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Event mixing in O2

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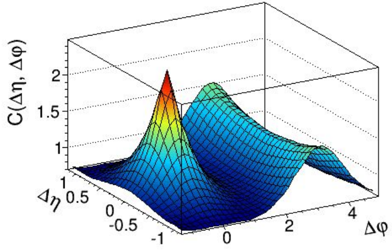
A novel algorithm of event mixing for ALICE Run 3

Angular and femtoscopic correlations: analyzing QGP initial state and thermalization mechanisms

Correlation function:

$$S(\Delta\eta, \Delta\phi) = \frac{d^2 N^{signal}}{\Delta\eta\Delta\phi} \quad B(\Delta\eta, \Delta\phi) = \frac{d^2 N^{mixed}}{\Delta\eta\Delta\phi}$$

$$C(\Delta\eta, \Delta\phi) = \frac{N^{mixed}}{N^{signal}} \frac{S(\Delta\eta, \Delta\phi)}{B(\Delta\eta, \Delta\phi)}$$



Event mixing: **pairs of tracks** (V0s/cascades/…) from **2 different collisions** from the **same bin,** e.g., multiplicity and z-vertex intervals.

Run 2: sort collisions into **a vector of mixing buffers**, at the same time select pairs in a double loop

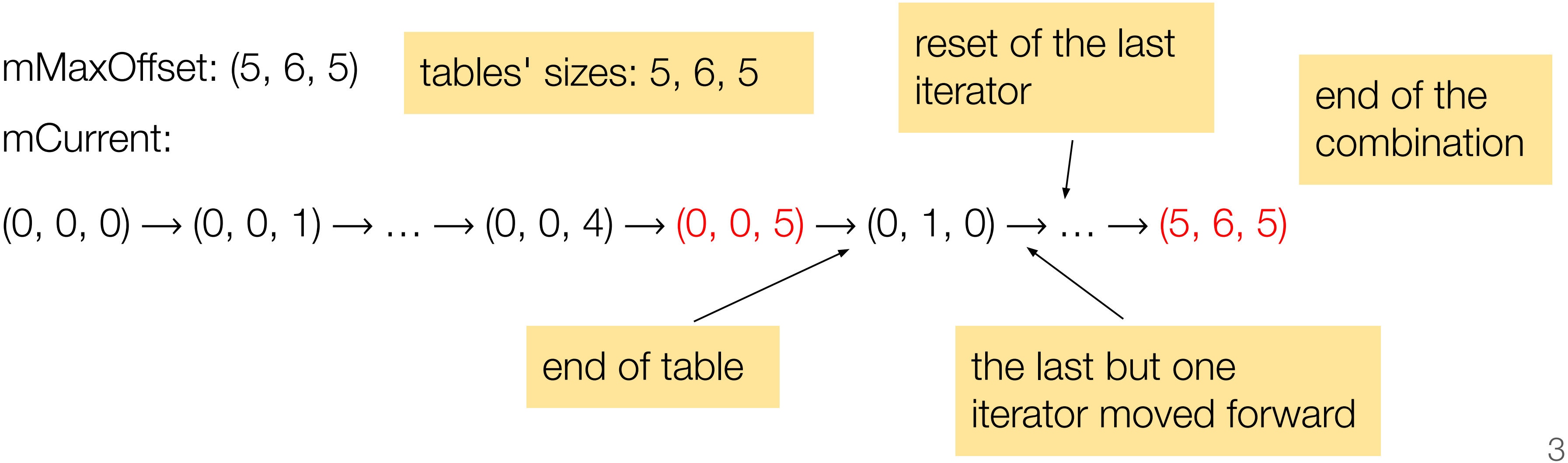
Run 3: many more collisions → **big** memory and time **overhead**
Idea: **lazy** generation (one at time) of combinations of elements, **without data copies**
mixed-event pairs: **binned combinations** of collisions + full track combinations
Universal – any n-tuple, any table.

How to implement combinations **effectively**?

combinations – pairs, triples, … of elements from a table or different tables

Memory to store all tuples: **O(n!)** where n is the table size –> **too much!**
–> **Lazy** generation – one tuple by one

iterator – refers to a certain row in a table



mMaxOffset: (5, 6, 5)

tables' sizes: 5, 6, 5

mCurrent:

(0, 0, 0) ⟶ (0, 0, 1) ⟶ … ⟶ (0, 0, 4) ⟶ (0, 0, 5) ⟶ (0, 1, 0) ⟶ … ⟶ (5, 6, 5)

reset of the last iterator

end of the combination

end of table

the last but one iterator moved forward

Basic combination policies

Table sizes: (5, 6)

