersten Teil der Schleife lädt jeder Thread jeweils eine Stelle in die Summanden-Matrizen A und B. Da dies im Shared Memory erfolgt, sind an der \_\_syncthreads-Stelle beide Summanden-Matrizen kollektiv blockweise befüllt und können für die folgende Rechenphase verwendet werden, die pro Block als innere Schleife ein Element für die Ergebnismatrix berechnet. Auch hier berechnen die Threads einzeln die Zellen der Ergebnismatrix, das Laden der Summanden-Matrizen erfolgt jedoch effizienzsteigernd kollektiv pro Block. Abschließend wird der berechnete Wert in dem jeweiligen Element der Ergebnismatrix gespeichert.

Der eigentliche Kernelaufruf mit den vor- und nachgelagerten Speicherübertragungen unterscheidet sich in beiden Varianten nicht:

cudaMemcpy(d\_a, h\_a, size, cudaMemcpyHostToDevice);  
cudaMemcpy(d\_b, h\_b, size, cudaMemcpyHostToDevice);

dgemm\_gpu\_shared << < gridDim, blockDim >> > (d\_a, d\_b, d\_c, n);

cudaMemcpy(h\_c, d\_c, size, cudaMemcpyDeviceToHost);

Dieser Kernel bleibt auch identisch, wenn für die Ergebnismatrix im Host statt malloc (h\_c = (float\*)malloc(size);) cudaMalloc (cudaMallocHost((void\*\*)&h\_c, size);) verwendet wird (und entsprechend cudaFreeHost(h\_c); statt free(h\_c);). Die Lösungsansätze sind damit lokal begrenzt und miteinander kombinierbar.

# 2. Messergebnisse

Es wurden pro Programmvariante und pro Matrixgröße jeweils 1000 Durchläufe gemessen. Davor wurde das Programm dreimal durchlaufen lassen, um Initialverzögerungen in der Gesamtheit zu vermeiden.

Performance-Werte (time\* bezeichnet die Zeitmessung aus der Vorlage) **ohne** Shared-Memory

