CS709a: Algorithms and Complexity

Focus: Spatial Data Structures and Algorithms

Instructor: Dan Coming
dan.coming@dri.edu

Thursdays 4:00-6:45pm
Office hours after class
(or by appointment)

Today

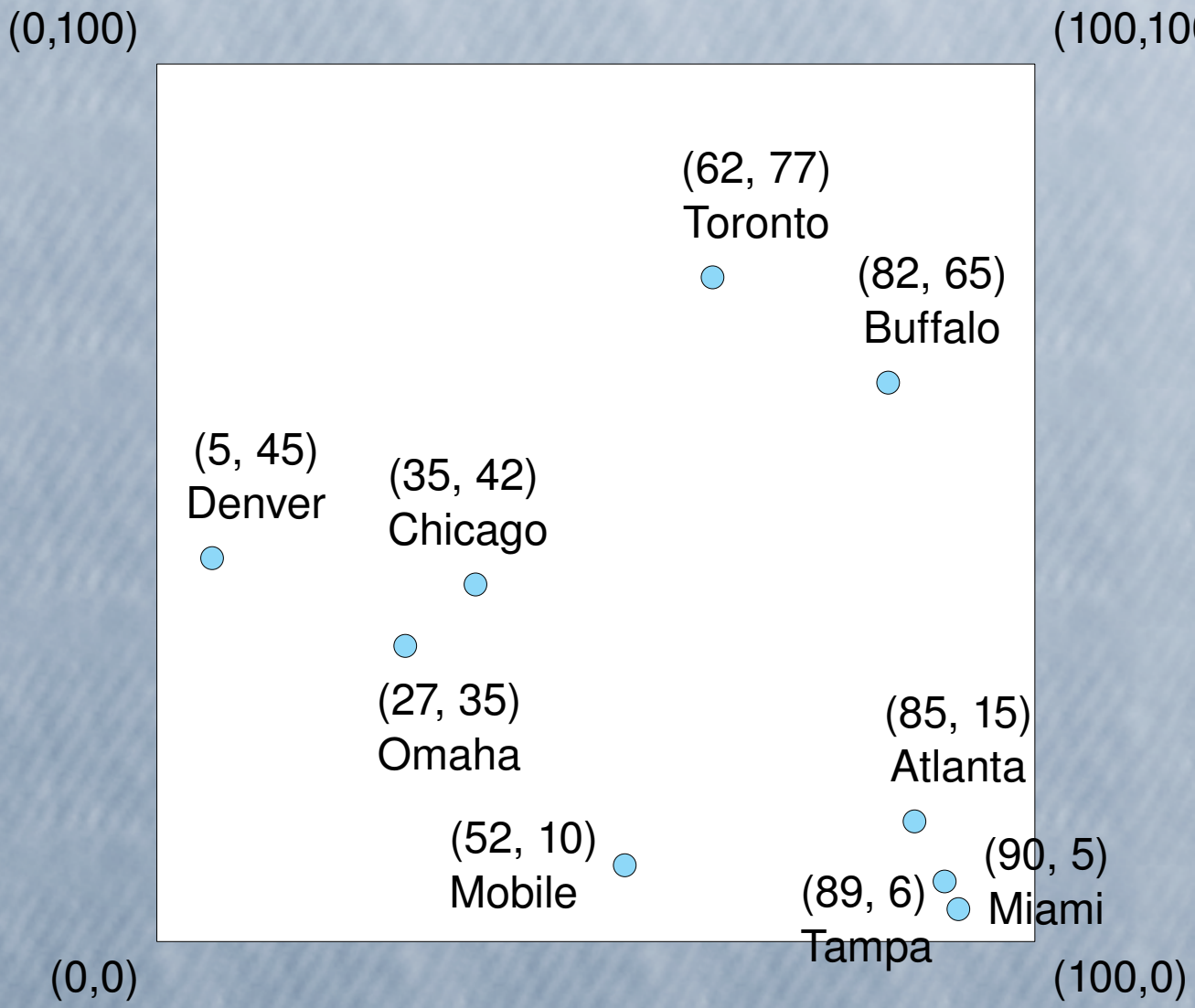
- Overview of spatial data structures
- Groups for Project 1
- Paper presentation schedule

Spatial Data Structures

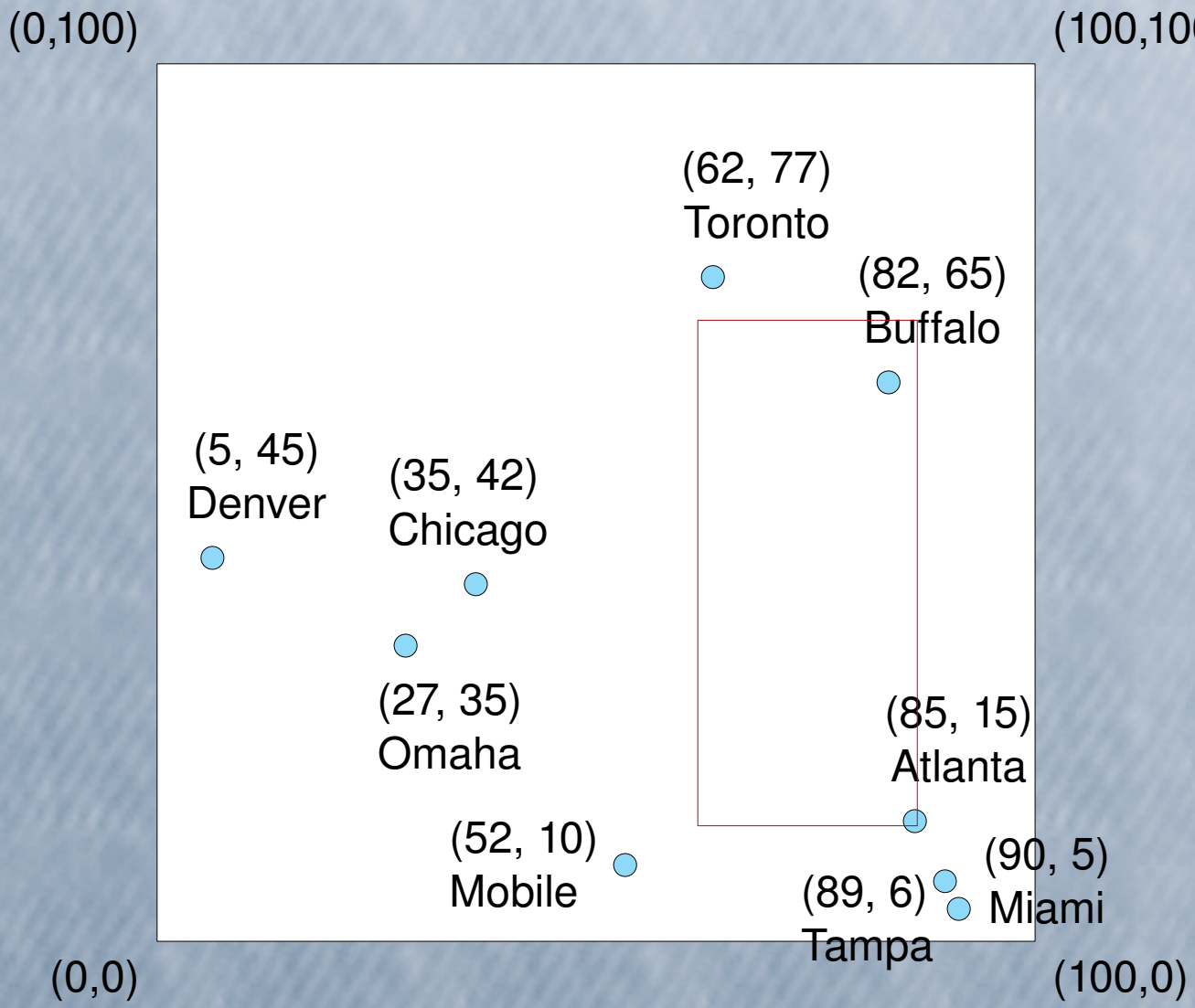
- Object-space vs World/Image space
- Examples:
  - Regular / Irregular Grid
  - Range Tree
  - Quadtree / Octree
  - kd-tree / Binary Space Partition (BSP)-Tree
  - Bounding Volume Hierarchy

Object vs. World Space

Range Search on Point Data



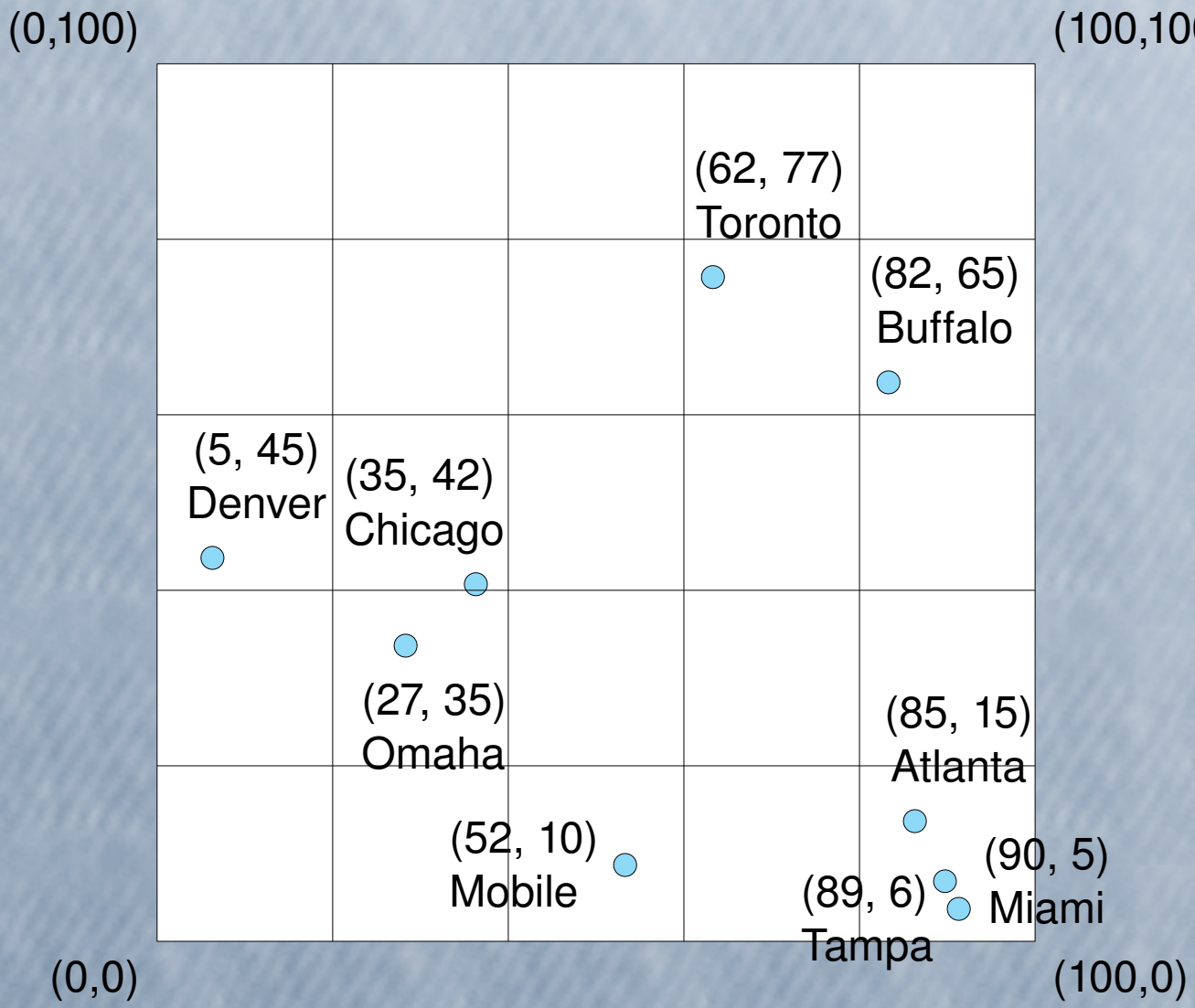
Range Search (61, 14) to (89, 71)



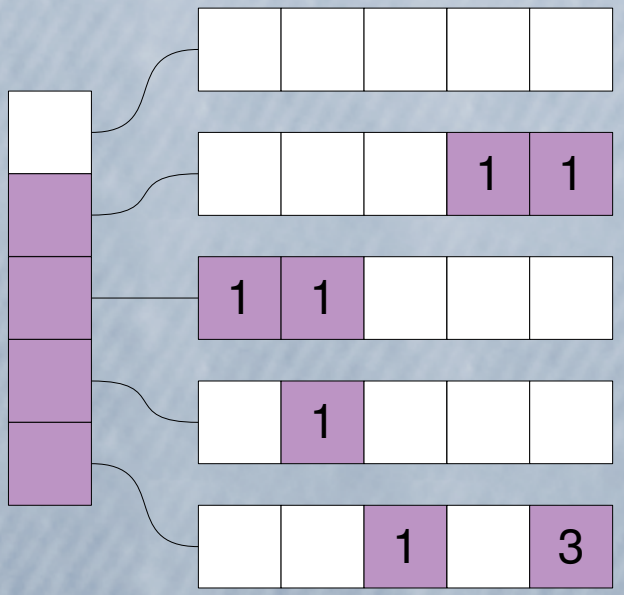
Brute Force Range Query

```
function RangeSearch(real mins[], real maxs[]
                                    int d, city_type results[])
  for each city in Cities
    for i = 0 to d – 1
      if city.x[i] >= mins[i] AND city.x[i] <= maxs[i]
        results.push_back(city);
      fi
    end
  end
end
```

Regular Grids

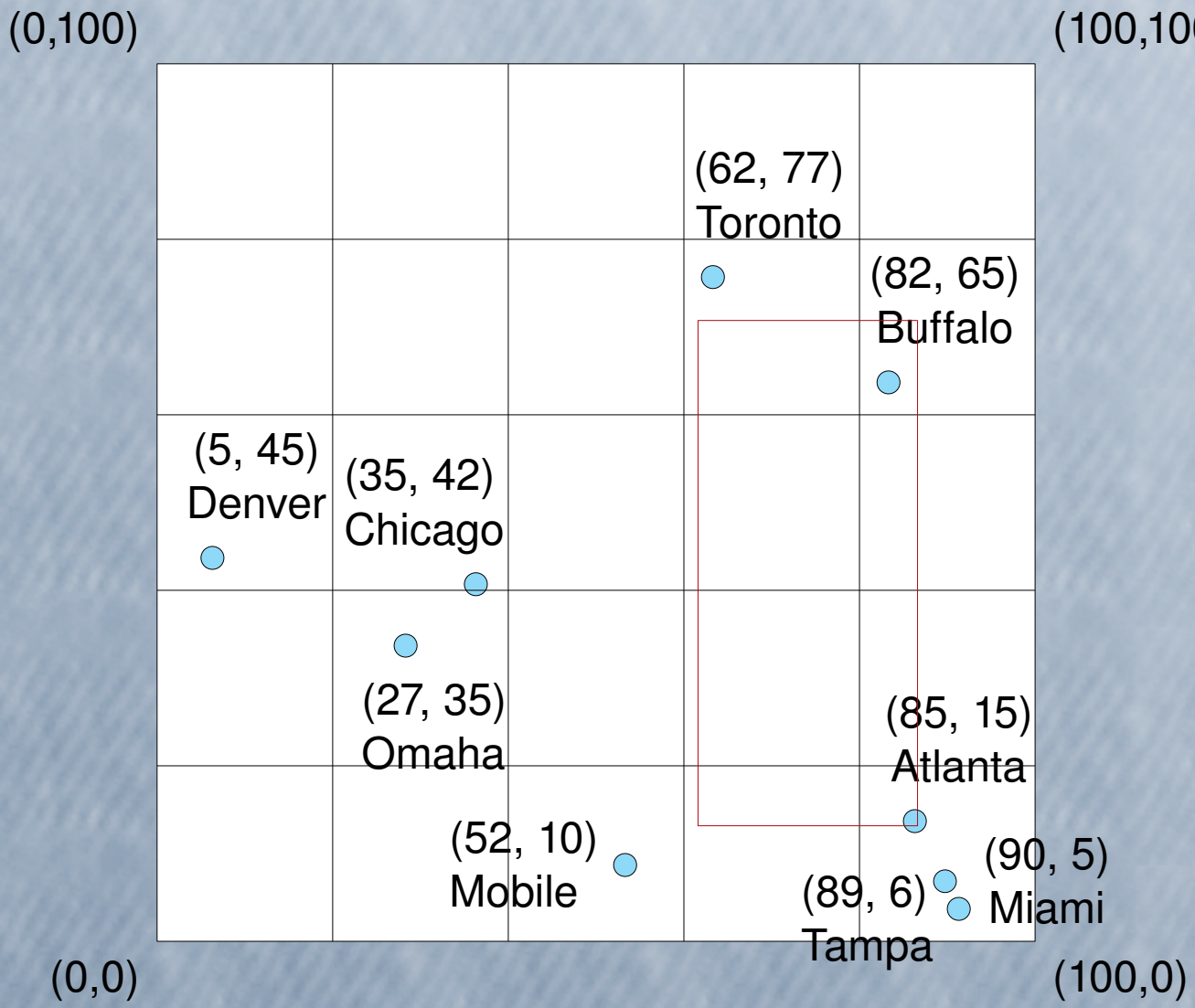


Matrix as ND Array



(Could also use sparse matrix representations)

Regular Grids



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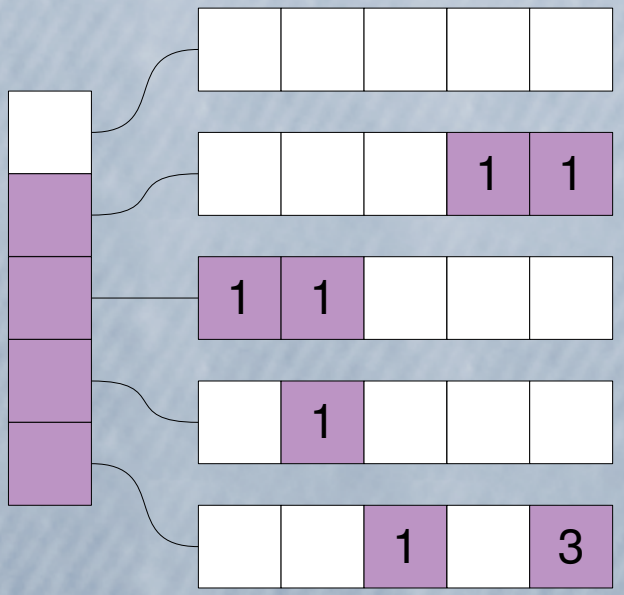

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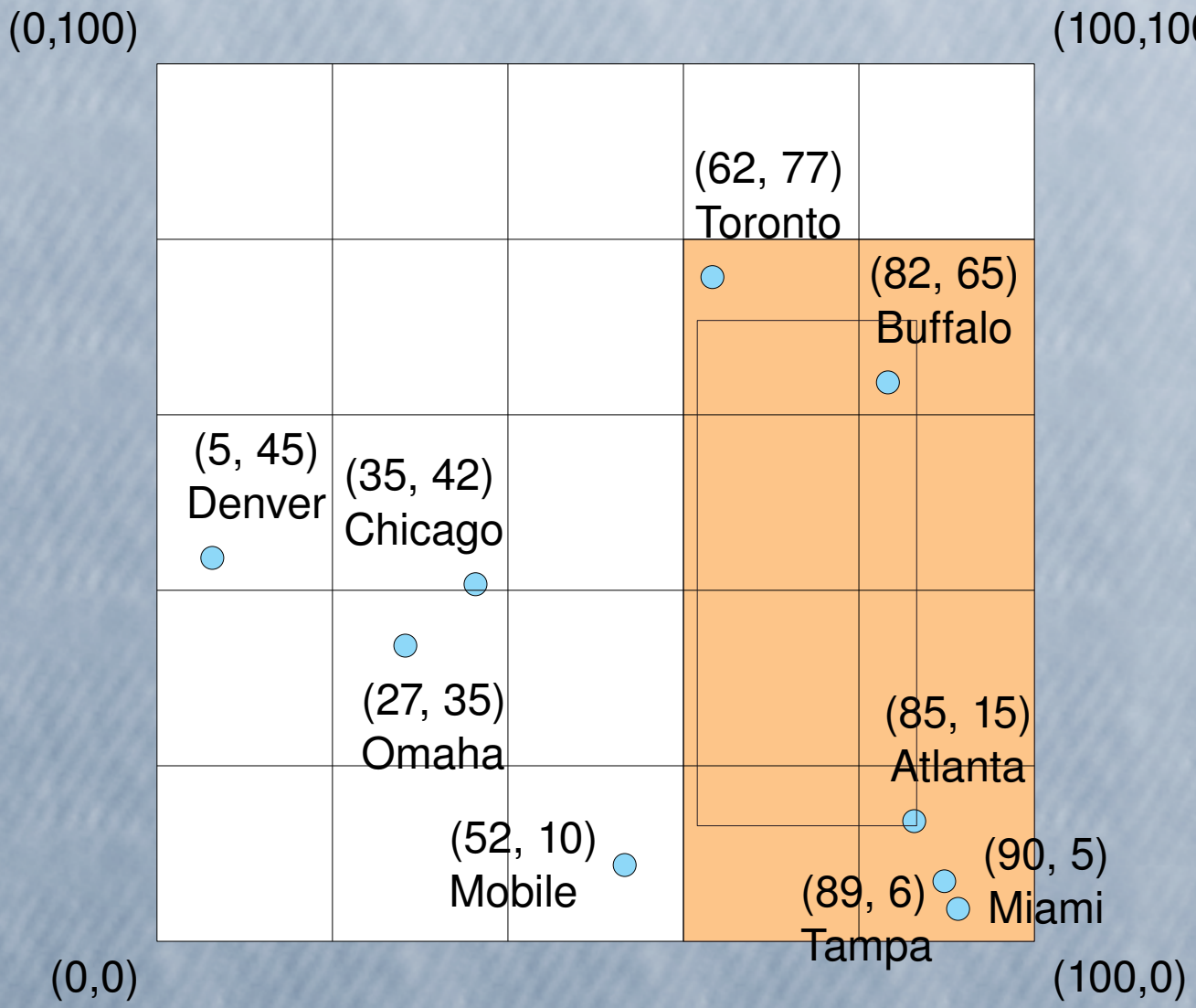
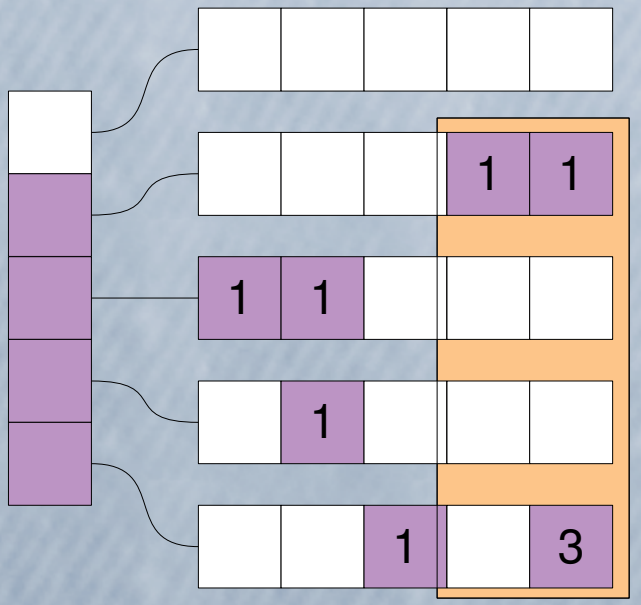
Range Search on Regular Grids

