The Impact of Memory Management on OpenFoam Performance

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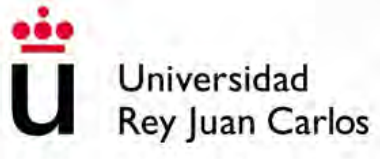
Gabriel M. Magalhães, J. Miguel Nóbrega



AGENDA

1. Motivation
2. Open Foam Memory Usage
3. Memory Pool Design
4. Experimental Results
5. Conclusions and Future Work

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1. **Motivation**
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Motivation

- OpenFoam: **Field**, Operation And Manipulation
- Fields memory requirements are centralized in the **List class**.
- Modifying List we can change the **memory management**.

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OpenFoam Memory Usage

- In the normal use of OpenFoam **many allocations** are made
  - Allocations for **temporal** results are often overlooked

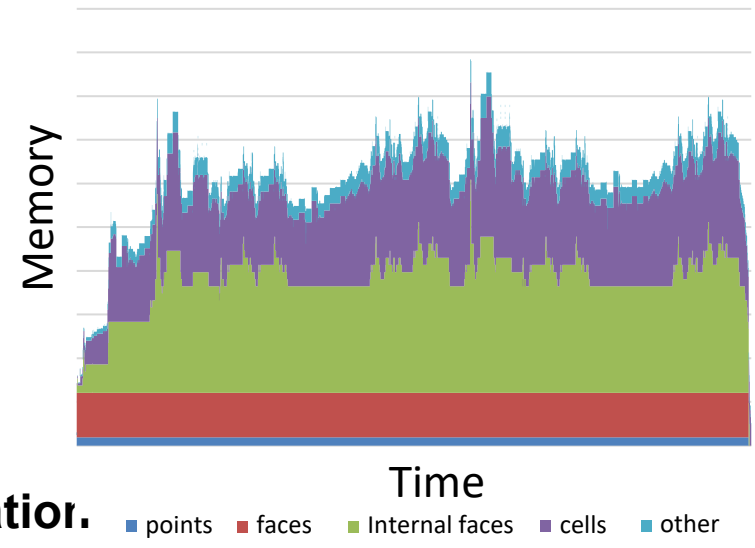
```
r = A + B * C;

r = A + <temp>;

r = <temp>;
```

- This happens with many types of data such as **scalars**, **vectors**, **tensors**, etc.

OpenFoam Memory Usage

- In the chart:
  - Every rise is an allocation
  - Every fall is a free
  - Two iterations are shown

- **Our plan**:
  - Do the allocations on the **first iteration**.
  - **Never free** memory
  - **Reuse** already allocated memory



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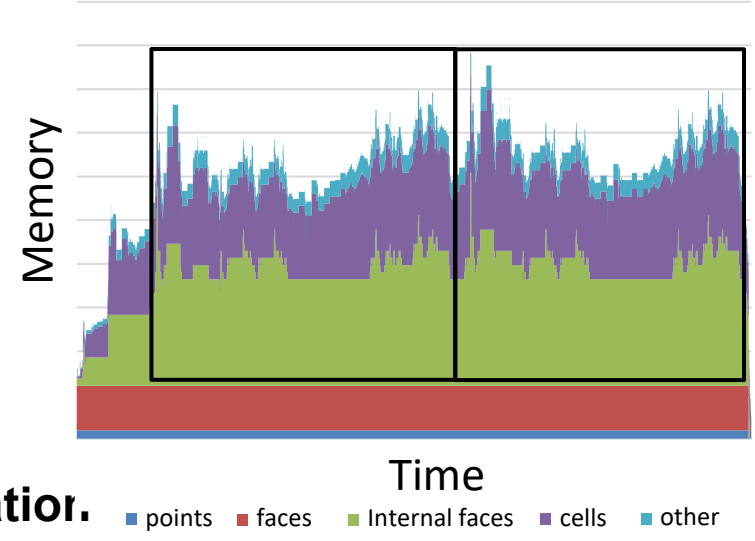

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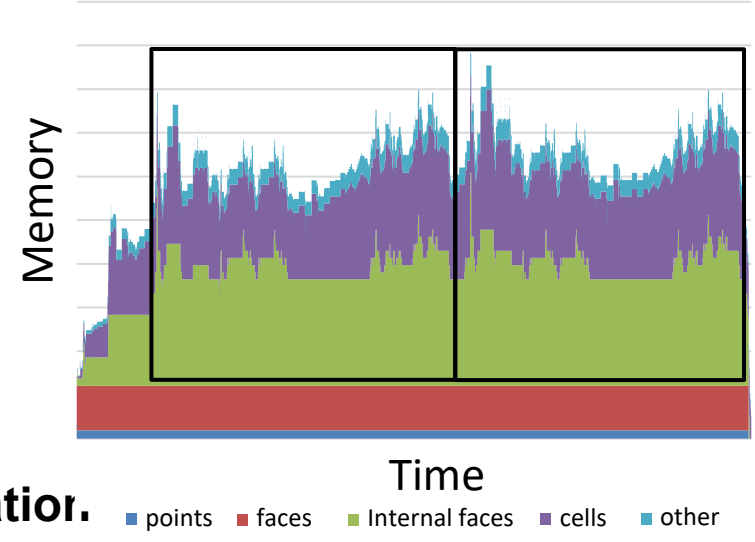
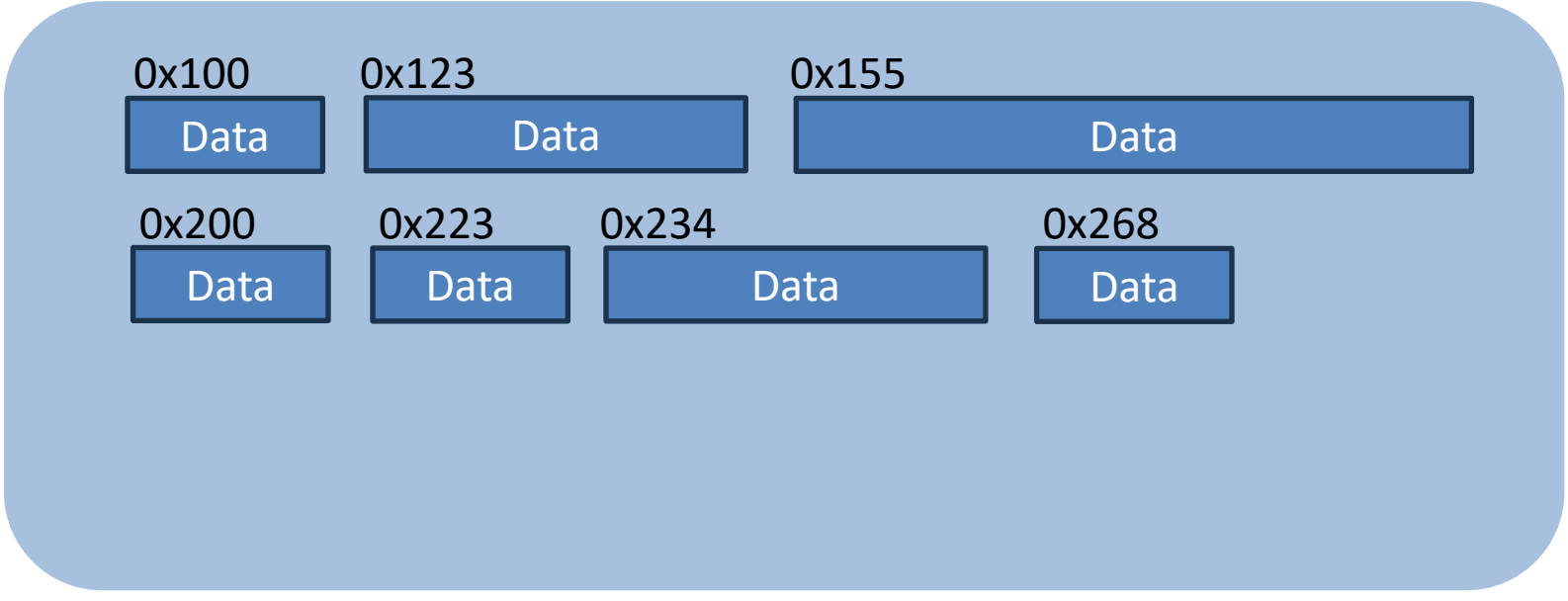