|  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| cudaMallocHost | |  |  |  |  |  | malloc |  |  |  |  |  |
| 512 | Min | Max | Avg | Median | StdDV |  | 512 | Min | Max | Avg | Median | StdDV |
| time\* | 0,946688 | 1,69901 | 1,0460512 | 1,00605 | 0,0838215 |  | time\* | 1,17203 | 1,87408 | 1,2774056 | 1,24563 | 0,0689187 |
| GFLOPS | 78,9977 | 141,776 | 129,02654 | 133,411 | 9,0423662 |  | GFLOPS | 71,6179 | 114,517 | 105,35212 | 107,751 | 5,2462578 |
| Memcpy AB | 0,302208 | 0,766752 | 0,3591351 | 0,343488 | 0,0364443 |  | Memcpy AB | 0,315392 | 0,69488 | 0,3605798 | 0,34808 | 0,0298162 |
| Memcpy C | 0,110912 | 0,608832 | 0,1442635 | 0,144064 | 0,0288057 |  | Memcpy C | 0,306304 | 1,01773 | 0,3768914 | 0,375568 | 0,0304776 |
| Kernel | 0,453696 | 1,14925 | 0,5185861 | 0,498576 | 0,0479421 |  | Kernel | 0,457184 | 0,686784 | 0,514522 | 0,498592 | 0,0353772 |
| Malloc | 0 | 0 | 0 | 0 | 0 |  | Malloc | 0 | 0 | 0 | 0 | 0 |
| Sync | 9,184E-41 | 0,029024 | 0,0002108 | 9,184E-41 | 0,0022288 |  | Sync | 0 | 0,03456 | 0,0004369 | 0 | 0,0026756 |
| Free | 0 | 0,639808 | 0,0016272 | 0 | 0,0299101 |  | Free | 4,592E-41 | 0,285152 | 0,0005589 | 4,592E-41 | 0,012487 |
|  |  |  |  |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |
| 1024 | Min | Max | Avg | Median | StdDV |  | 1024 | Min | Max | Avg | Median | StdDV |
| time\* | 4,07136 | 6,84022 | 4,2739906 | 4,19192 | 0,2124928 |  | time\* | 4,54576 | 5,94986 | 4,8507635 | 4,769725 | 0,1817098 |
| GFLOPS | 156,975 | 263,73 | 251,74995 | 256,146 | 10,63562 |  | GFLOPS | 180,465 | 236,207 | 221,64814 | 225,1155 | 7,8342647 |
| Memcpy AB | 1,14349 | 2,79235 | 1,3025048 | 1,254015 | 0,1296619 |  | Memcpy AB | 1,06349 | 2,01261 | 1,3052738 | 1,25987 | 0,1105454 |
| Memcpy C | 0,351616 | 0,848288 | 0,3865595 | 0,38376 | 0,0253804 |  | Memcpy C | 0,872704 | 1,53946 | 0,9628799 | 0,944464 | 0,0636112 |
| Kernel | 2,48848 | 4,24214 | 2,5607391 | 2,531055 | 0,1078837 |  | Kernel | 2,48358 | 3,14179 | 2,5571385 | 2,53178 | 0,0676479 |
| Malloc | 0 | 0 | 0 | 0 | 0 |  | Malloc | 0 | 0 | 0 | 0 | 0 |
| Sync | 9,184E-41 | 0,045376 | 0,0060542 | 9,184E-41 | 0,0092427 |  | Sync | 0 | 0,064992 | 0,0017705 | 0 | 0,0068201 |
| Free | 0 | 1,9656 | 0,0079705 | 0 | 0,0947497 |  | Free | 4,592E-41 | 4,592E-41 | 4,592E-41 | 4,592E-41 | 1,025E-54 |
|  |  |  |  |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |
| 2048 | Min | Max | Avg | Median | StdDV |  | 2048 | Min | Max | Avg | Median | StdDV |
| time\* | 24,7137 | 27,1219 | 25,139674 | 24,99295 | 0,3208342 |  | time\* | 26,7029 | 30,4027 | 27,515046 | 27,4958 | 0,5365273 |
| GFLOPS | 316,716 | 347,578 | 341,74267 | 343,6945 | 4,2547508 |  | GFLOPS | 282,539 | 321,686 | 312,30703 | 312,4095 | 5,9813658 |
| Memcpy AB | 4,71318 | 7,00282 | 5,1608915 | 5,02725 | 0,2762679 |  | Memcpy AB | 4,7567 | 8,57373 | 5,1742859 | 5,04264 | 0,3141374 |
| Memcpy C | 1,30701 | 2,2127 | 1,3599818 | 1,34928 | 0,0427196 |  | Memcpy C | 3,10643 | 5,44563 | 3,7058759 | 3,839105 | 0,3819952 |
| Kernel | 18,5243 | 19,6244 | 18,594692 | 18,5618 | 0,0939767 |  | Kernel | 18,5081 | 19,3565 | 18,611126 | 18,5499 | 0,1447408 |
| Malloc | 0 | 0 | 0 | 0 | 0 |  | Malloc | 0 | 0 | 0 | 0 | 0 |
| Sync | 9,184E-41 | 0,053856 | 0,0038639 | 9,184E-41 | 0,0089173 |  | Sync | 0 | 0,040992 | 0,0035625 | 0 | 0,0079251 |
| Free | 0 | 5,35517 | 0,0108717 | 0 | 0,2094153 |  | Free | 4,592E-41 | 2,58995 | 0,026123 | 4,592E-41 | 0,2376638 |
|  |  |  |  |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |
| 4096 | Min | Max | Avg | Median | StdDV |  | 4096 | Min | Max | Avg | Median | StdDV |
| time\* | 163,118 | 175,692 | 166,30676 | 166,162 | 1,3753697 |  | time\* | 170,484 | 184,767 | 175,47906 | 175,4235 | 2,1347221 |
| GFLOPS | 391,135 | 421,287 | 413,23723 | 413,5685 | 3,3909494 |  | GFLOPS | 371,926 | 403,084 | 391,66835 | 391,7345 | 4,7412498 |
| Memcpy AB | 19,3296 | 26,426 | 20,140434 | 19,71745 | 0,891597 |  | Memcpy AB | 19,3324 | 30,3247 | 20,156469 | 19,65525 | 1,1178266 |
| Memcpy C | 5,13632 | 5,97424 | 5,2442444 | 5,24064 | 0,0670424 |  | Memcpy C | 12,1167 | 24,074 | 14,833525 | 15,41065 | 1,4551799 |
| Kernel | 138,457 | 151,024 | 140,88606 | 140,903 | 0,9850845 |  | Kernel | 137,7 | 150,659 | 140,45705 | 140,3515 | 1,0172193 |
| Malloc | 0 | 0 | 0 | 0 | 0 |  | Malloc | 0 | 0 | 0 | 0 | 0 |
| Sync | 9,184E-41 | 0,132992 | 0,0155059 | 0,013472 | 0,0099771 |  | Sync | 0 | 0,05456 | 0,0132438 | 0,01184 | 0,0113593 |
| Free | 0 | 11,7296 | 0,2391352 | 0 | 1,4991395 |  | Free | 4,592E-41 | 8,56243 | 0,1101977 | 4,592E-41 | 0,926086 |
|  |  |  |  |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |
| 8192 | Min | Max | Avg | Median | StdDV |  | 8192 | Min | Max | Avg | Median | StdDV |
| time\* | 1234,69 | 1290,79 | 1250,8837 | 1250,53 | 4,1849247 |  | time\* | 1265,47 | 1303,23 | 1283,5868 | 1282,845 | 5,1337371 |
| GFLOPS | 425,908 | 445,257 | 439,49877 | 439,619 | 1,4603504 |  | GFLOPS | 421,841 | 434,43 | 428,30343 | 428,544 | 1,710706 |
| Memcpy AB | 76,3994 | 98,5012 | 79,149555 | 78,29075 | 2,7063597 |  | Memcpy AB | 76,6571 | 98,6102 | 79,621877 | 78,7785 | 2,6465592 |
| Memcpy C | 20,4095 | 21,7081 | 20,530708 | 20,51935 | 0,1027108 |  | Memcpy C | 47,7187 | 65,3011 | 51,613802 | 50,59145 | 3,4395067 |
| Kernel | 1137,13 | 1180,43 | 1151,1612 | 1151,245 | 2,7225433 |  | Kernel | 1136,38 | 1160,16 | 1152,3156 | 1152,455 | 2,7184182 |
| Malloc | 0 | 0 | 0 | 0 | 0 |  | Malloc | 0 | 0 | 0 | 0 | 0 |
| Sync | 9,184E-41 | 0,042176 | 0,0166362 | 0,01296 | 0,0075229 |  | Sync | 0 | 0,0728 | 0,0173955 | 0,013696 | 0,0087534 |
| Free | 0 | 47,5131 | 1,2294351 | 0 | 7,1463988 |  | Free | 4,592E-41 | 39,2644 | 2,6995996 | 4,592E-41 | 9,1327474 |
|  |  |  |  |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |
| 16384 | Min | Max | Avg | Median | StdDV |  | 16384 | Min | Max | Avg | Median | StdDV |
| time\* | 9512,5 | 9732,91 | 9673,6269 | 9674,205 | 13,604817 |  | time\* | 9692,4 | 9859,78 | 9804,859 | 9801,57 | 16,732561 |
| GFLOPS | 451,874 | 462,344 | 454,64388 | 454,616 | 0,6452805 |  | GFLOPS | 446,059 | 453,762 | 448,55915 | 448,7085 | 0,765139 |
| Memcpy AB | 305,185 | 344,239 | 313,23932 | 312,1695 | 4,9897346 |  | Memcpy AB | 303,997 | 367,736 | 312,20696 | 310,572 | 6,3974645 |
| Memcpy C | 81,448 | 82,6819 | 81,611521 | 81,5936 | 0,1123282 |  | Memcpy C | 193,304 | 263,749 | 212,23627 | 208,3105 | 14,313307 |
| Kernel | 9117,91 | 9332,09 | 9278,7338 | 9279,89 | 12,793718 |  | Kernel | 9184,67 | 9292,85 | 9280,3828 | 9280,96 | 6,4051086 |
| Malloc | 0 | 0 | 0 | 0 | 0 |  | Malloc | 0 | 0 | 0 | 0 | 0 |
| Sync | 0,009888 | 0,64416 | 0,0185912 | 0,013312 | 0,0222059 |  | Sync | 0,008864 | 0,150944 | 0,019 | 0,014048 | 0,0104399 |
| Free | 0 | 208,545 | 40,32415 | 0 | 70,597972 |  | Free | 4,592E-41 | 146,567 | 16,024808 | 4,592E-41 | 40,329592 |