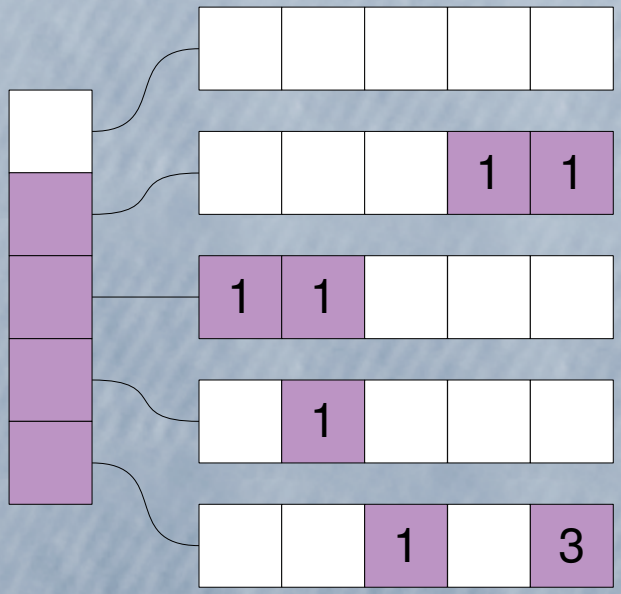


Matrix as ND Array

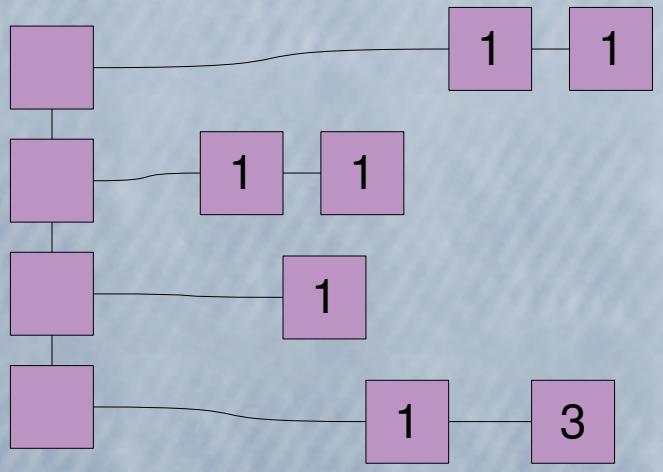


Sparse Matrix Representation

Matrix as ND Array

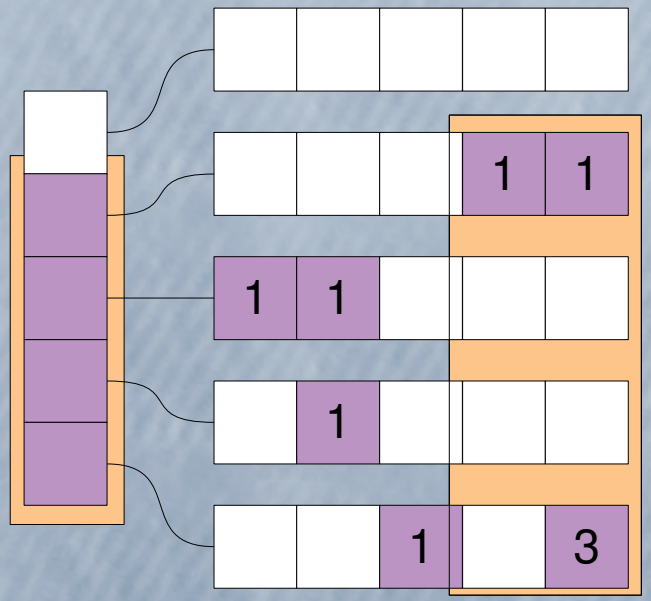


Matrix as Lists

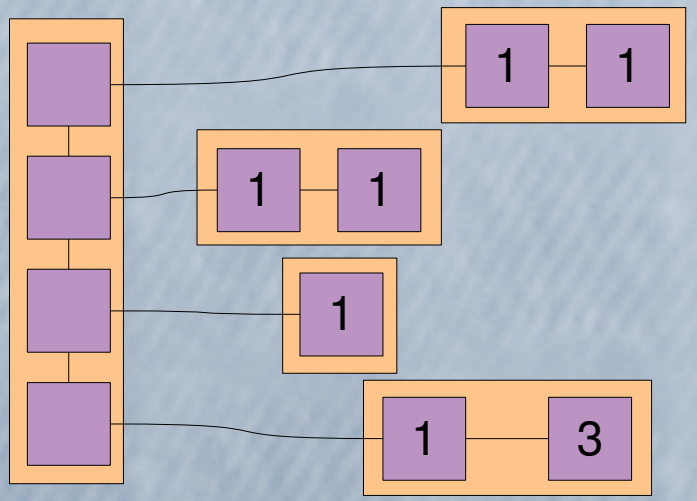


Memory Access Comparison

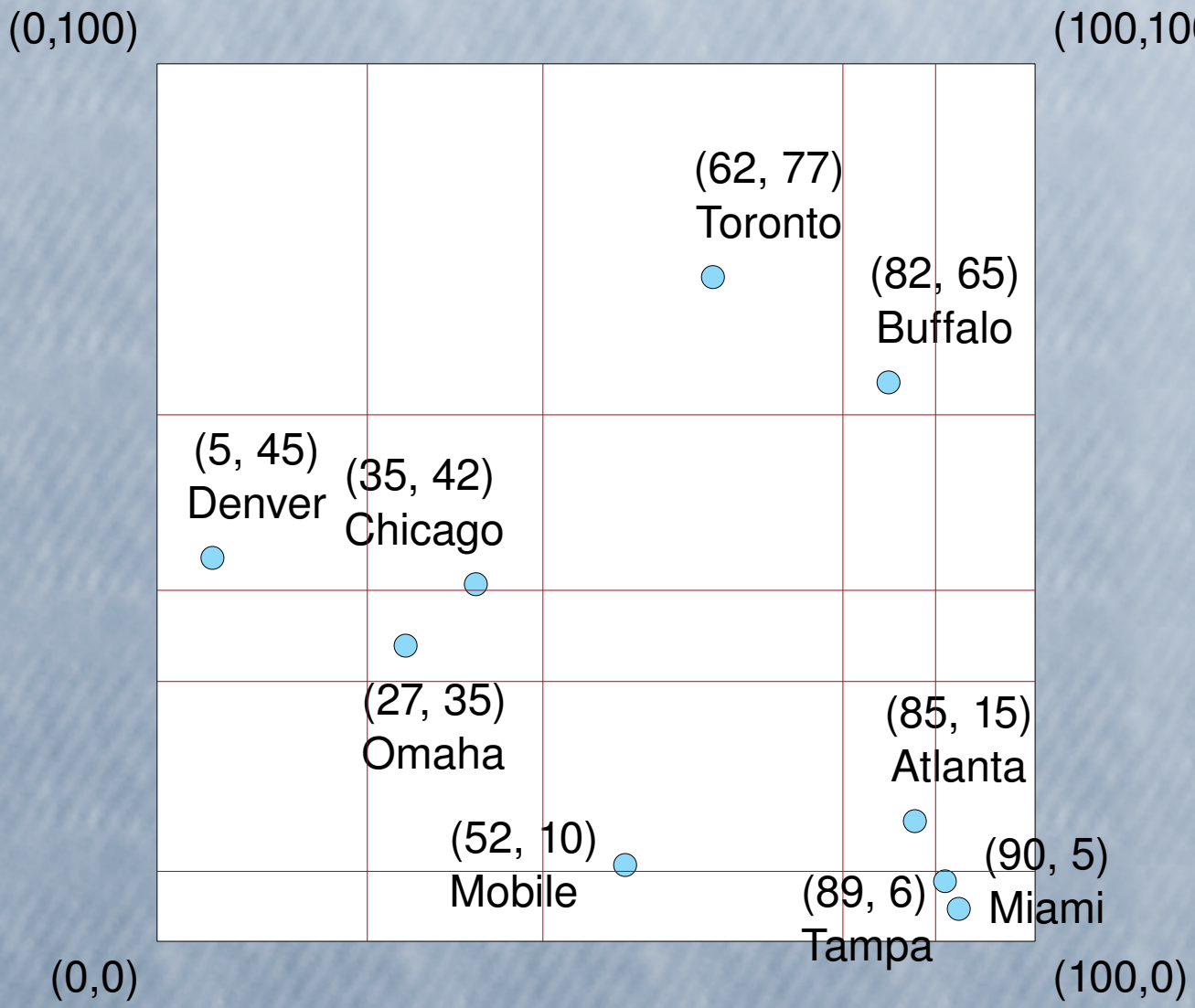
Matrix as ND Array



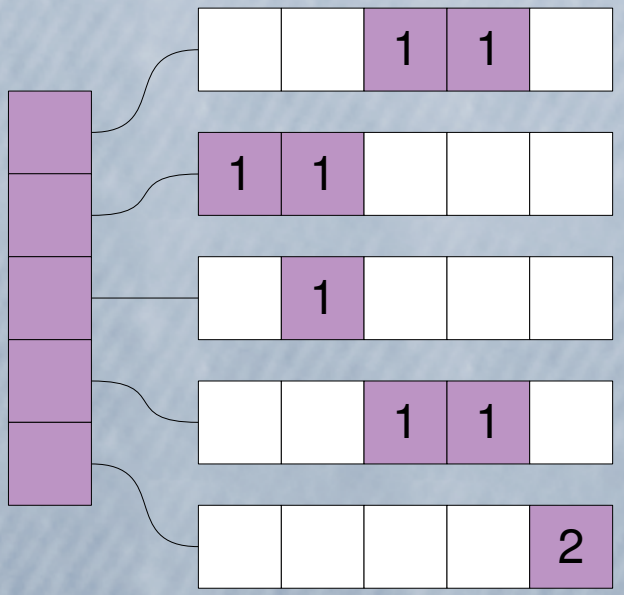
Matrix as Lists



Irregular Grids

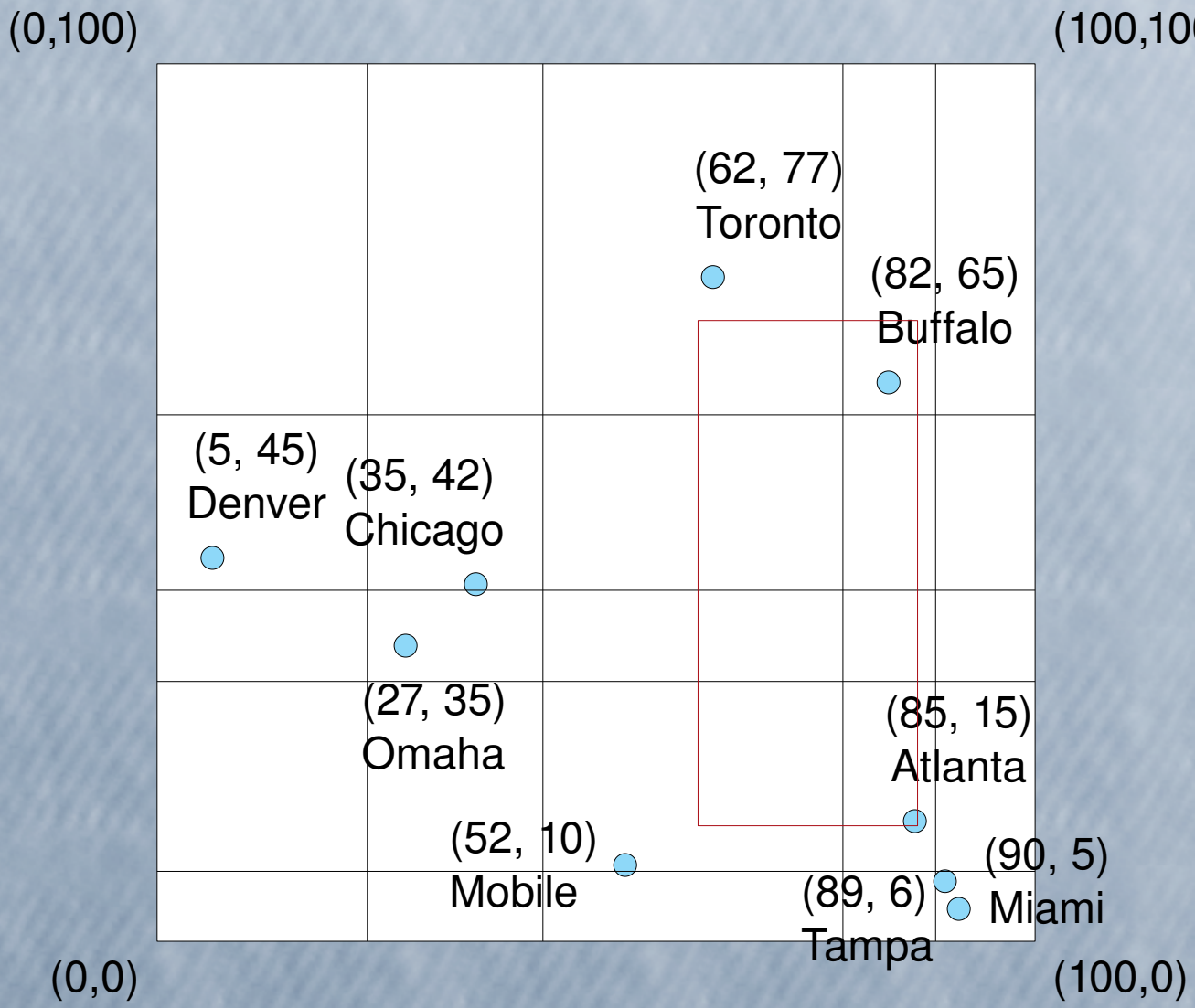


Matrix as ND Array

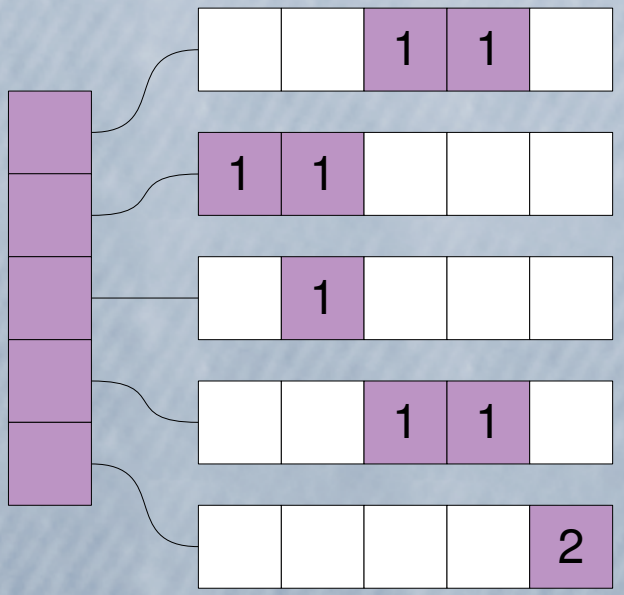


(Could also use sparse matrix representations)

Irregular Grids



Matrix as ND Array



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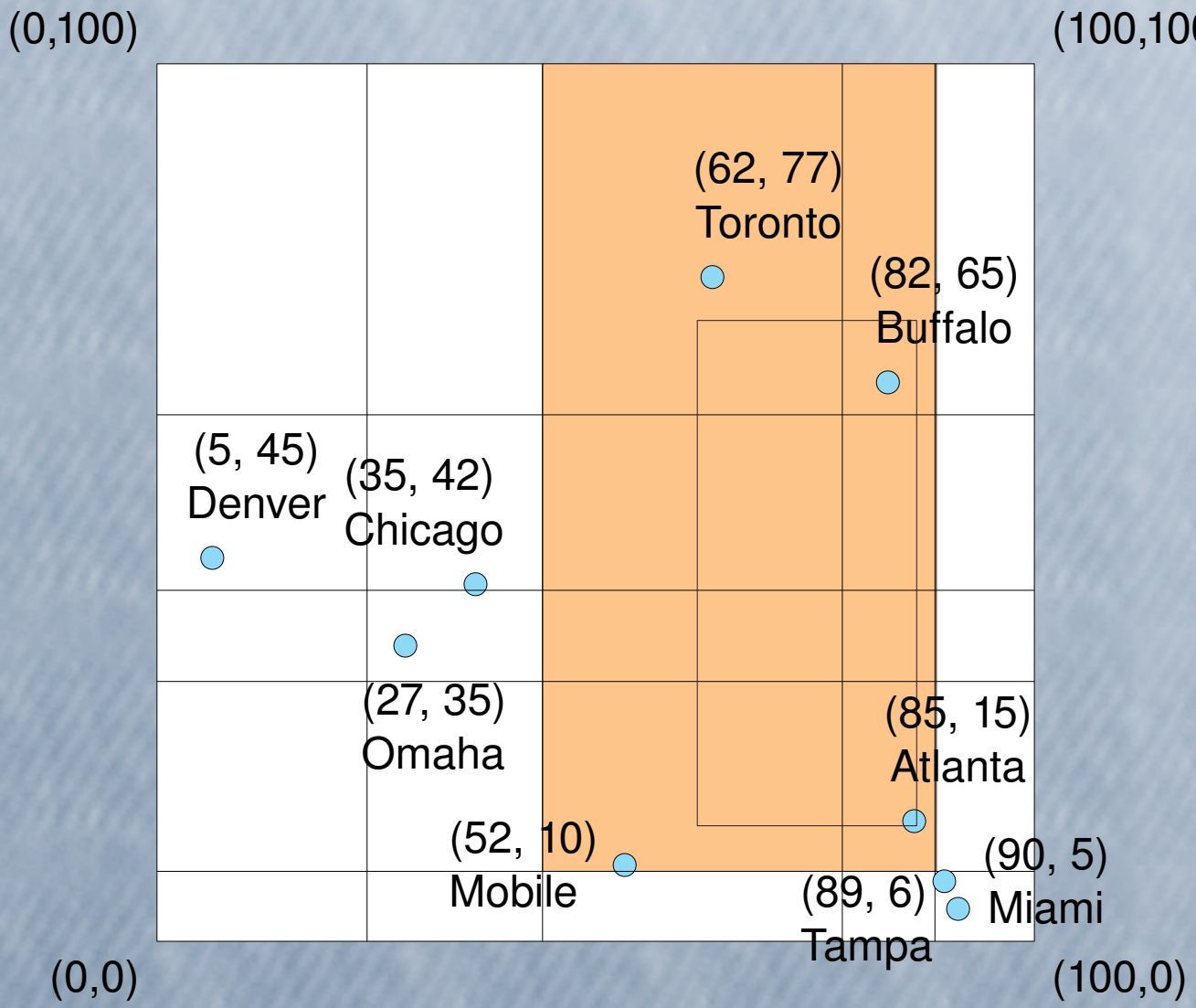
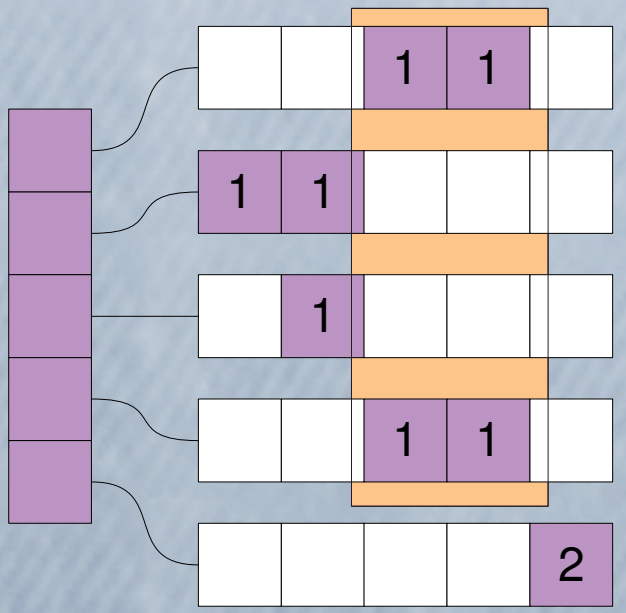
Range Search on Irregular Grids