~27k allocations and frees per iteration

OpenFoam Memory Usage

- OpenFoam memory footprint



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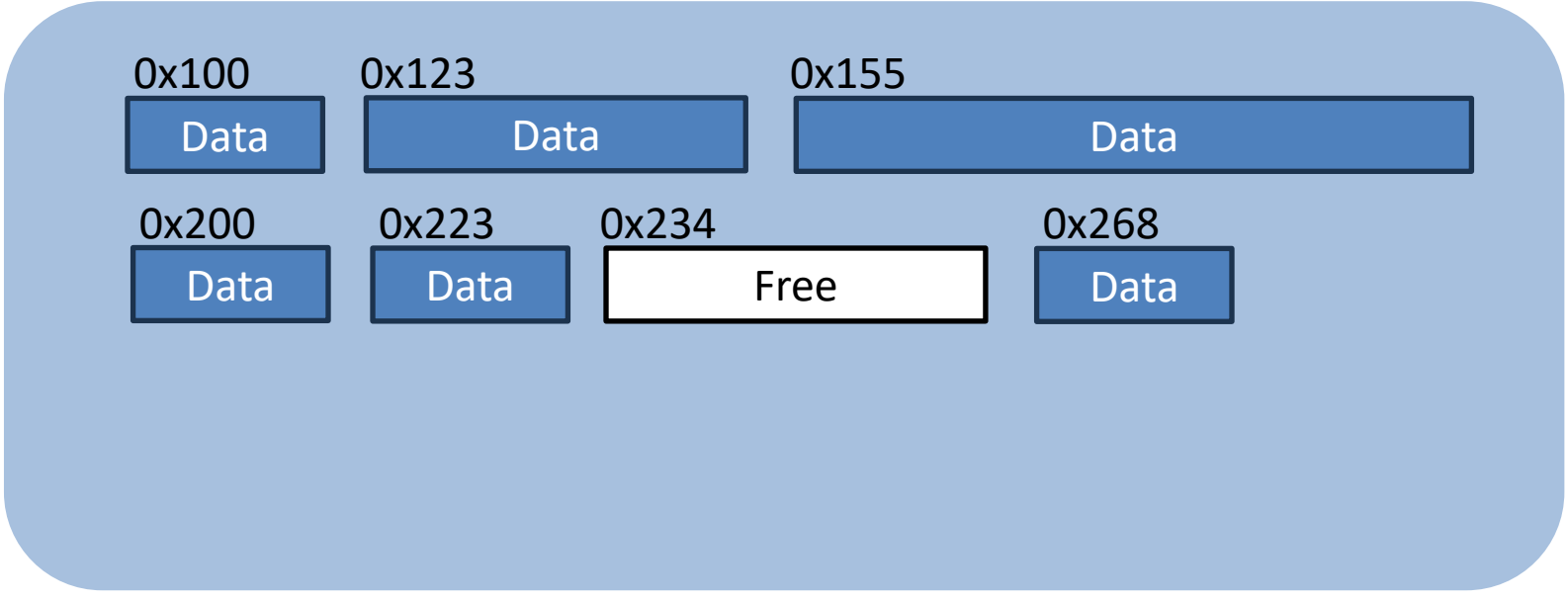

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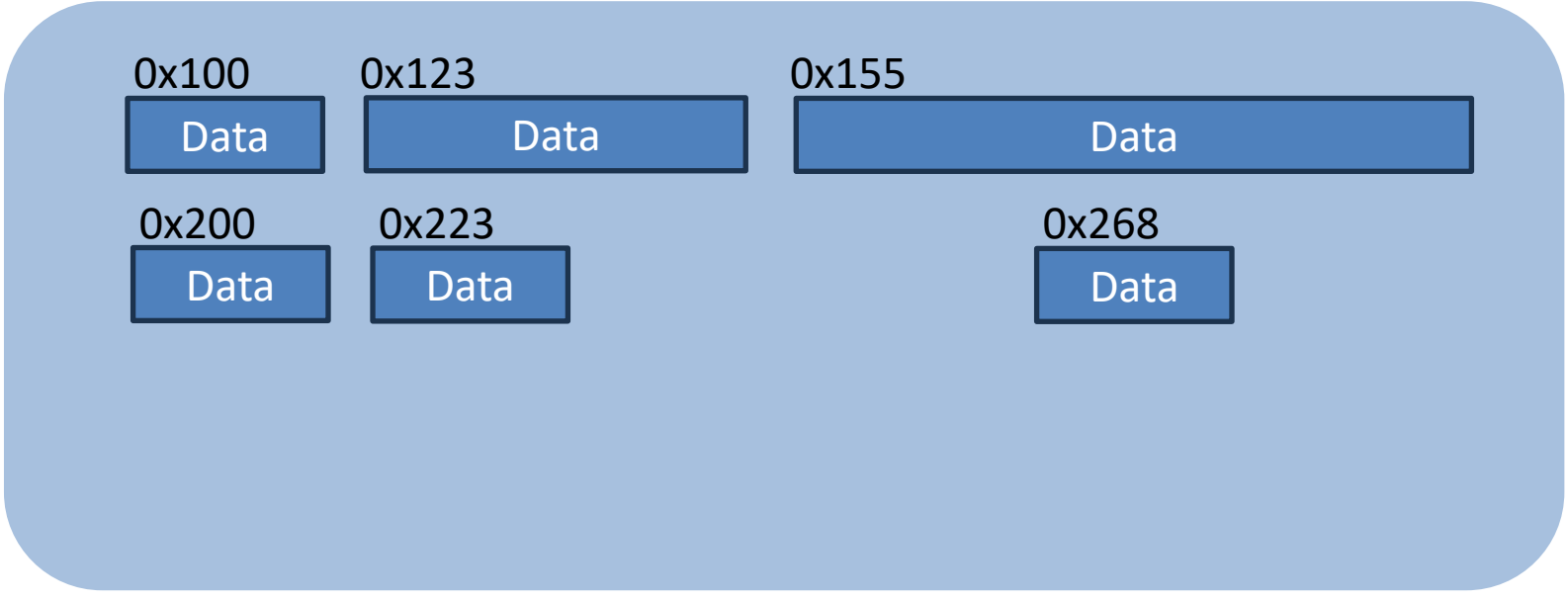