Performance-Werte (time\* bezeichnet die Zeitmessung aus der Vorlage) **mit** Shared-Memory

|  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| cuaMallocHost | |  |  |  |  |  | malloc |  |  |  |  |  |
|  | Min | Max | Avg | Median | StdDV |  | 512 | Min | Max | Avg | Median | StdDV |
| time\* | 0,833376 | 1,47494 | 0,9345564 | 0,899184 | 0,0793089 |  | time\* | 1,03648 | 2,05306 | 1,1852434 | 1,148355 | 0,0863869 |
| GFLOPS | 90,9985 | 161,053 | 144,52774 | 149,266 | 10,800351 |  | GFLOPS | 65,3746 | 129,494 | 113,7738 | 116,8785 | 7,3866781 |
| Memcpy AB | 0,300192 | 0,615936 | 0,3518778 | 0,339872 | 0,0320899 |  | Memcpy AB | 0,308992 | 0,7624 | 0,3553332 | 0,34288 | 0,0312141 |
| Memcpy C | 0,110528 | 0,390784 | 0,1196524 | 0,115296 | 0,0129242 |  | Memcpy C | 0,296128 | 0,679744 | 0,3579996 | 0,35504 | 0,0265191 |
| Kernel | 0,380736 | 0,881792 | 0,4409861 | 0,426272 | 0,0410766 |  | Kernel | 0,379488 | 0,951968 | 0,4484274 | 0,431584 | 0,0437184 |
| Malloc | 0 | 0 | 0 | 0 | 0 |  | Malloc | 0 | 0 | 0 | 0 | 0 |
| Sync | 9,184E-41 | 0,032832 | 0,0020914 | 9,184E-41 | 0,0065876 |  | Sync | 0 | 0,035936 | 0,006436 | 0 | 0,0105857 |
| Free | 0 | 0,481088 | 0,001814 | 0 | 0,028732 |  | Free | 4,592E-41 | 4,592E-41 | 4,592E-41 | 4,592E-41 | 1,025E-54 |
|  |  |  |  |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |
| 1024 | Min | Max | Avg | Median | StdDV |  | 1024 | Min | Max | Avg | Median | StdDV |
| time\* | 3,48051 | 7,38285 | 3,6734605 | 3,61955 | 0,1746216 |  | time\* | 4,04237 | 5,86912 | 4,423978 | 4,339745 | 0,2077646 |
| GFLOPS | 145,437 | 308,501 | 292,78149 | 296,65 | 10,626725 |  | GFLOPS | 182,948 | 265,622 | 243,1979 | 247,4205 | 10,432011 |
| Memcpy AB | 1,11232 | 4,98406 | 1,2870407 | 1,24971 | 0,1541721 |  | Memcpy AB | 1,02294 | 2,69395 | 1,298605 | 1,253245 | 0,1314083 |
| Memcpy C | 0,354304 | 0,702912 | 0,3864022 | 0,386144 | 0,0182991 |  | Memcpy C | 0,893056 | 2,01613 | 1,1158326 | 1,096385 | 0,0997476 |
| Kernel | 1,91962 | 2,50106 | 1,9767759 | 1,9625 | 0,0462429 |  | Kernel | 1,92147 | 2,67427 | 1,9846921 | 1,96694 | 0,0589361 |
| Malloc | 0 | 0 | 0 | 0 | 0 |  | Malloc | 0 | 0 | 0 | 0 | 0 |
| Sync | 9,184E-41 | 0,09168 | 0,0007139 | 9,184E-41 | 0,004837 |  | Sync | 0 | 0,03856 | 0,0017038 | 0 | 0,0045784 |
| Free | 0 | 1,22467 | 0,0050619 | 0 | 0,0726717 |  | Free | 4,592E-41 | 4,592E-41 | 4,592E-41 | 4,592E-41 | 1,025E-54 |
|  |  |  |  |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |
| 2048 | Min | Max | Avg | Median | StdDV |  | 2048 | Min | Max | Avg | Median | StdDV |
| time\* | 20,4411 | 23,3727 | 20,745271 | 20,5732 | 0,3697147 |  | time\* | 22,4515 | 26,2594 | 23,398019 | 23,1859 | 0,4610628 |
| GFLOPS | 367,52 | 420,229 | 414,19326 | 417,529 | 7,082879 |  | GFLOPS | 327,118 | 382,6 | 367,26063 | 370,481 | 7,0251219 |
| Memcpy AB | 4,92685 | 7,5449 | 5,1597053 | 5,025025 | 0,2947296 |  | Memcpy AB | 4,88099 | 7,80067 | 5,1742376 | 5,03058 | 0,3023247 |
| Memcpy C | 1,31293 | 2,36973 | 1,3568424 | 1,347955 | 0,0481771 |  | Memcpy C | 3,20838 | 5,5591 | 3,9797984 | 3,893875 | 0,2119543 |
| Kernel | 14,1228 | 14,9174 | 14,204708 | 14,156 | 0,1258028 |  | Kernel | 14,1199 | 15,0907 | 14,217358 | 14,17645 | 0,1246896 |
| Malloc | 0 | 0 | 0 | 0 | 0 |  | Malloc | 0 | 0 | 0 | 0 | 0 |
| Sync | 9,184E-41 | 0,057664 | 0,0025359 | 9,184E-41 | 0,0074539 |  | Sync | 0 | 0,077344 | 0,0030605 | 0 | 0,0093115 |
| Free | 0 | 2,93158 | 0,0056223 | 0 | 0,1257087 |  | Free | 4,592E-41 | 4,592E-41 | 4,592E-41 | 4,592E-41 | 1,025E-54 |
