Acceleration of the PndSttCellTrackFinder by implementing on a GPU

June 8, 2015

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Structure of the Trackfinder

PndSttCellTrackletGenerator.cxx

1. Primary tracklets: use of cellular automaton
2. Combination of tracklets: use of Riemann Fit
3. Add remaining hits to best fitting track

Faulty: Fit to center of the tubes

PndSttHitCorrector.cxx

Correct points for Riemann Fit by calculating tangents to the isochrones

PndSttCellTrackFinderData.cxx

For data exchange

Parallelize!

How to parallelize?

Graphics Processing Unit (GPU)

- General Purpose GPUs (GPGPUs)
- much more processing cores than a CPU
- for massively parallel calculations

CUDA

- API model for parallel computing on GPUs created by NVIDIA
- CUDA C: extension of C/C++
- enables task and data parallelism

How to parallelize?

Parallelism at two levels

Algorithm-level

parallelize the trackfinding algorithm in itself

- useful for computation-intensive parts

Event-level

execute the trackfinder for hundreds/thousands of events at the same time

- promises high speedup

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Start

→ Quick reminder

PndSttHitCorrector.cxx

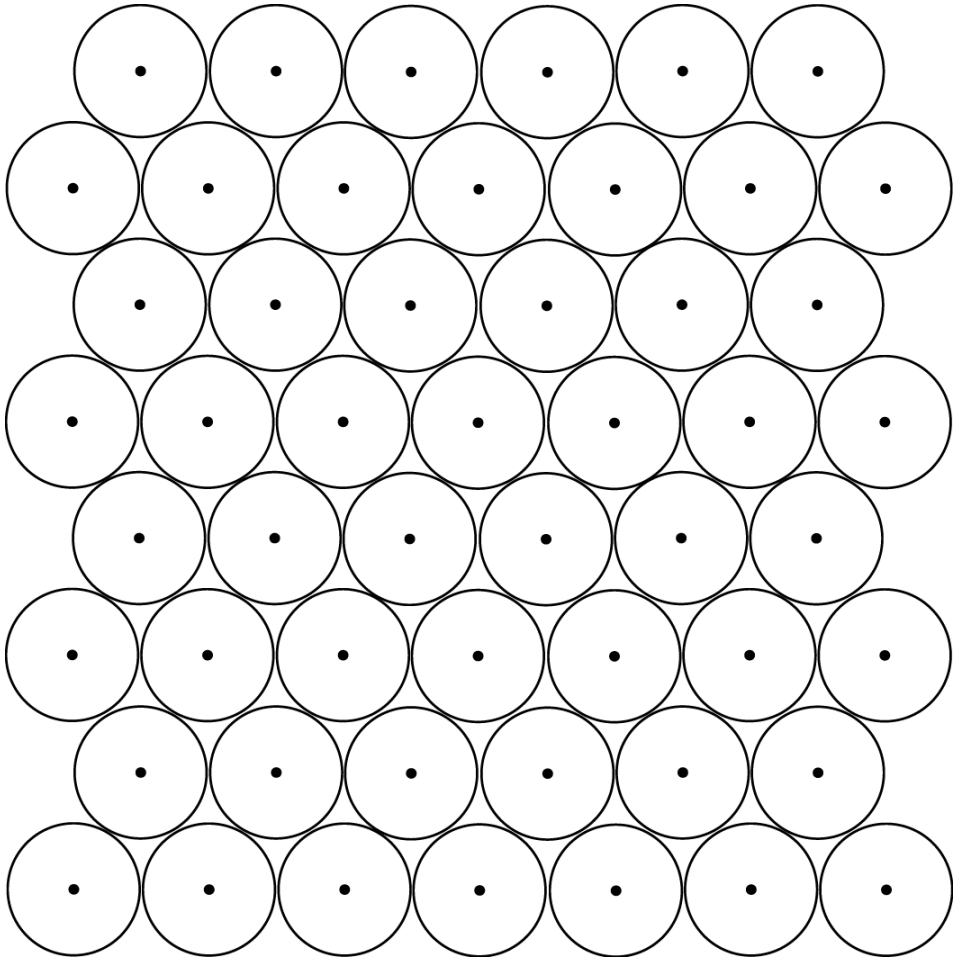
Correct points for Riemann Fit by calculating tangents to the isochrones

PndSttCellTrackFinderData.cxx

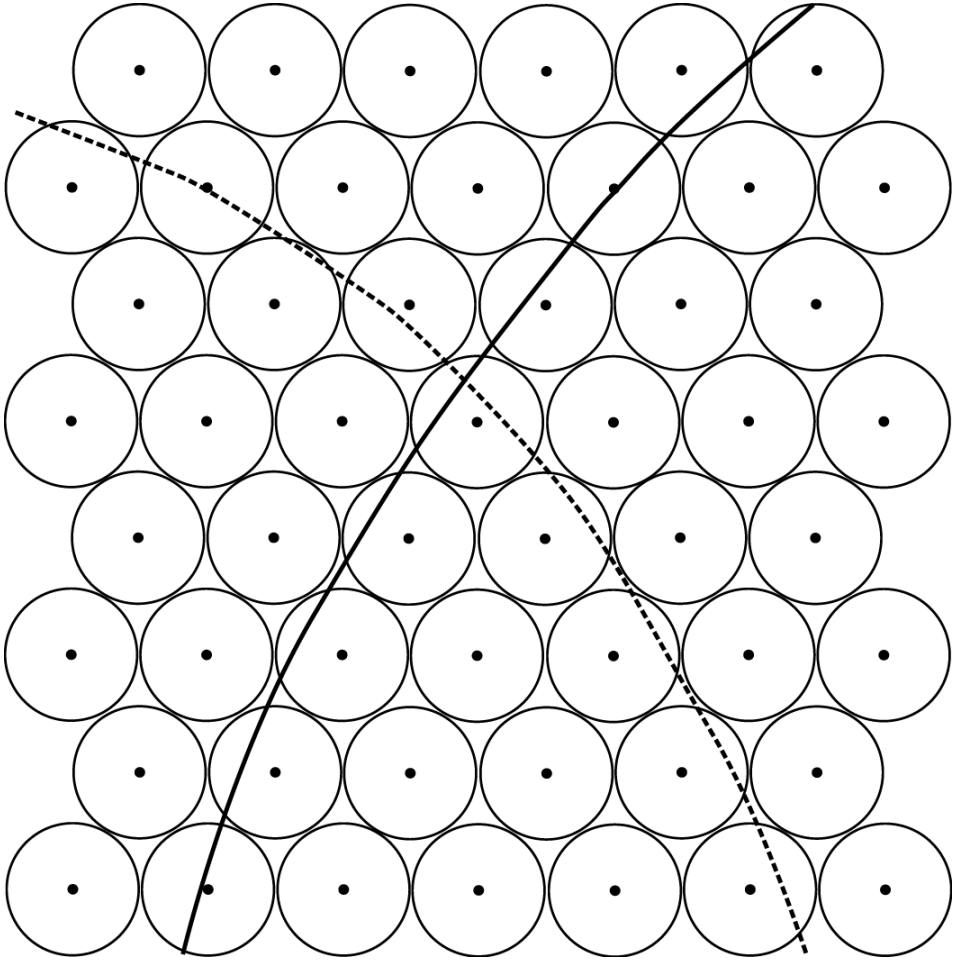
For data exchange

Parallelize!

TrackletGenerator
Cellular Automaton



TrackletGenerator
Cellular Automaton



TrackletGenerator
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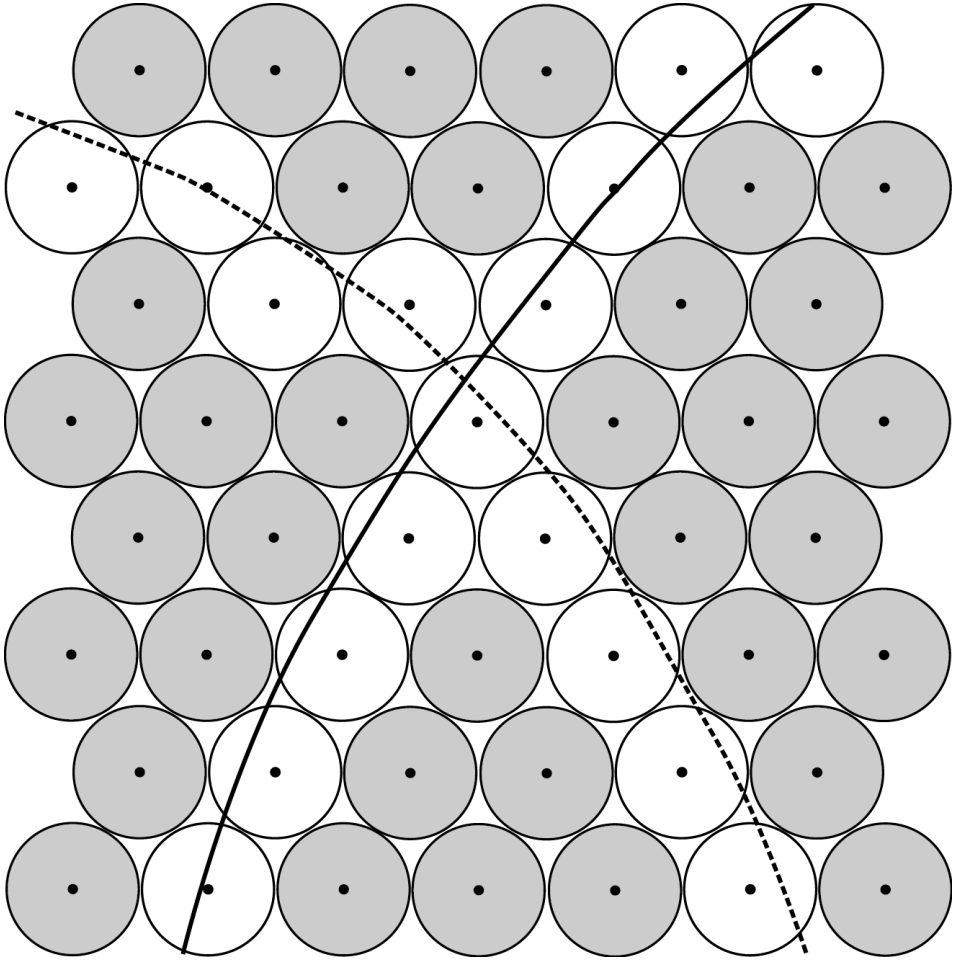