Matrix as ND Array



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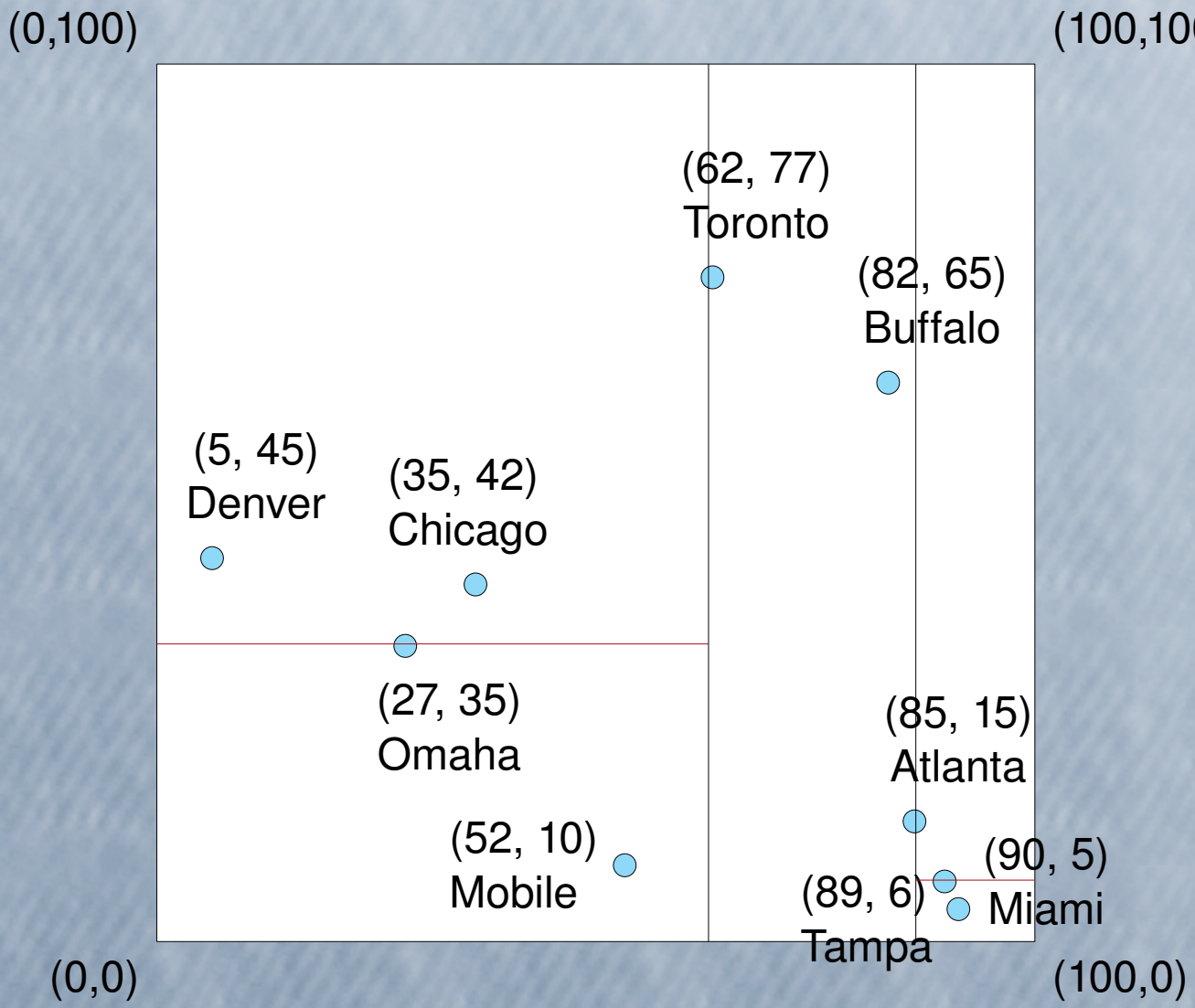
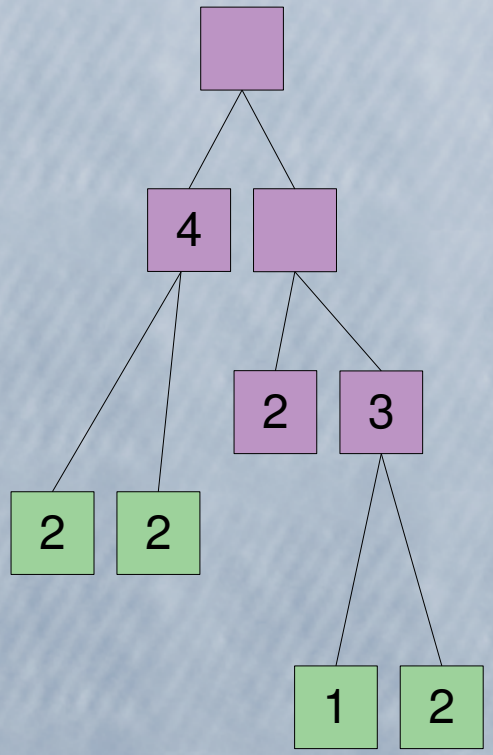
Multidimensional Range Trees



Multidimensional
Tree Data Structure



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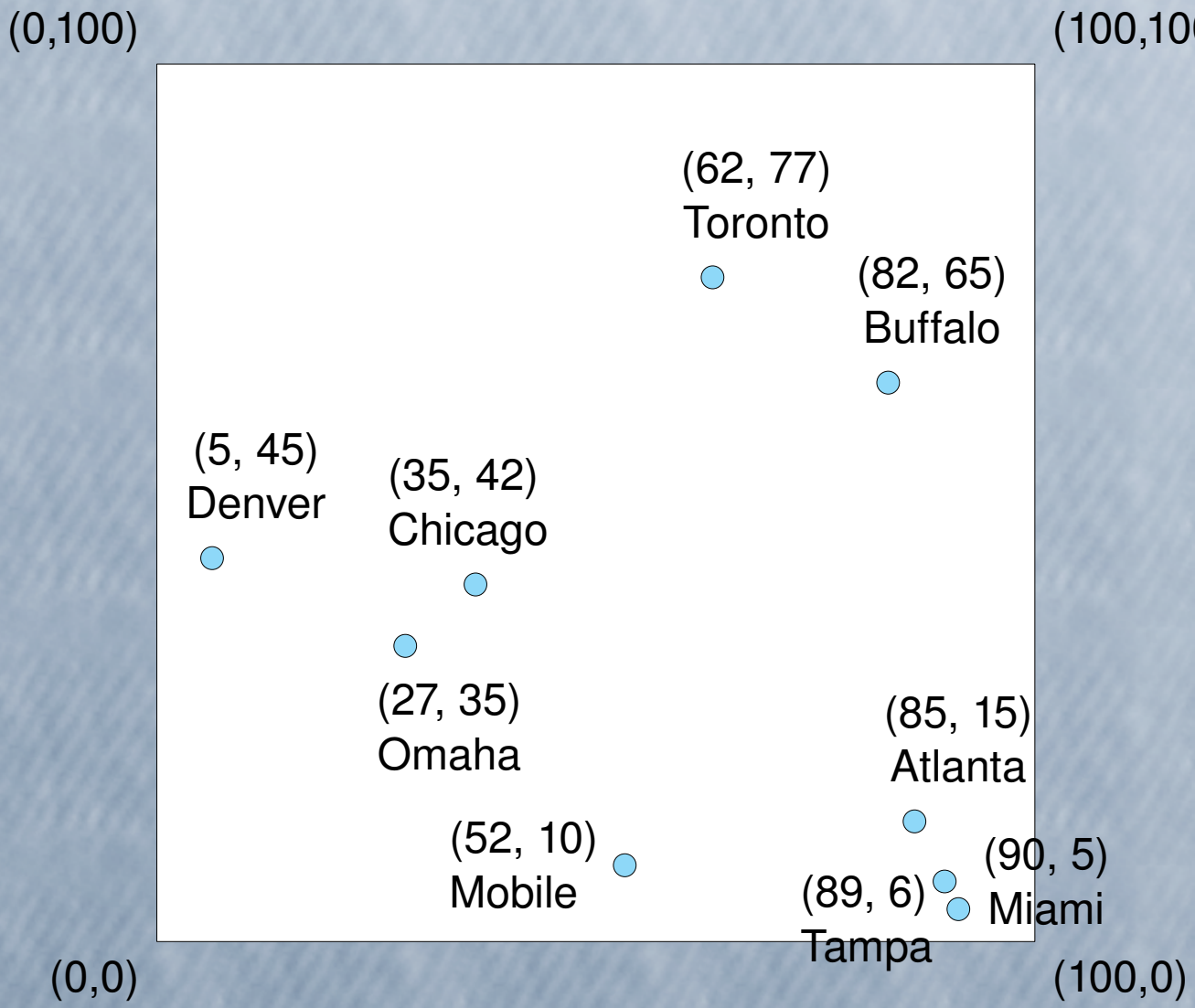
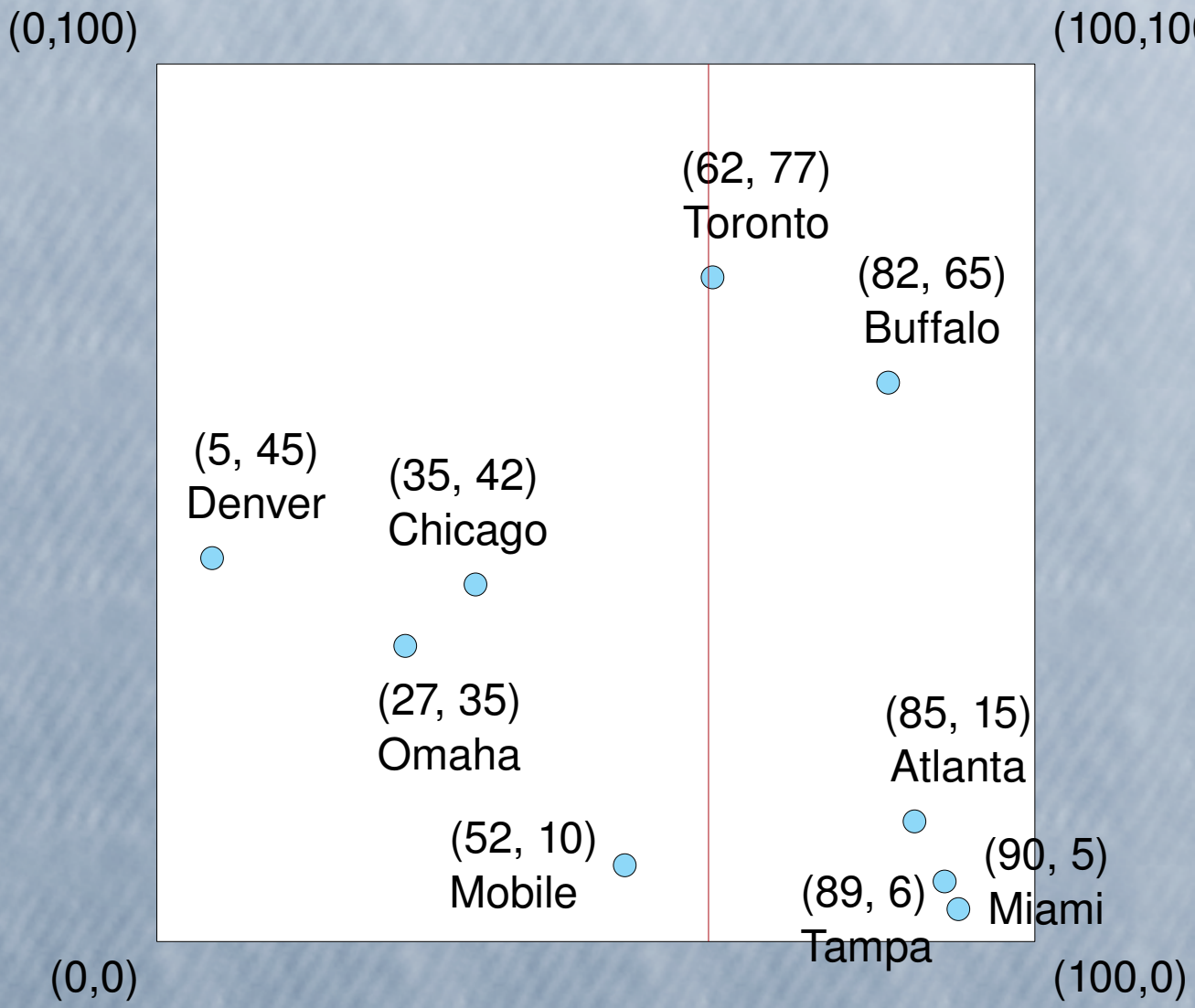


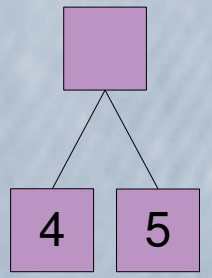
x_0-Tree Data Structure

9

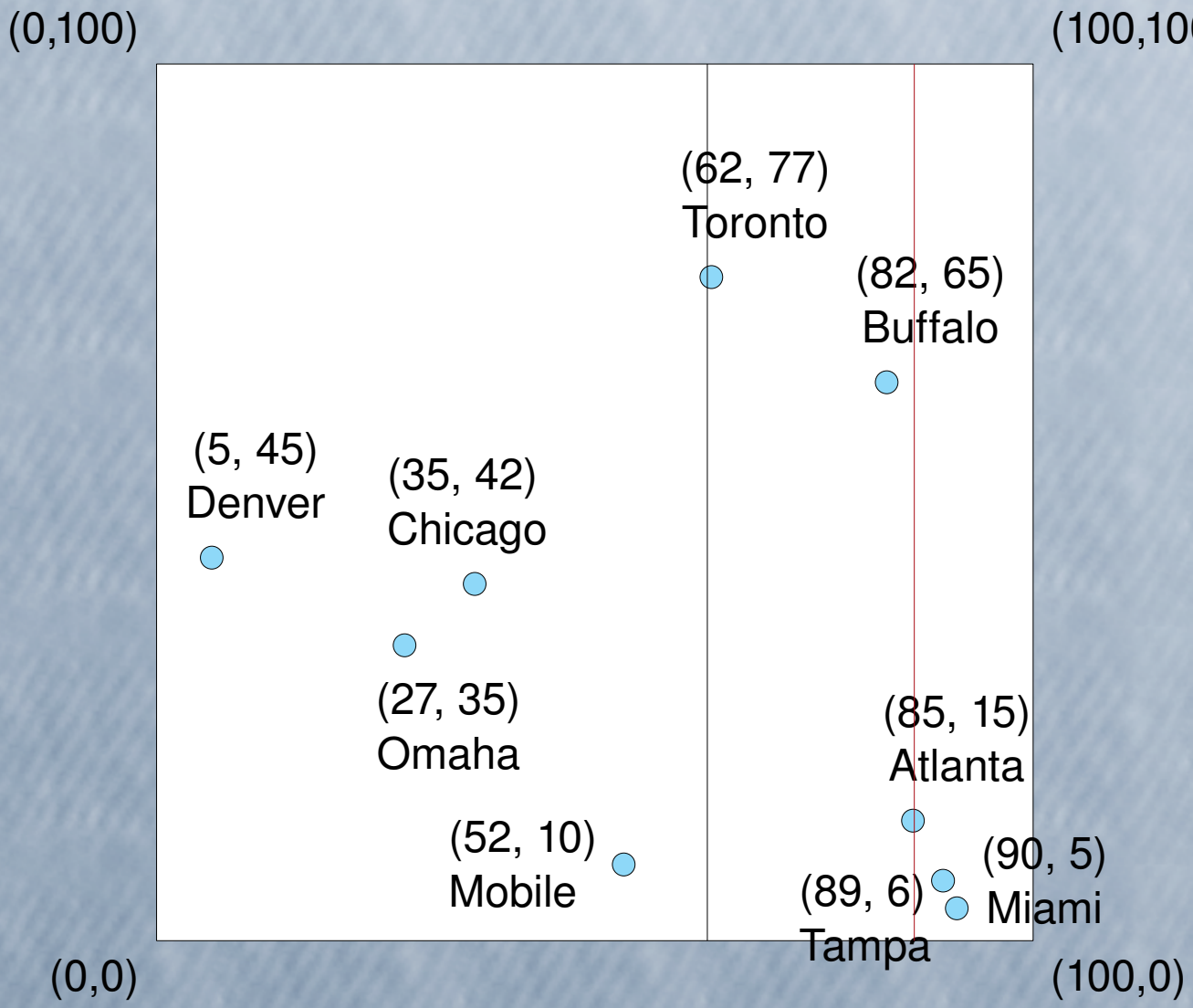
Range Trees



x_0-Tree Data Structure



Multidimensional Range Trees



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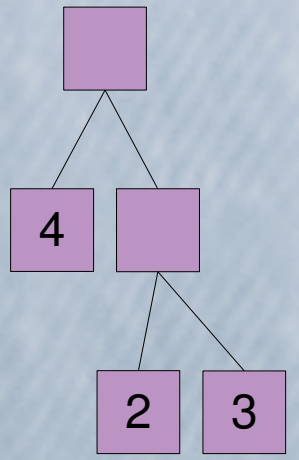
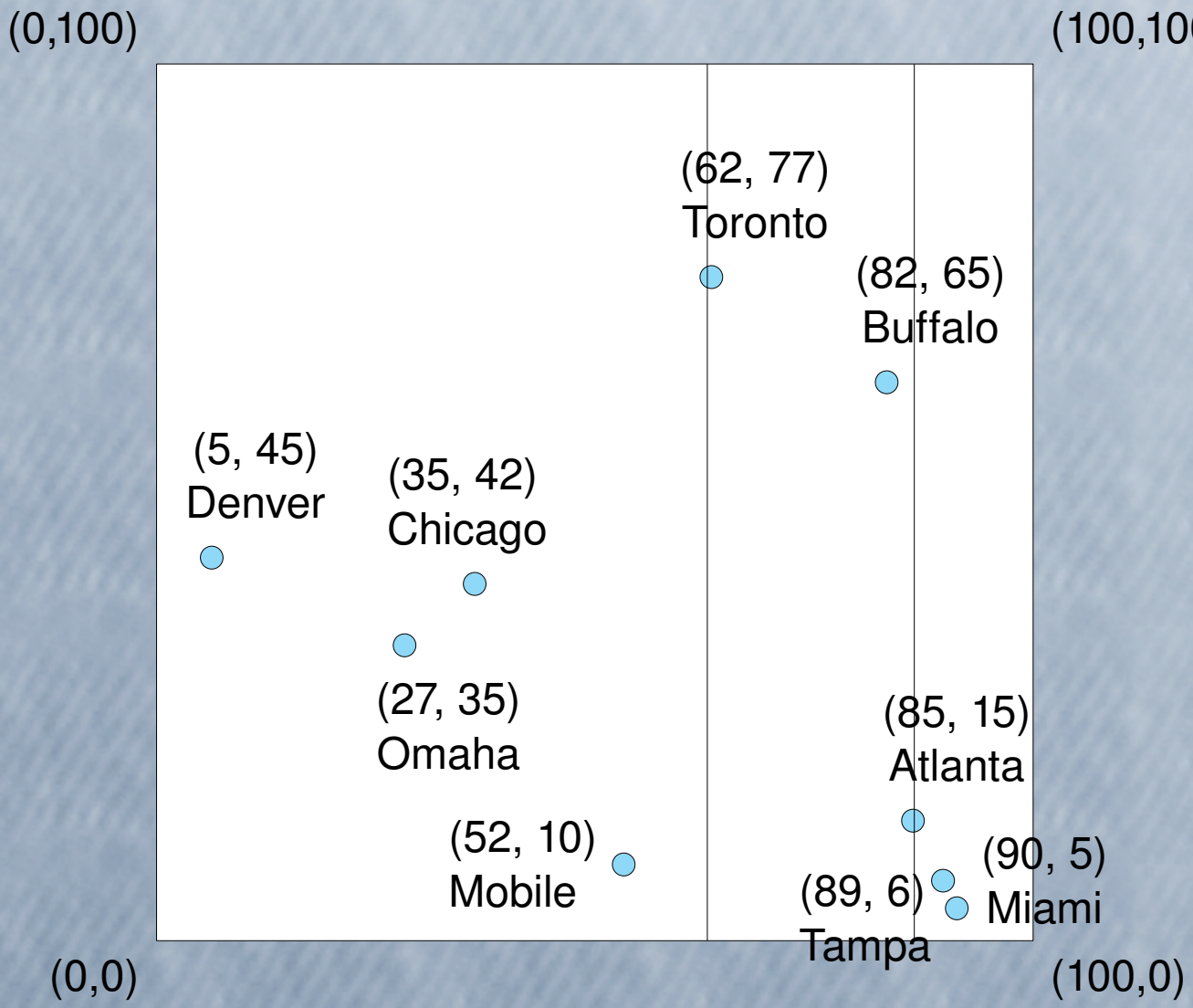
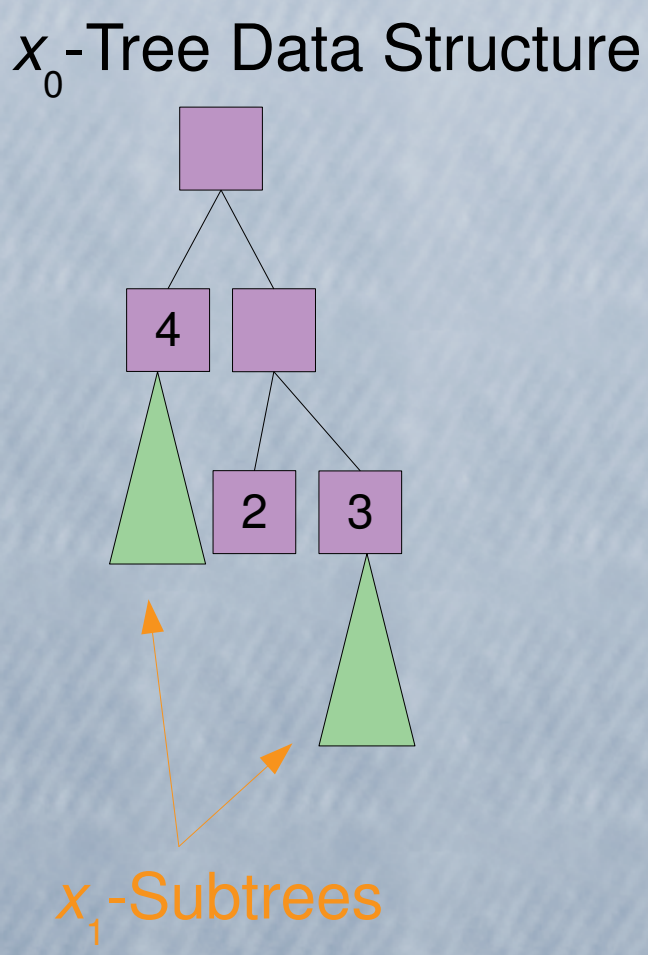