|  |  |  |  |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |
| 4096 | Min | Max | Avg | Median | StdDV |  | 4096 | Min | Max | Avg | Median | StdDV |
| time\* | 127,482 | 140,875 | 129,71732 | 129,4175 | 1,1994893 |  | time\* | 136,092 | 149,516 | 140,60192 | 140,3555 | 1,5805885 |
| GFLOPS | 487,803 | 539,051 | 529,80796 | 530,9905 | 4,8281019 |  | GFLOPS | 459,614 | 504,947 | 488,81325 | 489,61 | 5,442879 |
| Memcpy AB | 19,2993 | 25,0475 | 20,242316 | 19,79305 | 0,965899 |  | Memcpy AB | 19,3103 | 27,5022 | 20,551932 | 20,3162 | 1,0999072 |
| Memcpy C | 5,13472 | 6,22317 | 5,2349689 | 5,232915 | 0,0750469 |  | Memcpy C | 12,1033 | 20,8324 | 15,842569 | 15,595 | 0,7361919 |
| Kernel | 101,452 | 112,466 | 104,20467 | 104,1375 | 0,6180919 |  | Kernel | 102,444 | 112,417 | 104,17511 | 104,123 | 0,6239416 |
| Malloc | 0 | 0 | 0 | 0 | 0 |  | Malloc | 0 | 0 | 0 | 0 | 0 |
| Sync | 9,184E-41 | 0,257568 | 0,0126716 | 0,01264 | 0,0136532 |  | Sync | 0 | 0,077056 | 0,013623 | 0,012144 | 0,0111741 |
| Free | 0 | 15,3909 | 0,169089 | 0 | 1,427228 |  | Free | 4,592E-41 | 4,592E-41 | 4,592E-41 | 4,592E-41 | 1,025E-54 |
|  |  |  |  |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |
| 8192 | Min | Max | Avg | Median | StdDV |  | 8192 | Min | Max | Avg | Median | StdDV |
| time\* | 959,774 | 986,062 | 967,80954 | 967,446 | 2,5797021 |  | time\* | 990,441 | 1021,71 | 1002,8886 | 1003,11 | 4,5462573 |
| GFLOPS | 557,527 | 572,797 | 568,04535 | 568,255 | 1,5092701 |  | GFLOPS | 538,076 | 555,062 | 548,18355 | 548,0505 | 2,4843319 |
| Memcpy AB | 76,4801 | 96,4425 | 79,157434 | 78,56205 | 2,2395637 |  | Memcpy AB | 76,3972 | 96,4633 | 79,490934 | 78,89975 | 2,3358661 |
| Memcpy C | 20,4078 | 21,33 | 20,530134 | 20,52355 | 0,0922711 |  | Memcpy C | 47,5777 | 71,8161 | 55,290573 | 56,3573 | 3,6798717 |
| Kernel | 861,778 | 872,218 | 868,08339 | 868,1 | 1,4061365 |  | Kernel | 860,823 | 871,936 | 868,07629 | 868,25 | 1,6333311 |
| Malloc | 0 | 0 | 0 | 0 | 0 |  | Malloc | 0 | 0 | 0 | 0 | 0 |
| Sync | 9,184E-41 | 0,094496 | 0,0183201 | 0,01632 | 0,0096548 |  | Sync | 0 | 0,058368 | 0,0167937 | 0,013152 | 0,0084852 |
| Free | 0 | 55,8043 | 7,0429729 | 0 | 16,40987 |  | Free | 4,592E-41 | 4,592E-41 | 4,592E-41 | 4,592E-41 | 1,025E-54 |
|  |  |  |  |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |
| 16384 | Min | Max | Avg | Median | StdDV |  | 16384 | Min | Max | Avg | Median | StdDV |
| time\* | 7324,12 | 7455,86 | 7388,7921 | 7388,12 | 8,5704244 |  | time\* | 7444,52 | 7730,73 | 7511,4517 | 7507,495 | 20,813465 |
| GFLOPS | 589,878 | 600,488 | 595,23293 | 595,286 | 0,6905385 |  | GFLOPS | 568,904 | 590,777 | 585,51667 | 585,821 | 1,6130219 |
| Memcpy AB | 305,926 | 373,778 | 314,73231 | 313,7555 | 5,3451004 |  | Memcpy AB | 303,589 | 377,258 | 312,18258 | 310,394 | 7,5990726 |
| Memcpy C | 81,4469 | 83,353 | 81,669115 | 81,62525 | 0,1878092 |  | Memcpy C | 193,144 | 435,434 | 210,72614 | 205,5965 | 15,930064 |
| Kernel | 6927,88 | 7008,75 | 6992,3469 | 6992,015 | 7,0558878 |  | Kernel | 6933,87 | 7063,36 | 6988,5075 | 6987,405 | 7,8472953 |
| Malloc | 0 | 0 | 0 | 0 | 0 |  | Malloc | 0 | 0 | 0 | 0 | 0 |
| Sync | 9,184E-41 | 0,170592 | 0,0212598 | 0,016304 | 0,0112832 |  | Sync | 0,008352 | 0,113952 | 0,0178667 | 0,012384 | 0,0104104 |
| Free | 0 | 200,893 | 41,326097 | 0 | 72,574312 |  | Free | 4,592E-41 | 4,592E-41 | 4,592E-41 | 4,592E-41 | 1,025E-54 |