1. **Full:** (0, 0), …, (0, 5), **(1, 0)**, …, (1, 5), …, **(4, 0)**, …, (4, 5)
   a. always reset an iterator to table begin
2. **Upper:** (0, 0), …, (0, 5), **(1, 1)**, …, (1, 5), …, **(4, 4)**, (4, 5)
   a. reset to the position of the left iterator
   b. no repetitions of pairs like (0, 1) and (1, 0)
3. **Strictly upper:** (0, 1), …, (0, 5), **(1, 2)**, …, (1, 5), …, **(3, 5)**
   a. reset to the position of the left iterator + 1
   b. max position: (table size - distance from the rightmost iterator) = (4, 6)
   c. no repetitions of pairs like (0, 1) and (1, 0)
   d. no repeated positions within a single tuple, e.g., (0, 0)

Block / binned combination policies

Tuples of elements sharing **a common value** in a specified column, e.g., **a bin number**.

Analogously to basic policies, we have full / upper / strictly upper block combinations.

Different tables:

CombinationsBlockUpperIndexPolicy
CombinationsBlockFullIndexPolicy

Tuples from the same table:

CombinationsBlockUpperSameIndexPolicy
CombinationsBlockFullIndexPolicy
CombinationsBlockStrictlyUpperIndexPolicy

Helper functions (shortcuts)

type – e.g., `aod::Tracks`.
2 different track partitions
have the same C++ type!

Accepts only **same type tables**, applies **block strictly upper** policy

```
selfCombinations(binningPolicy, categoryNeighbours, outsider, tables...)

selfPairCombinations(binningPolicy, categoryNeighbours, outsider, table)

selfTripleCombinations(binningPolicy, categoryNeighbours, outsider, table)
```

If tables are of the same type, applies **block strictly upper**, otherwise **block upper** policy

```
combinations(binningPolicy, categoryNeighbours, outsider, tables...)
```

If tables are the same, applies **strictly upper**, otherwise **upper** policy

```
combinations(tables...)

pairCombinations(table), tripleCombinations(table)
```

Applies **selected combination policy**

```
combinations(combinationPolicy)
```

Using combinations

See some examples in the trackCombinations.cxx tutorial and O2 documentation

```
void process(aod::Tracks const& tracks) {
  for (auto& [track1, track2] : combinations(tracks, tracks)) { ... } // Strictly upper
}
```

tuple size deduced from the number of arguments

```
void process(Tracks const& tracks, V0s const& v0s) {
  for (auto& [track, v0] : combinations(CombinationsFullIndexPolicy(tracks, v0s))) { ... }
}

struct BinnedTrackCombinations {
  std::vector<double> xBins{VARIABLE_WIDTH, -0.064, -0.062, -0.060, 0.066, 0.068, 0.070, 0.072};
  std::vector<double> yBins{VARIABLE_WIDTH, -0.320, -0.301, -0.300, 0.330, 0.340, 0.350, 0.360};
  ColumnBinningPolicy<aod::track::X, aod::track::Y> trackBinning{{xBins, yBins}, true};

  void process(aod::Tracks const& tracks)
  {
    // Strictly upper tracks binned by x and y position
    for (auto& [t0, t1] : selfCombinations(trackBinning, 5, -1, tracks, tracks)) { ... }
  }
};
```

Additional parameters for block combinations

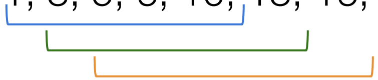
```
selfCombinations(trackBinning, 5, -1, tracks, tracks)
```

Outsider: bin number that should be skipped, e.g., -1 that marks bin over- and underflow.

For performance reasons, we do not want to combine tuples across the whole bin, but only in smaller bin segments (**"sliding windows"**).
The window size is equal to the parameter **category neighbours** + 1.

Example

category neighbours: 4, sliding window size: 5
row numbers in a bin: 1, 3, 5, 6, 10, 13, 16, 19, 23, 26, 29, 34, 36, 38



strictly upper pairs: (1, 3), (1, 5), (1, 6), (1, 10), (3, 5), (3, 6), (3, 10), (3, 13), (5, 6), (5, 10), (5, 13) , (5, 16)

To get the behavior without sliding windows, set category neighbours to a very high value.

