Speedup approaches in a TPC Cellular Automaton track finder

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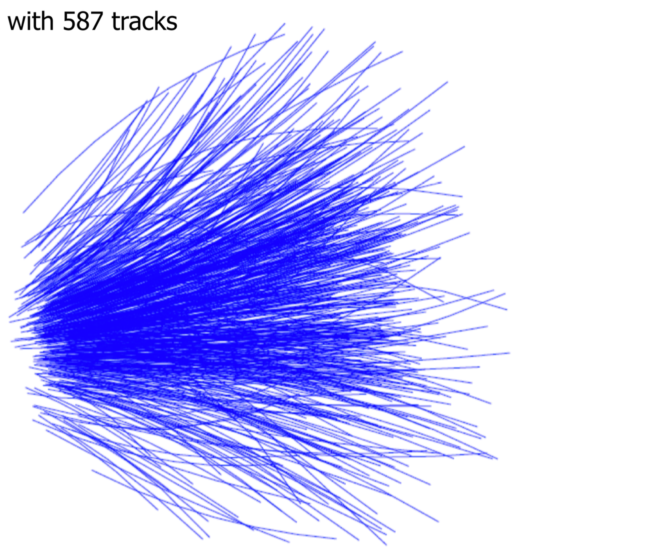
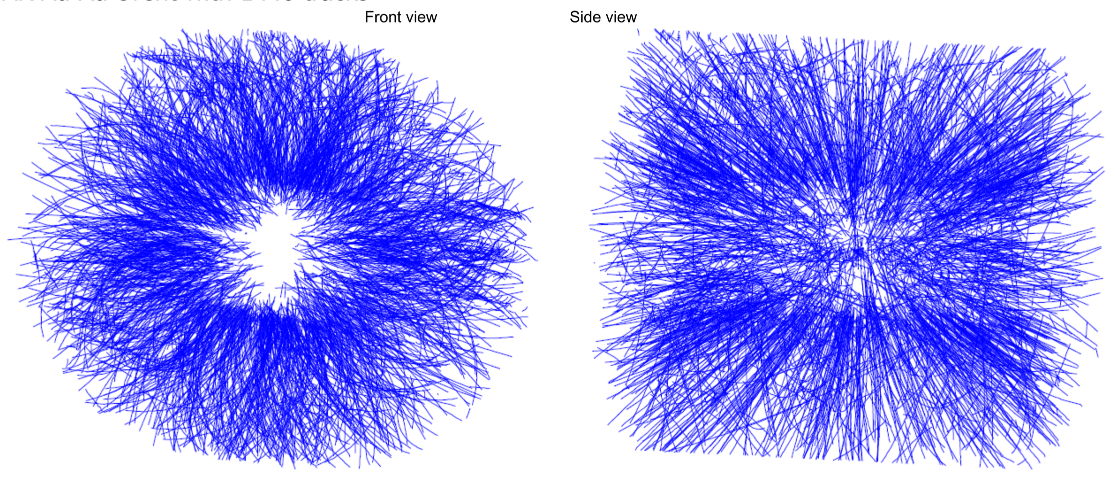
CA track finder in the CBM and STAR experiment