TrackletGenerator
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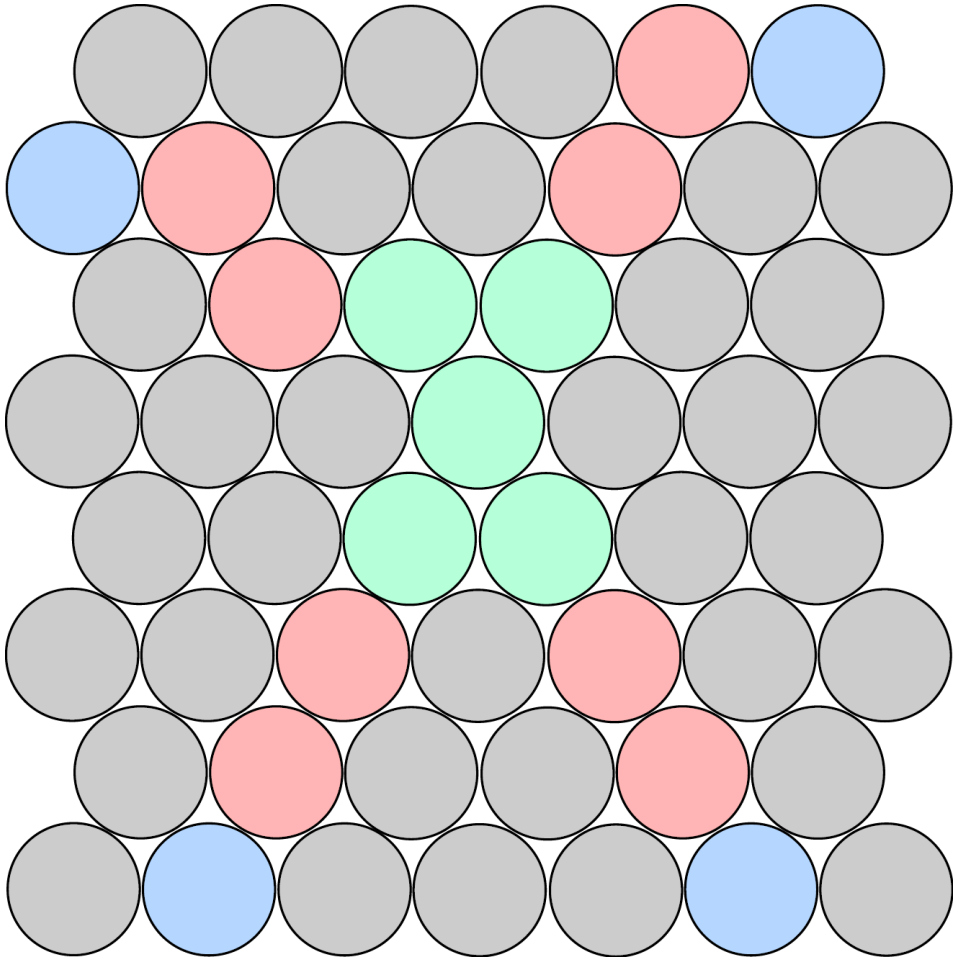


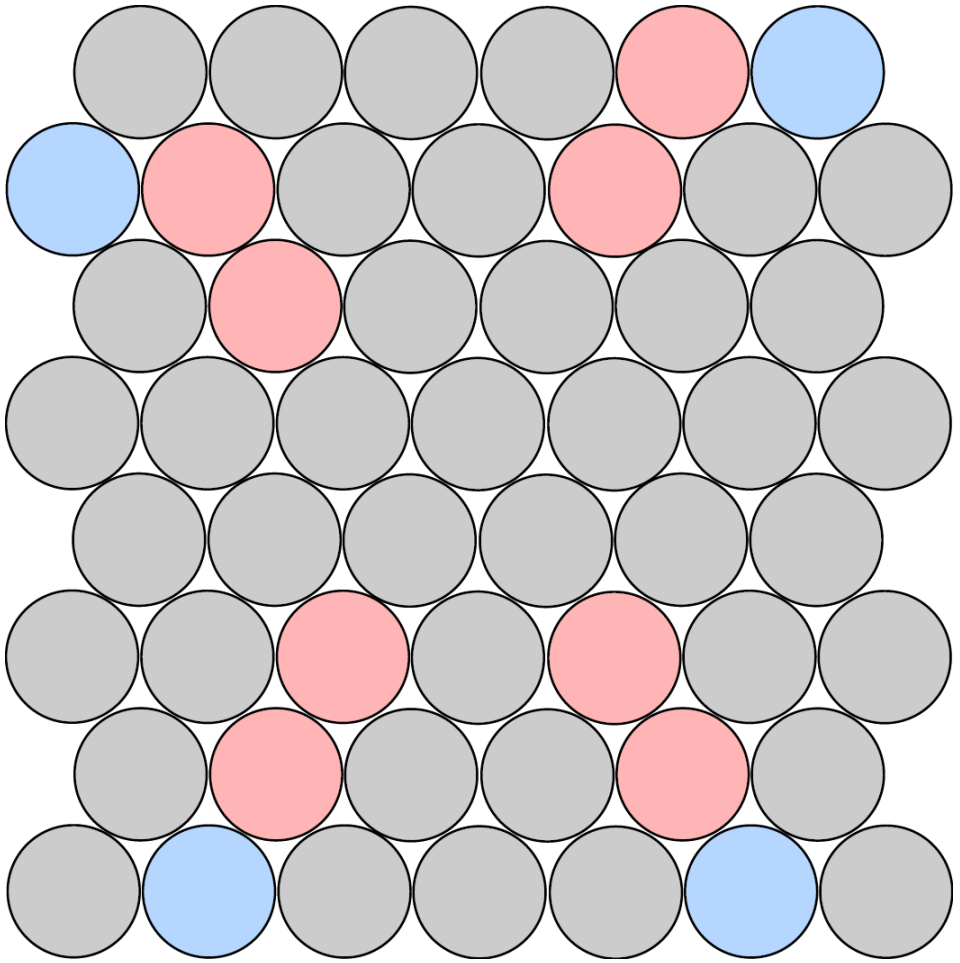
Number of Neighbors:

1 unambiguous

2

> 2 ambiguous

TrackletGenerator
Cellular Automaton – Unambiguous hits



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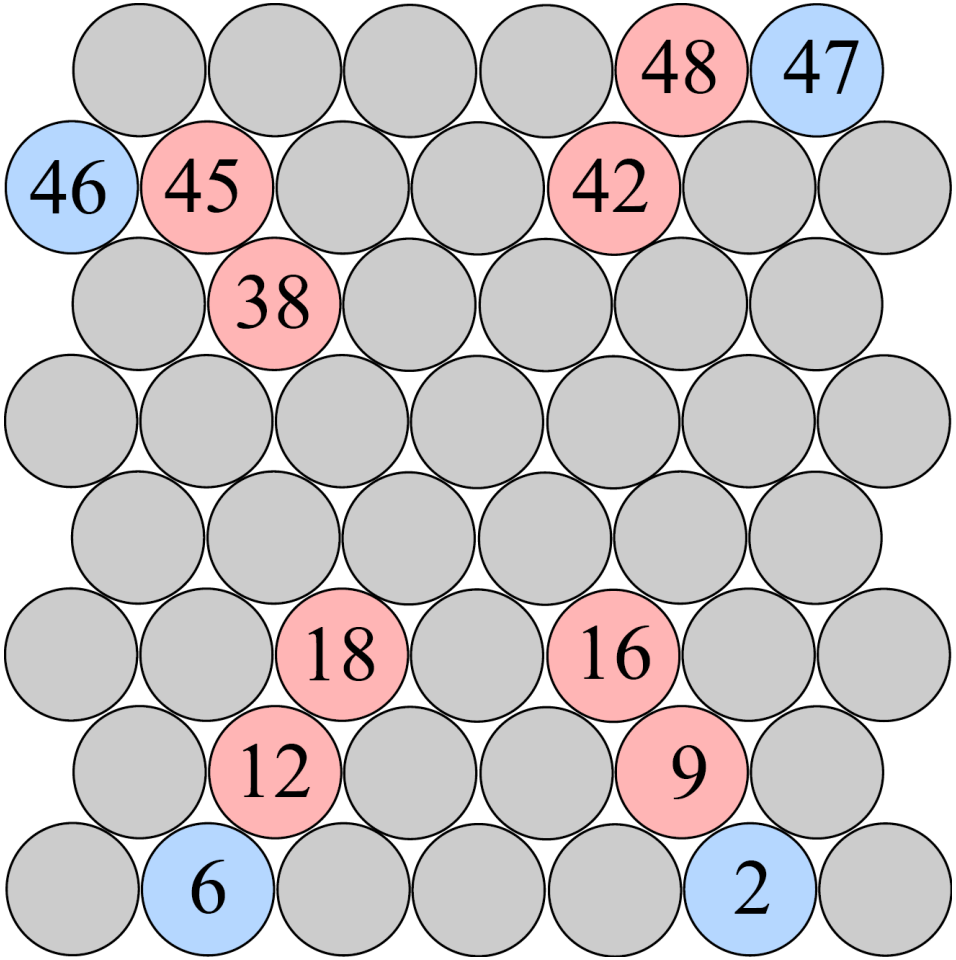
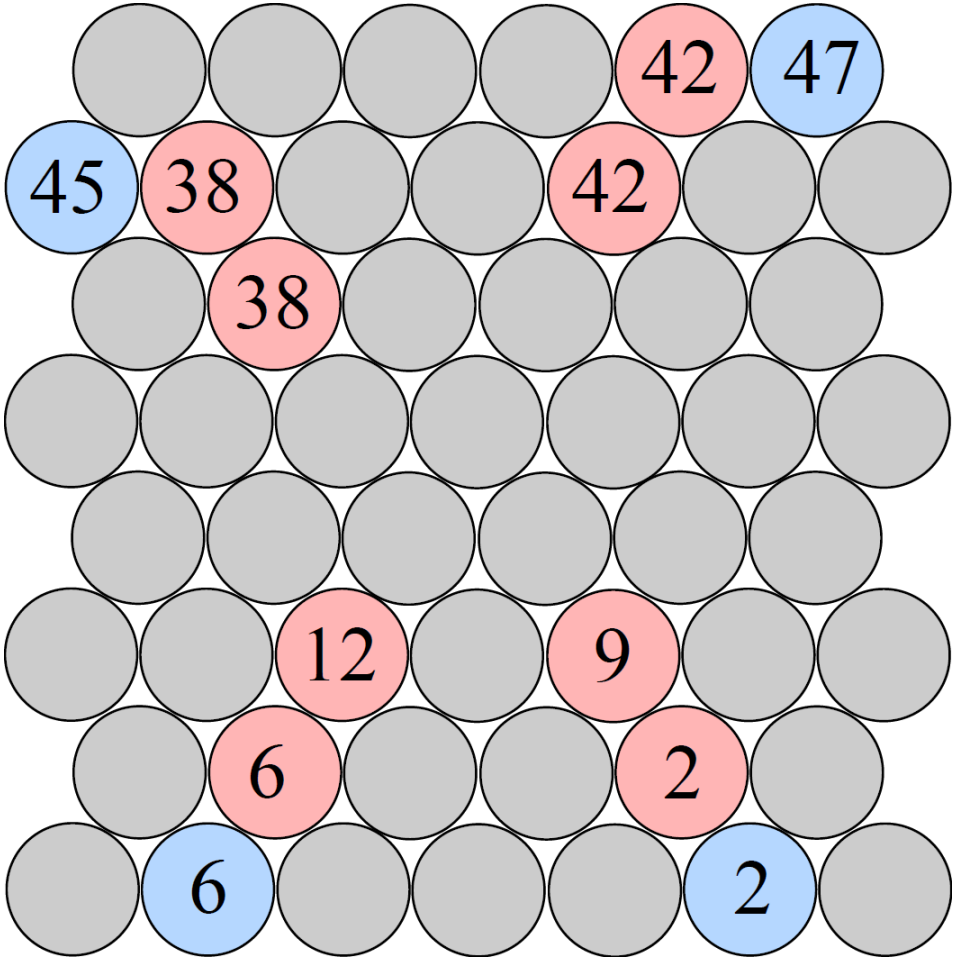
TrackletGenerator
Cellular Automaton – Unambiguous hits