Multidimensional Range Trees





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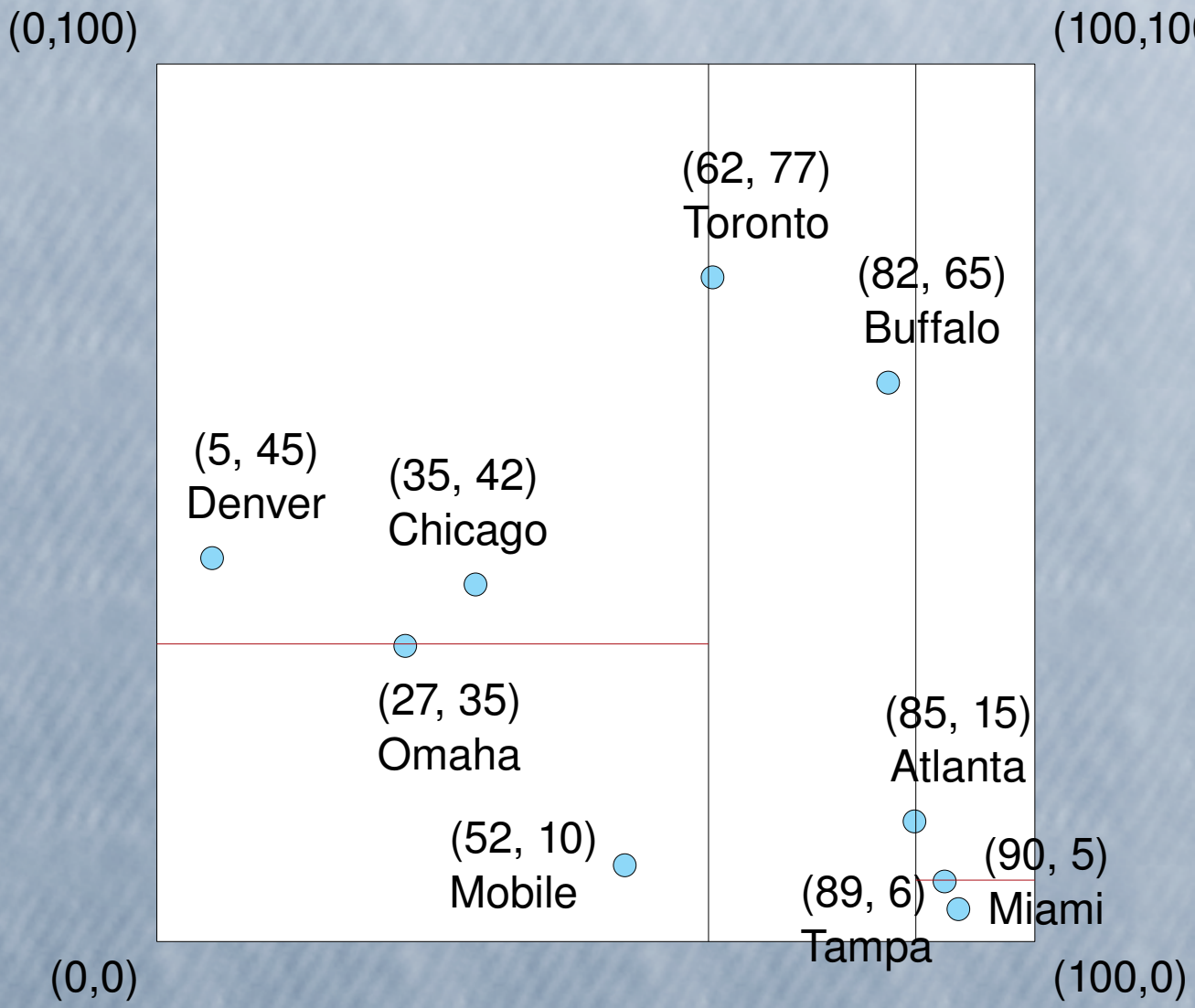

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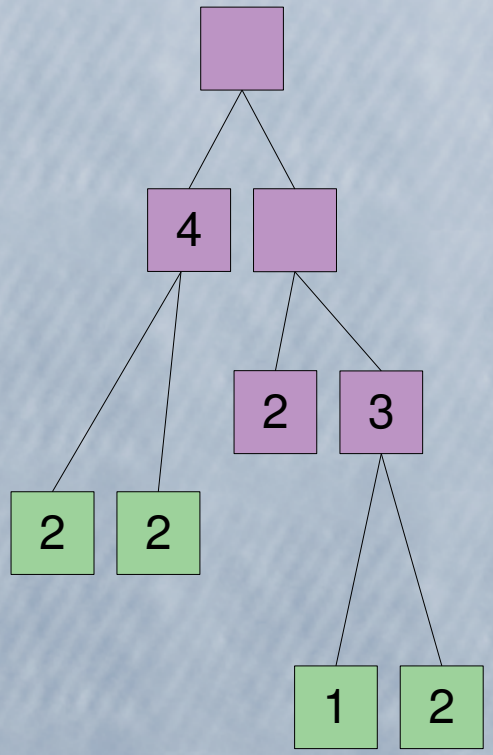
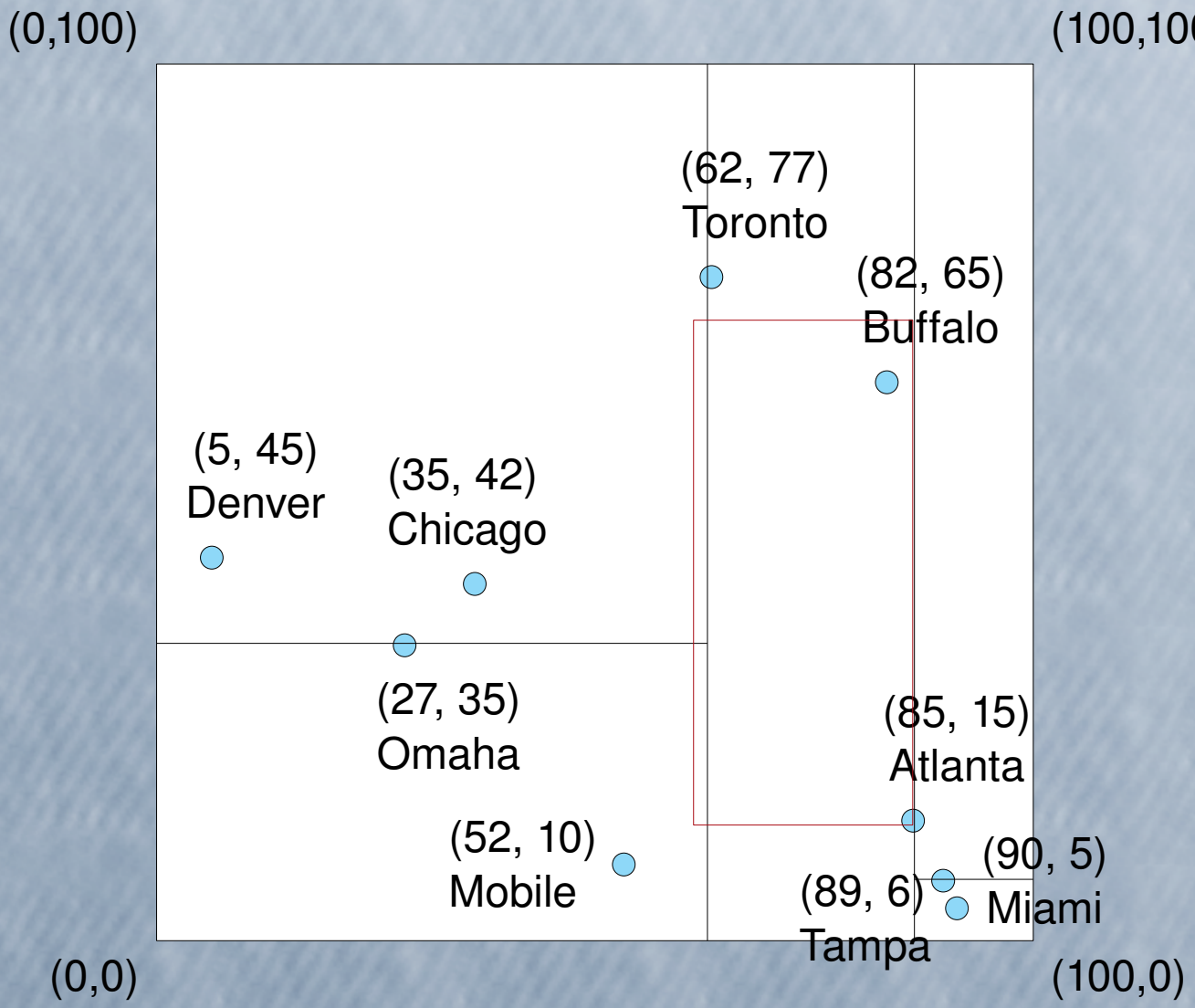


Range Query on Multidimensional Range Trees



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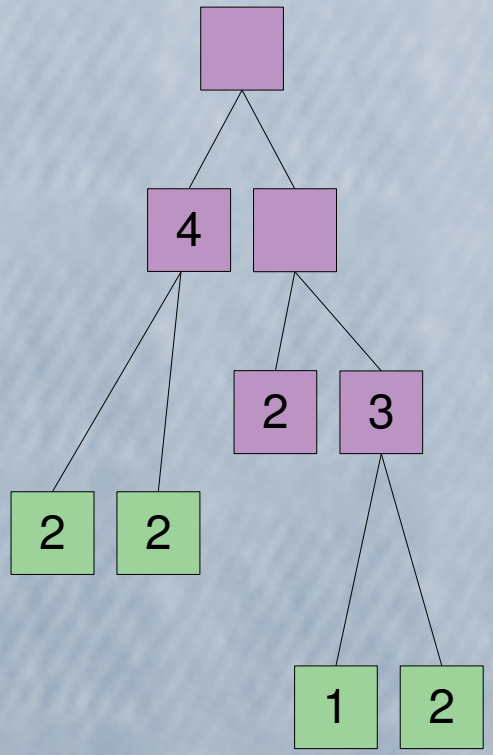

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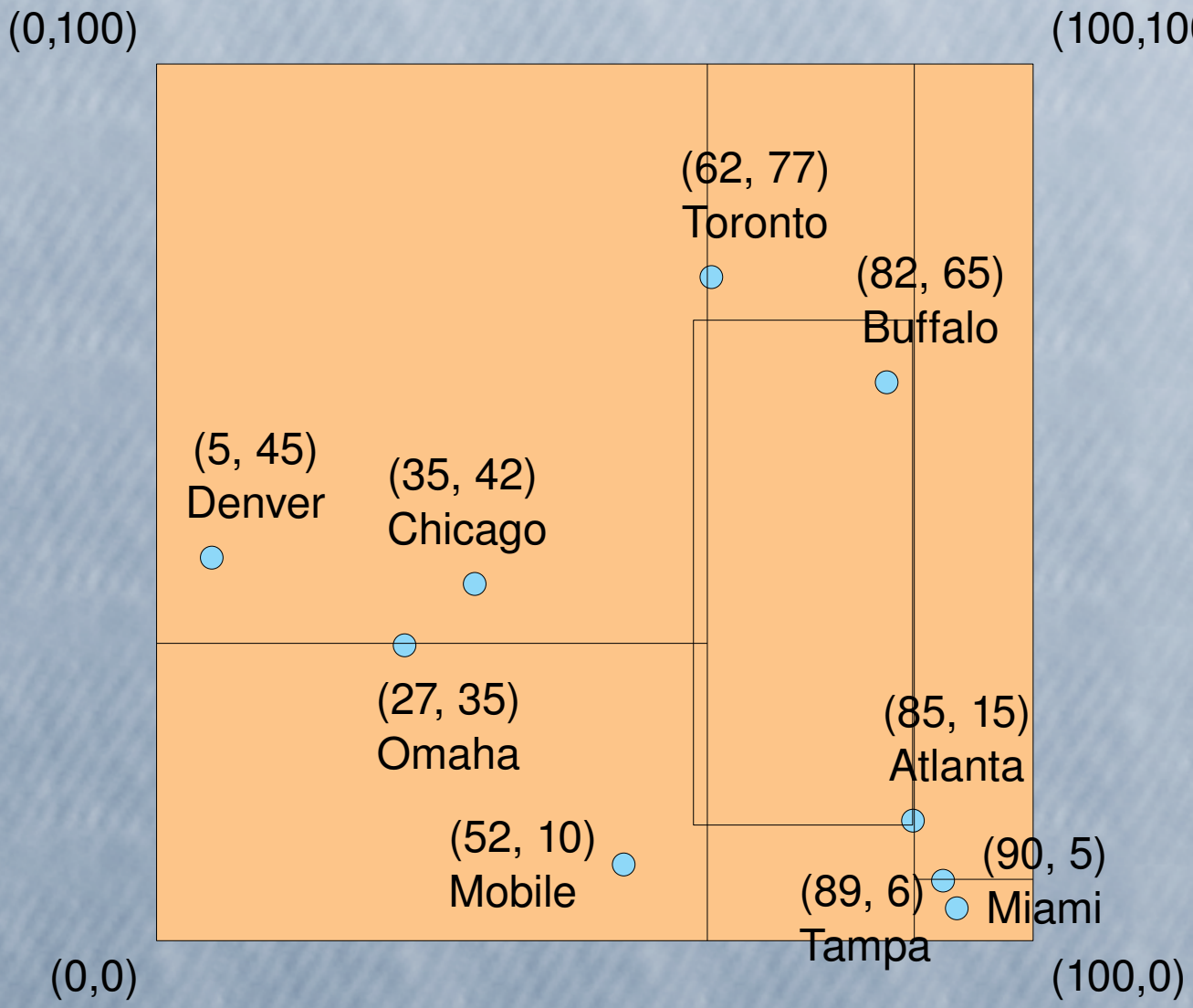

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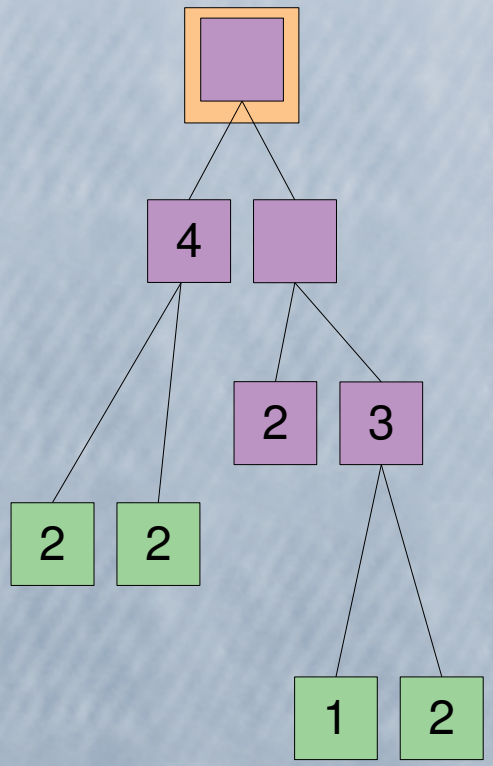

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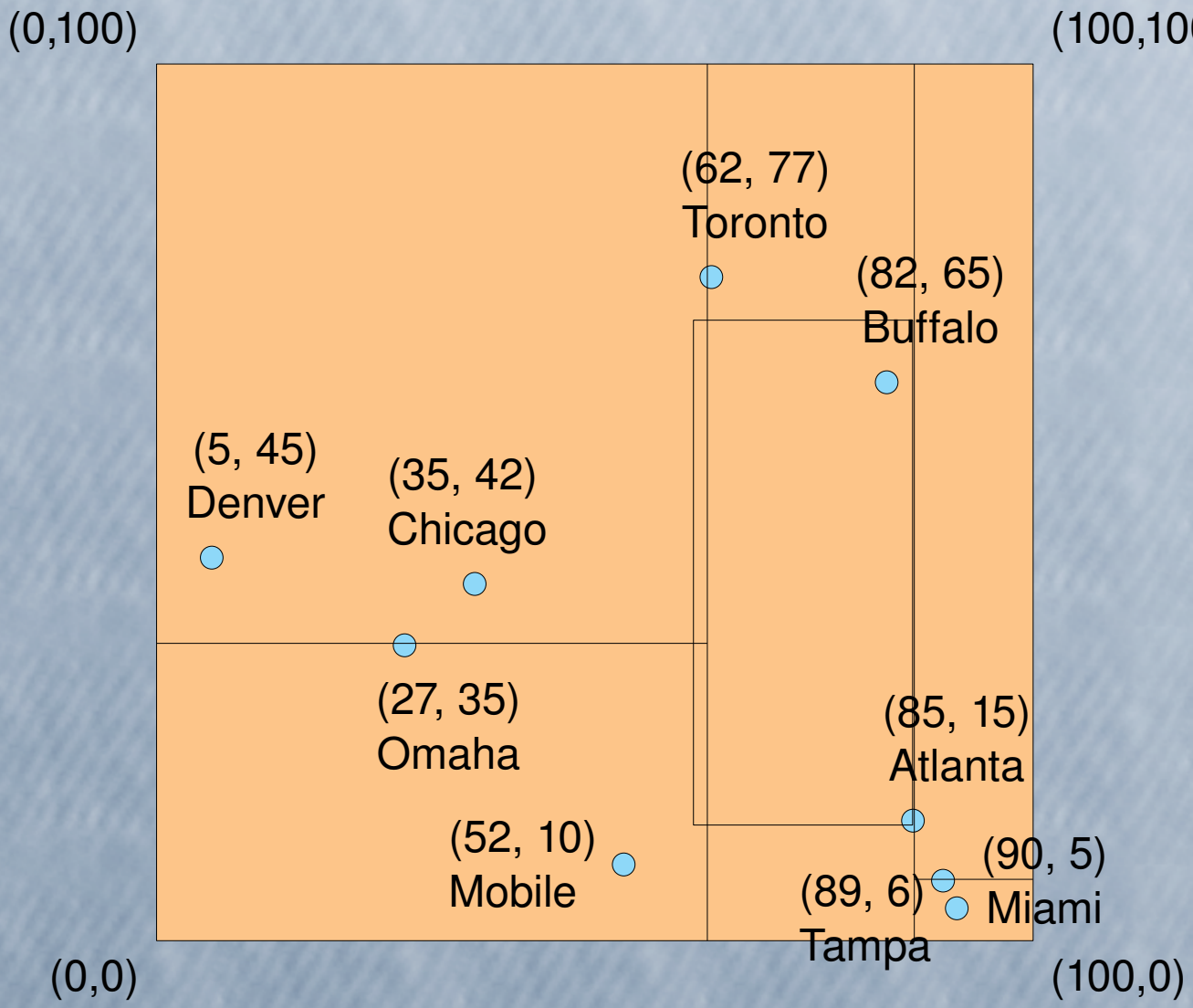
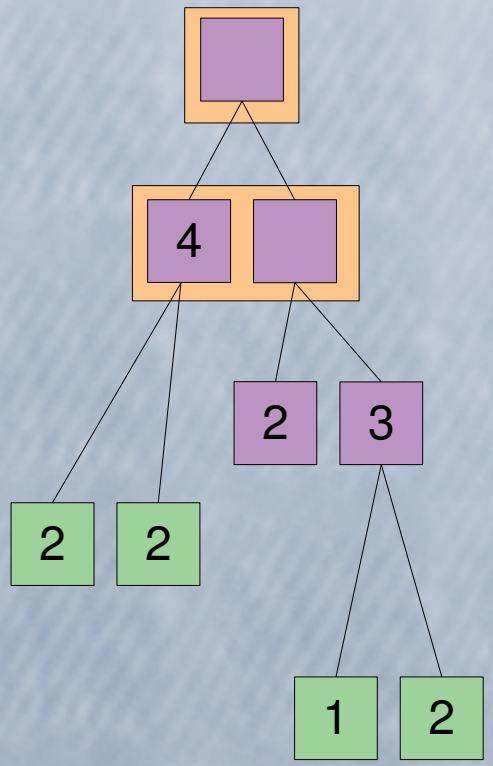
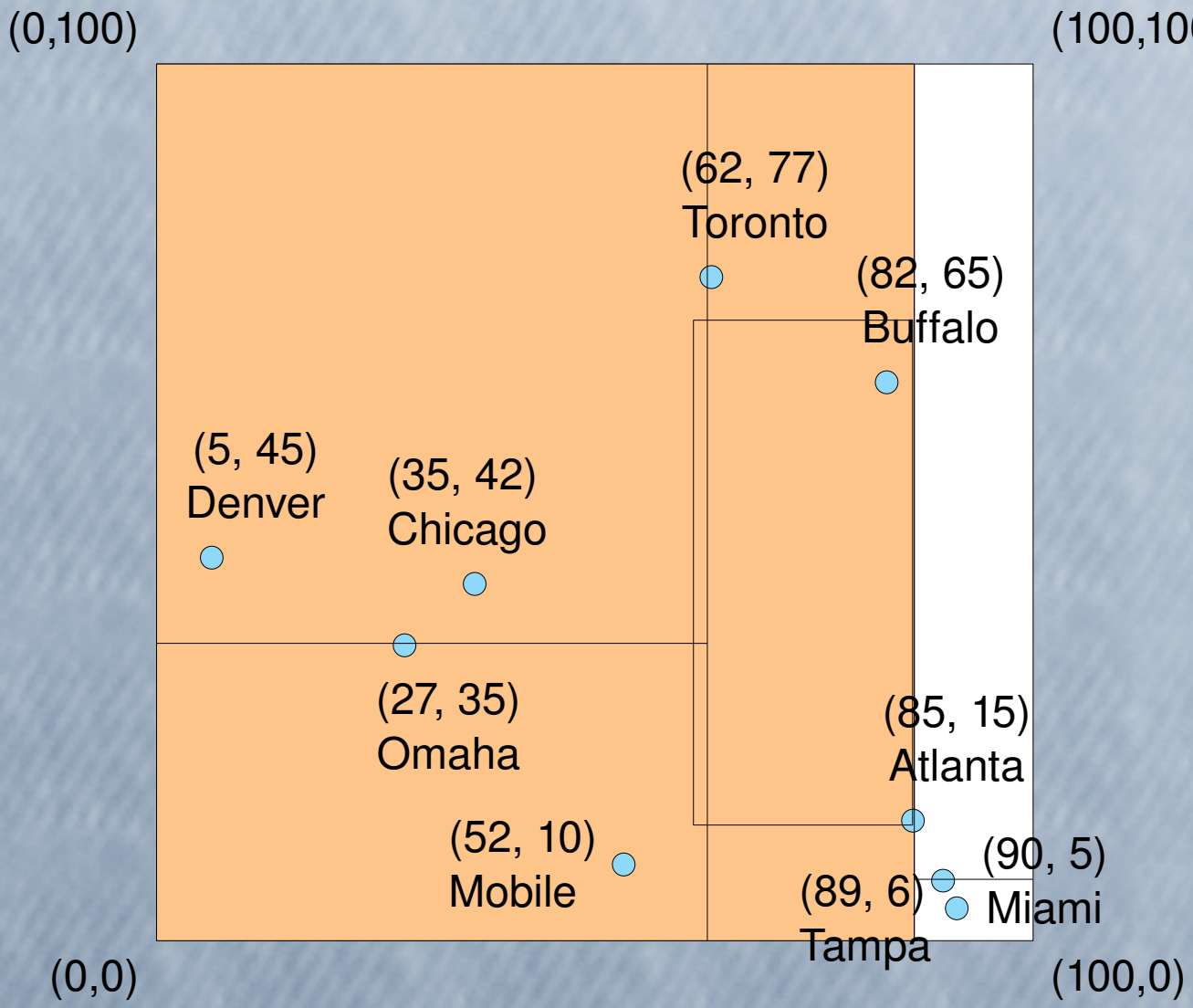