# 3. Vergleiche und Schlussfolgerungen

## 3.1. cudaMallocHost statt malloc

### 3.1.1. Performance-Vergleich cudaMallocHost vs. malloc ohne Shared-Memory

Werte: (malloc - cudaMallocHost) / malloc

|  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| 512 | Min | Max | Avg | Median | StdDV |  | 1024 | Min | Max | Avg | Median | StdDV |
| time\* | 19,23% | 9,34% | 18,11% | 19,23% | -21,62% |  | time\* | 10,44% | -14,96% | 11,89% | 12,11% | -16,94% |
| GFLOPS | -10,30% | -23,80% | -22,47% | -23,81% | -72,36% |  | GFLOPS | 13,02% | -11,65% | -13,58% | -13,78% | -35,76% |
| Memcpy AB | 4,18% | -10,34% | 0,40% | 1,32% | -22,23% |  | Memcpy AB | -7,52% | -38,74% | 0,21% | 0,46% | -17,29% |
| Memcpy C | 63,79% | 40,18% | 61,72% | 61,64% | 5,49% |  | Memcpy C | 59,71% | 44,90% | 59,85% | 59,37% | 60,10% |
| Kernel | 0,76% | -67,34% | -0,79% | 0,00% | -35,52% |  | Kernel | -0,20% | -35,02% | -0,14% | 0,03% | -59,48% |
| Malloc | 0,00% | 0,00% | 0,00% | 0,00% | 0,00% |  | Malloc | 0,00% | 0,00% | 0,00% | 0,00% | 0,00% |
| Sync | 0,00% | 16,02% | 51,74% | 0,00% | 16,70% |  | Sync | 0,00% | 30,18% | -241,95% | 0,00% | -35,52% |
| Free | 100,00% | -124,37% | -191,15% | 100,00% | -139,53% |  | Free | 100,00% | 0,00% | 0,00% | 100,00% | 0,00% |
|  |  |  |  |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |
| 2048 | Min | Max | Avg | Median | StdDV |  | 4096 | Min | Max | Avg | Median | StdDV |
| time\* | 7,45% | 10,79% | 8,63% | 9,10% | 40,20% |  | time\* | 4,32% | 4,91% | 5,23% | 5,28% | 35,57% |
| GFLOPS | -12,10% | -8,05% | -9,43% | -10,01% | 28,87% |  | GFLOPS | -5,16% | -4,52% | -5,51% | -5,57% | 28,48% |
| Memcpy AB | 0,91% | 18,32% | 0,26% | 0,31% | 12,06% |  | Memcpy AB | 0,01% | 12,86% | 0,08% | -0,32% | 20,24% |
| Memcpy C | 57,93% | 59,37% | 63,30% | 64,85% | 88,82% |  | Memcpy C | 57,61% | 75,18% | 64,65% | 65,99% | 95,39% |
| Kernel | -0,09% | -1,38% | 0,09% | -0,06% | 35,07% |  | Kernel | -0,55% | -0,24% | -0,31% | -0,39% | 3,16% |
| Malloc | 0,00% | 0,00% | 0,00% | 0,00% | 0,00% |  | Malloc | 0,00% | 0,00% | 0,00% | 0,00% | 0,00% |
| Sync | 0,00% | -31,38% | -8,46% | 0,00% | -12,52% |  | Sync | 0,00% | -143,75% | -17,08% | -13,78% | 12,17% |
| Free | 100,00% | -106,77% | 58,38% | 100,00% | 11,89% |  | Free | 100,00% | -36,99% | -117,01% | 100,00% | -61,88% |
|  |  |  |  |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |
| 8192 | Min | Max | Avg | Median | StdDV |  | 16384 | Min | Max | Avg | Median | StdDV |
| time\* | 2,43% | 0,95% | 2,55% | 2,52% | 18,48% |  | time\* | 1,86% | 1,29% | 1,34% | 1,30% | 18,69% |
| GFLOPS | -0,96% | -2,49% | -2,61% | -2,58% | 14,63% |  | GFLOPS | -1,30% | -1,89% | -1,36% | -1,32% | 15,66% |
| Memcpy AB | 0,34% | 0,11% | 0,59% | 0,62% | -2,26% |  | Memcpy AB | -0,39% | 6,39% | -0,33% | -0,51% | 22,00% |
| Memcpy C | 57,23% | 66,76% | 60,22% | 59,44% | 97,01% |  | Memcpy C | 57,87% | 68,65% | 61,55% | 60,83% | 99,22% |
| Kernel | -0,07% | -1,75% | 0,10% | 0,10% | -0,15% |  | Kernel | 0,73% | -0,42% | 0,02% | 0,01% | -99,74% |
| Malloc | 0,00% | 0,00% | 0,00% | 0,00% | 0,00% |  | Malloc | 0,00% | 0,00% | 0,00% | 0,00% | 0,00% |
| Sync | 0,00% | 42,07% | 4,36% | 5,37% | 14,06% |  | Sync | -11,55% | -326,75% | 2,15% | 5,24% | -112,70% |
| Free | 100,00% | -21,01% | 54,46% | 100,00% | 21,75% |  | Free | 100,00% | -42,29% | -151,64% | 100,00% | -75,05% |

Bei der Matrix-Größe von 1024 ist ein Leistungsgewinn von ca. 12 % Zeit und 14 % GFLOPS anfangs beachtlich, davor bei einer Größe von 512 bereits mit ca. 18 % (GFLOS ca. 22 %). Mit zunehmender Matrix-Größe sinkt dieser deutlich. Bereits bei 2048 beträgt er nur noch knapp 9 % (Zeit und GFLOPS), bei 4096 nur noch ca. 5 % (Zeit und GFLOPS), bei 8192 fällt er auf unter 3 % (Zeit und GFLOPS), bei 16384 nur noch ca. 1 % (Zeit und GFLOPS). Ein wesentlicher Faktor ist die deutlich verkürzte Zeit Memcpy-Zeit für C, welche allgemein bei ca. 60 % liegt. Die Differenzen in den übrigen Größen (Kernel, Sync, Free, Malloc, Memcpy AB) dürften zufällig sein.

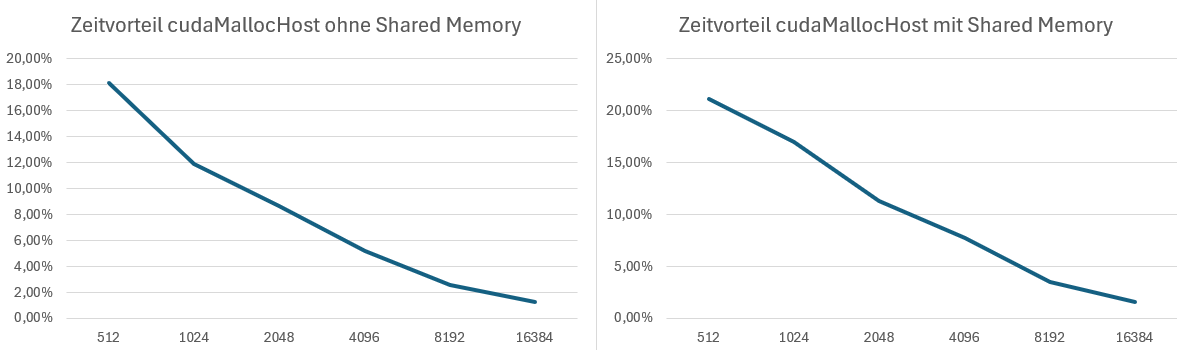
### 3.1.2. Performance-Vergleich cudaMallocHost vs. malloc mit Shared-Memory