Cell: Straw with hit and one or two neighbors

Rule: Compare your status with the status of your neighbors and take the smallest one

TrackletGenerator
Cellular Automaton – Unambiguous hits



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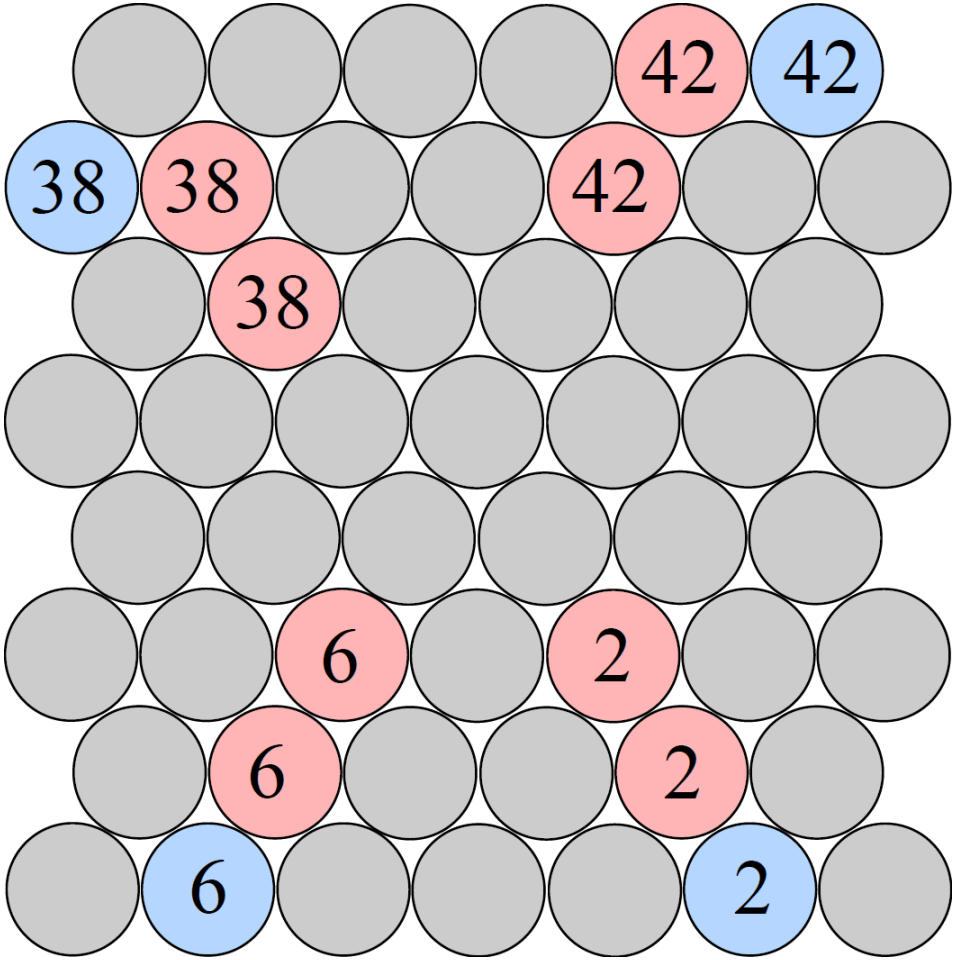

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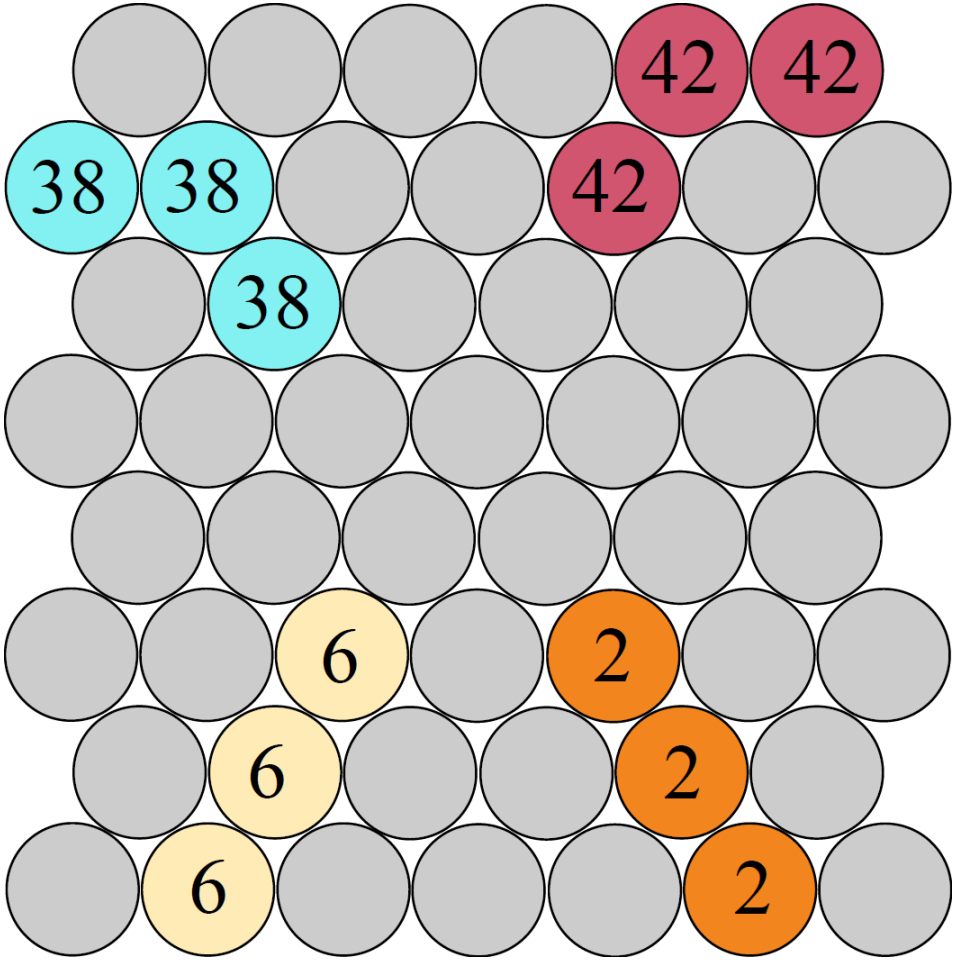

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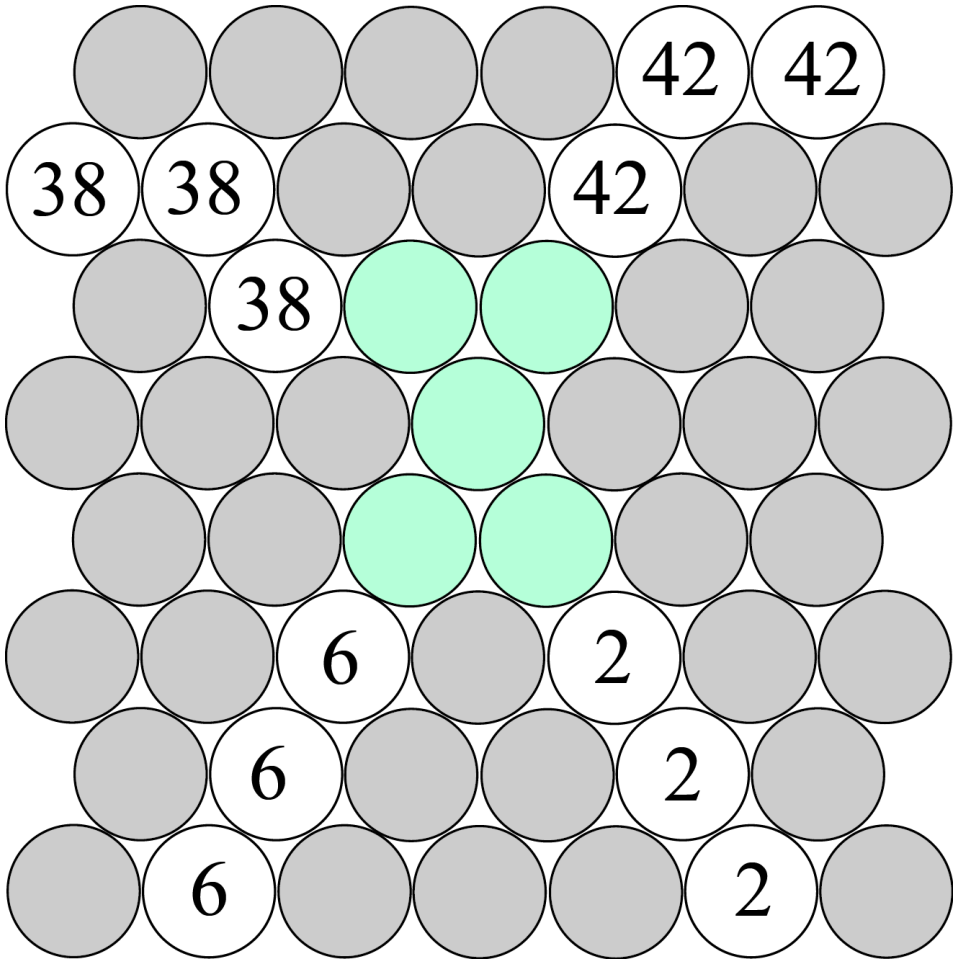
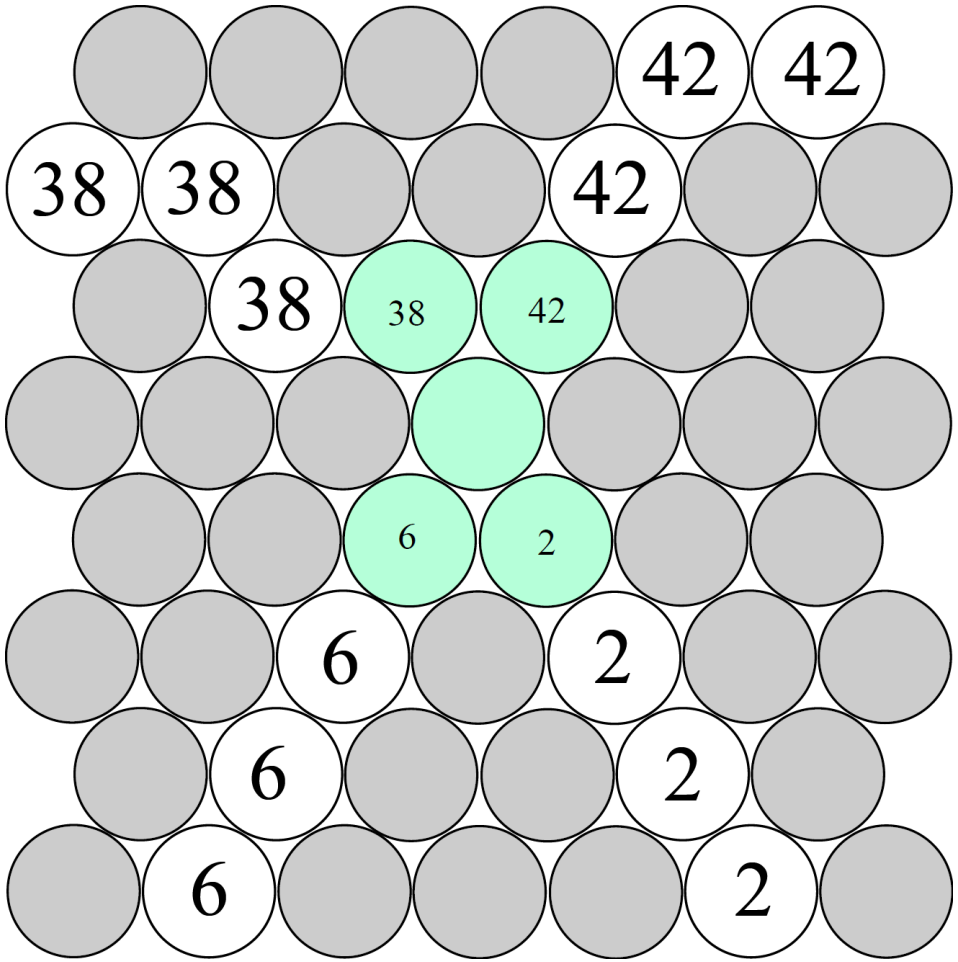
Cellular Automaton – Ambiguous hits