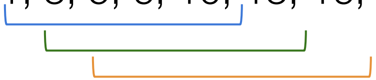
Weighted combinations

You might need to calculate **weights** for your event mixing. You can get useful variables:

- `currentWindowNeighbours()`
  - the number of other collisions to pair with
  - smaller if we are at the end of the sliding window or bin
- bool `isNewWindow()` – true only for the first pair from each sliding window

Example

category neighbours: 4, sliding window size: 5
row numbers in a bin: 1, 3, 5, 6, 10, 13, 16, 19, 23, 26, 29, 34, 36, 38



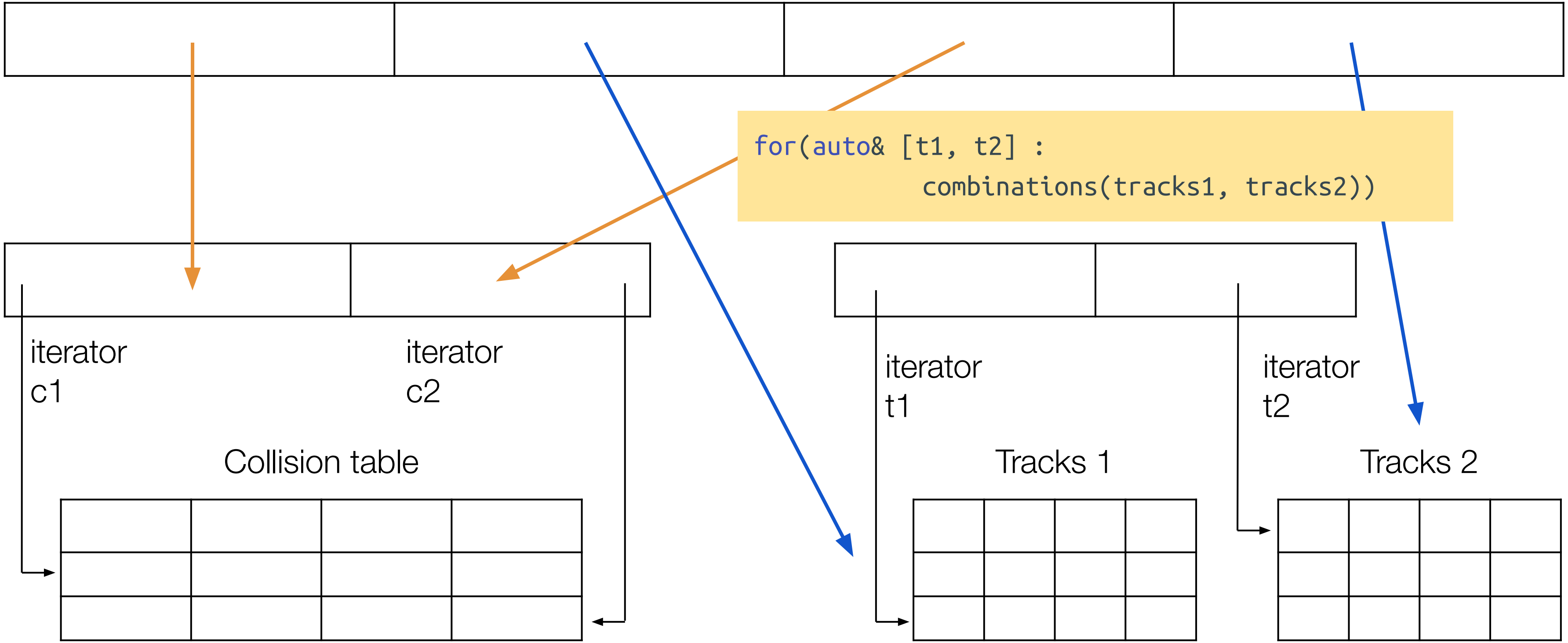
strictly upper pairs: **(1, 3)**, (1, 5), (1, 6), (1, 10), **(3, 5)**, (3, 6), (3, 10), (3, 13), **(5, 6)**, (5, 10), (5, 13) , (5, 16)
`currentWindowNeighbours()`: 4, 3, 2, 1, 4, 3, 2, 1, 4, 3, 2, 1

NOTE: Different behaviour for upper and full index policy, use with caution!
Code example: a mixing test, real-life analysis: Jan Fiete's correlations

Event mixing

```
ColumnBinningPolicy<collision::PosX, collision::PosY> binning{{xBins,yBins}};
SameKindPair<aod::Collisions, aod::Tracks> pair{binning};
for (auto& [c1, tracks1, c2, tracks2] : pair) { ... }
```

`tracks1` (`tracks2`) contains only tracks from the collision `c1` (`c2`)



```
for(auto& [t1, t2] :
          combinations(tracks1, tracks2))
```

Using event mixing

See examples in the eventMixing.cxx tutorial described in O2 documentation here and here.