Werte: (malloc - cudaMallocHost) / malloc

|  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| 512 | Min | Max | Avg | Median | StdDV |  | 1024 | Min | Max | Avg | Median | StdDV |
| time\* | 19,60% | 28,16% | 21,15% | 21,70% | 8,19% |  | time\* | 13,90% | -25,79% | 16,96% | 16,60% | 15,95% |
| GFLOPS | -39,20% | -24,37% | -27,03% | -27,71% | -46,21% |  | GFLOPS | 20,50% | -16,14% | -20,39% | -19,90% | -1,87% |
| Memcpy AB | 2,85% | 19,21% | 0,97% | 0,88% | -2,81% |  | Memcpy AB | -8,74% | -85,01% | 0,89% | 0,28% | -17,32% |
| Memcpy C | 62,68% | 42,51% | 66,58% | 67,53% | 51,26% |  | Memcpy C | 60,33% | 65,14% | 65,37% | 64,78% | 81,65% |
| Kernel | -0,33% | 7,37% | 1,66% | 1,23% | 6,04% |  | Kernel | 0,10% | 6,48% | 0,40% | 0,23% | 21,54% |
| Malloc | 0,00% | 0,00% | 0,00% | 0,00% | 0,00% |  | Malloc | 0,00% | 0,00% | 0,00% | 0,00% | 0,00% |
| Sync | 0,00% | 8,64% | 67,51% | 0,00% | 37,77% |  | Sync | 0,00% | -137,76% | 58,10% | 0,00% | -5,65% |
| Free | 100,00% | 0,00% | 0,00% | 100,00% | 0,00% |  | Free | 100,00% | 0,00% | 0,00% | 100,00% | 0,00% |
|  |  |  |  |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |
| 2048 | Min | Max | Avg | Median | StdDV |  | 4096 | Min | Max | Avg | Median | StdDV |
| time\* | 8,95% | 10,99% | 11,34% | 11,27% | 19,81% |  | time\* | 6,33% | 5,78% | 7,74% | 7,79% | 24,11% |
| GFLOPS | -12,35% | -9,84% | -12,78% | -12,70% | -0,82% |  | GFLOPS | -6,13% | -6,75% | -8,39% | -8,45% | 11,30% |
| Memcpy AB | -0,94% | 3,28% | 0,28% | 0,11% | 2,51% |  | Memcpy AB | 0,06% | 8,93% | 1,51% | 2,58% | 12,18% |
| Memcpy C | 59,08% | 57,37% | 65,91% | 65,38% | 77,27% |  | Memcpy C | 57,58% | 70,13% | 66,96% | 66,44% | 89,81% |
| Kernel | -0,02% | 1,15% | 0,09% | 0,14% | -0,89% |  | Kernel | 0,97% | -0,04% | -0,03% | -0,01% | 0,94% |
| Malloc | 0,00% | 0,00% | 0,00% | 0,00% | 0,00% |  | Malloc | 0,00% | 0,00% | 0,00% | 0,00% | 0,00% |
| Sync | 0,00% | 25,44% | 17,14% | 0,00% | 19,95% |  | Sync | 0,00% | -234,26% | 6,98% | -4,08% | -22,19% |
| Free | 100,00% | 0,00% | 0,00% | 100,00% | 0,00% |  | Free | 100,00% | 0,00% | 0,00% | 100,00% | 0,00% |
|  |  |  |  |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |
| 8192 | Min | Max | Avg | Median | StdDV |  | 16384 | Min | Max | Avg | Median | StdDV |
| time\* | 3,10% | 3,49% | 3,50% | 3,56% | 43,26% |  | time\* | 1,62% | 3,56% | 1,63% | 1,59% | 58,82% |
| GFLOPS | -3,61% | -3,20% | -3,62% | -3,69% | 39,25% |  | GFLOPS | -3,69% | -1,64% | -1,66% | -1,62% | 57,19% |
| Memcpy AB | -0,11% | 0,02% | 0,42% | 0,43% | 4,12% |  | Memcpy AB | -0,77% | 0,92% | -0,82% | -1,08% | 29,66% |
| Memcpy C | 57,11% | 70,30% | 62,87% | 63,58% | 97,49% |  | Memcpy C | 57,83% | 80,86% | 61,24% | 60,30% | 98,82% |
| Kernel | -0,11% | -0,03% | 0,00% | 0,02% | 13,91% |  | Kernel | 0,09% | 0,77% | -0,05% | -0,07% | 10,09% |
| Malloc | 0,00% | 0,00% | 0,00% | 0,00% | 0,00% |  | Malloc | 0,00% | 0,00% | 0,00% | 0,00% | 0,00% |
| Sync | 0,00% | -61,90% | -9,09% | -24,09% | -13,78% |  | Sync | 100,00% | -49,71% | -18,99% | -31,65% | -8,38% |
| Free | 100,00% | 0,00% | 0,00% | 100,00% | 0,00% |  | Free | 100,00% | 0,00% | 0,00% | 100,00% | 0,00% |

Auch hier trägt die Reduktion in Memcpy für C im Wesentlichen zum Leistungsgewinn von jeweils ca. 65 % bei, bei höheren Größen etwas abfallend auf ca. 60 %. Mit zunehmender Größe fällt der Leistungsgewinn insgesamt ab, beginnend von ca. 20 % Zeit (GFLOPS knapp 30 %) bis auf ca. 2 % (Zeit und GFLOPS). Die Auswirkungen auf die Kernelzeit sind unwesentlich, ebenso die Veränderungen bei den übrigen Stationen.

Im Ergebnis zeigt sich die optimierende Wirkung von CudaMallocHost hinreichend deutlich.



Verwendet wurden die Average-Werte.

Die Abnahme im Zeitgewinn erklärt sich daraus, dass mit zunehmender Matrixgröße der lineare Performance-Gewinn in der Übertragung hinter der höherkomplexen Berechnung (Matrixmultiplikation: grundsätzlich O(n³), mit Parallelität in den hier verwendeten Modellen auf bis zu O(n²) reduzierbar) zurückfällt. Da die Abszisse exponentiell ist, würde die Kurve bei linearer Streckung der Abszisse deutlich konvexer sein und vermutlich gegen einen Wert im kleineren einstelligen Prozentbereich konvergieren.