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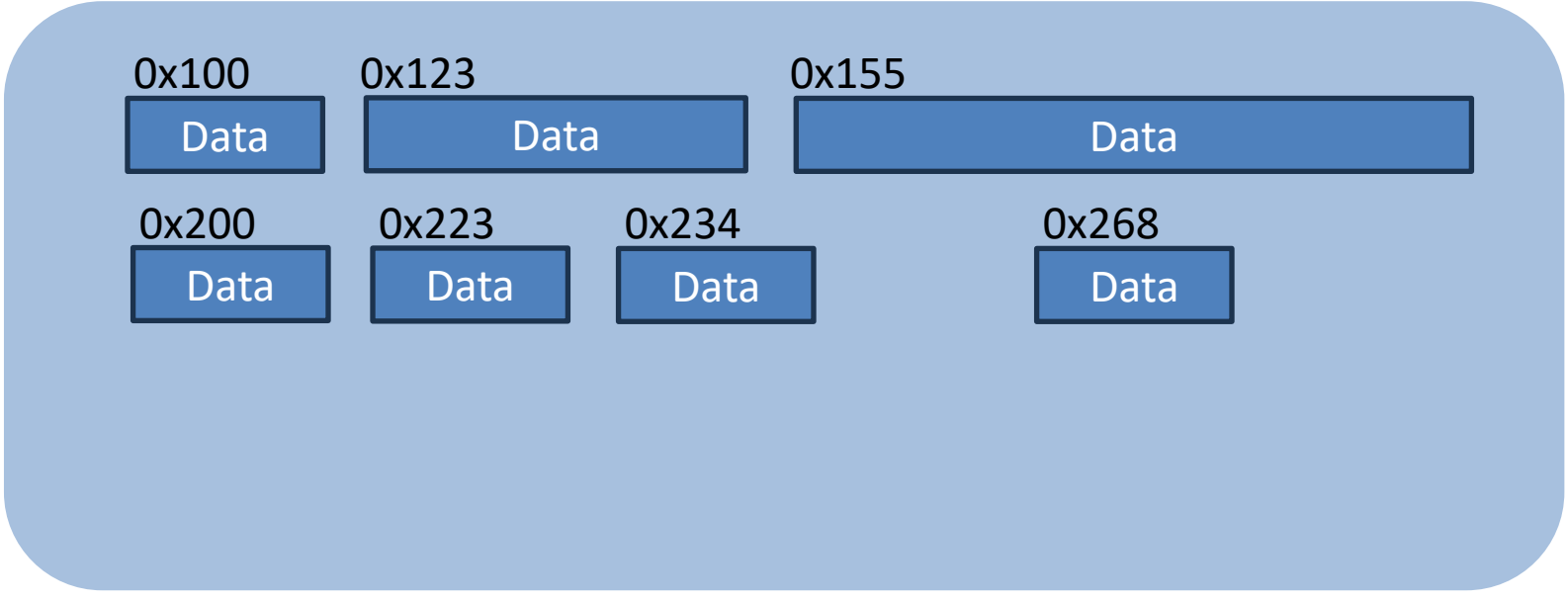

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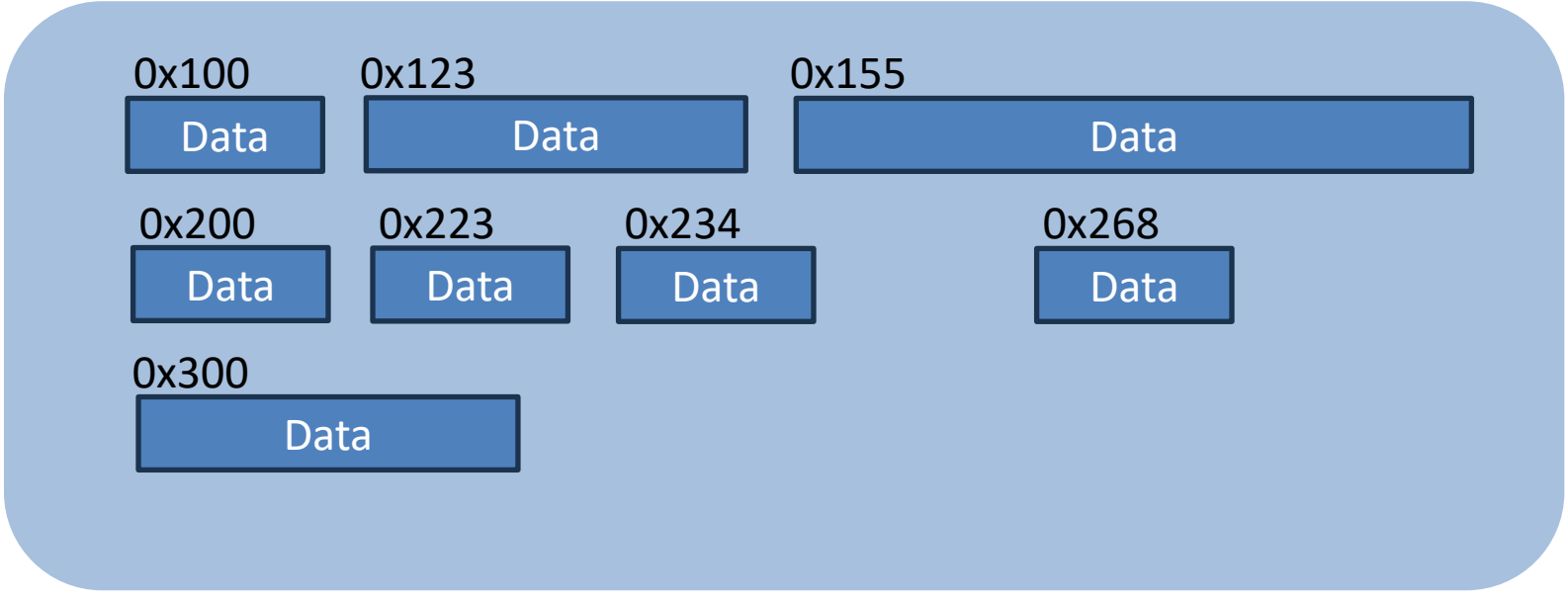

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Memory Pool Design

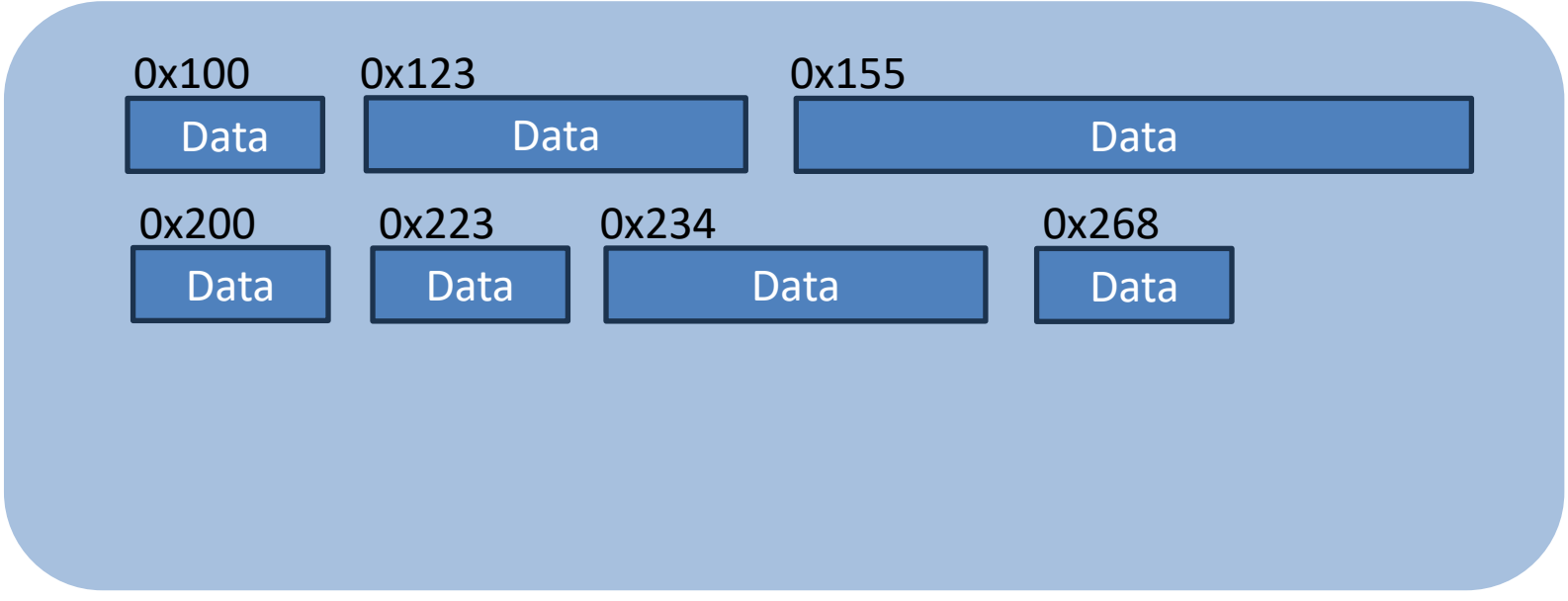
- The general idea is to make de **allocations, reuse and never free**.
  - Keep track of **“unused”** memory blocks.