Multidimensional Tree Data Structure



Range Query on Multidimensional Range Trees



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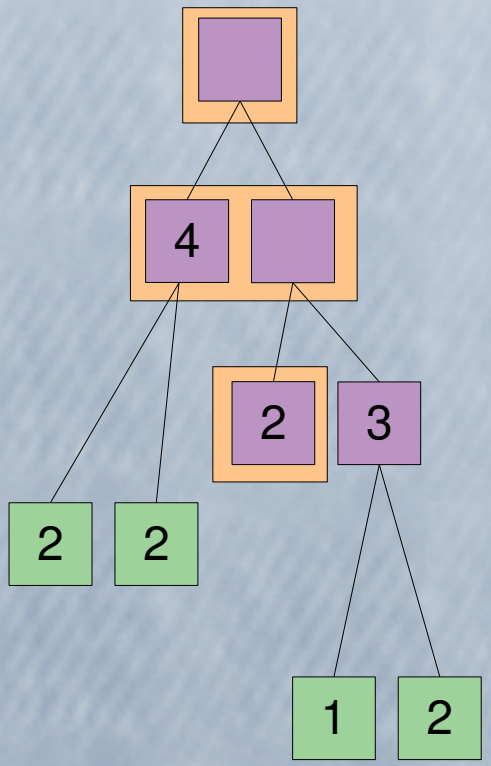

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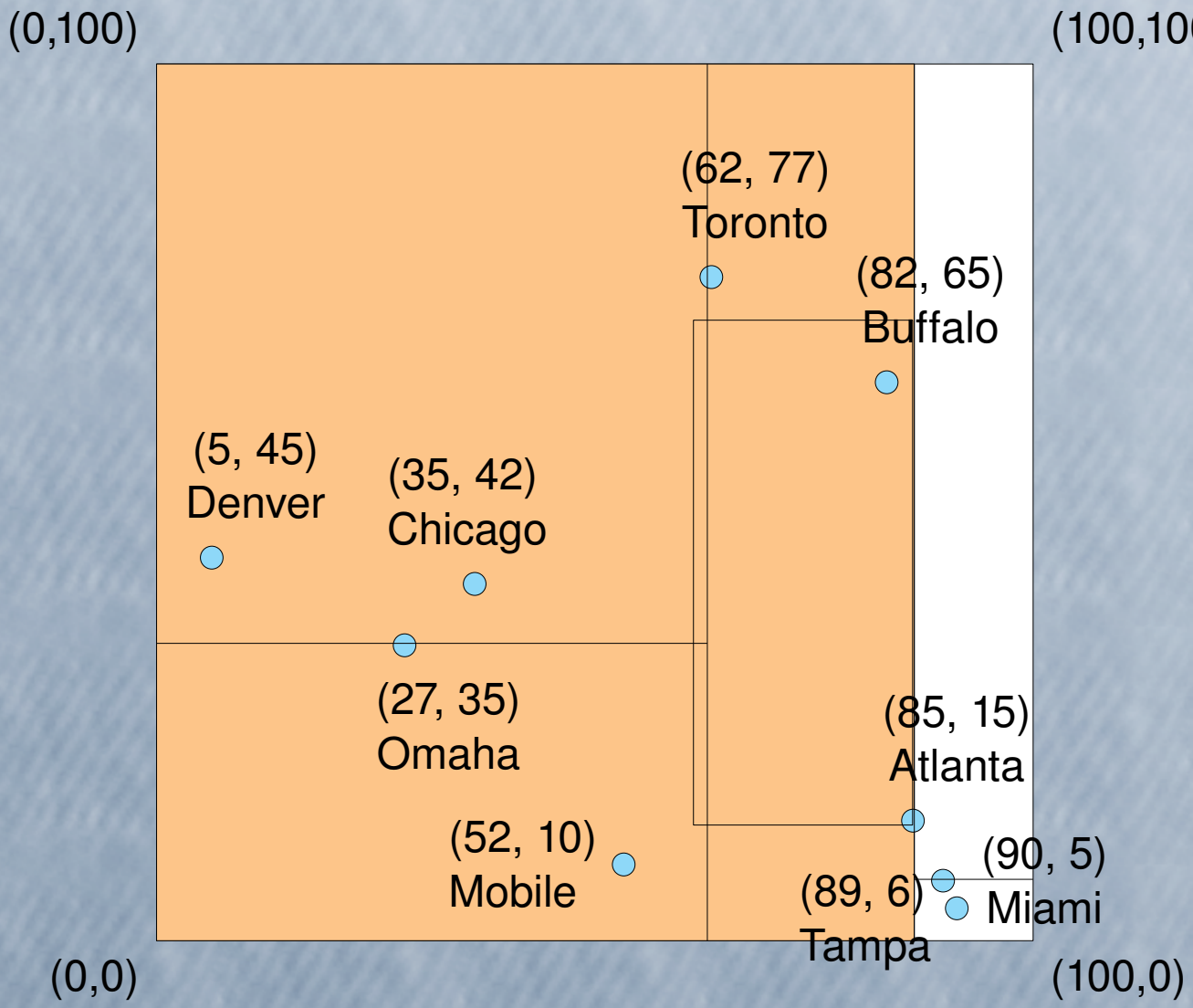

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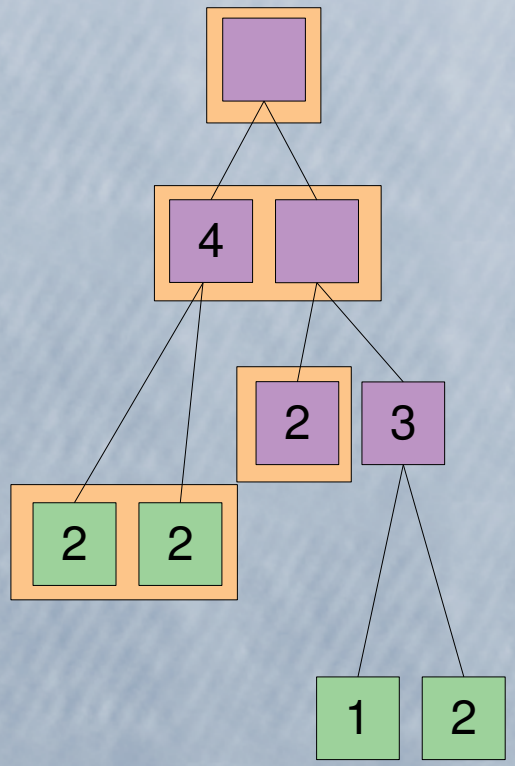
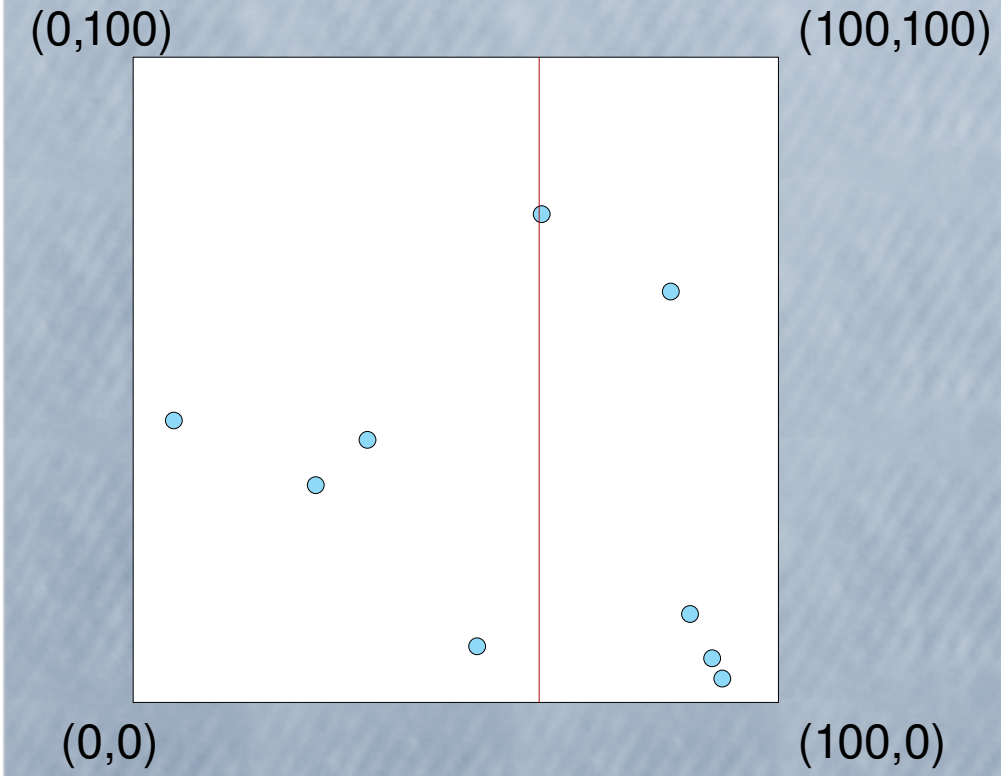
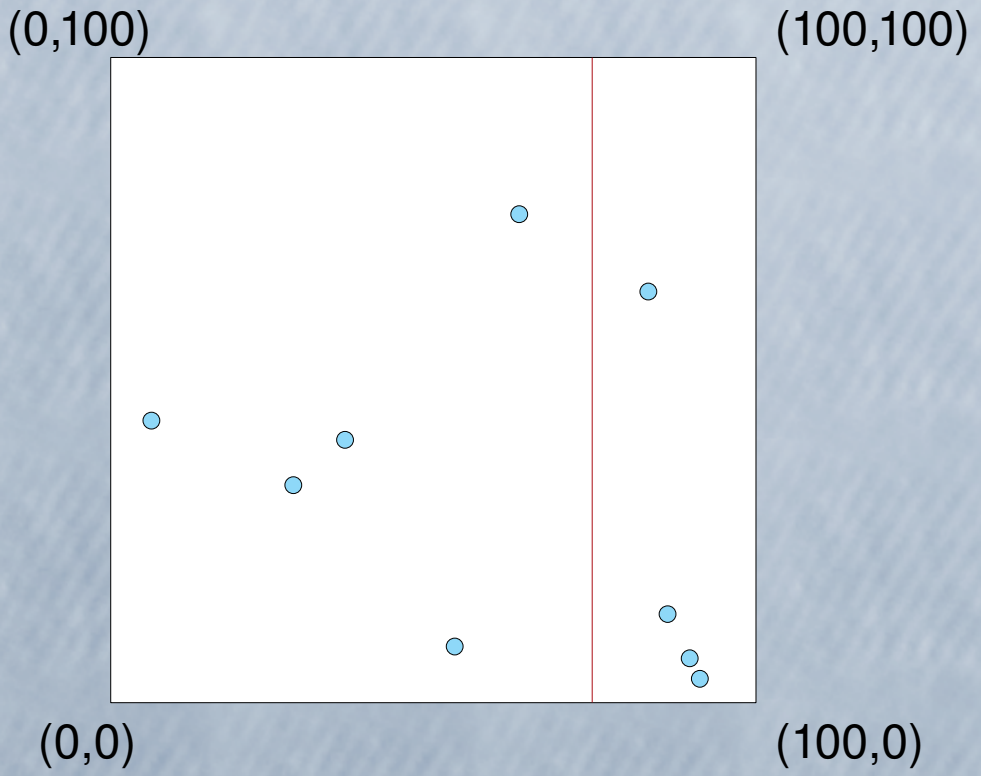
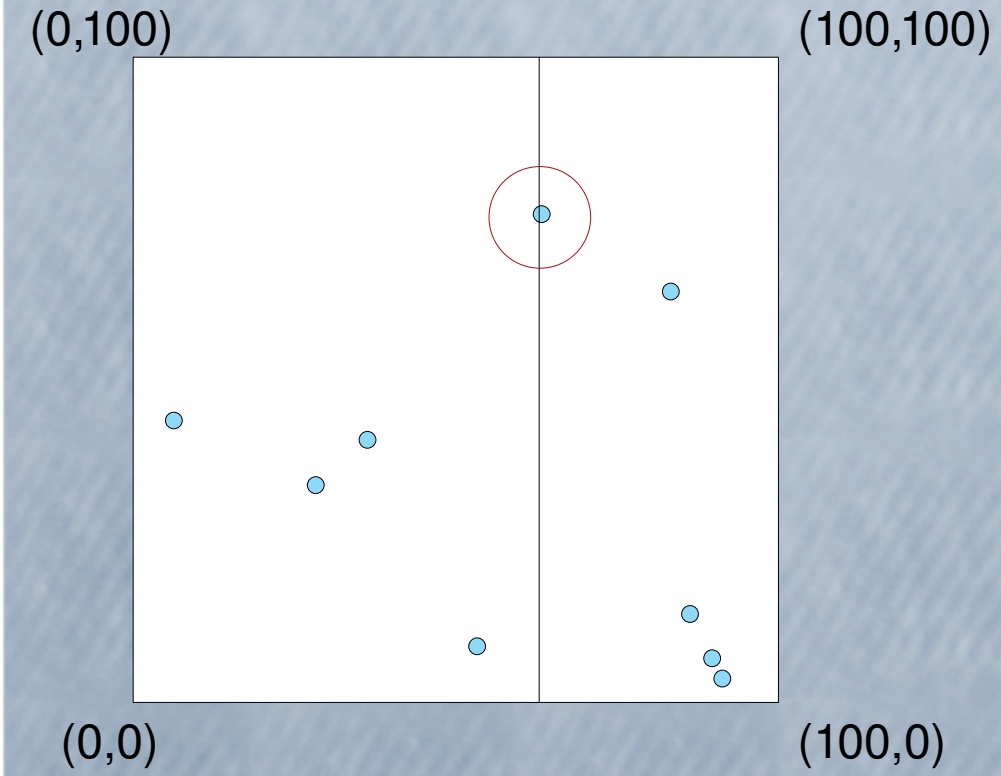


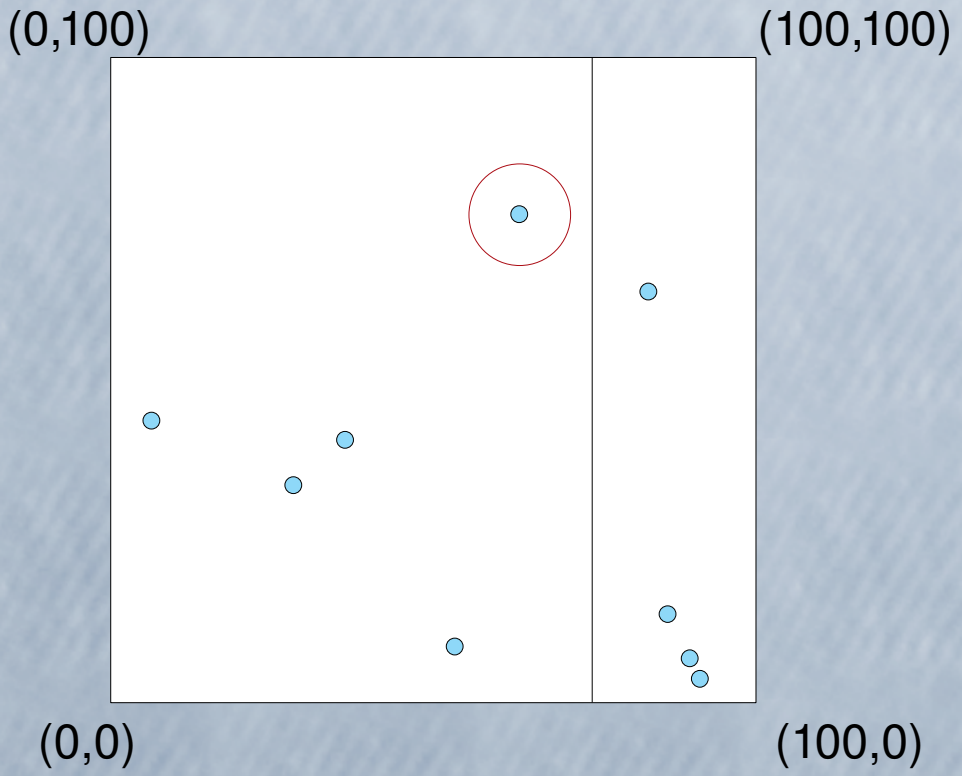
Split On Points or Between Points?





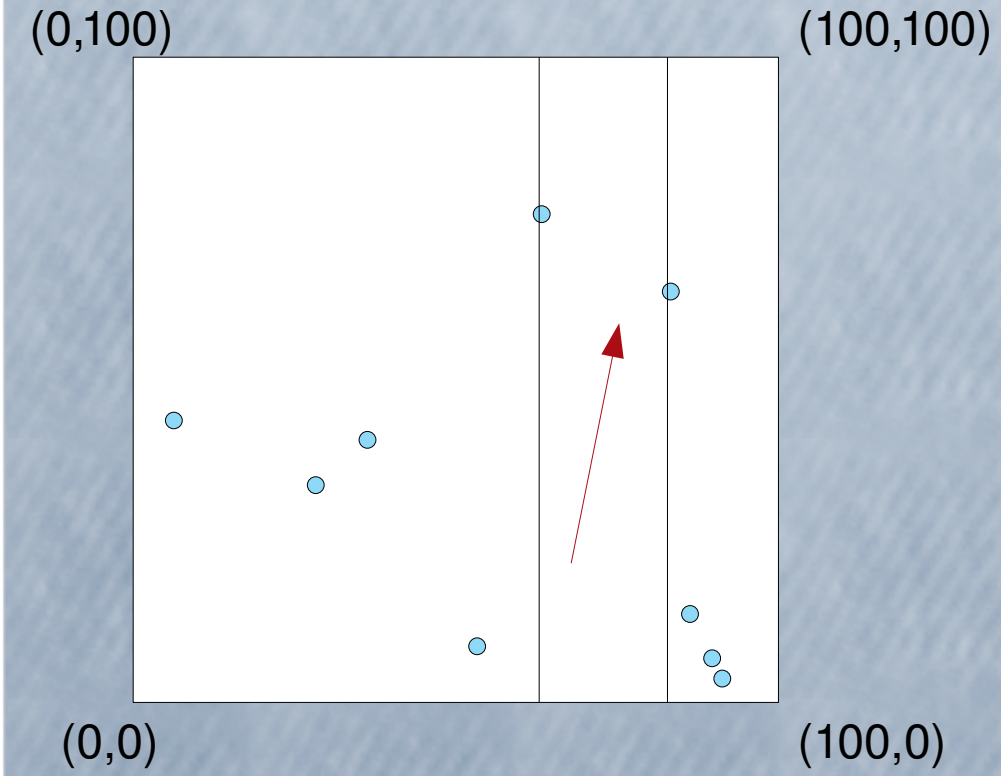
Split On Points or Between Points?

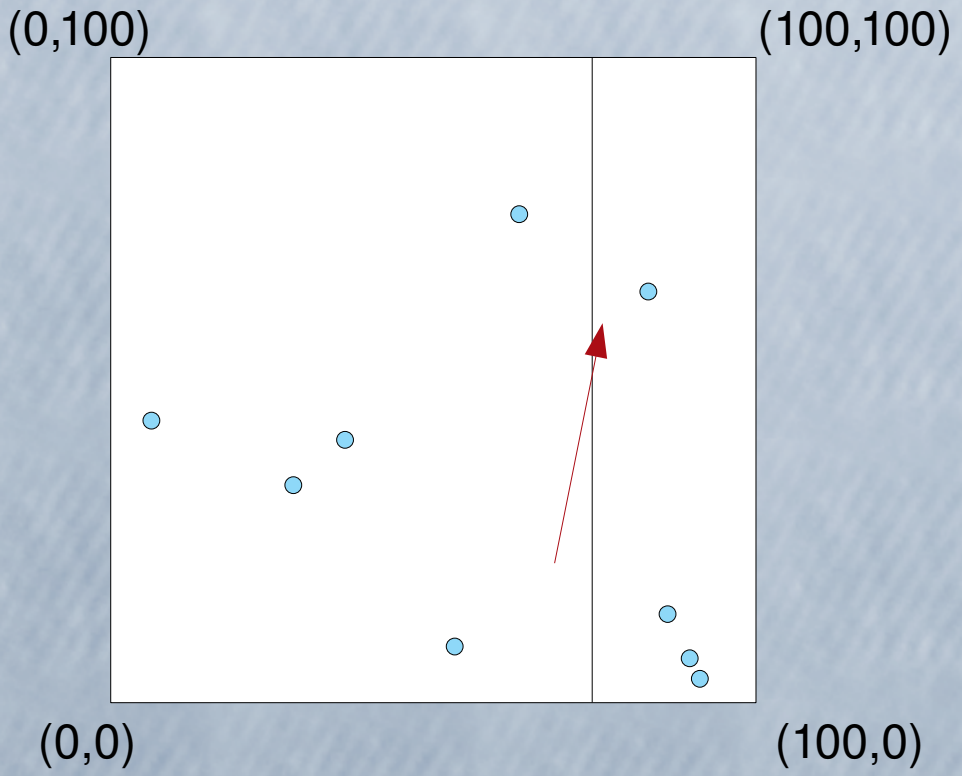




- Radius search, neighbor search...

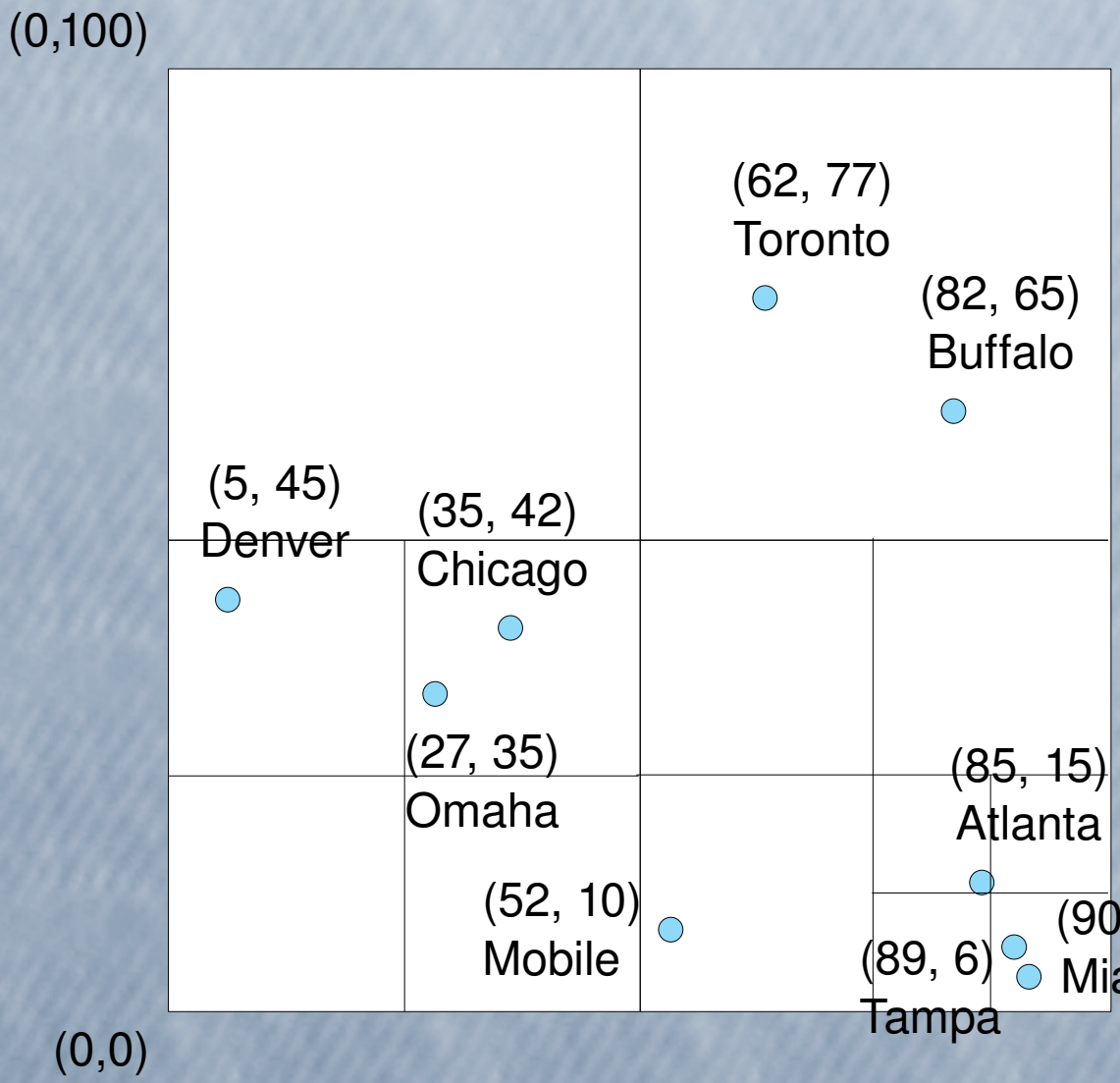
Split On Points or Between Points?