## 3.2. Verwendung von Shared Memory

### 3.2.1. Performance-Vergleich Shared-Memory mit malloc

Werte: (ohne\_Shared\_Memory – mit\_Shared\_Memory) / ohne\_Shared\_Memory

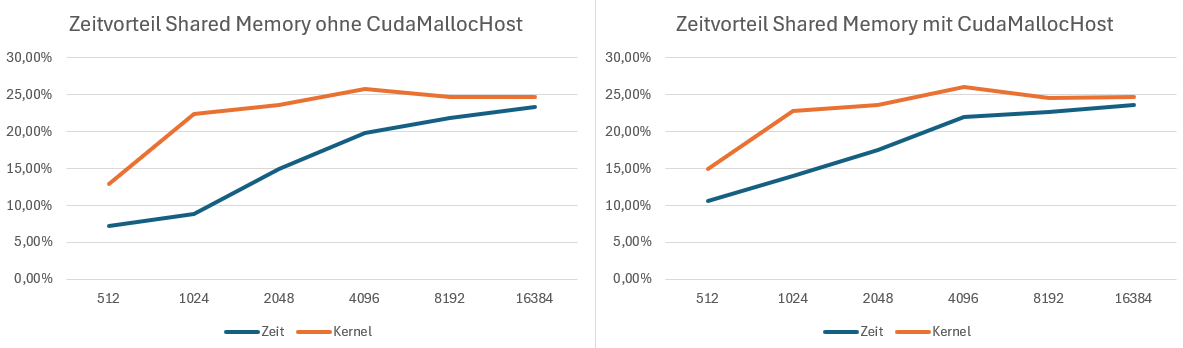
|  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| 512 | Min | Max | Avg | Median | StdDV |  | 1024 | Min | Max | Avg | Median | StdDV |
| time\* | 11,57% | -9,55% | 7,21% | 7,81% | -25,35% |  | time\* | 11,07% | 1,36% | 8,80% | 9,01% | -14,34% |
| GFLOPS | 8,72% | -13,08% | -7,99% | -8,47% | -40,80% |  | GFLOPS | -1,38% | -12,45% | -9,72% | -9,91% | -33,16% |
| Memcpy AB | 2,03% | -9,72% | 1,46% | 1,49% | -4,69% |  | Memcpy AB | 3,81% | -33,85% | 0,51% | 0,53% | -18,87% |
| Memcpy C | 3,32% | 33,21% | 5,01% | 5,47% | 12,99% |  | Memcpy C | -2,33% | -30,96% | -15,88% | -16,09% | -56,81% |
| Kernel | 16,99% | -38,61% | 12,85% | 13,44% | -23,58% |  | Kernel | 22,63% | 14,88% | 22,39% | 22,31% | 12,88% |
| Malloc | 0,00% | 0,00% | 0,00% | 0,00% | 0,00% |  | Malloc | 0,00% | 0,00% | 0,00% | 0,00% | 0,00% |
| Sync | 0,00% | -3,98% | -1373,02% | 0,00% | -295,64% |  | Sync | 0,00% | 40,67% | 3,76% | 0,00% | 32,87% |
| Free | 0,00% | 100,00% | 100,00% | 0,00% | 100,00% |  | Free | 0,00% | 0,00% | 0,00% | 0,00% | 0,00% |
|  |  |  |  |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |
| 2048 | Min | Max | Avg | Median | StdDV |  | 4096 | Min | Max | Avg | Median | StdDV |
| time\* | 15,92% | 13,63% | 14,96% | 15,67% | 14,07% |  | time\* | 20,17% | 19,08% | 19,88% | 19,99% | 25,96% |
| GFLOPS | -15,78% | -18,94% | -17,60% | -18,59% | -17,45% |  | GFLOPS | -23,58% | -25,27% | -24,80% | -24,99% | -14,80% |
| Memcpy AB | -2,61% | 9,02% | 0,00% | 0,24% | 3,76% |  | Memcpy AB | 0,11% | 9,31% | -1,96% | -3,36% | 1,60% |
| Memcpy C | -3,28% | -2,08% | -7,39% | -1,43% | 44,51% |  | Memcpy C | 0,11% | 13,47% | -6,80% | -1,20% | 49,41% |
| Kernel | 23,71% | 22,04% | 23,61% | 23,58% | 13,85% |  | Kernel | 25,60% | 25,38% | 25,83% | 25,81% | 38,66% |
| Malloc | 0,00% | 0,00% | 0,00% | 0,00% | 0,00% |  | Malloc | 0,00% | 0,00% | 0,00% | 0,00% | 0,00% |
| Sync | 0,00% | -88,68% | 14,09% | 0,00% | -17,49% |  | Sync | 0,00% | -41,23% | -2,86% | -2,57% | 1,63% |
| Free | 0,00% | 100,00% | 100,00% | 0,00% | 100,00% |  | Free | 0,00% | 100,00% | 100,00% | 0,00% | 100,00% |
|  |  |  |  |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |
| 8192 | Min | Max | Avg | Median | StdDV |  | 16384 | Min | Max | Avg | Median | StdDV |
| time\* | 21,73% | 21,60% | 21,87% | 21,81% | 11,44% |  | time\* | 23,19% | 21,59% | 23,39% | 23,41% | -24,39% |
| GFLOPS | -27,55% | -27,77% | -27,99% | -27,89% | -45,22% |  | GFLOPS | -27,54% | -30,20% | -30,53% | -30,56% | -110,81% |
| Memcpy AB | 0,34% | 2,18% | 0,16% | -0,15% | 11,74% |  | Memcpy AB | 0,13% | -2,59% | 0,01% | 0,06% | -18,78% |
| Memcpy C | 0,30% | -9,98% | -7,12% | -11,40% | -6,99% |  | Memcpy C | 0,08% | -65,09% | 0,71% | 1,30% | -11,30% |
| Kernel | 24,25% | 24,84% | 24,67% | 24,66% | 39,92% |  | Kernel | 24,51% | 23,99% | 24,70% | 24,71% | -22,52% |
| Malloc | 0,00% | 0,00% | 0,00% | 0,00% | 0,00% |  | Malloc | 0,00% | 0,00% | 0,00% | 0,00% | 0,00% |
| Sync | 0,00% | 19,82% | 3,46% | 3,97% | 3,06% |  | Sync | 5,78% | 24,51% | 5,96% | 11,85% | 0,28% |
| Free | 0,00% | 100,00% | 100,00% | 0,00% | 100,00% |  | Free | 0,00% | 100,00% | 100,00% | 0,00% | 100,00% |

Durch shared memory konnten ebenfalls Gewinne in der Gesamtperformane erzielt werden, welche mit zunehmender Größe ca.7 % (Zeit) bzw. 8 % (GFLOPS) bis hin zu etwas über 20 % bzw. ca. 30 % (GFLOPS) zunahmen. Die Zunahme im Gewinn nahm jedoch mit größer werdender Matrix ab, die Gewinnkurve verflacht damit. Haupttreiber ist der Gewinn im Kernel welcher sich mit zunehmender Matrixgröße steigert, allerdings verschlechtert sich der Gewinn von der Größe 4096 auf 8192, von 8192 auf 16384 blieb er in etwas gleich. Die Werte bei den Speicherübertragungen sind unwesentlich, die übrigen Werte sind hier ebenfalls aussagelos.