- Foam::List:
  - Allocations mainly in `alloc`, `realloc` and `setSize`
  - Frees in `clear` and `destructors`.

- Memory pool:
  - If there is an “unused” memory block, it **reuses** it, otherwise it makes an **allocation**.
  - On frees, marks the memory block as **“unused”** but does **not free** the memory.

Memory Pool Design

- Our memory footprint



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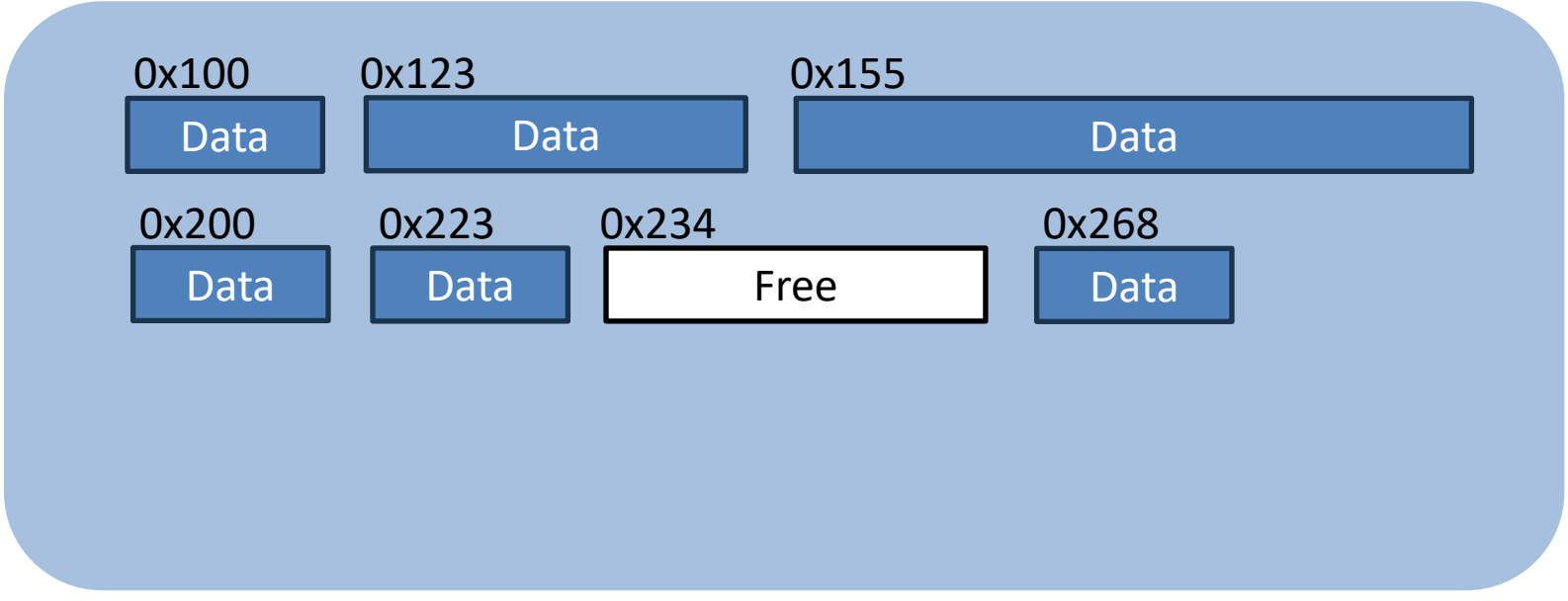

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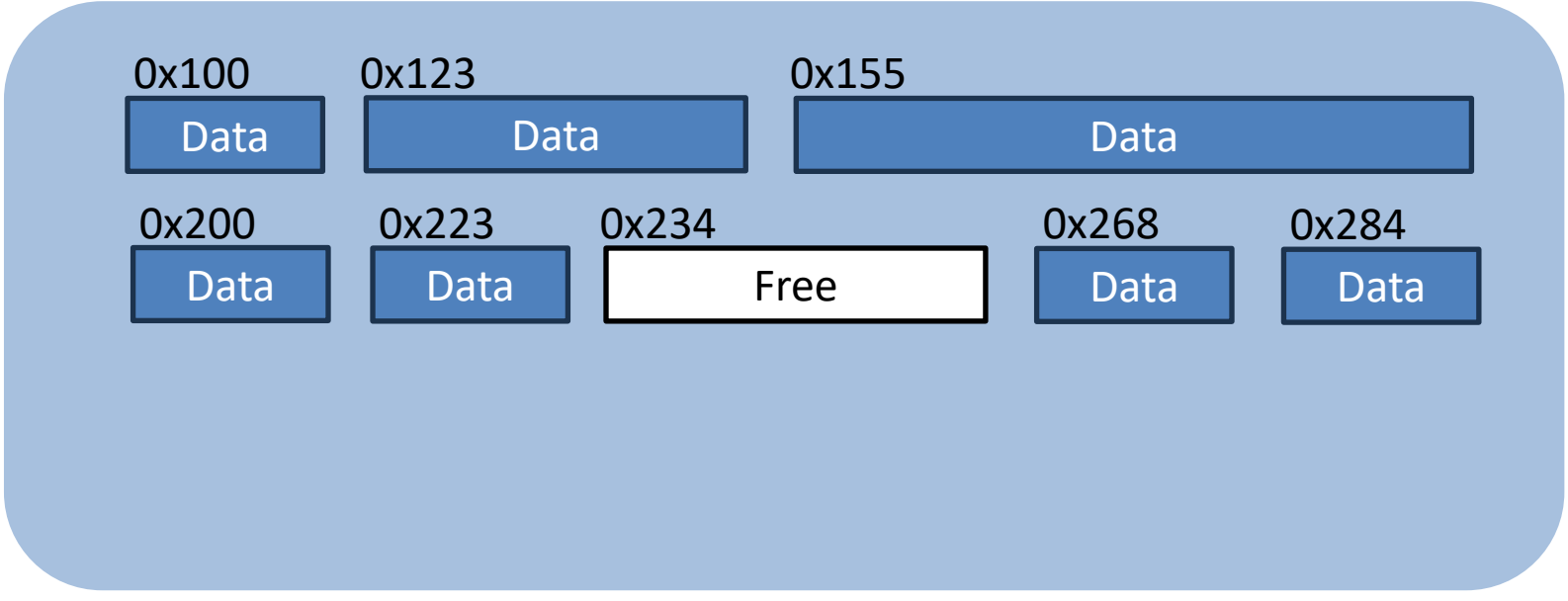