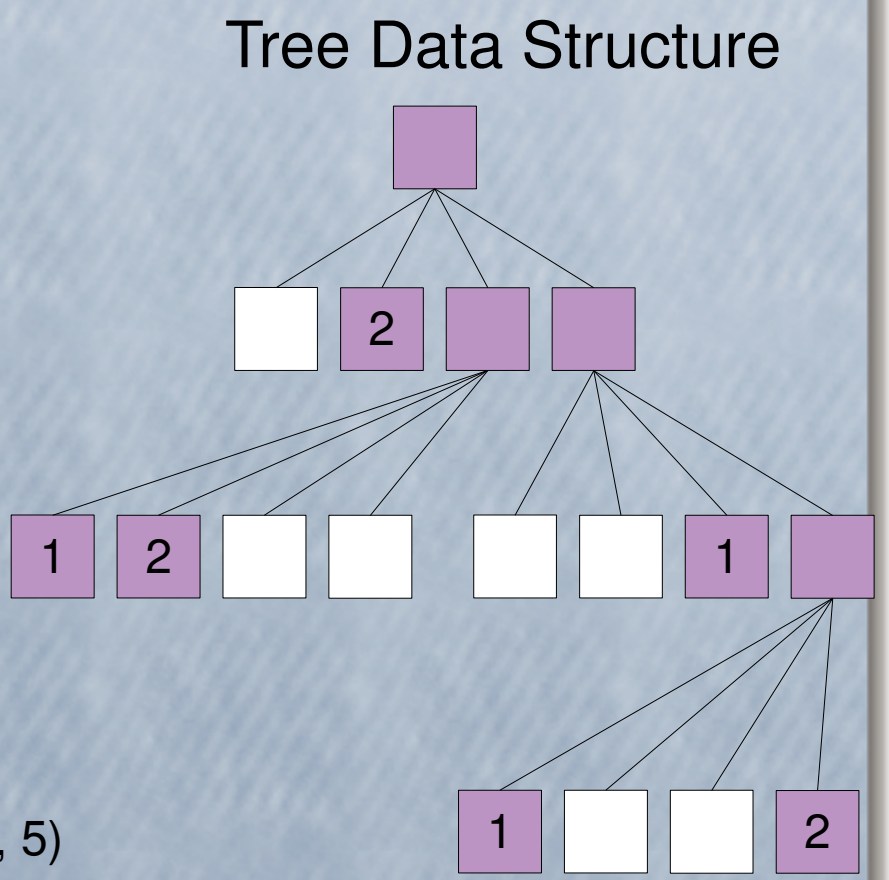




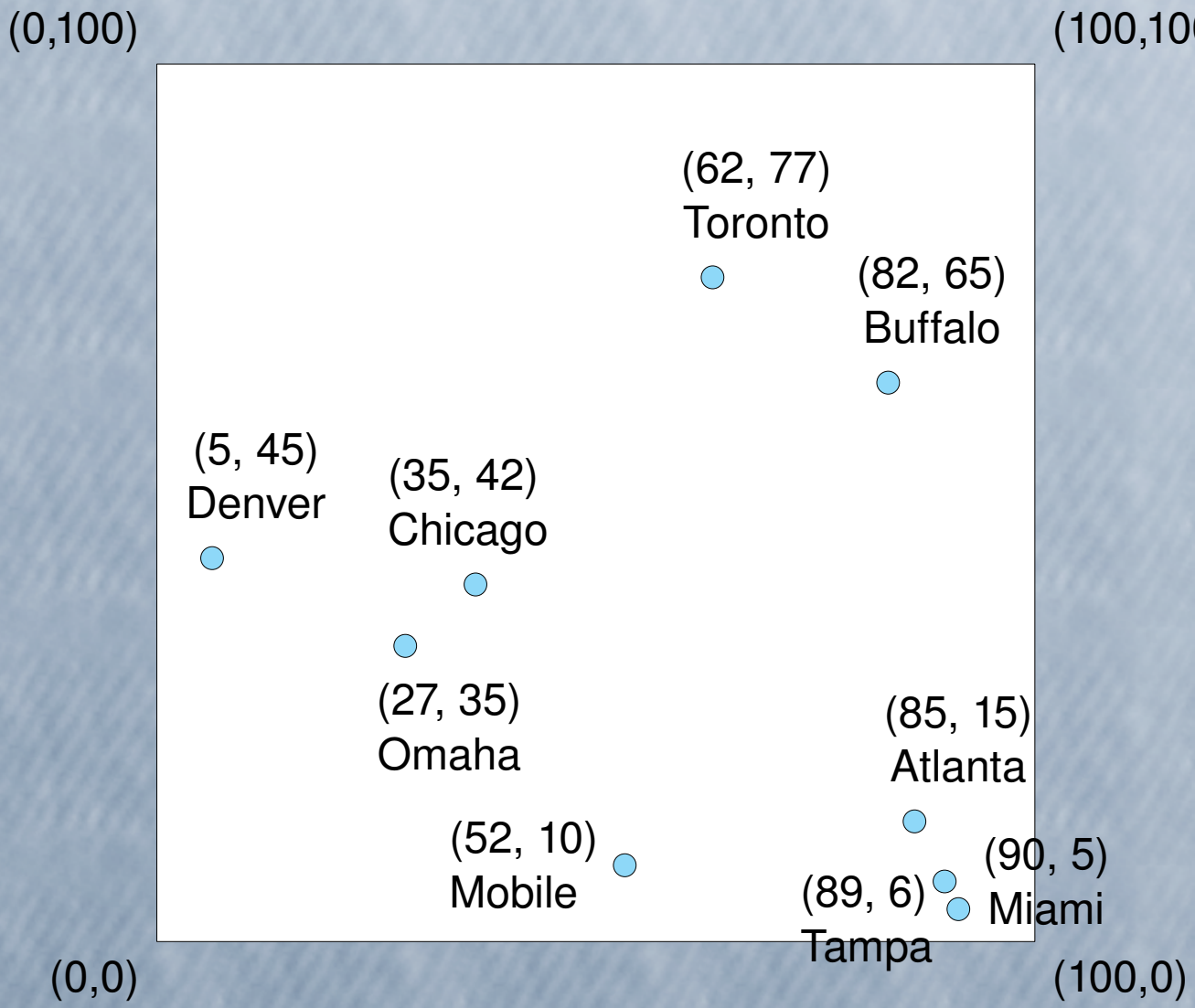
- Empty space culling – Ray Tracing

Quadtrees


(0,100)
(100,100)
(62, 77)
Toronto
(82, 65)
Buffalo
(5, 45)
Denver
(35, 42)
Chicago
(27, 35)
Omaha
(85, 15)
Atlanta
(52, 10)
Mobile
(90, 5)
Miami
(89, 6)
Tampa
(0,0)
(100,0)


Tree Data Structure
2
1
2
1
1
2

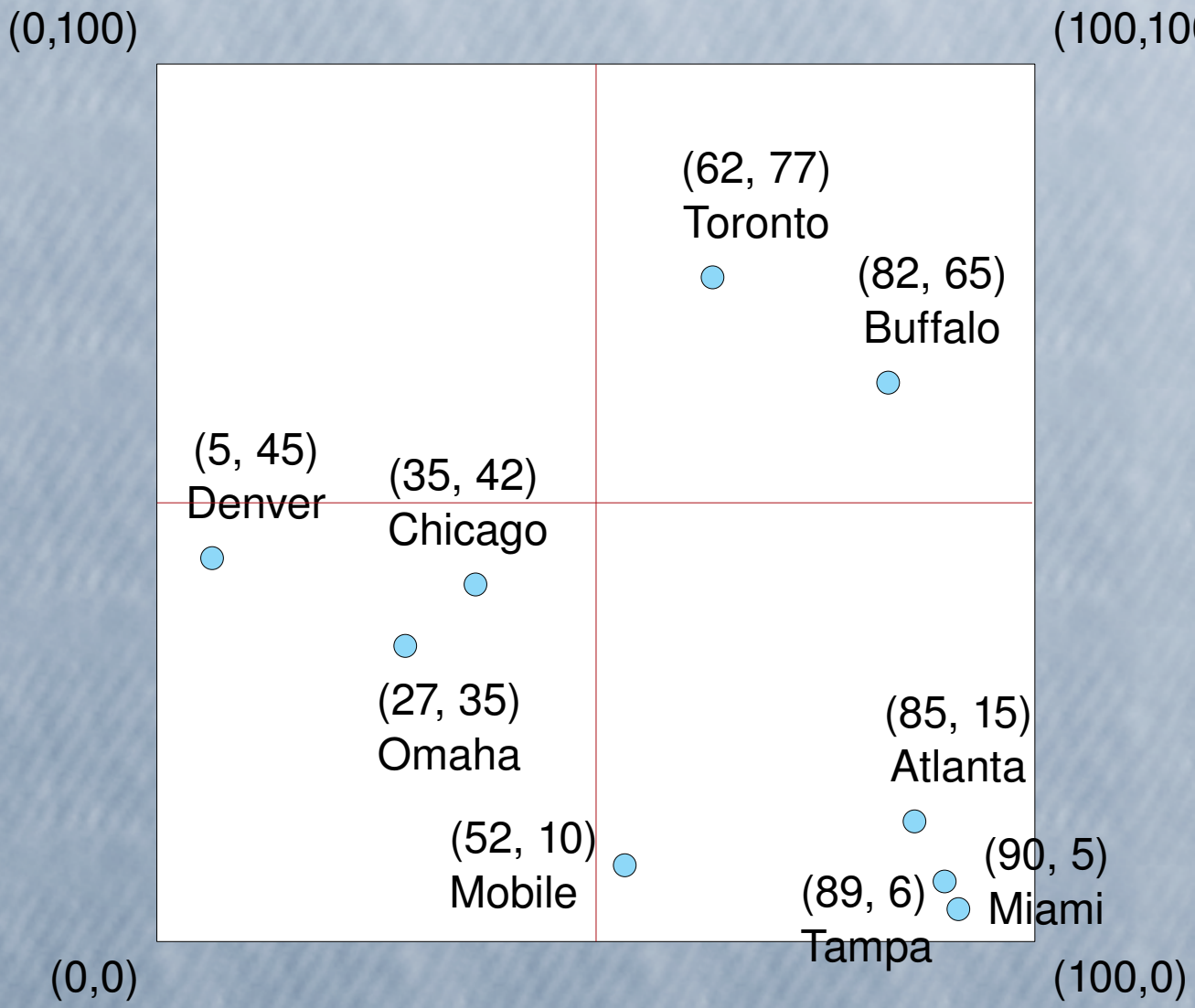
Quadtrees



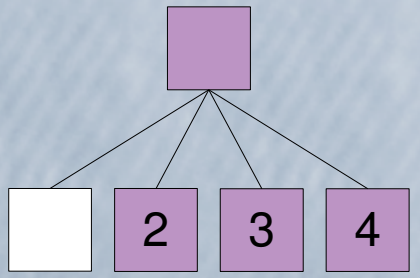
Tree Data Structure

9

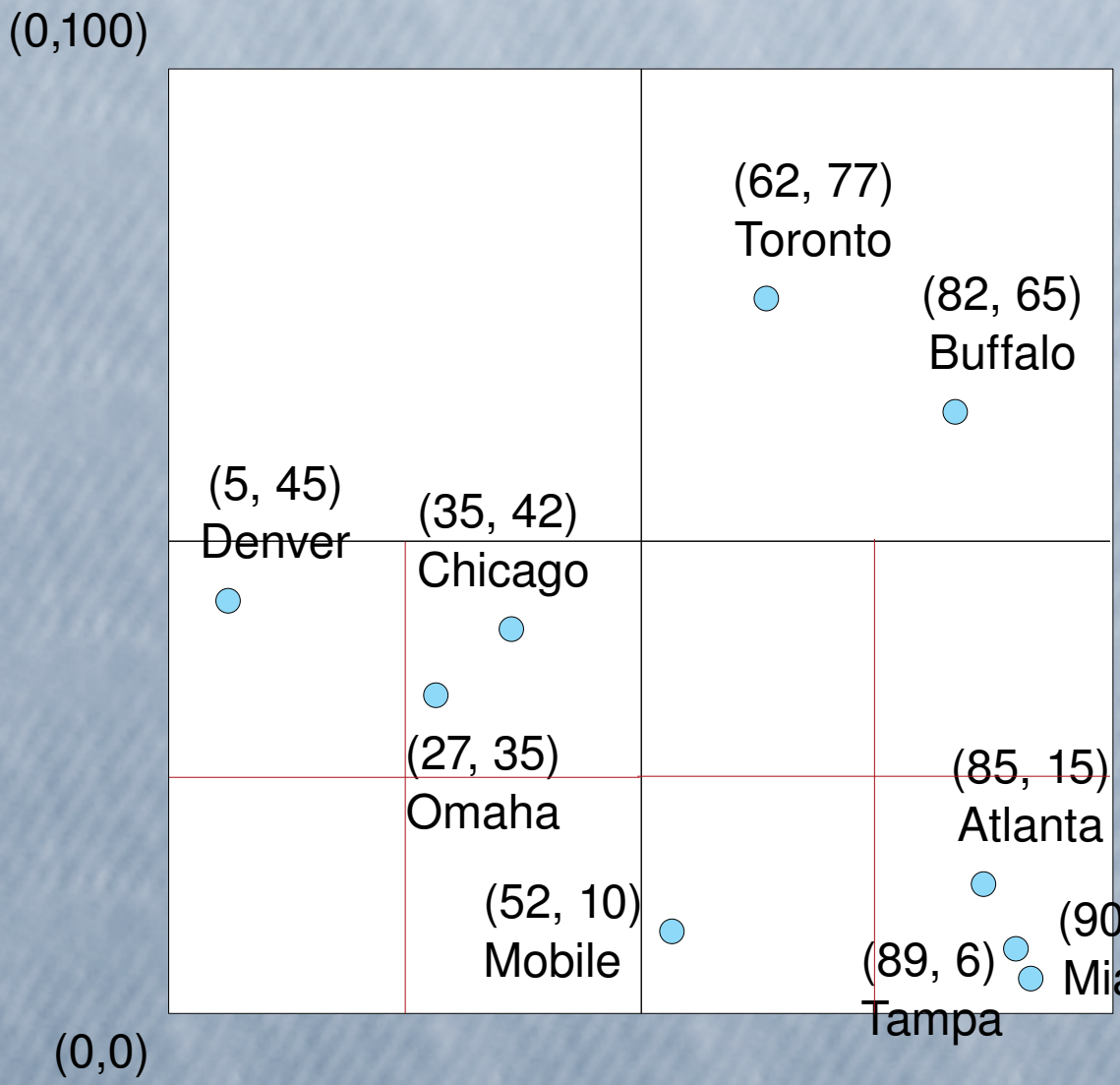
Quadtrees



Tree Data Structure



Quadtrees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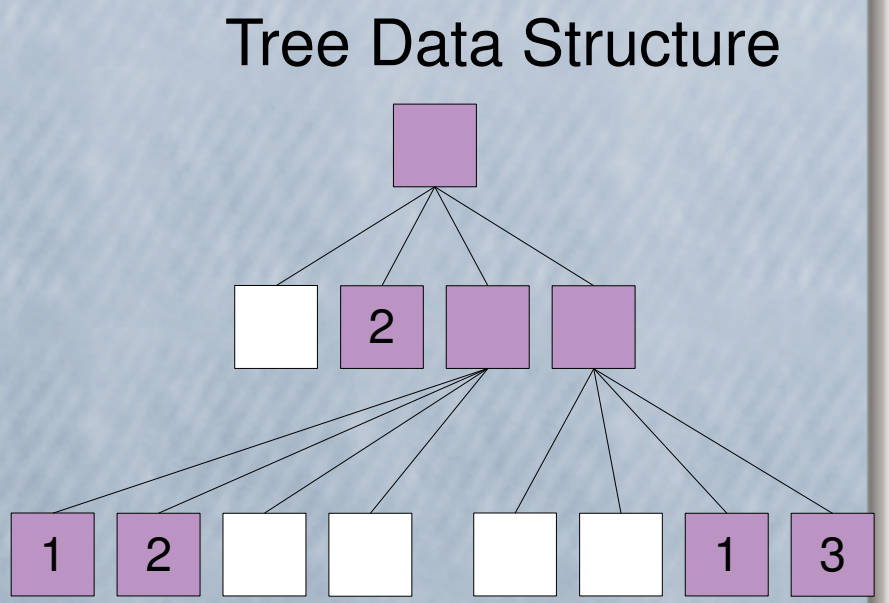
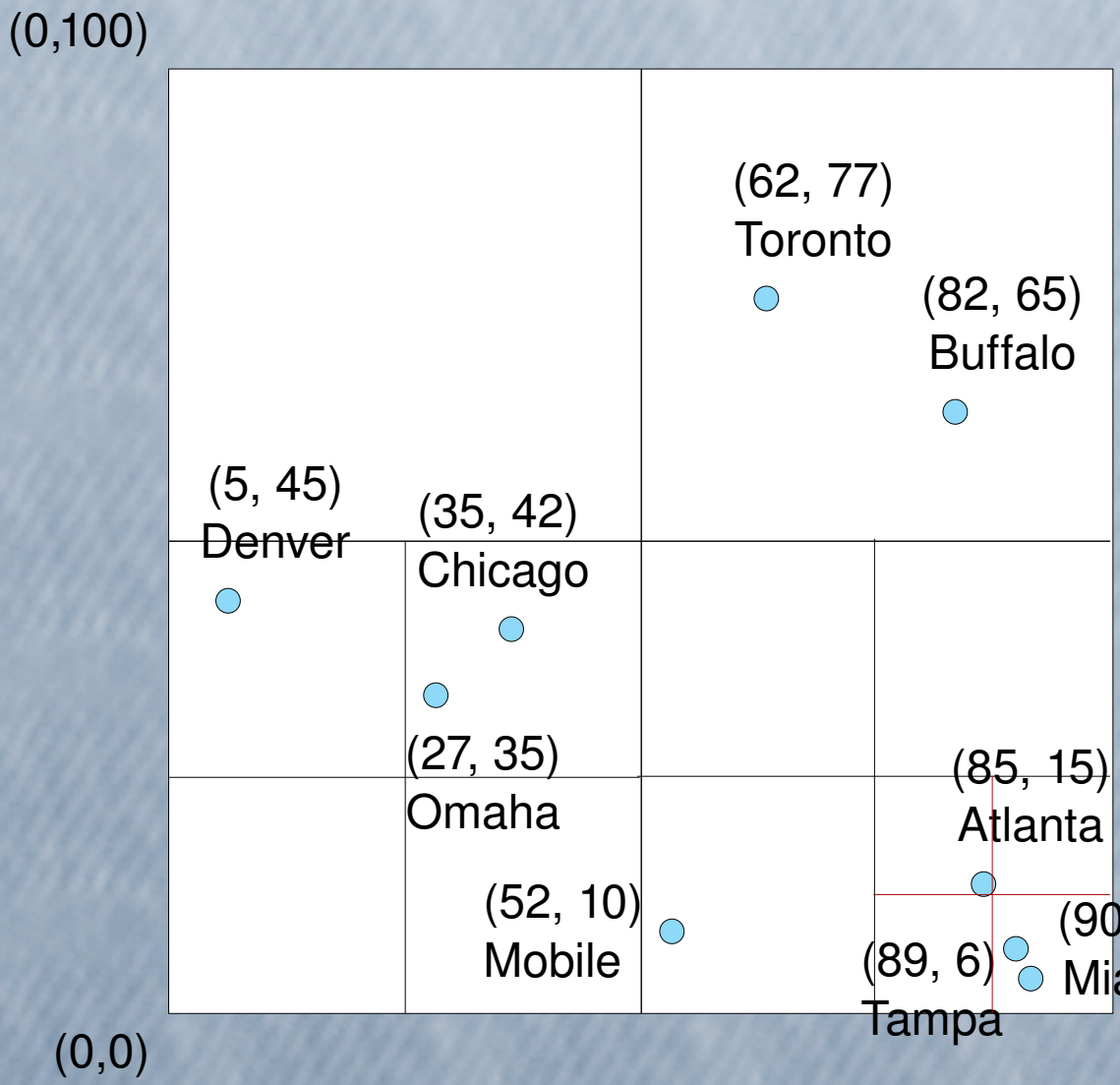
(100,0)