BinningPolicy: array of bins, bool `ignoreOverflows` – if true, then under- and overflow values get bin -1
SameKindPair: binning policy, number of events to mix, bin number to ignore

```
struct MixedEvents {
  SliceCache cache;
  std::vector<double> xBins{VARIABLE_WIDTH, -0.064, -0.062, -0.060, 0.066, 0.068, 0.070, 0.072};
  std::vector<double> yBins{VARIABLE_WIDTH, -0.320, -0.301, -0.300, 0.330, 0.340, 0.350, 0.360};

  using BinningType = ColumnBinningPolicy<aod::collision::PosX, aod::collision::PosY>;
  BinningType binningOnPositions{{xBins, yBins}, true};
  SameKindPair<aod::Collisions, aod::Tracks, BinningType> pair{binningOnPositions, 5, -1, &cache};

  void process(aod::Collisions const& collisions, aod::Tracks const& tracks) {
    for (auto& [c1, tracks1, c2, tracks2] : pair) {
       // example of using tracks from mixing - iterate over all track pairs
      for (auto& [t1, t2] : combinations(CombinationsFullIndexPolicy(tracks1, tracks2))) { ... }
    }
  }
};
```

same order of bins args!

Mixing types

SameKindPair: pairs of same associated tables, e.g., tracks
Pair: pairs of possibly different tables, e.g., tracks + V0s
SameKindTriple, Triple: analogously

```
struct MixedEventsTripleVariousKinds {
  SliceCache cache;
  BinningType binningOnPositions{{xBins, yBins, zBins}, true};
  Triple<aod::Collisions, aod::Tracks, aod::V0s, aod::Tracks, BinningType>
                                                           triple{binningOnPositions, 5, -1, &cache};
  void process(aod::Collisions const& collisions, aod::Tracks const& tracks, aod::V0s const& v0s)
  {
    // tracks1 is an aod::Tracks table of tracks belonging to collision c1 (aod::Collision::iterator)
    // tracks2 is an aod::V0s table of V0s belonging to collision c2 (aod::Collision::iterator)
    // tracks3 is an aod::Tracks table of tracks belonging to collision c3 (aod::Collision::iterator)
    for (auto& [c1, tracks1, c2, tracks2, c3, tracks3] : triple) {
      for (auto& [t1, t2, t3] : combinations(CombinationsFullIndexPolicy(tracks1, tracks2, tracks3)))
            { ... }
    }
  }
};
```

Even more universality

Other mixed pairs than strictly upper:

```
using BinningType = ColumnBinningPolicy<aod::collision::PosX, aod::collision::PosY>;
using GroupingPolicy = o2::soa::CombinationsBlockFullIndexPolicy<BinningType, int,
                                                                aod::Collisions, aod::Collisions>
Pair<aod::Collisions, aod::Tracks, aod::Tracks, BinningType, int, GroupingPolicy>
```

This will repeat collision pairs like (0, 1) and (1, 0) – probably you won't use it in most cases.

Going beyond pair/tuples:

```
GroupedCombinationsGenerator(binningPolicy, categoryNeighbours, outsider, groupingTable,
                                 associatedTablesTuple)
```

No predefined binning policy for tuples bigger than triples – you need to write it yourself.

Using dynamic columns

Most prominent example: mixing in z-vertex and **multiplicity V0M** bins.

Full code here.

```
struct MixedEventsDynamicColumns {
  SliceCache cache;
  using aodCollisions = soa::Join<aod::Collisions, aod::Mults>;
  std::vector<double> zBins{7, -7, 7};
  std::vector<double> multBins{VARIABLE_WIDTH, 0, 5, 10, 20, 30, 40, 50, 100.1};
  using BinningType = ColumnBinningPolicy<aod::collision::PosZ,
                                    aod::mult::MultFV0M<aod::mult::MultFV0A, aod::mult::MultFV0C>>;
  BinningType corrBinning{{zBins, multBins}, true};
  SameKindPair<aodCollisions, aod::Tracks, BinningType> pair{corrBinning, 5, -1, &cache};

  void process(aodCollisions& collisions, aod::Tracks const& tracks) {
    for (auto& [c1, tracks1, c2, tracks2] : pair) {
      for (auto& [t1, t2] : combinations(CombinationsFullIndexPolicy(tracks1, tracks2))) { ... }
    }
  }
};
```

Lambda binning policy

Sometimes binning parameters are **more complex** than a single column.
For example: multiplicity defined as `tracks.size()`.

Lambda policy: **user-defined calculation of bin numbers**.
Only inside `process()`

Tutorial
Real-life example:
HF flow task

```
auto getTracksSize =
    [&tracks](aod::Collision const& col) {
    auto associatedTracks = tracks.sliceByCached(o2::aod::track::collisionId, col.globalIndex());
    return associatedTracks.size();
};
using BinningType = FlexibleBinningPolicy<std::tuple<decltype(getTracksSize)>,
                                          aod::collision::PosZ, decltype(getTracksSize)>;
BinningType binningWithLambda{{getTracksSize}, {axisVertex, axisMultiplicity}, true};

auto tracksTuple = std::make_tuple(tracks);
SameKindPair<aod::Collisions, aod::Tracks, BinningType> pair{binningWithLambda, 5, -1,
                                                              collisions, tracksTuple, &cache};
```

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Thank you for your attention!

Backup