Cell: Straw with hit and more than two neighbors

Rule: Copy the status of all your neighbors into your status

TrackletGenerator
Cellular Automaton – Ambiguous hits



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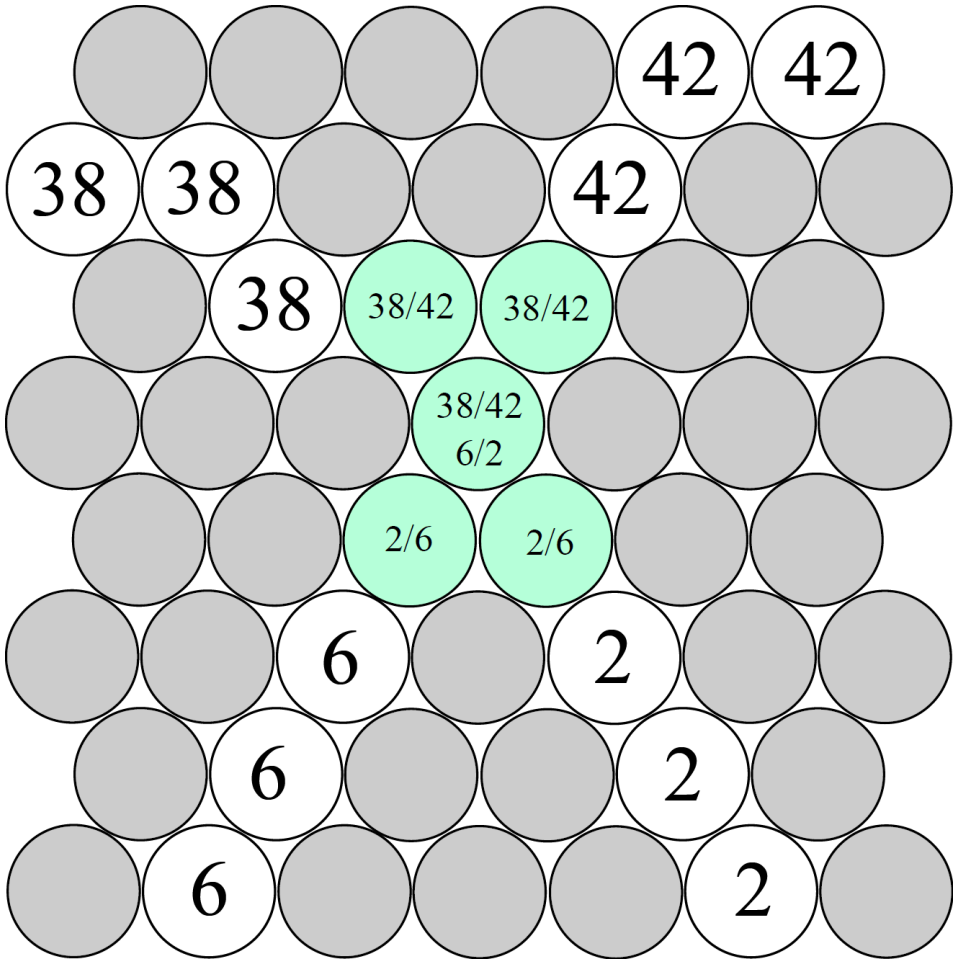
Cellular Automaton – Ambiguous hits



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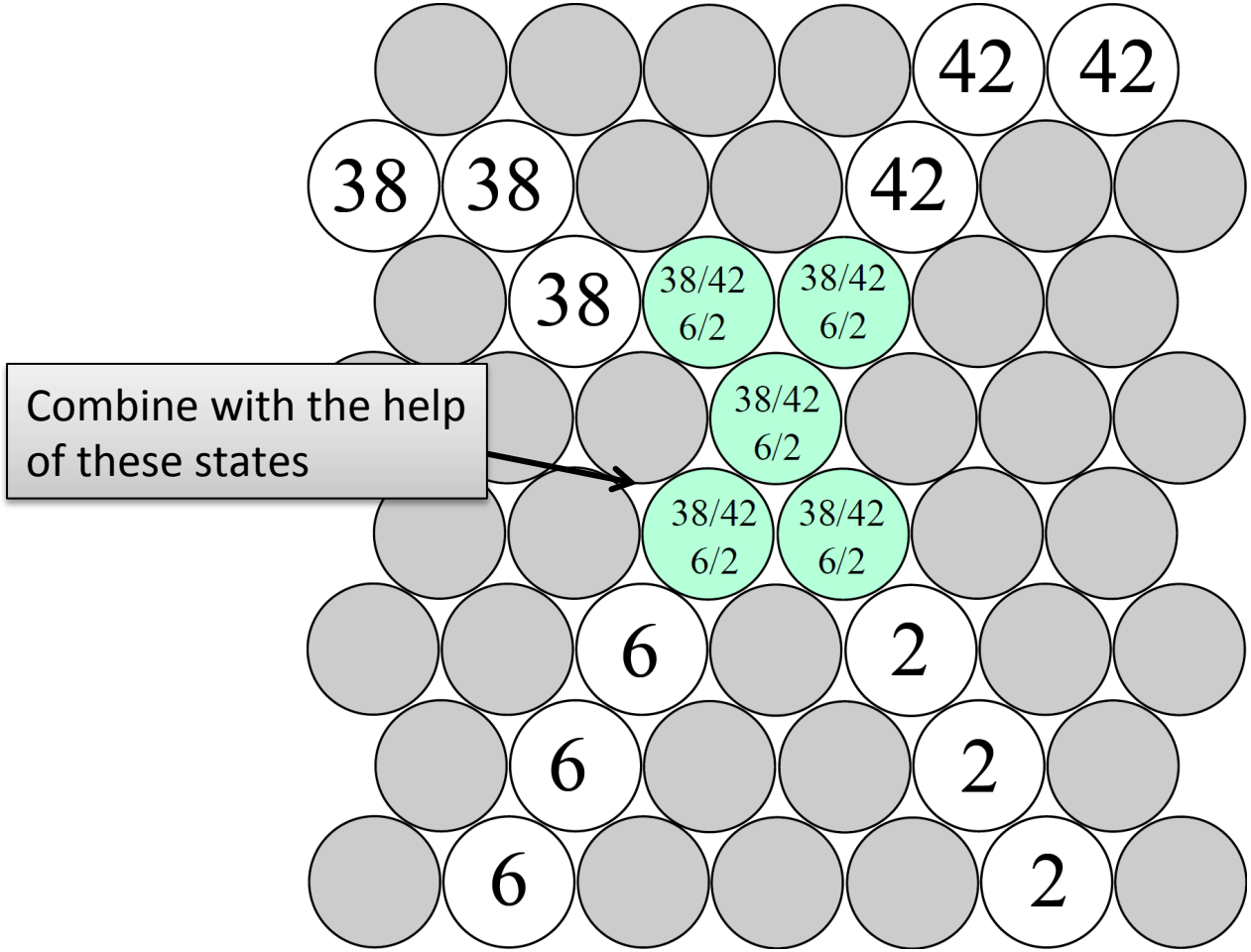
Cellular Automaton – Ambiguous hits