CBM Au-Au event with 587 tracks

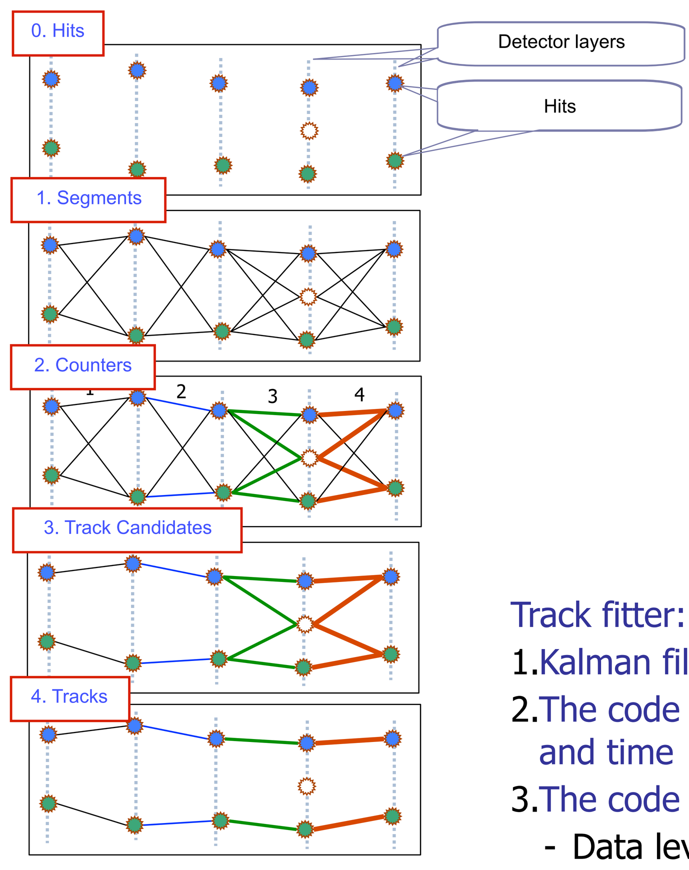


- CBM - future fixed-target heavy-ion experiment at FAIR, Darmstadt, Germany.
- Interaction rate: 10^5-10^7 collisions per second.
- Up to 1000 charged particles/collision.
- High speed and efficiency of the reconstruction algorithms are required.
- The algorithms have to be highly parallelised and scalable.
- CBM event reconstruction: Kalman Filter and Cellular Automaton.

STAR Au-Au event with 1446 tracks



- STAR - collider experiment at RHIC, BNL.
- Up to 200 AGeV Au-Au collisions.
- Main detector – TPC.
- Standard Sti track reconstruction is based on track following.
- Increased RIHC luminosity.
- Upgrade the reconstruction algorithms for:
  - vectorization
  - multi-threading
  - many-core systems
- Study of the CA tracking algorithm within FAIR Phase 0.



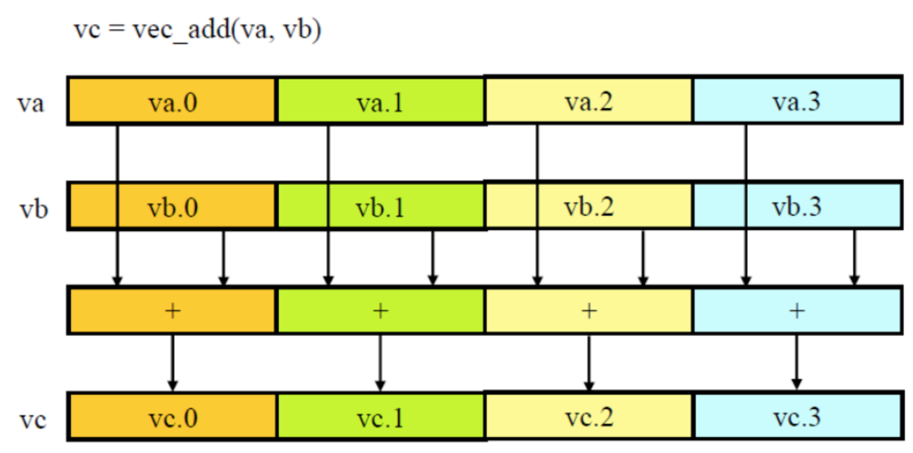
Cellular Automaton algorithm:
1. Build short track segments.
2. Connect according to the track model, estimate a possible position on a track.
3. Tree structures appear, collect segments into track candidates.
4. Select the best track candidates.

Cellular Automaton preferences:
- local w.r.t. data
- intrinsically parallel
- extremely simple
- very fast

Perfect for many-core CPU/GPU !

Track fitter:
1. Kalman filter for track segments fit
2. The code is optimised with respect to both efficiency and time
3. The code is parallelised
   - Data level (SIMD instructions, 4 single-precision floating point calculations in parallel)
   - Task level (ITBB, parallelisation between cores)

Vectorization and data structures



- SIMD intrinsics with Vc headers are used.
- Faster calculations with the same hardware.
- Optimal for streaming calculations.
- Applicable for vectors with 4, 8, 16 elements.

Application of the SIMD intrinsics in CA
- Vectorisation of the grid structure: reduces the number of calls to the grid structure and creates data streams.
- Vectorisation of the track segment fitting and extrapolation.
- Vectorisation of tracks and segments selection.

Scalar objects:
- Good for data sorting - object information in the same cash line.
- Vectorization needs data movement.

```
float | X | Y | Z |   |
```

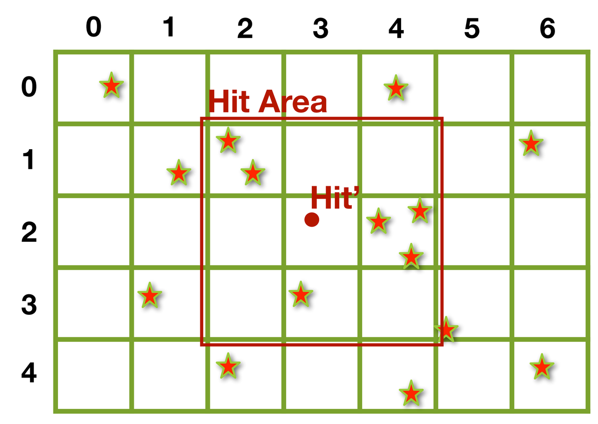
Vectorized objects:
- Good for stream calculations - data is grouped in vectors and ready for usage.
- Complicated data movements in case of combinatorics.

```
float_v | X | X | X | X |
float_v | Y | Y | Y | Y |
float_v | Z | Z | Z | Z |
```