### 3.2.2. Performance-Vergleich Shared-Memory mit cudaMallocHost

|  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| 512 | Min | Max | Avg | Median | StdDV |  | 1024 | Min | Max | Avg | Median | StdDV |
| time\* | 11,97% | 13,19% | 10,66% | 10,62% | 5,38% |  | time\* | 14,51% | -7,93% | 14,05% | 13,65% | 17,82% |
| GFLOPS | -15,19% | -13,60% | -12,01% | -11,88% | -19,44% |  | GFLOPS | 7,35% | -16,98% | -16,30% | -15,81% | 0,08% |
| Memcpy AB | 0,67% | 19,67% | 2,02% | 1,05% | 11,95% |  | Memcpy AB | 2,73% | -78,49% | 1,19% | 0,34% | -18,90% |
| Memcpy C | 0,35% | 35,81% | 17,06% | 19,97% | 55,13% |  | Memcpy C | -0,76% | 17,14% | 0,04% | -0,62% | 27,90% |
| Kernel | 16,08% | 23,27% | 14,96% | 14,50% | 14,32% |  | Kernel | 22,86% | 41,04% | 22,80% | 22,46% | 57,14% |
| Malloc | 0,00% | 0,00% | 0,00% | 0,00% | 0,00% |  | Malloc | 0,00% | 0,00% | 0,00% | 0,00% | 0,00% |
| Sync | 0,00% | -13,12% | -891,88% | 0,00% | -195,57% |  | Sync | 0,00% | -102,05% | 88,21% | 0,00% | 47,67% |
| Free | 0,00% | 24,81% | -11,48% | 0,00% | 3,94% |  | Free | 0,00% | 37,69% | 36,49% | 0,00% | 23,30% |
|  |  |  |  |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |
| 2048 | Min | Max | Avg | Median | StdDV |  | 4096 | Min | Max | Avg | Median | StdDV |
| time\* | 17,29% | 13,82% | 17,48% | 17,68% | -15,24% |  | time\* | 21,85% | 19,82% | 22,00% | 22,11% | 12,79% |
| GFLOPS | -16,04% | -20,90% | -21,20% | -21,48% | -66,47% |  | GFLOPS | -24,71% | -27,95% | -28,21% | -28,39% | -42,38% |
| Memcpy AB | -4,53% | -7,74% | 0,02% | 0,04% | -6,68% |  | Memcpy AB | 0,16% | 5,22% | -0,51% | -0,38% | -8,33% |
| Memcpy C | -0,45% | -7,10% | 0,23% | 0,10% | -12,78% |  | Memcpy C | 0,03% | -4,17% | 0,18% | 0,15% | -11,94% |
| Kernel | 23,76% | 23,99% | 23,61% | 23,74% | -33,87% |  | Kernel | 26,73% | 25,53% | 26,04% | 26,09% | 37,25% |
| Malloc | 0,00% | 0,00% | 0,00% | 0,00% | 0,00% |  | Malloc | 0,00% | 0,00% | 0,00% | 0,00% | 0,00% |
| Sync | 0,00% | -7,07% | 34,37% | 0,00% | 16,41% |  | Sync | 0,00% | -93,67% | 18,28% | 6,18% | -36,85% |
| Free | 0,00% | 45,26% | 48,28% | 0,00% | 39,97% |  | Free | 0,00% | -31,21% | 29,29% | 0,00% | 4,80% |
|  |  |  |  |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |
| 8192 | Min | Max | Avg | Median | StdDV |  | 16384 | Min | Max | Avg | Median | StdDV |
| time\* | 22,27% | 23,61% | 22,63% | 22,64% | 38,36% |  | time\* | 23,01% | 23,40% | 23,62% | 23,63% | 37,00% |
| GFLOPS | -30,90% | -28,64% | -29,25% | -29,26% | -3,35% |  | GFLOPS | -30,54% | -29,88% | -30,92% | -30,94% | -7,01% |
| Memcpy AB | -0,11% | 2,09% | -0,01% | -0,35% | 17,25% |  | Memcpy AB | -0,24% | -8,58% | -0,48% | -0,51% | -7,12% |
| Memcpy C | 0,01% | 1,74% | 0,00% | -0,02% | 10,16% |  | Memcpy C | 0,00% | -0,81% | -0,07% | -0,04% | -67,20% |
| Kernel | 24,21% | 26,11% | 24,59% | 24,59% | 48,35% |  | Kernel | 24,02% | 24,90% | 24,64% | 24,65% | 44,85% |
| Malloc | 0,00% | 0,00% | 0,00% | 0,00% | 0,00% |  | Malloc | 0,00% | 0,00% | 0,00% | 0,00% | 0,00% |
| Sync | 0,00% | -124,05% | -10,12% | -25,93% | -28,34% |  | Sync | 100,00% | 73,52% | -14,35% | -22,48% | 49,19% |
| Free | 0,00% | -17,45% | -472,86% | 0,00% | -129,62% |  | Free | 0,00% | 3,67% | -2,48% | 0,00% | -2,80% |

Auch hier konnte durch shared memory eine Leistungssteigerung mit ähnlichen Ausprägungen erreicht werden. Eine Tendenz einer Gewinnzunahme zeigte sich hier wie oben. Der wesentliche Anteil macht der Zugewinn direkt im Kernel aus, ebenfalls im Schritt von den Matrixgrößen 4096 auf 8192 zeigt sich eine Gewinnabnahme im Kernel sowie von 8192 auf 16384 eine gewisse Stabilität. Die Werte im Speicherübertragungen sind auch hier unwesentlich, die übrigen Werte sind ebenfalls aussagelos.



Verwendet wurden die Average-Werte. Die Zeitvorteile nehmen zu. Dies dürfte damit zusammenhängen, dass die eigentliche Arbeit in der höherkomplexen Matrixmultiplikation stattfindet. Das leichte Abfallen im Kernel von 4096 zu 8192 ist insoweit gegenläufig, so dass sich hier aufgrund der folgenden Verflachung ein lokales Maximum gebildet hat.