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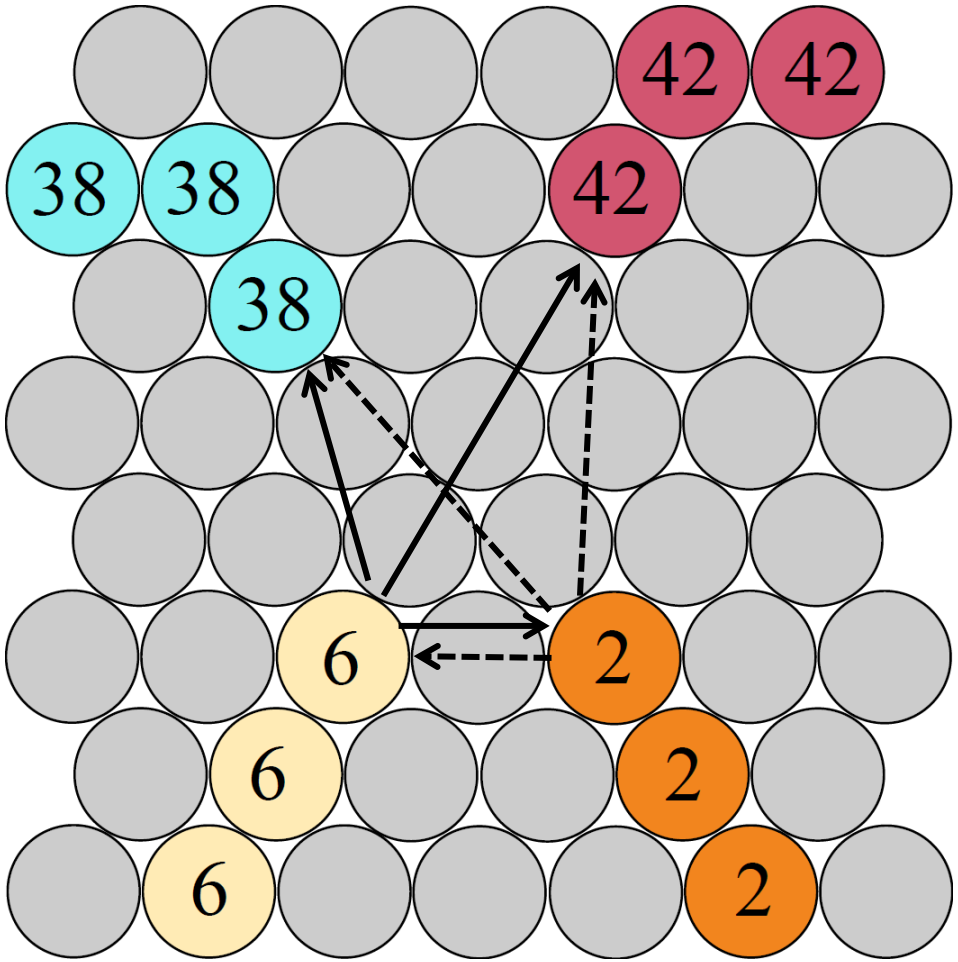
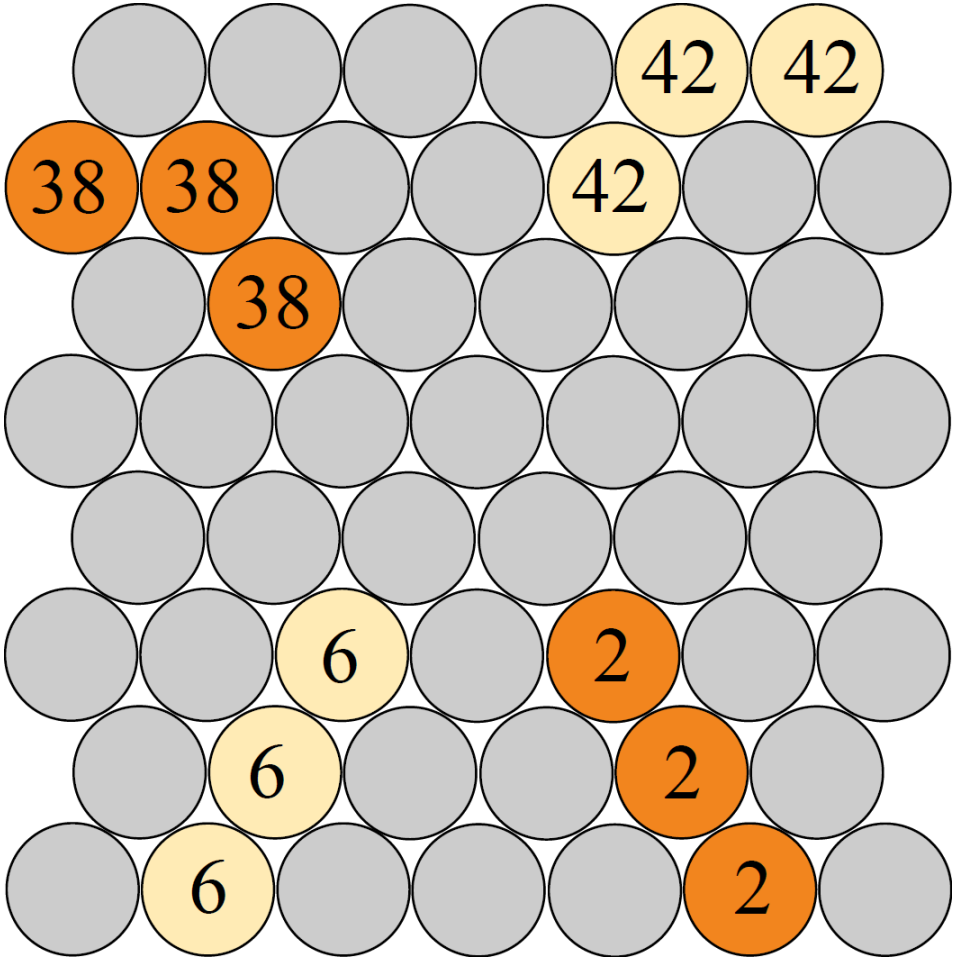
TrackletGenerator
Cellular Automaton – Combination



For inner tracklets:
test 3 combinations
with Riemann Fit

→ take the best one

TrackletGenerator
Cellular Automaton – Result



For inner tracklets:
test 3 combinations
with Riemann Fit

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CPU-Version
Data structures

- tubeID of active cells <-> tubeIDs of neighboring tubes that signals a hit

```
map<int, vector<int> > fHitNeighbors;
```

- tubeID of unambiguous cell <-> state of the tube

```
map<int, int> fStates;
```

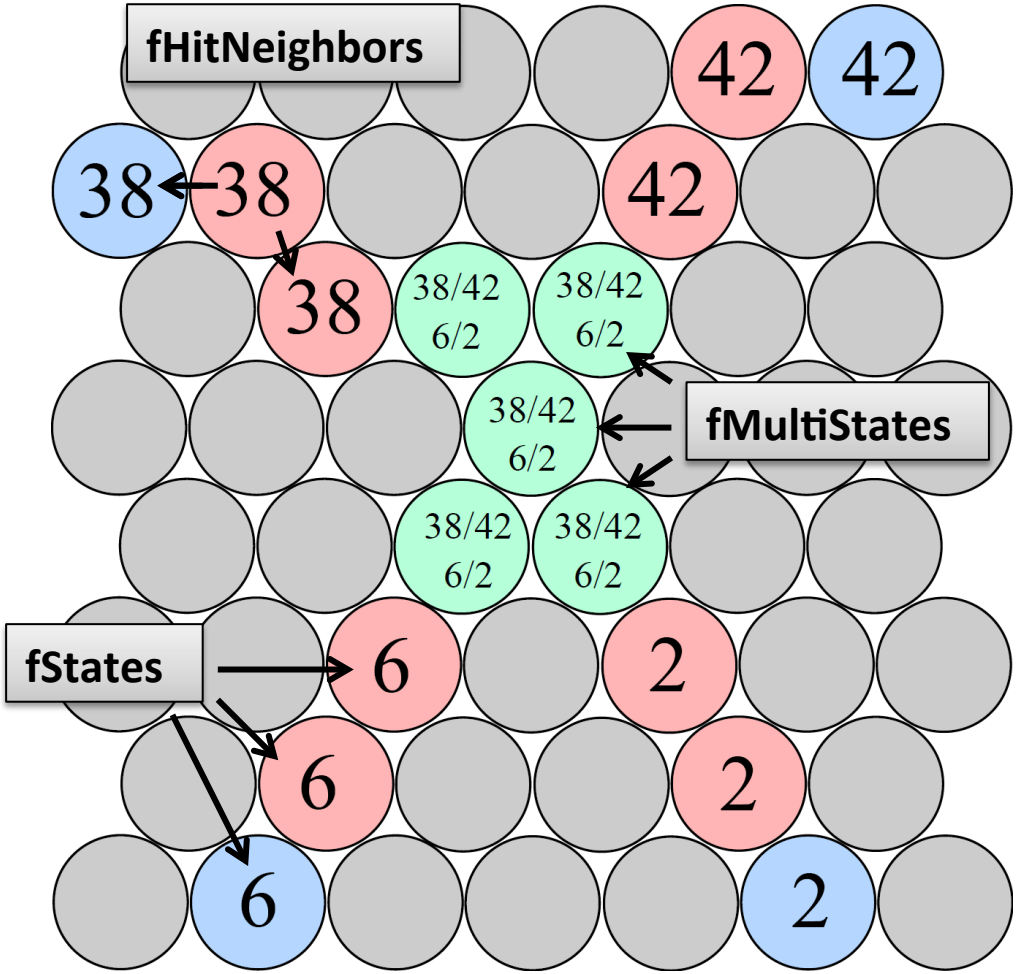
- tubeID of ambiguous cell <-> multistate of the

```
map<int, set<int> > fMultiStates;
```

Dynamic data structures:
- STL
- Flexible size
- Implicit memory management
- Easy in usage

Not available on the GPU!

CPU-Version
Data structures



Number of Neighbors:

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2

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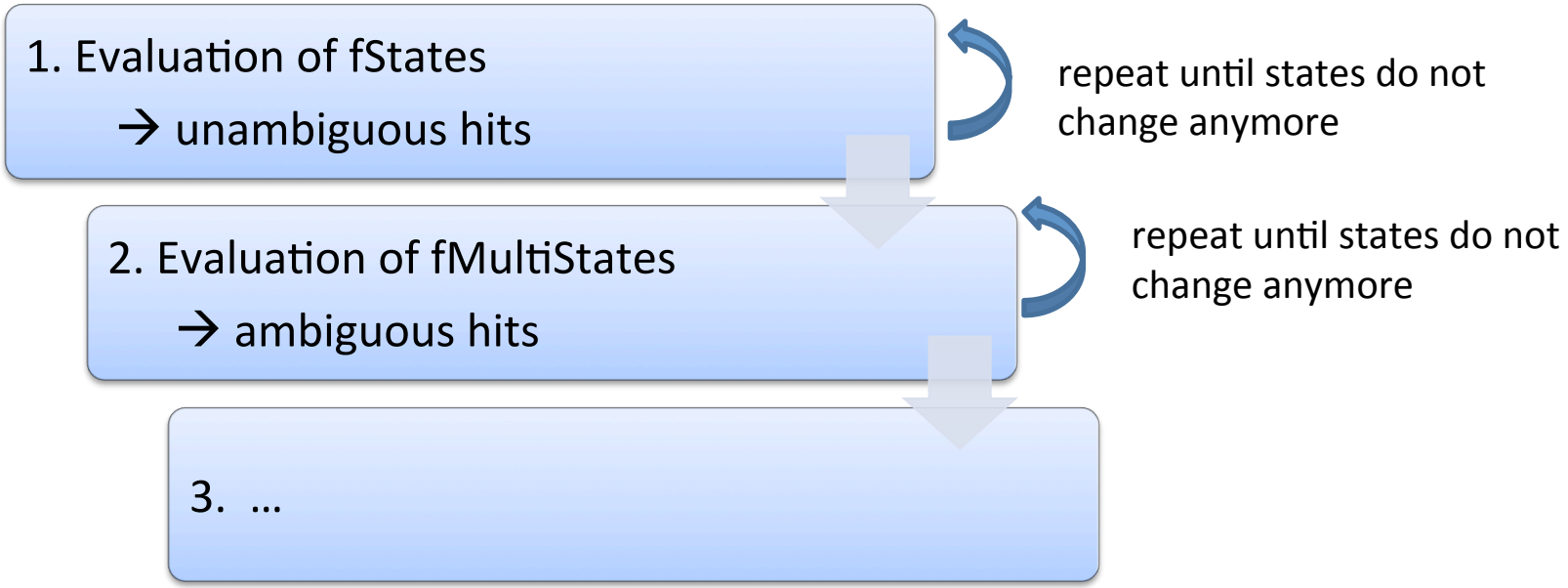
CPU-Version
Cellular automaton

