A SIMD implementation of the Deterministic Annealing Filter for the CBM experiment

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The main challenge of the CBM experiment is an extremely high track density. This leads to overlapping of the hits and the distortion of their position. In order to reduce an influence of the attached distorted or noise hits on the reconstructed track parameters the Deterministic Annealing Filter (DAF) [1] is under development within the Kalman filter (KF) package.

The idea of DAF is to introduce "temperature" depending weight to each hit and perform several filtration iterations gradually "cooling" the system. With "cooling" weights for noise hits are gradually decreasing to zero, while for true hits they are remaining high. After the first pass of the Kalman filter based smoother with equal weights the track position is predicted at every layer of the detector. Based on these predictions the probability, that a hit belongs to the track, and the weight of a hit are calculated. Decreasing the temperature the influence of noise hits is suppressed with each next iteration. On each iteration weights are recalculated using smoothed track parameters from the previous iteration.

Most modern CPUs has SIMD units, which currently can give speedup of factor 4 for single-precision floating-point calculations. In the nearest future speedups of 8 and 16 will be available. Therefore in order to utilize the whole potential of CPU the implementation of DAF should be based on the SIMD instruction set.

Currently the DAF implementation is based on the SIMD KF track fitter [2]. The Kalman filter mathematics has been modified in order to include weights of hits. Since DAF needs smoothed track parameters, the KF based smoother has been added to the KF package. The smoother is implemented as two Kalman filters processing in opposite directions: forward and backward. Parameters and covariance matrices of the track, that are calculated by these filters, are merged at the hit position. During the iteration in DAF the same hit weights are used both for the forward and backward filters. Weights are calculated by:

$$p = \frac{1}{1+\exp\left((\chi^2-\chi^2_{\text{cut}})/(2T)\right)},$$

where p is a weight of the hit on the station; T — "temperature" of the current iteration, the values of $T = 9$, 4, 1 and 0.1 are used in the algorithm; χ^2 is a squared distance between the hit and a smoothed track position normalized on the hit and track parameters errors; χ^2_{cut} is a threshold, which determines the region, where the hit is accepted (the value of $\chi_{\text{cut}} = 4$ has been used, that provides the probability of 99,995% to attach a correct hit for the normal distribution).

Tests for time and fit quality of the algorithm have been performed on the lxir039 computer with 2 Xeon X5550 processors at 2.7 GHz and 8 MB L3 cache, one core has been used. A setup of 2 stations of the Micro-Vertex Detector (MVD) and 8 stations of the Silicon Tracking System (STS) has been used. For tests 20000 long reference primary tracks, reconstructed with the CA track finder, have been used. The tracks could have on average up to 0.5% incorrectly attached hits.

To test the algorithm the hit on the 4^{th} STS station has been displaced by a certain amount of the hit error (σ_{hit} = 17 μm) along the X direction from the Monte-Carlo position. The percentage of rejected hits has been calculated on all stations of the detectors. The obtained results are given in Table . As one can see, the current implementation gives good noise hits rejection for distant hits. The execution time of DAF is 14 μs per track.

Table 1: Percentage of rejected hits depending on the distance from the shifted hit on the 4^{th} STS station to its Monte-Carlo position

Hit displacement		unshifted	5 σ_{hit}	10 σ_{hit}	20 σ_{hit}
MVD	1	0.4	0.4	0.4	0.4
	2	0.7	0.7	0.7	0.7
STS	1	0.3	0.3	0.3	0.3
	2	0.4	0.4	0.4	0.4
	3	0.4	0.7	0.8	0.5
	4	0.5	43.9	85.0	98.7
	5	0.5	1.6	1.6	0.8
	6	0.6	0.6	0.6	0.6
	7	0.6	0.6	0.6	0.6
	8	0.1	0.1	0.1	0.1

The DAF algorithm will be further investigated within the CA track finder.

References

[1] R. Frühwirth and A. Strandlie, Track fitting with ambiguities and noise: a study of elastic tracking and nonlinear filters. Comp. Phys. Comm. **120** (1999) 197

[2] S. Gorbunov *et al.*, Comp. Phys. Comm. **178** (2008) 374