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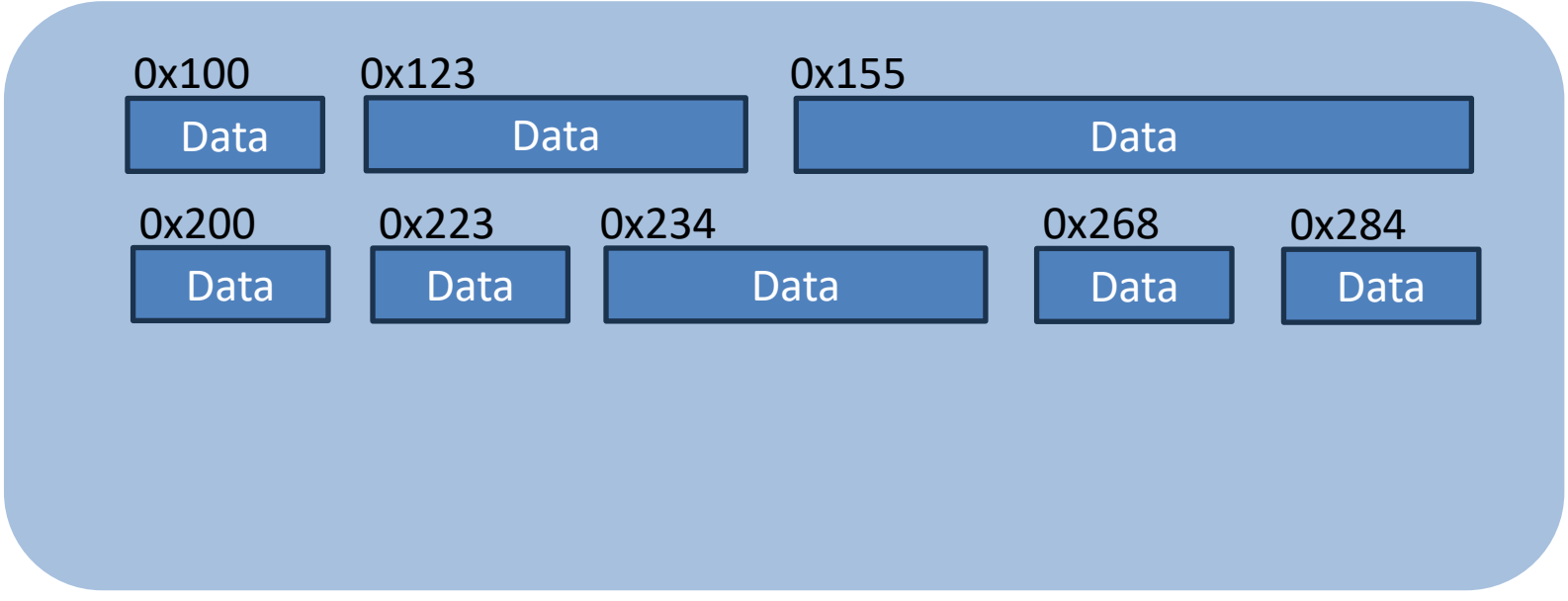

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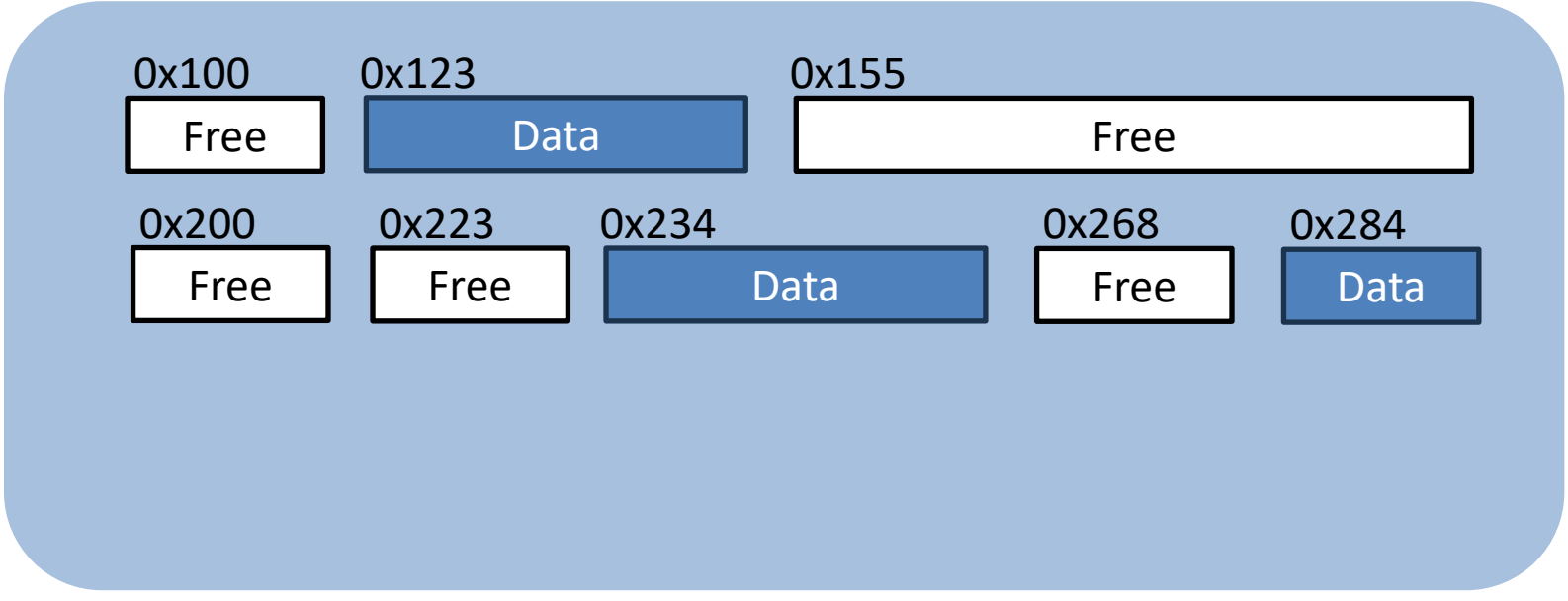

Memory Pool Design

- We thought we need store the pointers to the allocated memory blocks.
  - `std::deque` over `std::vector`
  - Use `std::unique_ptr` for automatic free when the program finish.
- Use a linked list to **store "unused" memory blocks** (pointers)
- We need a hash map (`std::unordered_map`) to link pointers with `std::unique_ptr`