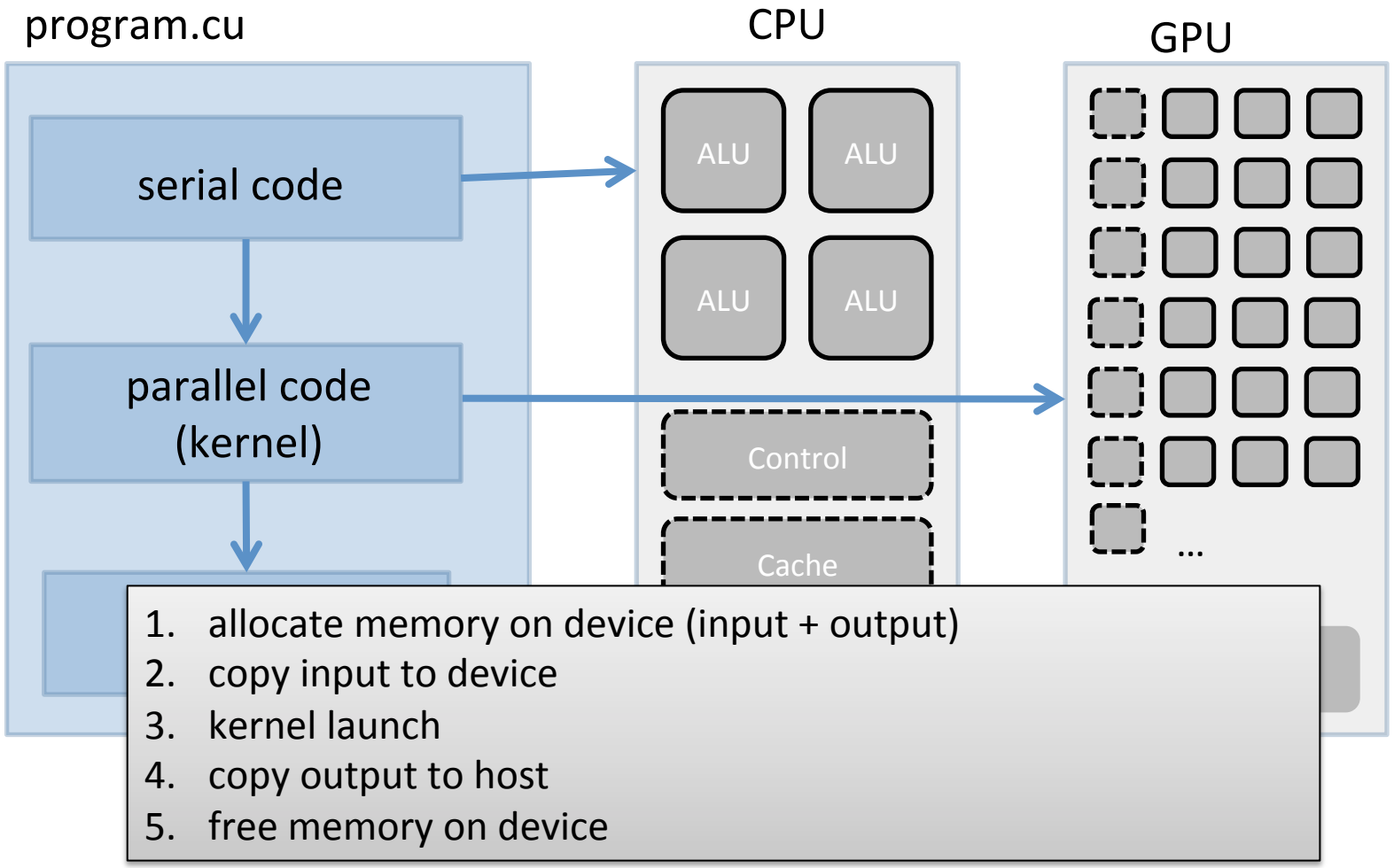
Serially executed steps:



→ Try to update all states in parallel

fMultistates depend on final fStates

GPU-Version
Programming model



GPU-Version
Data structures

static event data

- Number of tubes and tubeIDs
- Neighboring tubes
- skewed or not skewed

→ Copy once

dynamic event data

- SttHits
  - fHitNeighbors
  - fStates
  - fMultiStates

→ Copy for each event
→ calculate derived data on device

use **arrays with fixed sizes** instead of maps

balancing: memory usage <-> memory management

GPU-Version
Data structures

static event data

- variable number of neighbors: 2-22 (parallel/skewed)

→ wasting memory if one assumes that each tube has 22 neighbors

→ split information into 2 arrays

- skewed/unskewed: range request

```
#define NUM_STRAWS 4542
#define MAX_SKEWED_NEIGHBORS 22
#define MAX_UNSKEWED_NEIGHBORS 6
#define START_TUBE_ID_SKEWED 855
#define END_TUBE_ID_SKEWED 2956

int skewedTubes[NUM_SKEWED_STRAWS*MAX_SKEWED_NEIGHBORS]={0};
int unskewedTubes[NUM_UNSKEWED_STRAWS*MAX_UNSKEWED_NEIGHBORS]={0};
```

GPU-Version
Data structures

dynamic event data

- variable number of hit neighbors: 0-22

→ handle like static neighbor data

- memory for fState/fMultiState is allocated for each tube (hit/no hit)

→ easy access, but much memory

- number of multi-states for one tube is unknown

→ define max number, handle exception

```
#define MAX_MULTISTATE_NUM 20

cudaMalloc((void**) &dev_states, sizeof(int)*NUM_STRAWS);
cudaMalloc((void**) &dev_multiStates,
                    sizeof(int)*NUM_STRAWS*MAX_MULTISTATE_NUM);
```

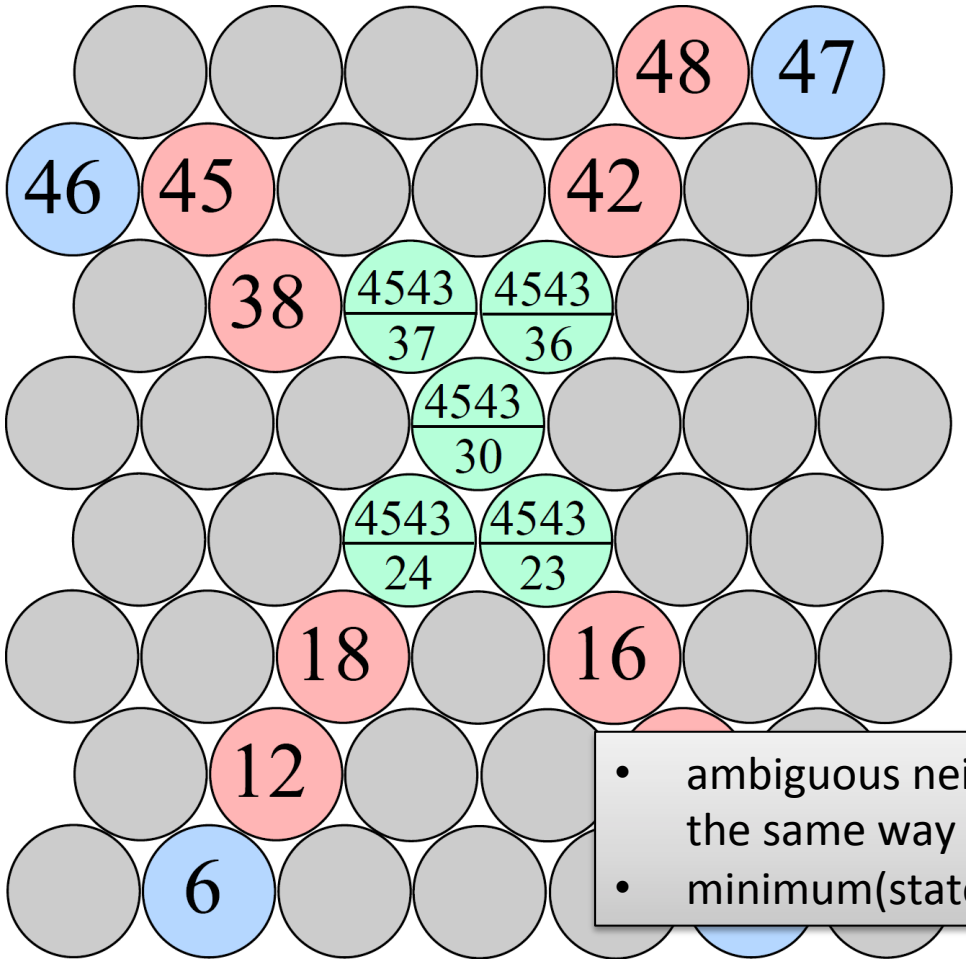
GPU-Version
Cellular automaton

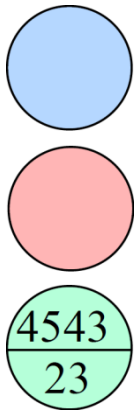
Evaluation of states

- kernel launch: one thread for each hit
- determine minimum in parallel for all hits
- calculate sum of all states in parallel
  → termination condition

- initialize state of ambiguous tubes with NUM_STRAWS+1
  → avoid unneccessary branching

GPU-Version
Cellular automaton – Unambiguous hits





unambiguous with state

ambiguous with max state / tubeID

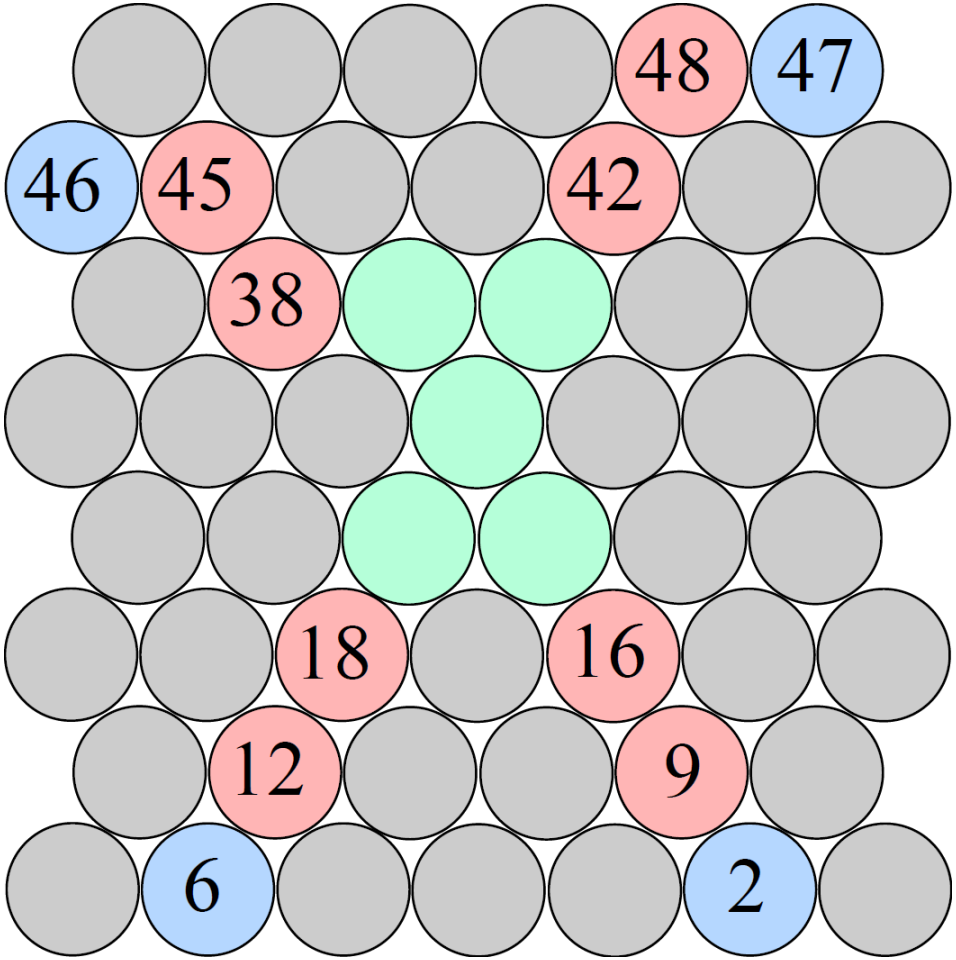
- ambiguous neighbors are treated in the same way as unambiguous ones
- minimum(state, 4543)=state