Structure of arrays:
- Data is grouped and ready fore use in vector mode.
- Faster combining variables into vectors in case of random memory access.

```
float [] | X | X | X | X | X | X | X |
float [] | Y | Y | Y | Y | Y | Y | Y |
float [] | Z | Z | Z | Z | Z | Z | Z |
```

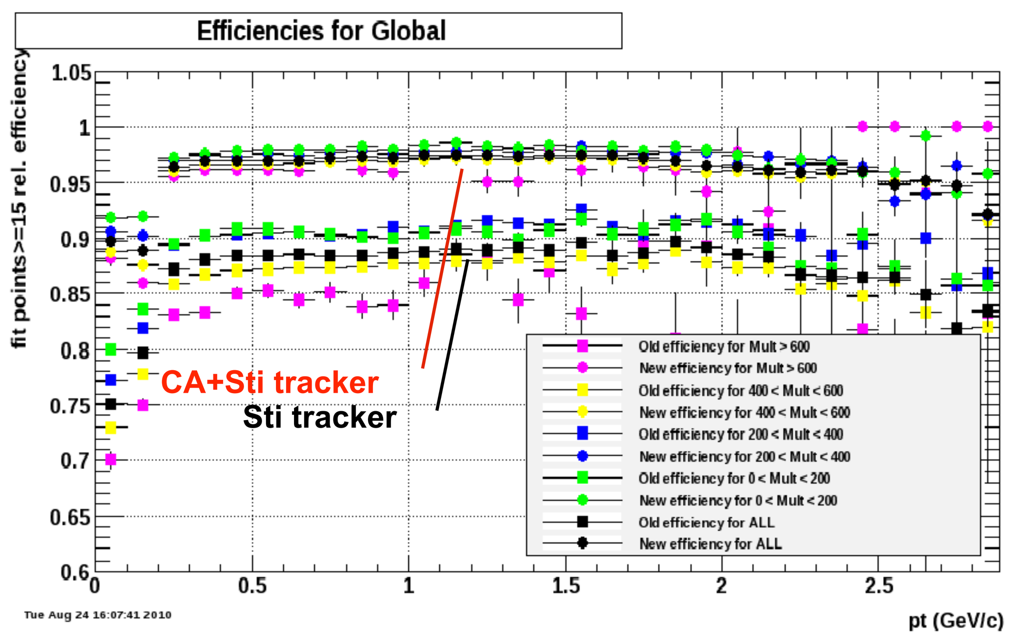
Grid structure helps to sort data and make fast and easy access to it.



- Hits are stored in memory line by line and ready for sequential access.
- Can estimate number of a bin by coordinates of the hit or point.
- Allows to get hit by number of bin without going through all of them.

Hit Area gives access to all hits in the surrounding area of in a neighbourhood of the selected point (Hit') with known coordinates.

TPC CA track finder



TPC CA alone efficiencies (%)

	Vectorized
Ref Set	97.5
AllSet	93.3
Clone	10.6
Ghost	13.7
Reco tracks/ev	650
Hits per track	22.4

All set: p ≥ 0.05 GeV/c
Reference set: p ≥ 1 GeV/c
Ghost: purity < 90%

CA track finder was installed in the STAR experiment and shows advantage over the standard Sit track finder based on the track following:
- Stable at high track multiplicity;
- Higher efficiency;
- About 10 time faster.

TPC CA track finder is used in online and offline reconstruction in STAR.

TPC CA tracking procedure improvements

For every TPC sector

Chains constructor
- Create triplets - 3-hit segments on neighbouring stations;
- Combine triplets into long chains of hits.

Scalar: 15.7 ms; Vector: 12.2 ms

Tracklets constructor
- Go through hit chains and fit them;
- Add more hits to tracklets if possible.

Scalar: 7.0 ms; Vector: 3.8 ms

Segments constructor
- Calculation of short segments allows to optimise memory usage.
- Optimal fit vectorization because of uniform segments length.

Mini merger
- Merging of segments inside of the slice.
- Vectorized selection of segments and merging procedure.
- Do not need to refit full tracks.

Global

Track merger
- Merge tracklets inside and between TPC slices.

Scalar: 18.4 ms; Vector: 12.0 ms

Track merger optimisation
- Vectorized track selection procedure.
- Track selection without refitting of tracks.
- Refit only merged tracks.
- Scalable on SSE and AVX.

Intel Xeon X5550 at 2.7GHz

Conclusions

- CA track finder is successfully applied in the CBM and STAR experiments.
- CA track finder procedure is fast, intrinsically parallel, and efficient.
- For efficient vectorization, optimal data structures are needed.
- The new scheme for data storage and organisation of data streams is proposed and being implemented.

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