Tree Data Structure
2
1
2
1
3

Quadtrees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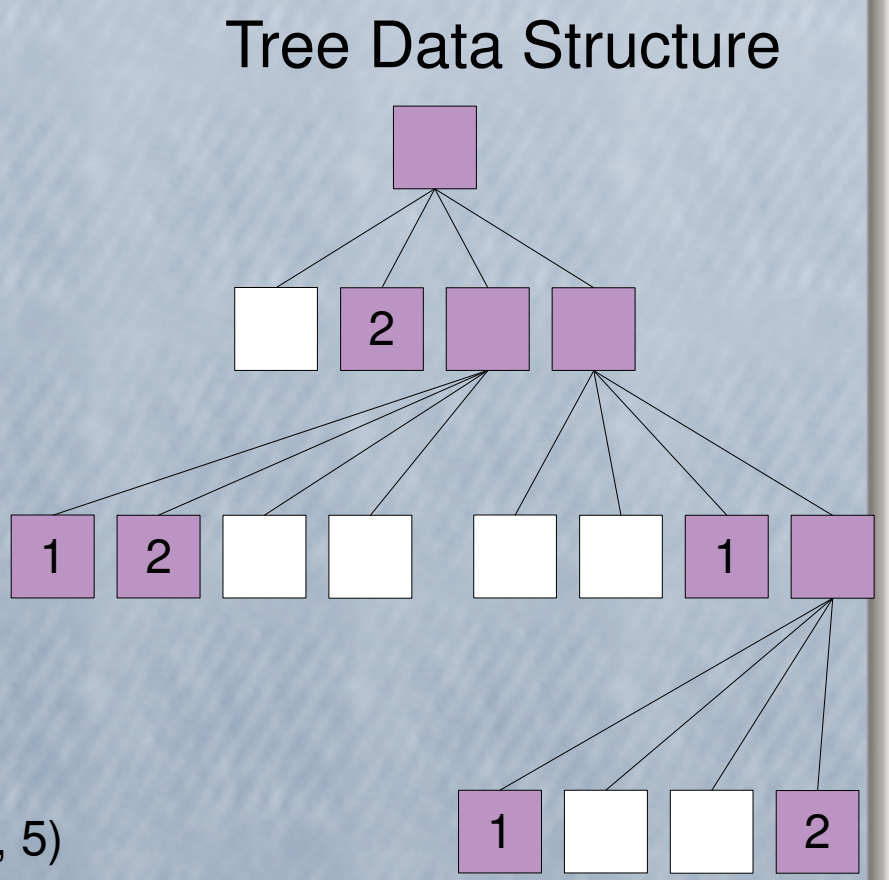
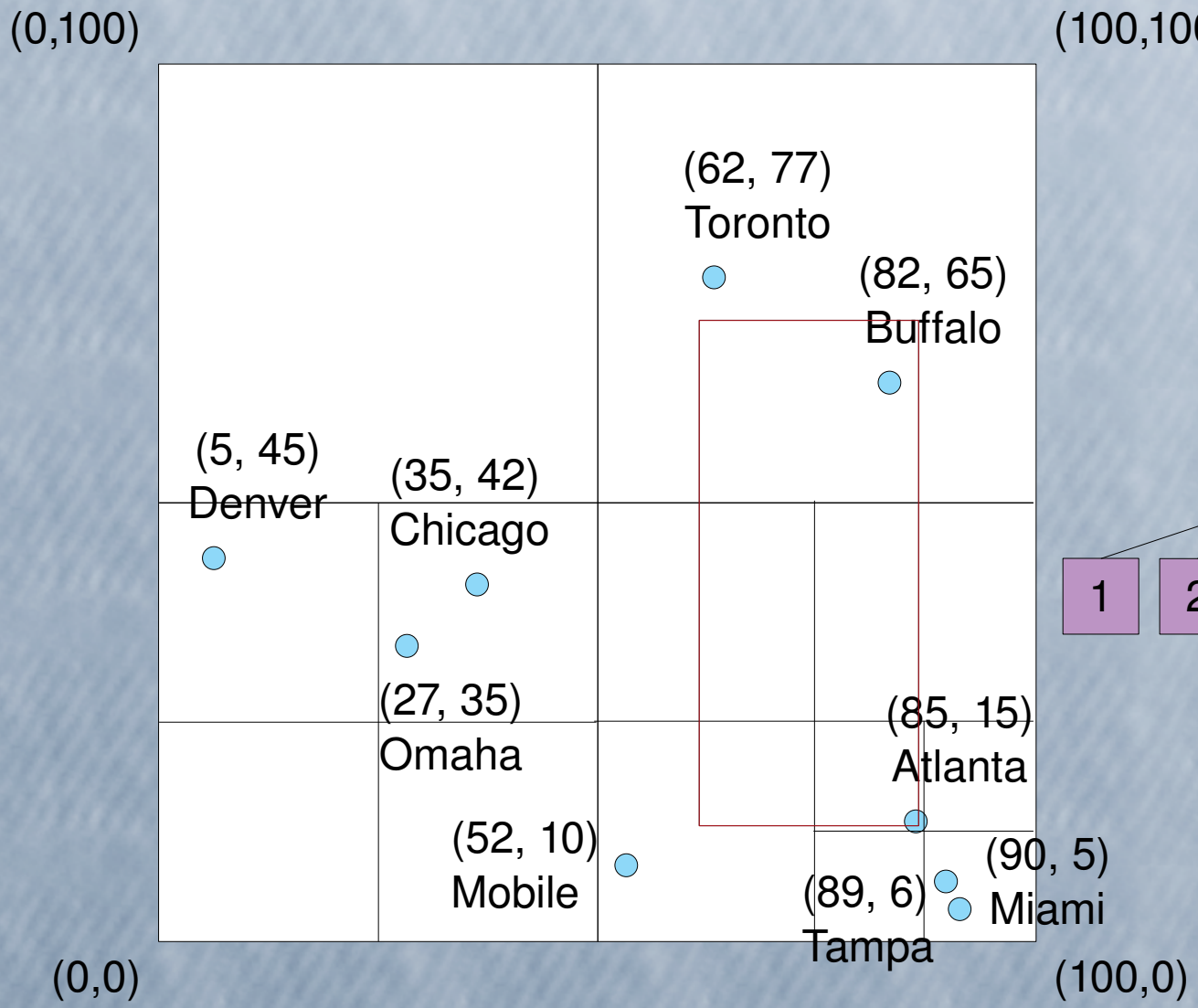
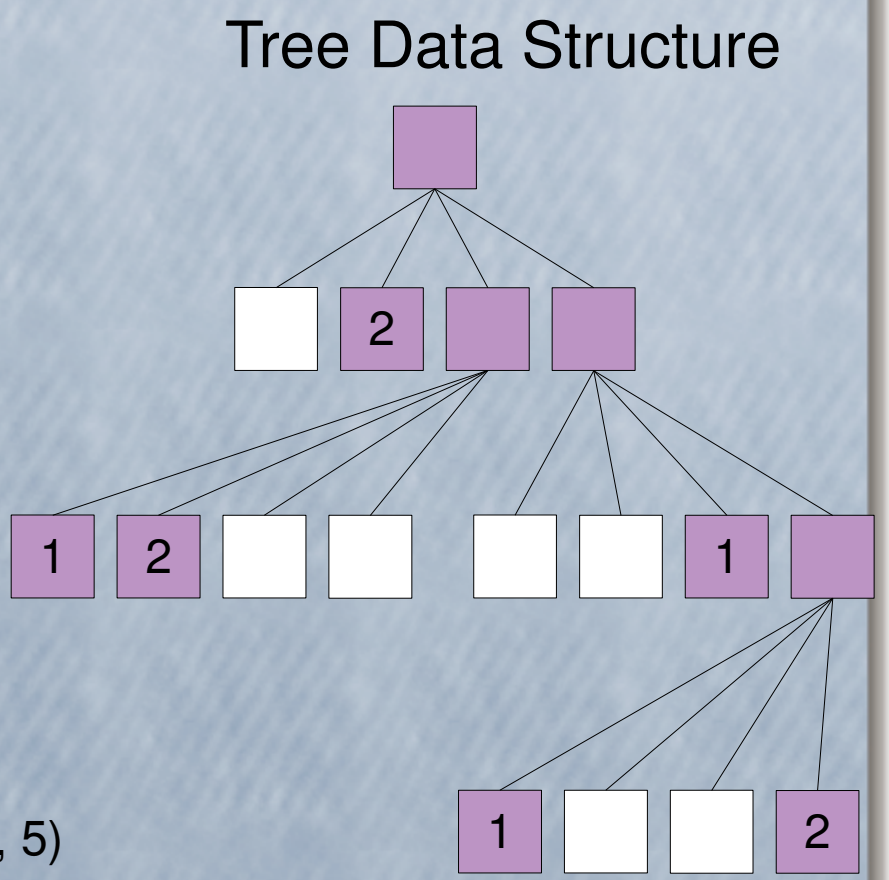
Atlanta
(52, 10)
Mobile
(90, 5)
Miami
(89, 6)
Tampa
(0,0)
(100,0)