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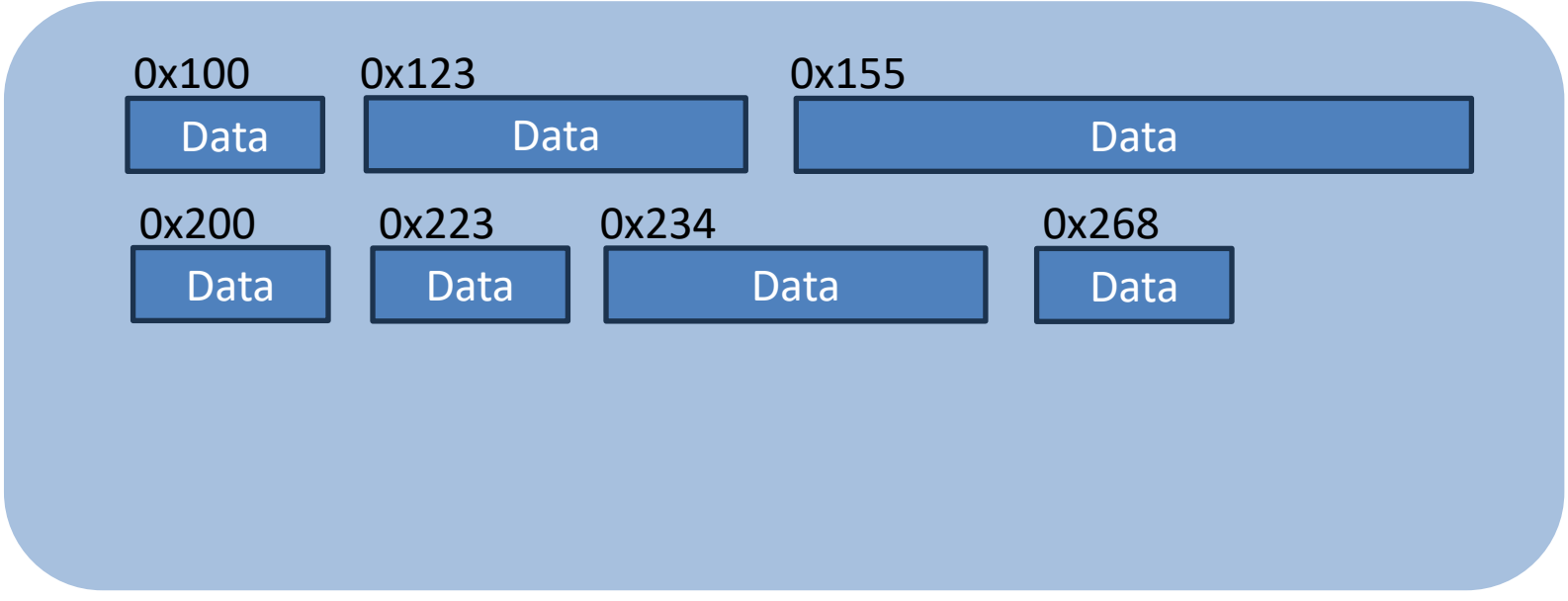
- Use a linked list to **store "unused" memory blocks** (pointers)
- We need a hash map (`std::unordered_map`) to link pointers with `std::unique_ptr`
- **~18k** call to alloc (from ~27k) only 1758 real memory allocations.
  - No frees

Memory Pool Design

- Dispose of unnecessary data structures (`deque`, `map`, `unique_ptr`)
  - Only need to keep track of **unused memory blocks**
- On **allocations**, make use of `malloc` (or `new`) and return the **pointer**.
- On **deallocations**, **store** the unused memory blocks

Memory Pool Design

- Improved memory footprint



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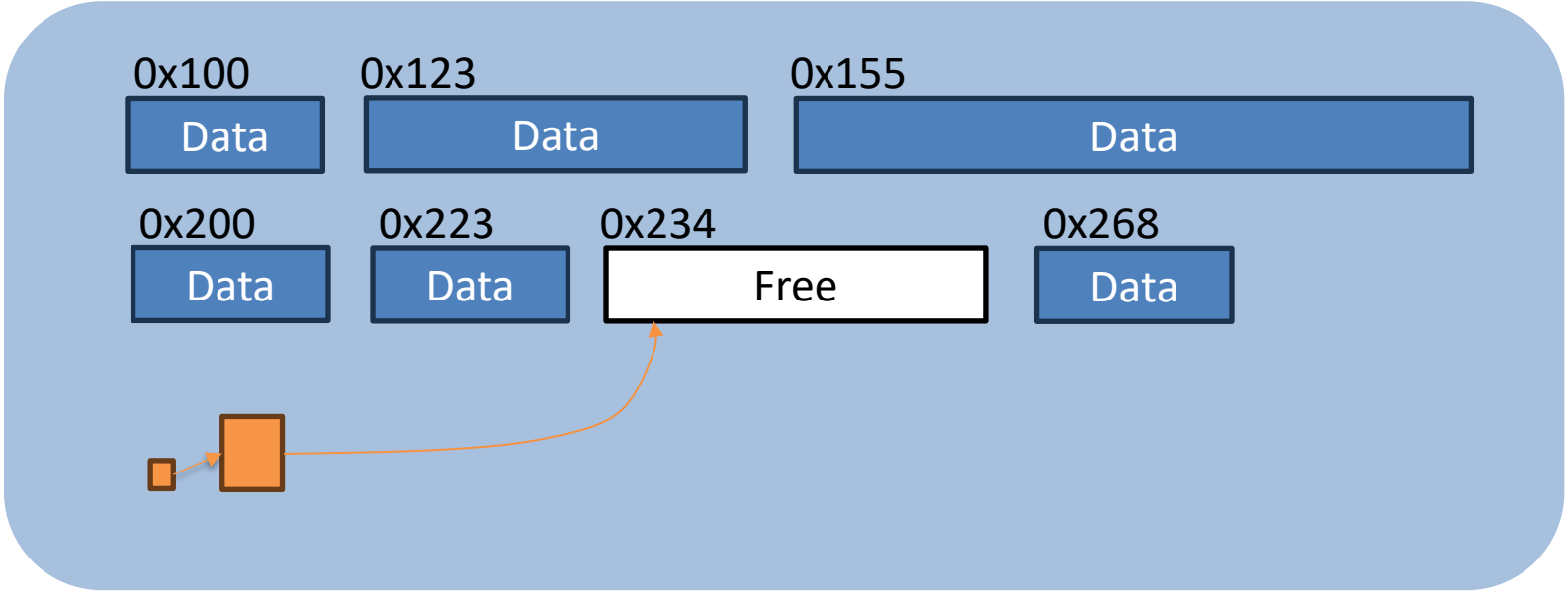

