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Aufgabenblatt 4

Aufgabe 4.1

```
Time scalar: 85.058 ms
Time SIMD:   20.9749 ms, speed up 4.05523
SIMD and scalar results are the same.
```

4_1.out

Der theoretische Speedup beim Einsatz von SIMD in diesem Beispiel beträgt 4. Das liegt daran, dass ein SIMD-Vektor vier float-Werte gleichzeitig verarbeiten kann. Somit werden vier Berechnungen parallel durchgeführt, während die skalare Version jede Berechnung einzeln ausführt.
In unserem Output ist der gemessene Speedup tatsächlich 4.
Das bedeutet, dass die SIMD-Version in diesem Fall viermal schneller ist als die skalare Version.

Aufgabe 4.2

```
// Ergebnisse für NVectors = 10000:

Time scalar: 0.168085 ms
Time SIMD1:   0.09799 ms, speed up 1.71533
Time SIMD2:   0.0751019 ms, speed up 2.2381
Time SIMD3:   0.0939369 ms, speed up 1.78934
Time SIMD4:   0.0741482 ms, speed up 2.26688
SIMD1 and scalar results are the same.
SIMD2 and scalar results are the same.
SIMD3 and scalar results are the same.
SIMD4 and scalar results are the same.
```

```
// Ergebnisse für NVectors = 10000000:

Time scalar: 166.557 ms
Time SIMD1:   99.0598 ms, speed up 1.68138
Time SIMD2:   81.12 ms, speed up 2.05322
Time SIMD3:   98.0229 ms, speed up 1.69916
Time SIMD4:   80.956 ms, speed up 2.05738
ERROR! SIMD1 and scalar results are not the same.
ERROR! SIMD2 and scalar results are not the same.
ERROR! SIMD3 and scalar results are not the same.
ERROR! SIMD4 and scalar results are not the same.
```

Beobachtung #1 - Die SIMD-Implementierungen mit reinterpret_cast sind schneller als die mit expliziten Kopien:

- Dies liegt daran, dass beim Kopieren jeder Wert einzeln aus dem Array geladen und in den SIMD-Vektor geschrieben werden muss, was zusätzlich viel Zeit braucht
- Mit reinterpret_cast kann der Speicherbereich direkt als SIMD-Vektor interpretiert werden, wodurch diese Zwischenschritte entfallen und die Daten effizienter verarbeitet werden können

Beobachtung #2 - Die SIMD-Implementierungen haben nur einen Speedup von 1.7-2.3x und nicht den theoretisch erwarteten 4x:

- Die CPU kann viel Zeit damit verbringen, auf Daten aus dem Arbeitsspeicher zu warten. SIMD kann Daten nur so schnell verarbeiten, wie sie geladen werden
- Bei kleinen Arrays passen alle Daten in den Cache, sodass sowohl Skalar- als auch SIMD-Code schnell sind und der Speedup geringer ausfällt
- Der Compiler kann den Skalar-Code optimieren, was den Unterschied verringern könnte

Beobachtung #3 - Kein großer Speedup-Unterschied zwischen kleinen und großen NVectors:

- Bei kleinen Arrays passen alle Daten in den Cache, bei großen Arrays sind beide Varianten speichergebunden und der Speedup bleibt ähnlich

Beobachtung #4 - Bei großer Problemgröße (NVectors = 10000000) stimmen die SIMD- und Skalar-Ergebnisse nicht exakt überein, bei kleiner Problemgröße (NVectors = 10000) jedoch schon:

- Bei sehr großen Arrays entstehen kleine Unterschiede zwischen den Ergebnissen, weil Computer mit Fließkommazahlen nur begrenzt genau rechnen können. Dadurch können sich die kleinen Abweichungen mit der Zeit aufsummieren

Aufgabe 4.3

siehe *CheckSum.cpp*

```
Time scalar: 97.5459 ms
Time INT:   23.9129 ms, speed up 4.07921
Time SIMD:   7.80392 ms, speed up 12.4996
Results are the same.
```

Aufgabe 4.4

ohne SIMD-Vektoren

```
[INFO] Epoch 1
[INFO] Training finished in 39
seconds.
[INFO] Accuracy Training: 87.49%
[INFO] Loss Training: 0.49
[INFO] Testing finished in 5 seconds.
[INFO] Accuracy Testing: 91.90%
[INFO] Loss Testing: 0.28


-----------------------------------
[INFO] Epoch 2
[INFO] Training finished in 39
seconds.
[INFO] Accuracy Training: 92.70%
[INFO] Loss Training: 0.26
[INFO] Testing finished in 5 seconds.
[INFO] Accuracy Testing: 93.96%
[INFO] Loss Testing: 0.21

-----------------------------------
[INFO] Epoch 3
[INFO] Training finished in 39
seconds.
[INFO] Accuracy Training: 94.34%
[INFO] Loss Training: 0.20
[INFO] Testing finished in 5 seconds.
[INFO] Accuracy Testing: 95.00%
[INFO] Loss Testing: 0.17

-----------------------------------
[INFO] Epoch 4
[INFO] Training finished in 39
seconds.
[INFO] Accuracy Training: 95.36%
[INFO] Loss Training: 0.16
[INFO] Testing finished in 5 seconds.
[INFO] Accuracy Testing: 95.74%
[INFO] Loss Testing: 0.15

-----------------------------------
[INFO] Epoch 5
[INFO] Training finished in 39
seconds.
[INFO] Accuracy Training: 96.07%
[INFO] Loss Training: 0.14
[INFO] Testing finished in 5 seconds.
[INFO] Accuracy Testing: 96.18%
[INFO] Loss Testing: 0.13
```