GPU-Version
Cellular automaton

Evaluation of multi-states

- some multi-states depend on final states
- copy tubeIDs instead of states:
  - outer tracklets: tubeID of first tube = state of this tracklet
  - inner tracklets: tubeID of ending tube of the tracklet is copied
- tubeIDs do not change and are independend of the states
  → parallel execution

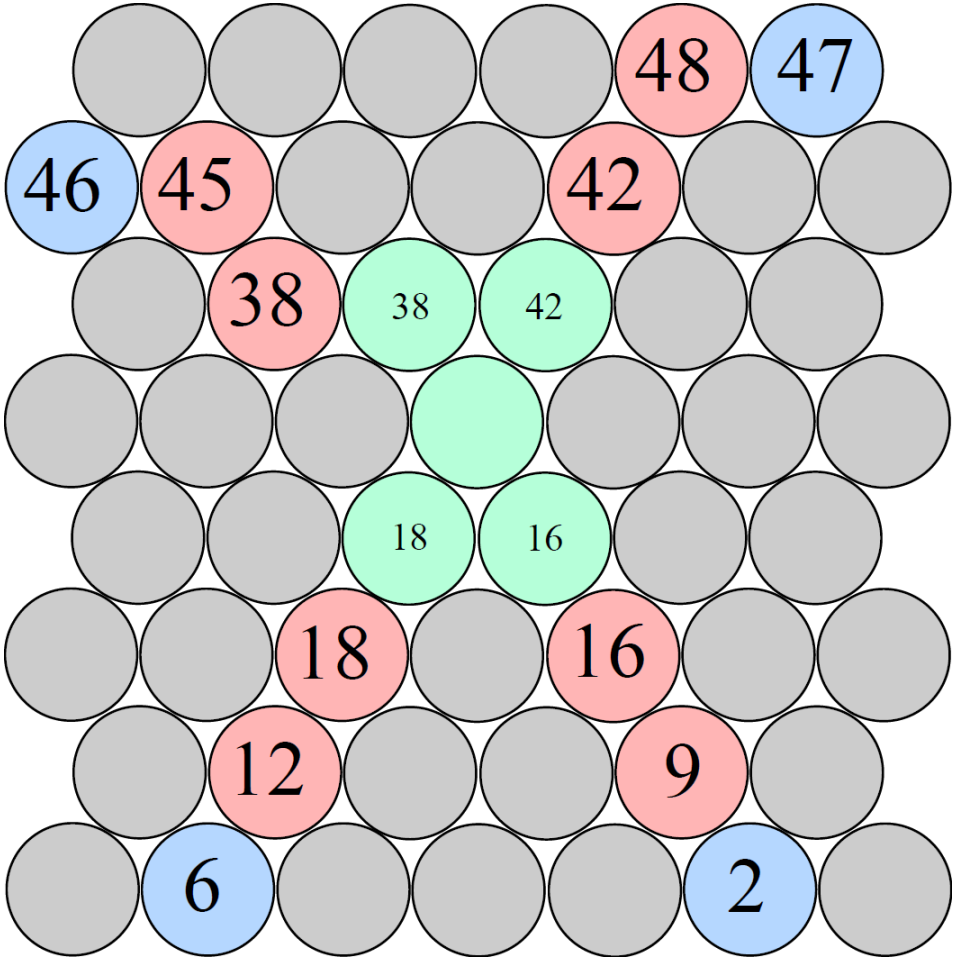
GPU-Version
Cellular automaton – Ambiguous hits



Cell: Straw with hit and more than two neighbors

Rule: Copy the **tubeID** of all your neighbors into your status

GPU-Version
Cellular automaton – Ambiguous hits



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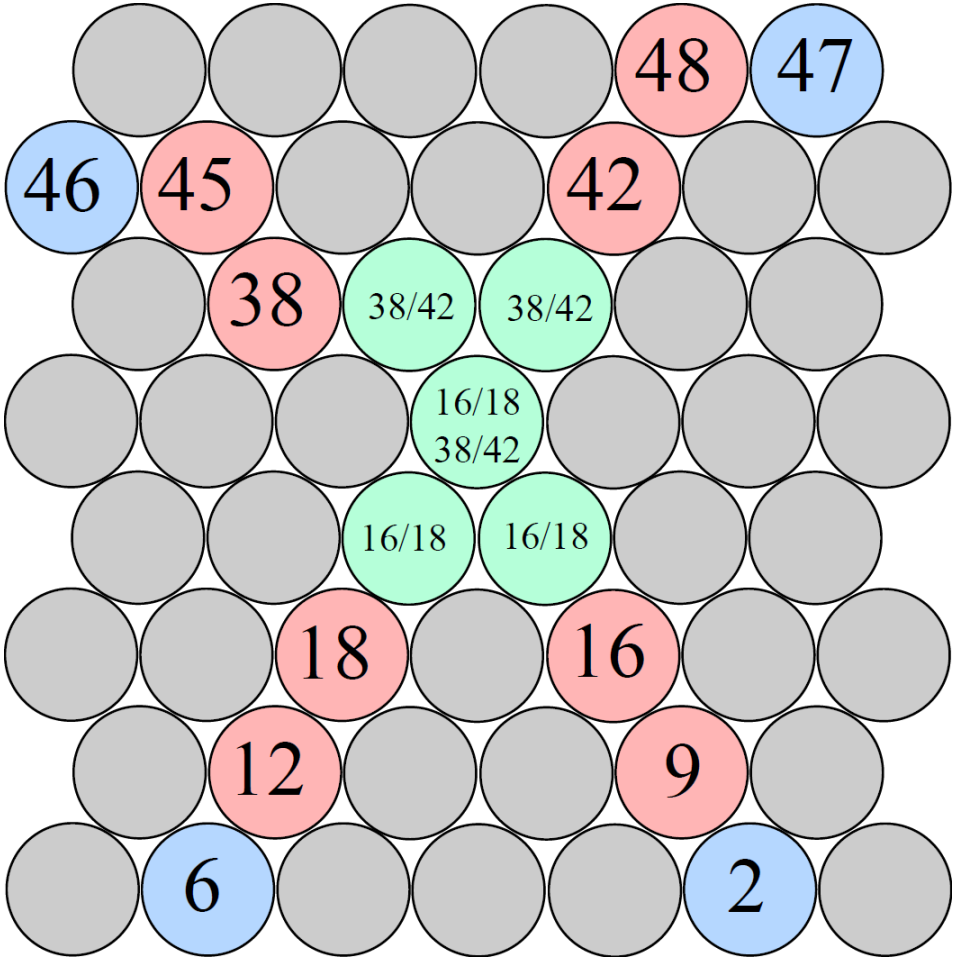

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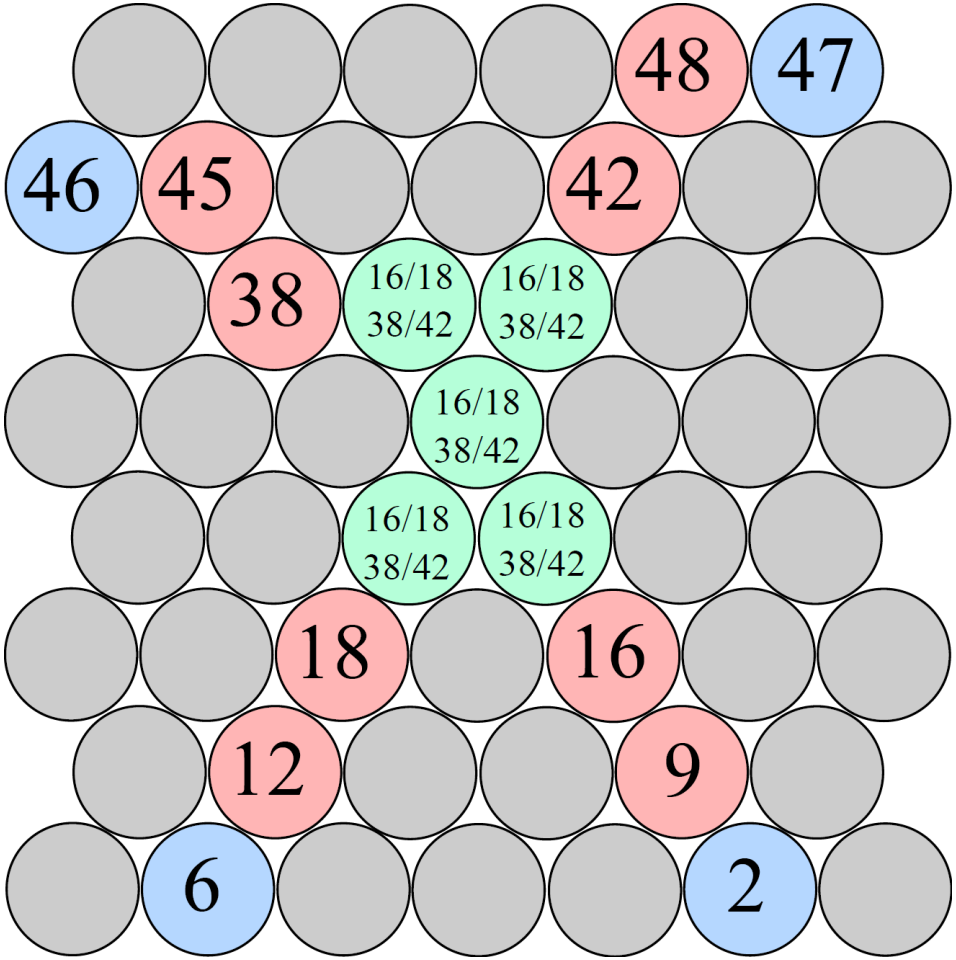