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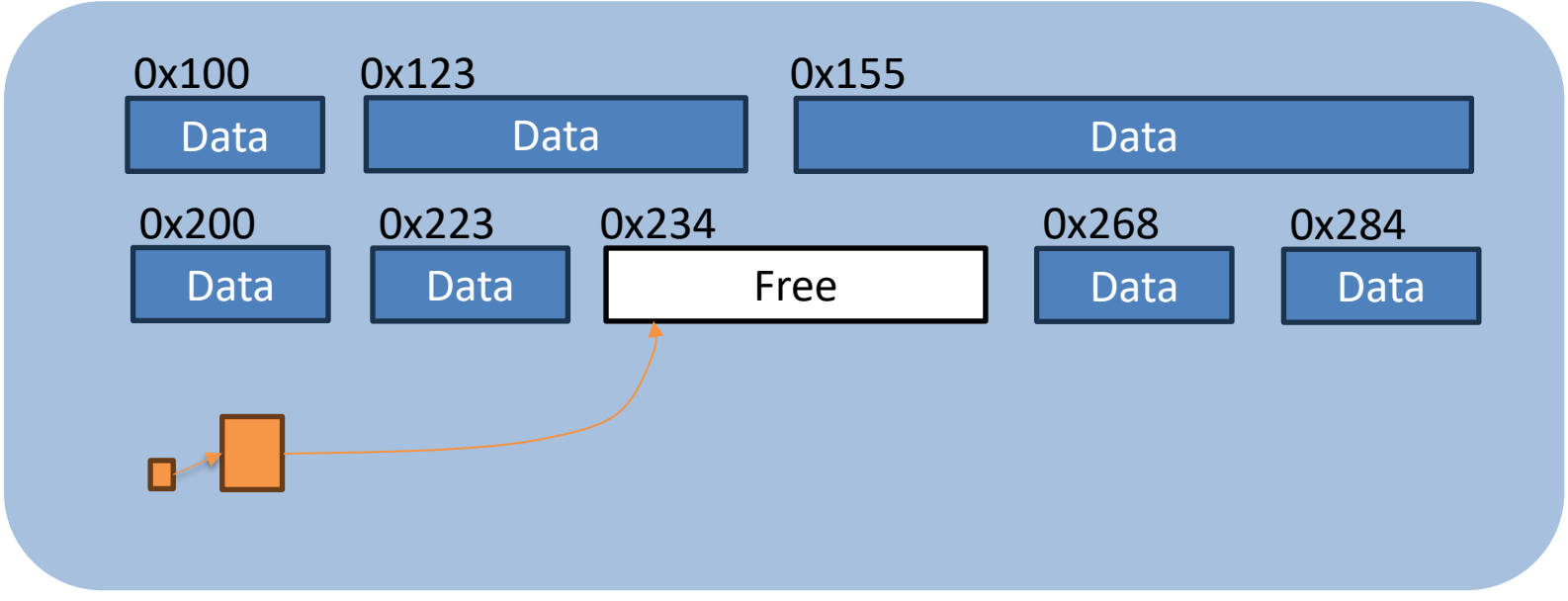

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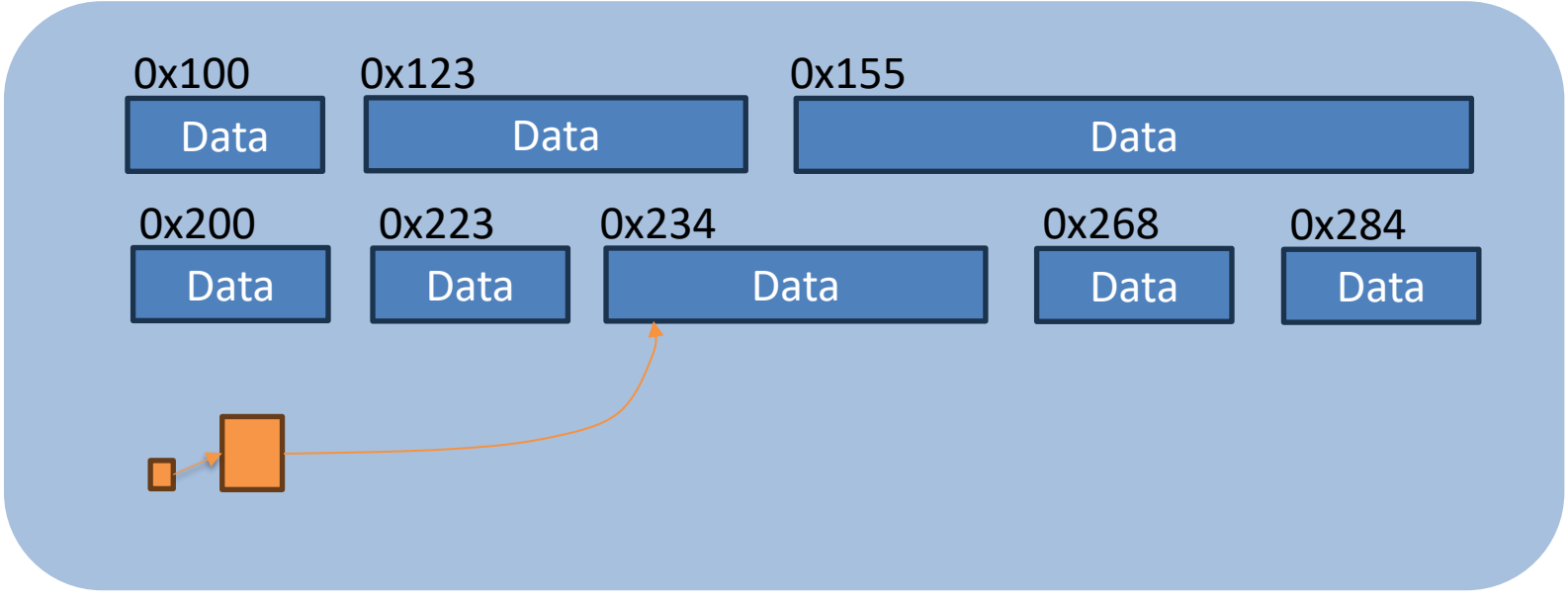

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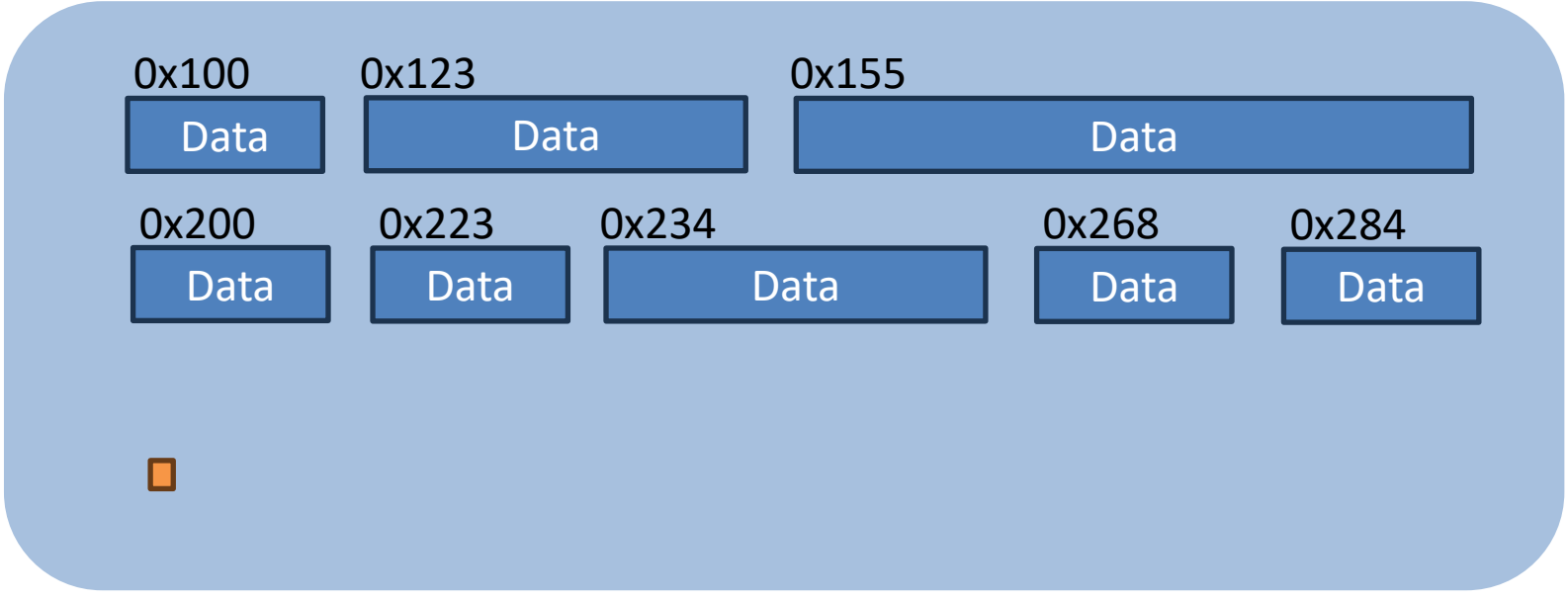