mit SIMD-Vektoren

```
[INFO] Epoch 1
[INFO] Training finished in 15
seconds.
[INFO] Accuracy Training: 87.49%
[INFO] Loss Training: 0.49
[INFO] Testing finished in 1 seconds.
[INFO] Accuracy Testing: 92.20%
[INFO] Loss Testing: 0.28


-----------------------------------
[INFO] Epoch 2
[INFO] Training finished in 15
seconds.
[INFO] Accuracy Training: 92.75%
[INFO] Loss Training: 0.26
[INFO] Testing finished in 1 seconds.
[INFO] Accuracy Testing: 94.06%
[INFO] Loss Testing: 0.21

-----------------------------------
[INFO] Epoch 3
[INFO] Training finished in 15
seconds.
[INFO] Accuracy Training: 94.35%
[INFO] Loss Training: 0.20
[INFO] Testing finished in 1 seconds.
[INFO] Accuracy Testing: 94.78%
[INFO] Loss Testing: 0.18

-----------------------------------
[INFO] Epoch 4
[INFO] Training finished in 15
seconds.
[INFO] Accuracy Training: 95.39%
[INFO] Loss Training: 0.16
[INFO] Testing finished in 1 seconds.
[INFO] Accuracy Testing: 95.72%
[INFO] Loss Testing: 0.15

-----------------------------------
[INFO] Epoch 5
[INFO] Training finished in 15
seconds.
[INFO] Accuracy Training: 96.14%
[INFO] Loss Training: 0.14
[INFO] Testing finished in 1 seconds.
[INFO] Accuracy Testing: 96.23%
[INFO] Loss Testing: 0.13
```

```
-----------------------------------
[INFO] Epoch 6
[INFO] Training finished in 39
seconds.
[INFO] Accuracy Training: 96.68%
[INFO] Loss Training: 0.12
[INFO] Testing finished in 5 seconds.
[INFO] Accuracy Testing: 96.70%
[INFO] Loss Testing: 0.11

-----------------------------------
[INFO] Epoch 7
[INFO] Training finished in 39
seconds.
[INFO] Accuracy Training: 97.03%
[INFO] Loss Training: 0.10
[INFO] Testing finished in 5 seconds.
[INFO] Accuracy Testing: 96.84%
[INFO] Loss Testing: 0.10

-----------------------------------
[INFO] Epoch 8
[INFO] Training finished in 39
seconds.
[INFO] Accuracy Training: 97.41%
[INFO] Loss Training: 0.09
[INFO] Testing finished in 5 seconds.
[INFO] Accuracy Testing: 97.01%
[INFO] Loss Testing: 0.10

-----------------------------------
[INFO] Epoch 9
[INFO] Training finished in 39
seconds.
[INFO] Accuracy Training: 97.67%
[INFO] Loss Training: 0.08
[INFO] Testing finished in 5 seconds.
[INFO] Accuracy Testing: 97.21%
[INFO] Loss Testing: 0.09

-----------------------------------
[INFO] Epoch 10
[INFO] Training finished in 39
seconds.
[INFO] Accuracy Training: 97.90%
[INFO] Loss Training: 0.07
[INFO] Testing finished in 5 seconds.
[INFO] Accuracy Testing: 97.47%
[INFO] Loss Testing: 0.09
```

```
-----------------------------------
[INFO] Epoch 6
[INFO] Training finished in 15
seconds.
[INFO] Accuracy Training: 96.75%
[INFO] Loss Training: 0.12
[INFO] Testing finished in 1 seconds.
[INFO] Accuracy Testing: 96.48%
[INFO] Loss Testing: 0.12

-----------------------------------
[INFO] Epoch 7
[INFO] Training finished in 15
seconds.
[INFO] Accuracy Training: 97.15%
[INFO] Loss Training: 0.10
[INFO] Testing finished in 1 seconds.
[INFO] Accuracy Testing: 96.88%
[INFO] Loss Testing: 0.11

-----------------------------------
[INFO] Epoch 8
[INFO] Training finished in 15
seconds.
[INFO] Accuracy Training: 97.48%
[INFO] Loss Training: 0.09
[INFO] Testing finished in 1 seconds.
[INFO] Accuracy Testing: 97.15%
[INFO] Loss Testing: 0.10

-----------------------------------
[INFO] Epoch 9
[INFO] Training finished in 15
seconds.
[INFO] Accuracy Training: 97.69%
[INFO] Loss Training: 0.08
[INFO] Testing finished in 1 seconds.
[INFO] Accuracy Testing: 97.22%
[INFO] Loss Testing: 0.09

-----------------------------------
[INFO] Epoch 10
[INFO] Training finished in 15
seconds.
[INFO] Accuracy Training: 97.98%
[INFO] Loss Training: 0.08
[INFO] Testing finished in 1 seconds.
[INFO] Accuracy Testing: 97.50%
[INFO] Loss Testing: 0.09
```

Gesamtzeit über 10 Epochen:

Ohne SIMD:	**mit SIMD:**
Trainingszeit: 10 * 39s = 390s	**Training:** 10 * 15s = 150s
Testingszeit: 10 * 5s = 50s	**Testing:** 10 * 1s = 10s
Gesamtzeit: 440s	**Gesamt:** 160 s

Speedup = $\frac{440s}{160s}$ = 2,75