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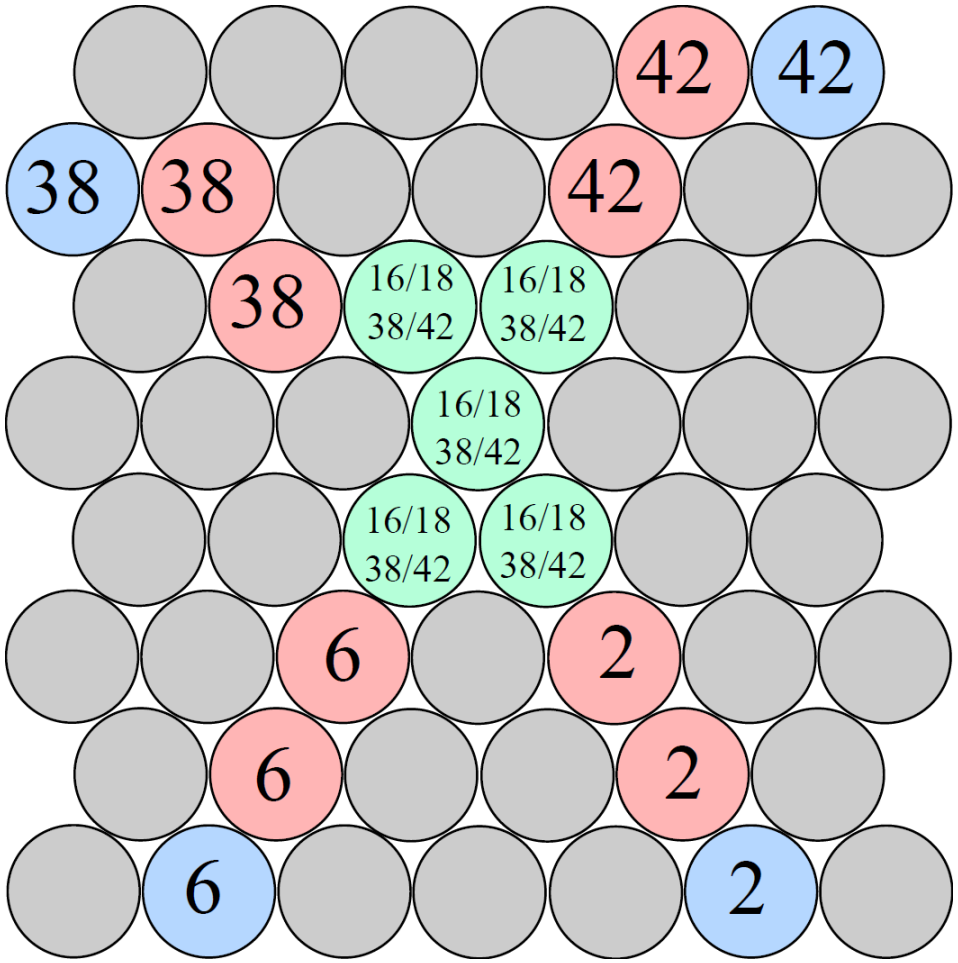
GPU-Version
Cellular automaton - Result



Final result of the parallel execution of EvaluateState() and EvaluateMultiState()

38/42: states of outer tracklets

16/18: tubeIDs of ending tubes of inner tracklets

GPU-Version
Cellular automaton

Number of multi-states

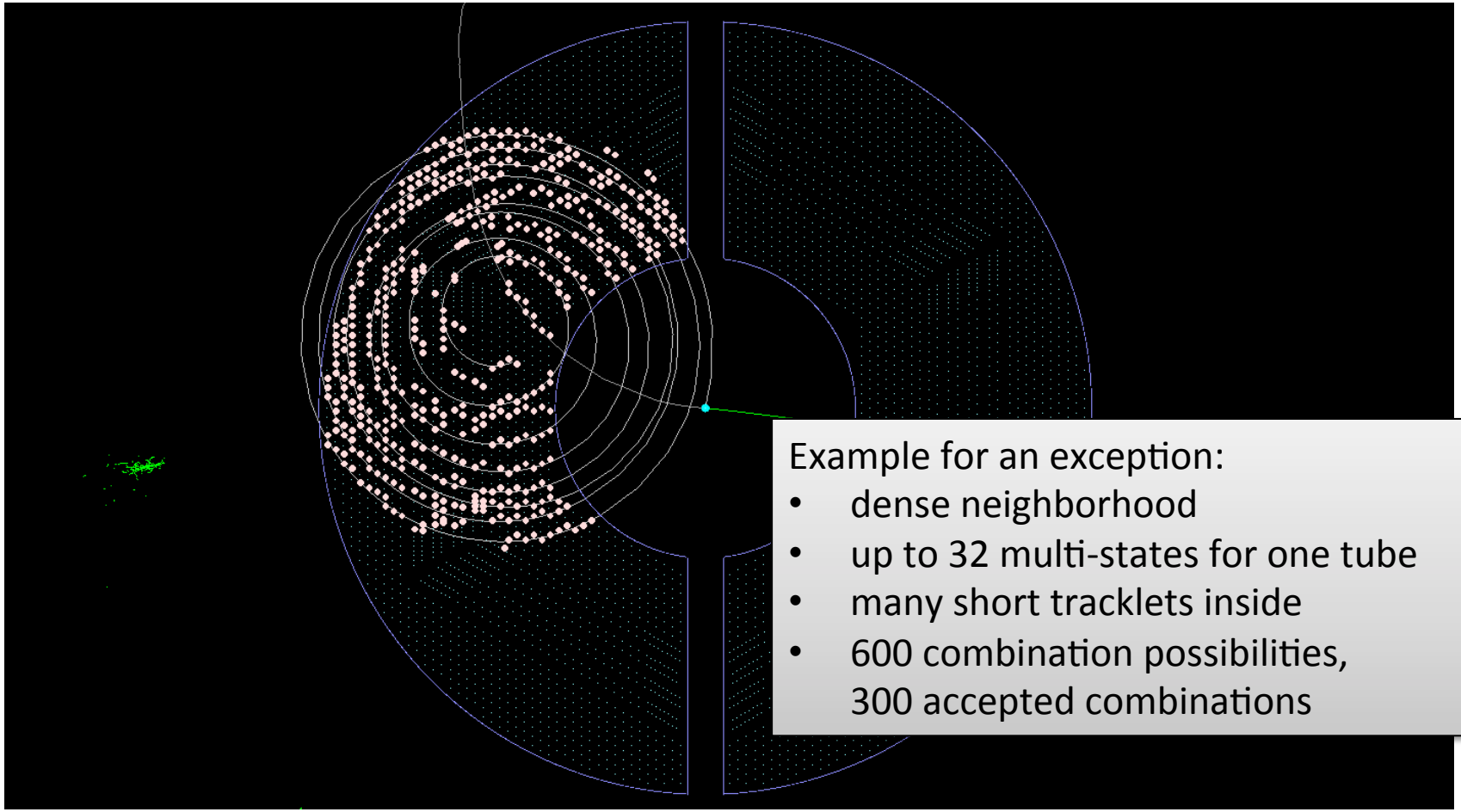
- unknown, variable for each event
- more memory results in longer execution time (looping over the data)

0≤MAX#≤5	5<MAX#≤10	10<MAX#≤20	20<MAX#
≈74%	≈20%	≈5%	≈1%

(first estimate, based on 1000 events)

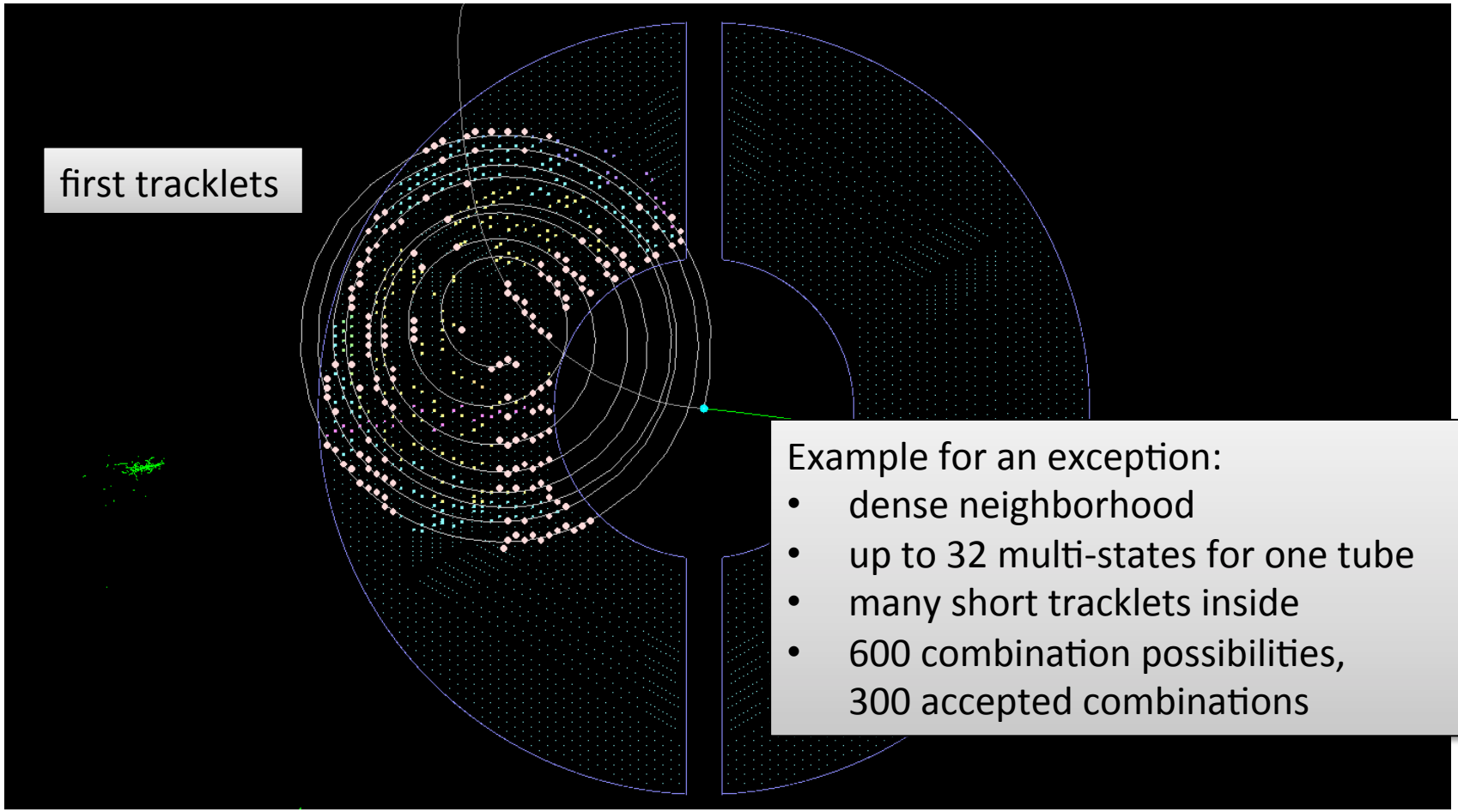
→ set max to 20
→ stop evaluation for exceptions

GPU-Version
Cellular automaton



Example for an exception:
- dense neighborhood
- up to 32 multi-states for one tube
- many short tracklets inside
- 600 combination possibilities, 300 accepted combinations

GPU-Version
Cellular automaton



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Outlook

- parallelism at event-level!
- parallelize other parts of the trackfinder
- optimization: memory management + access, loops, …

Thank you very much for your attention!