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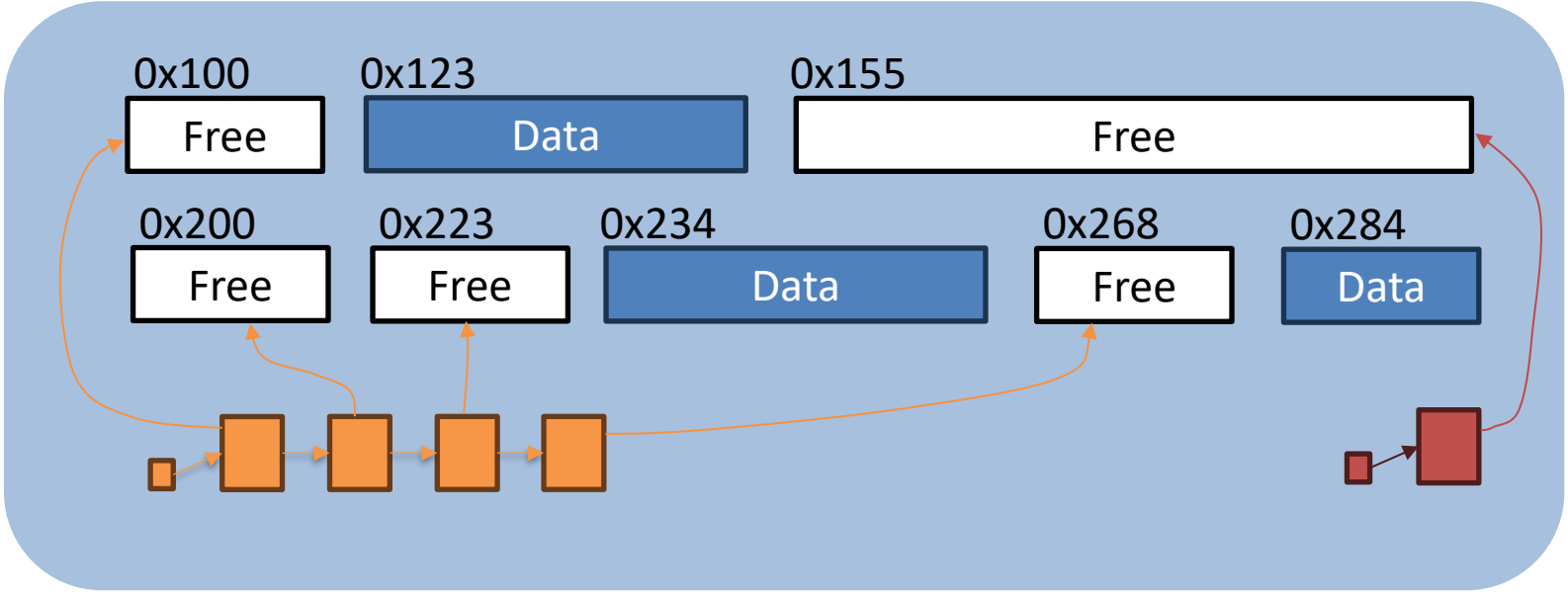

Memory Pool Design

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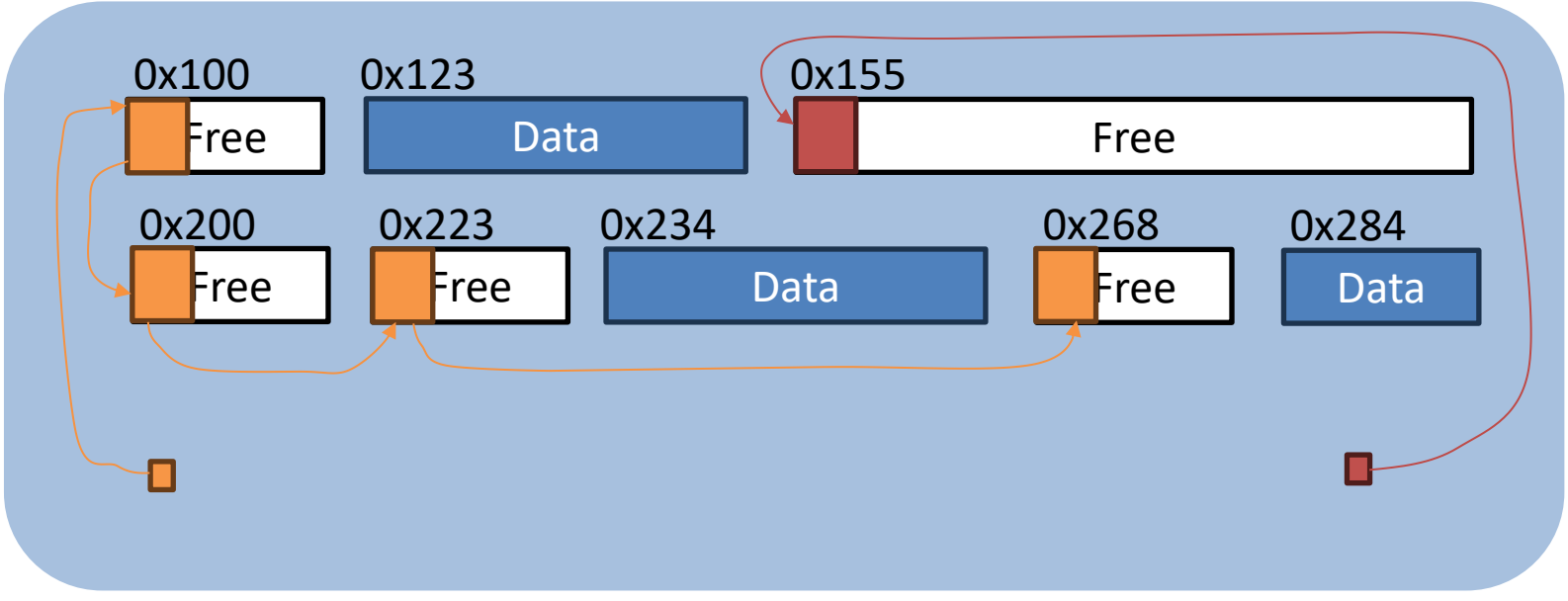

Memory Pool Design

- Dispose of unnecessary data structures (`deque`, `map`, `unique_ptr`)
  - Only need to keep track of **unused memory blocks**
- On **allocations**, make use of `malloc` (or `new`) and return the **pointer**.
- On **deallocations**, **store** the unused memory blocks **in the blocks themselves**.
- To **reduce** the number of "unused" lists, we only create **power-of-two** blocks of memory.

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Experimental results

- Per iteration: ~18k allocations (of ~27k)
  - 1758 are actually allocations
  - ~16k are reused memory
  - 0 of ~27k frees
- **Highly efficient** allocator, after first iteration is an access to a pointer.
- We did **not** achieve a clear **improvement**.
- We found some improvement in specific cases for **certain solvers**.

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Conclusions and Future Work

- **Improving** the memory usage is a very complex problem.
- **Memory Allocations** in simplified programs do not reflect their cost. The overlap of the reserves with the computation must be taken into account.
- **Work in progress**: more to learn about solvers memory usage.
- The use of the memory pool could help optimize data layout, leading to improved performance.

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Thank you

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