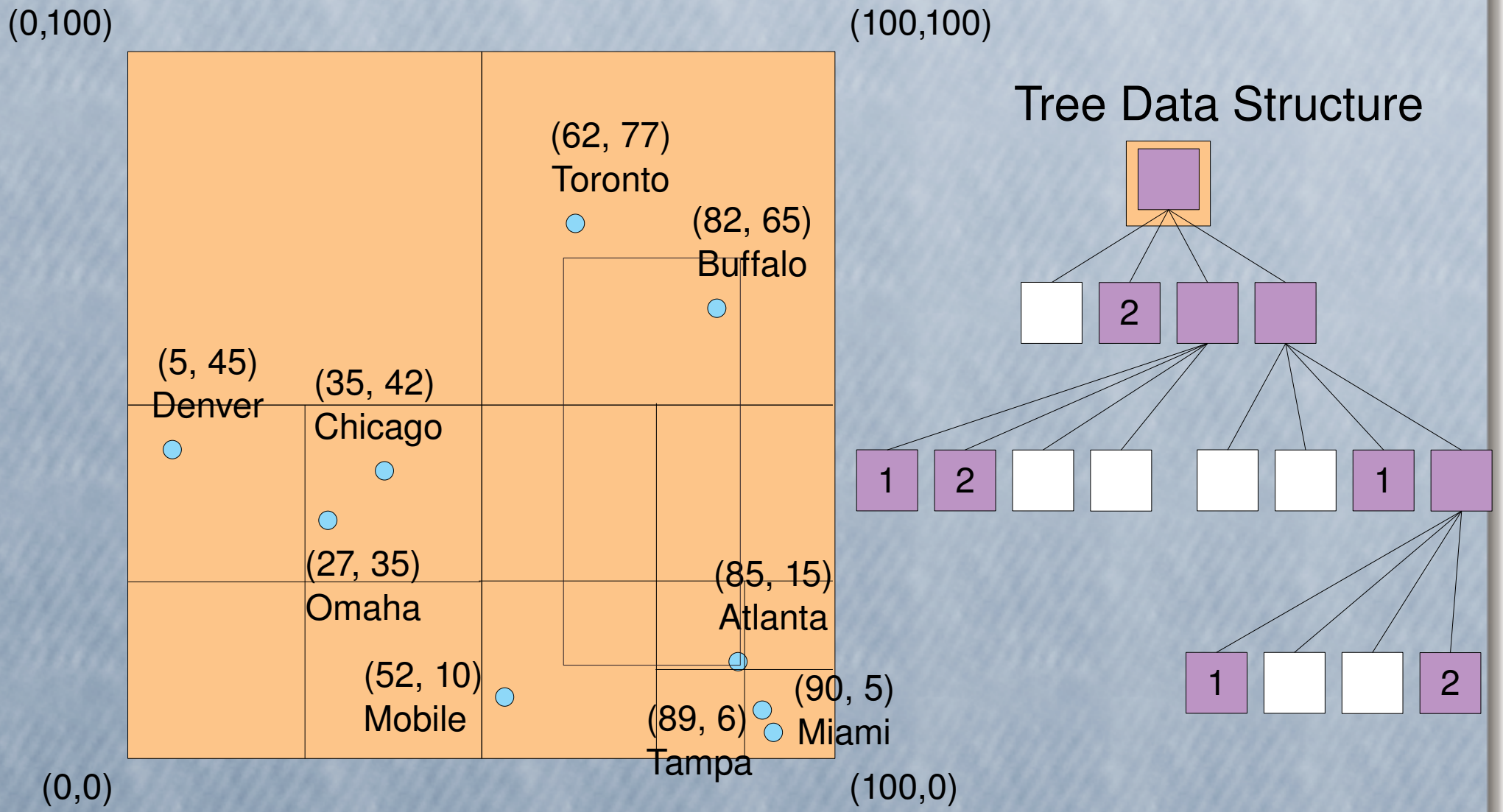

Tree Data Structure
2
1
2
1
1
2

Range Search on Quadtrees

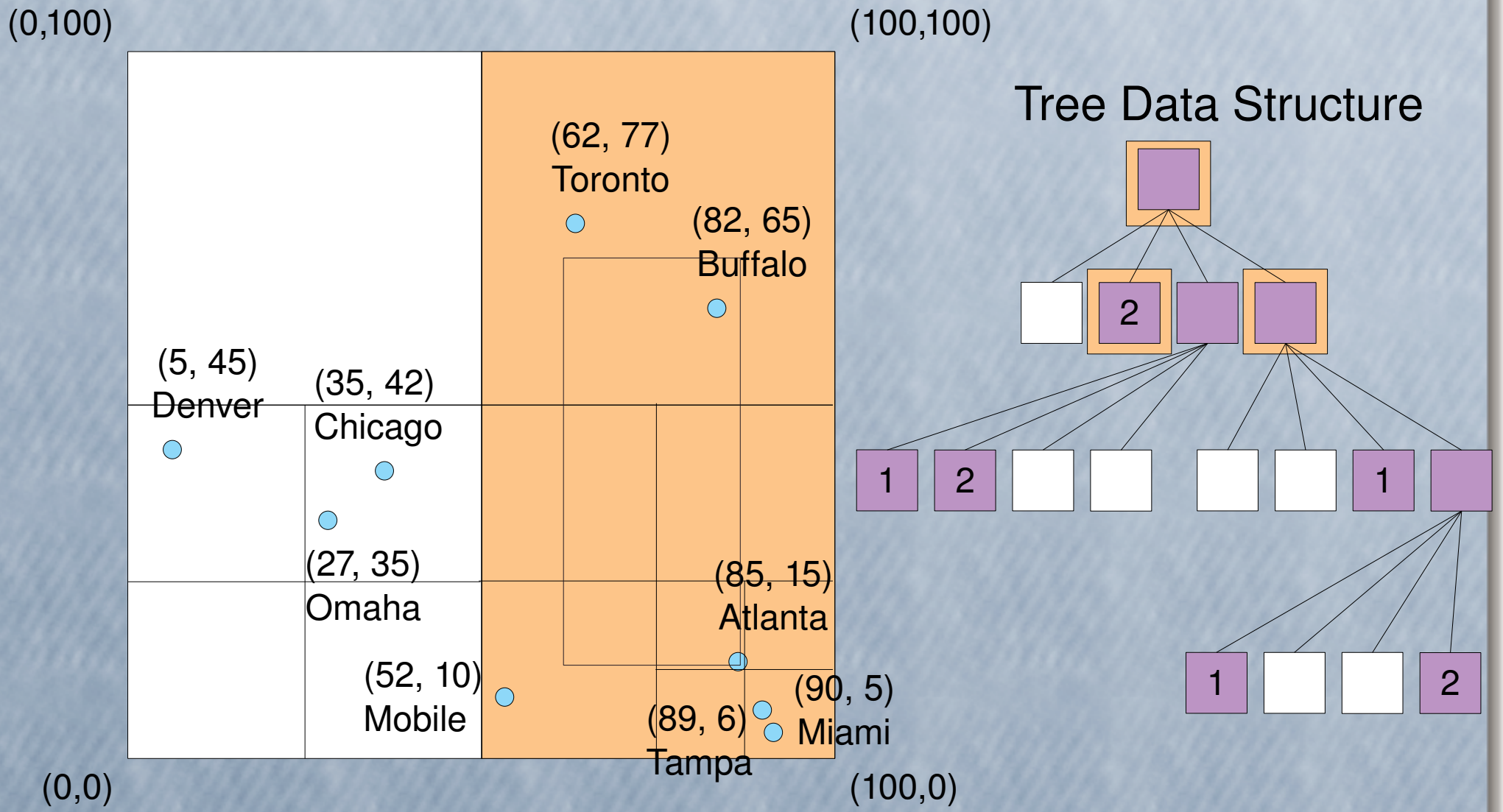




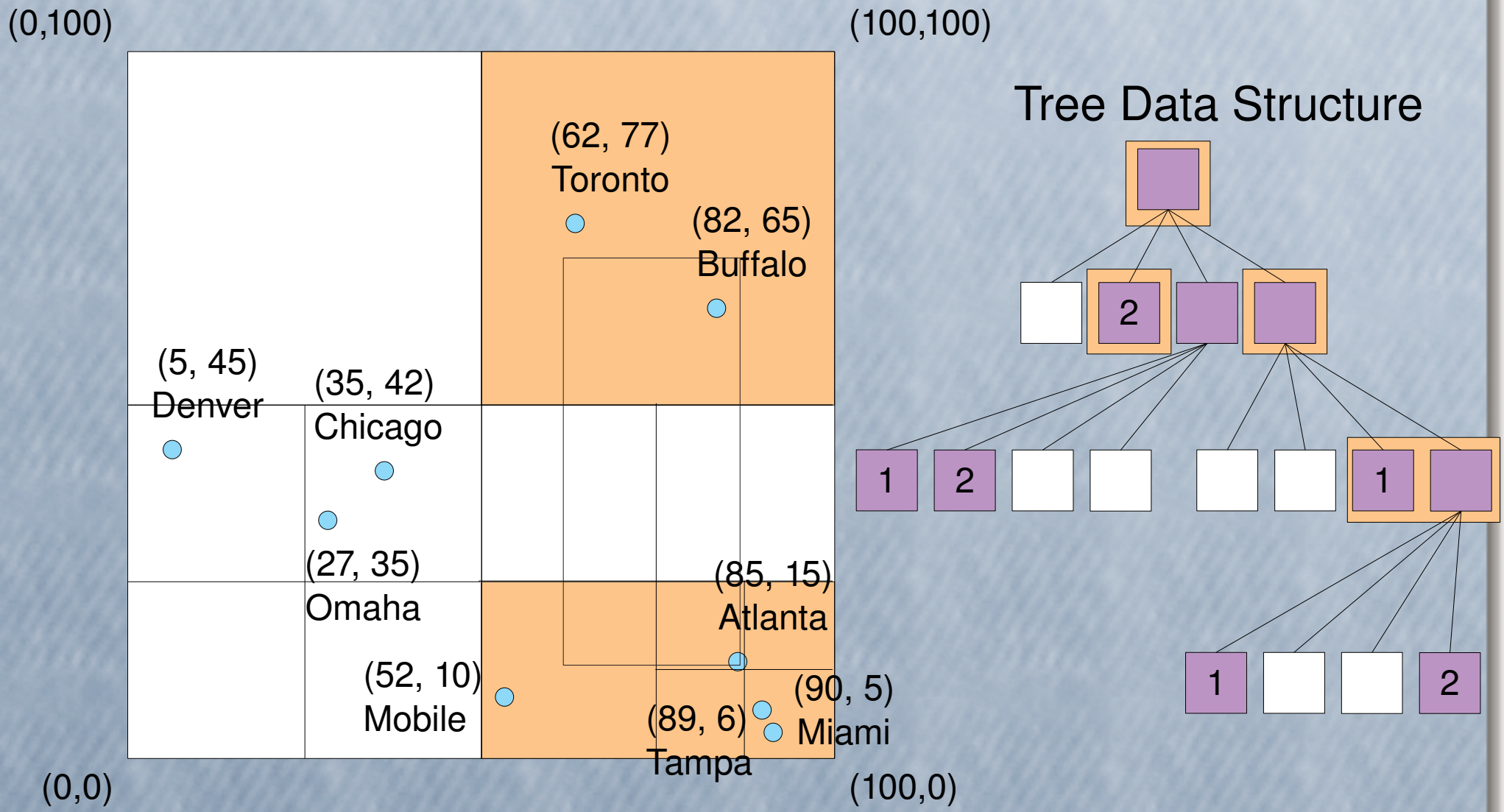
Range Search on Quadtrees



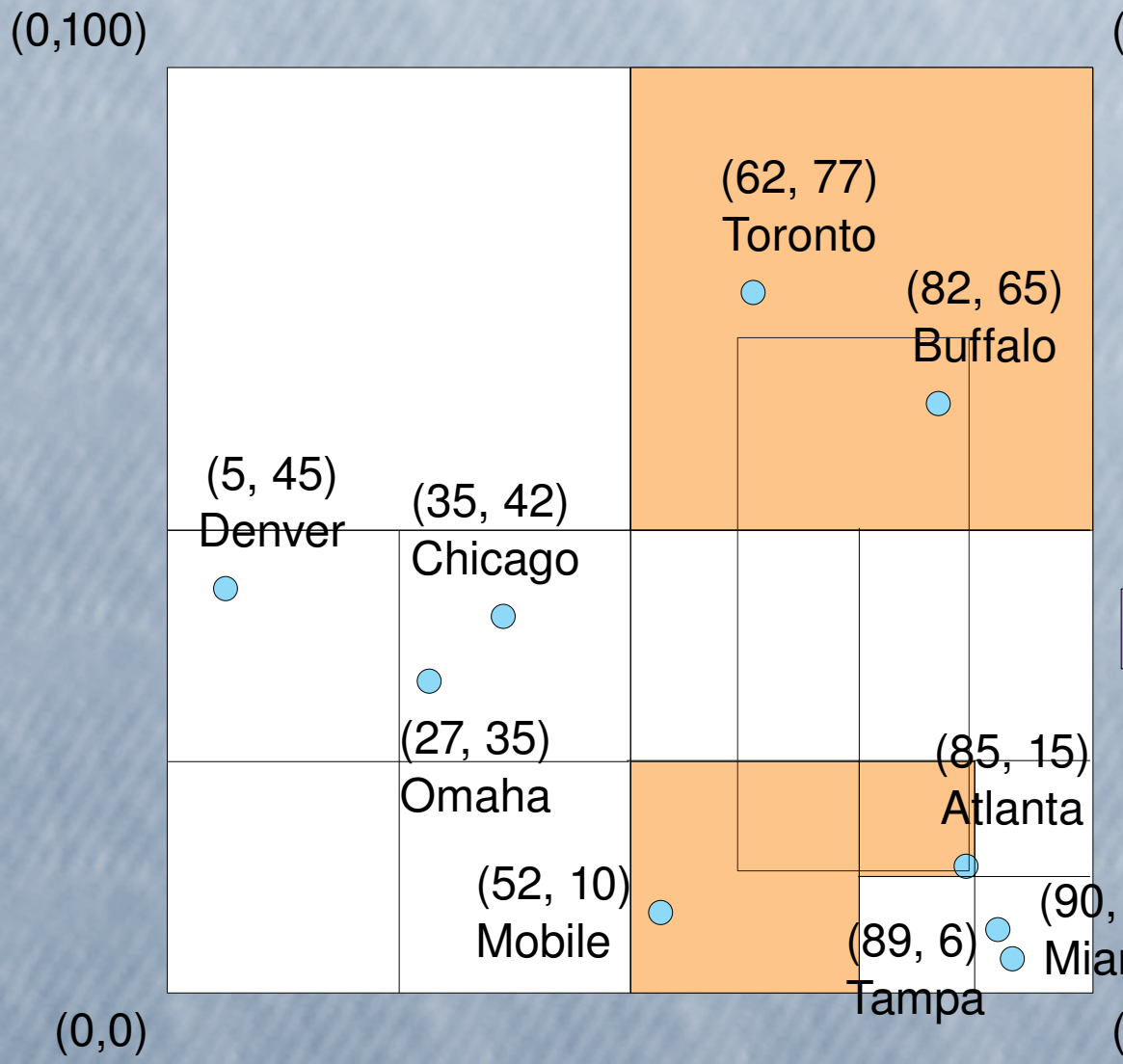
Range Search on Quadtrees

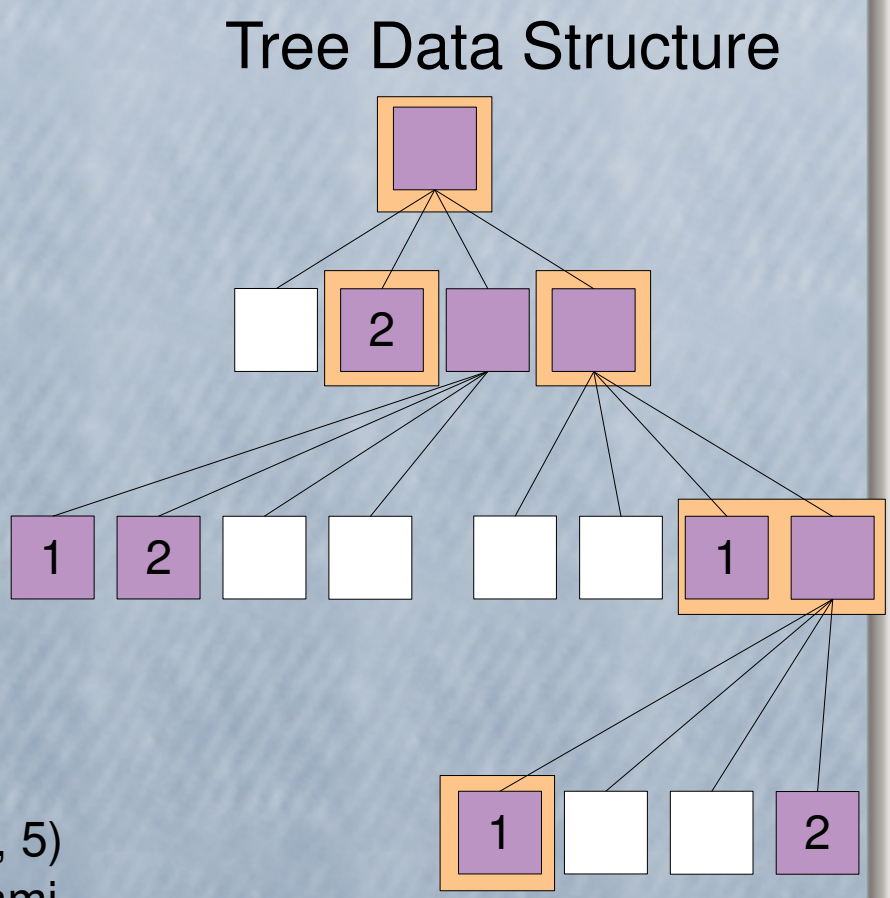


Range Search on Quadtrees

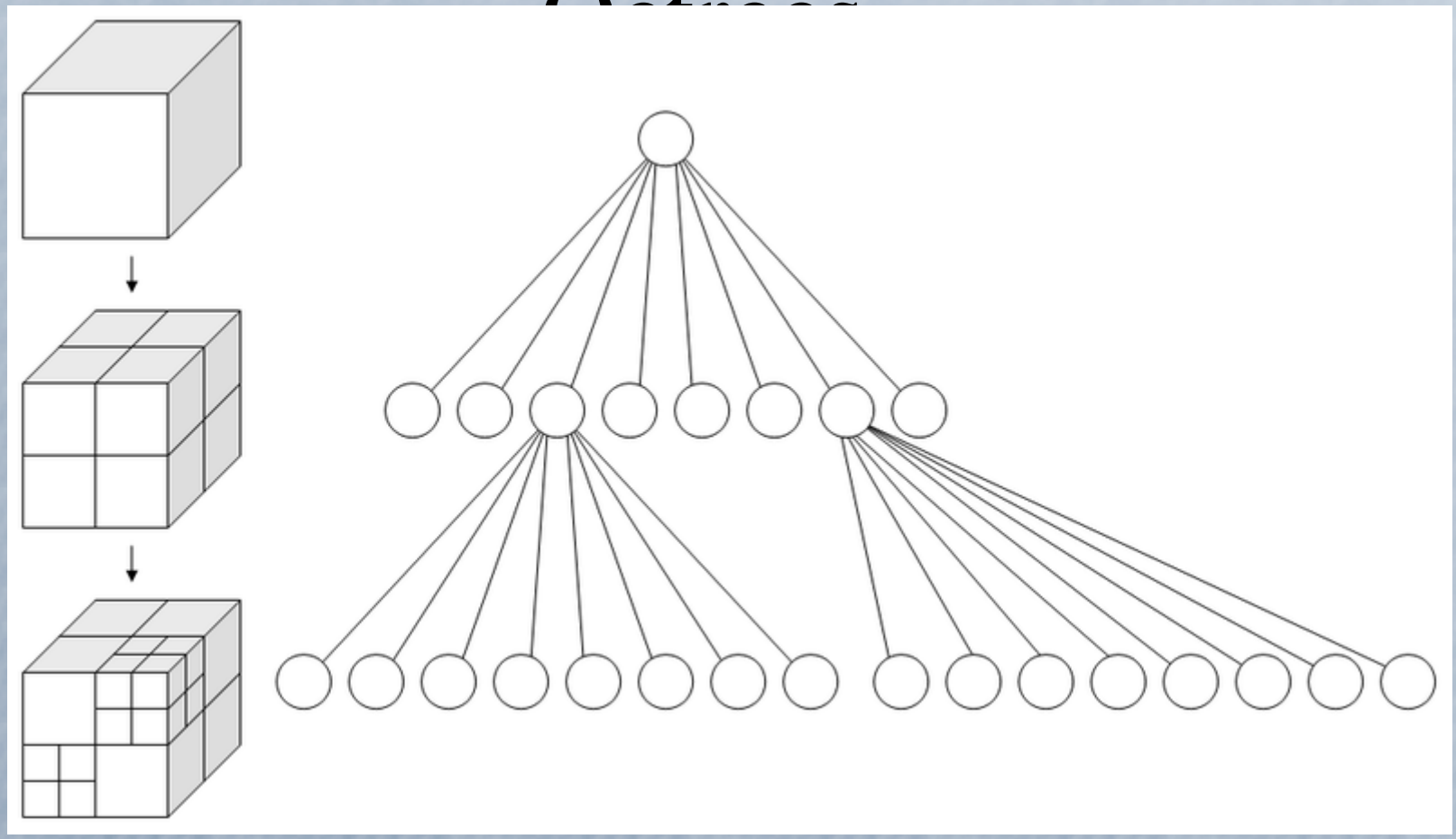


Range Search on Quadtrees





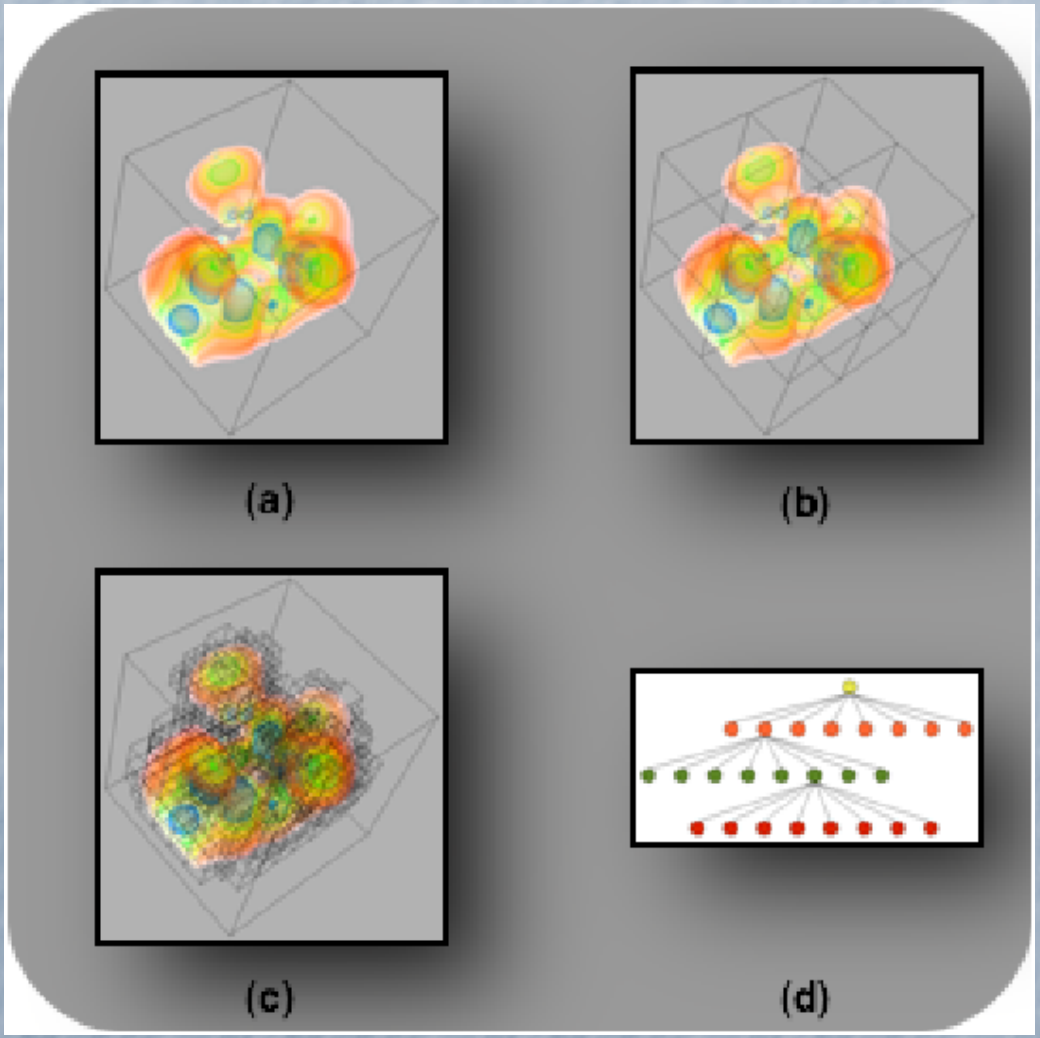
Octrees



- Simply an extension of Quadtrees to 3D
- 2x number of children per split as Quadtrees

Image source: http://en.wikipedia.org/wiki/File:Octree2.png

Octrees

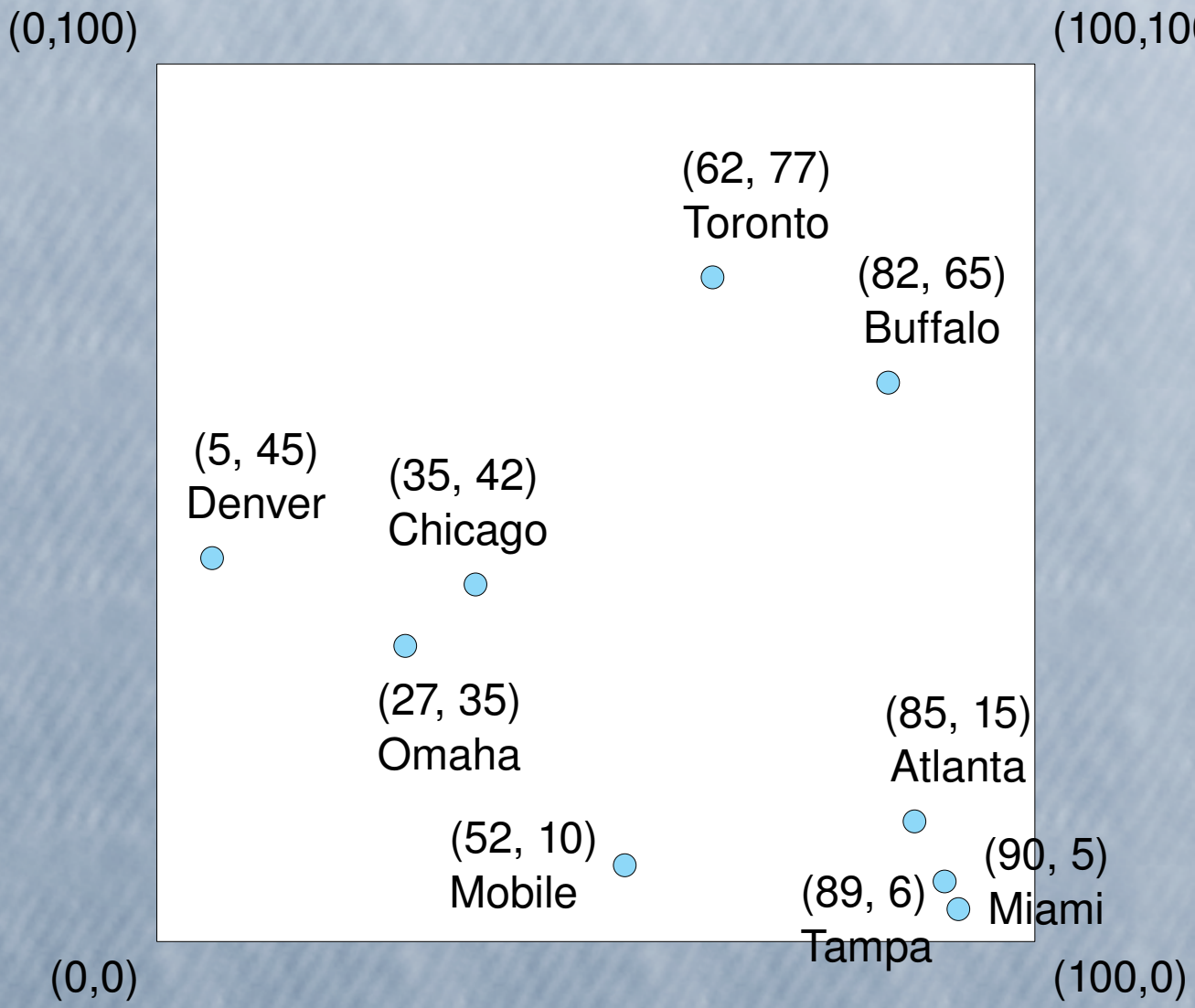


- Practical case: volume rendering
- (a) data
- (c) shows only leaf nodes, tightly fit the data

Splitting Heuristics

- Object space vs world space?
- What have we been using?

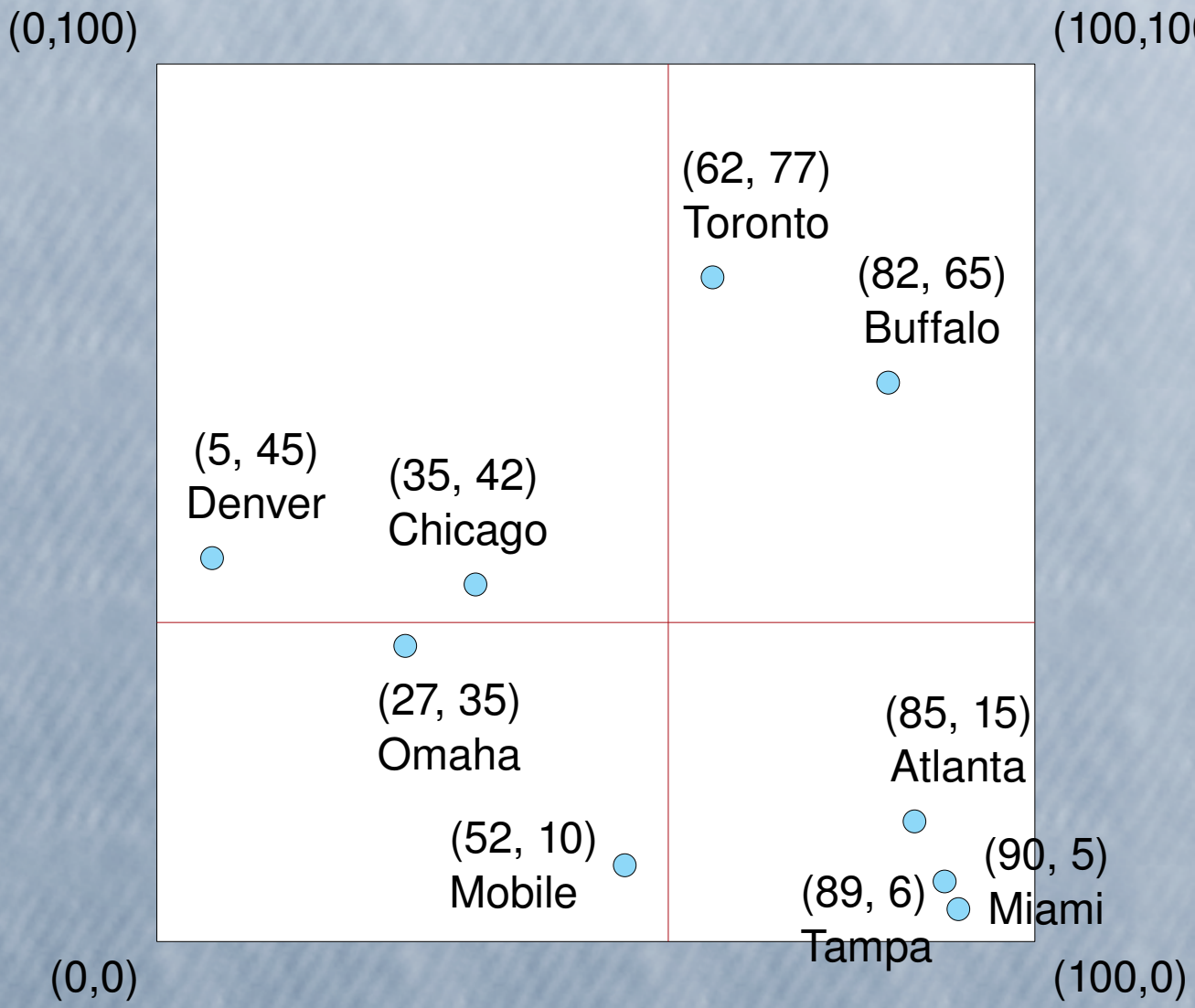
An Object-Space Split Heuristic



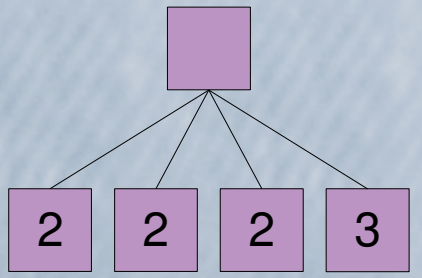
Tree Data Structure

9

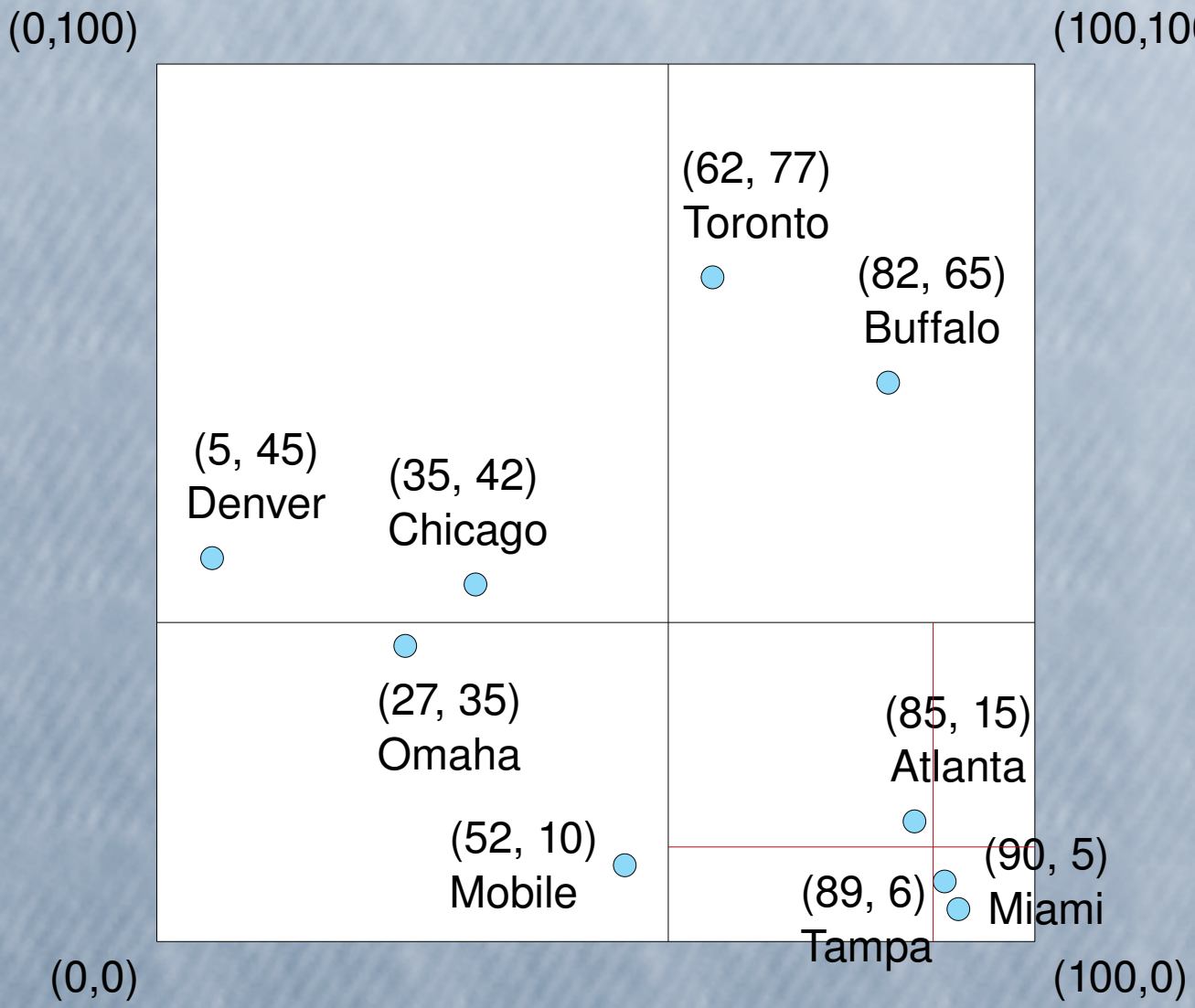
An Object-Space Split Heuristic



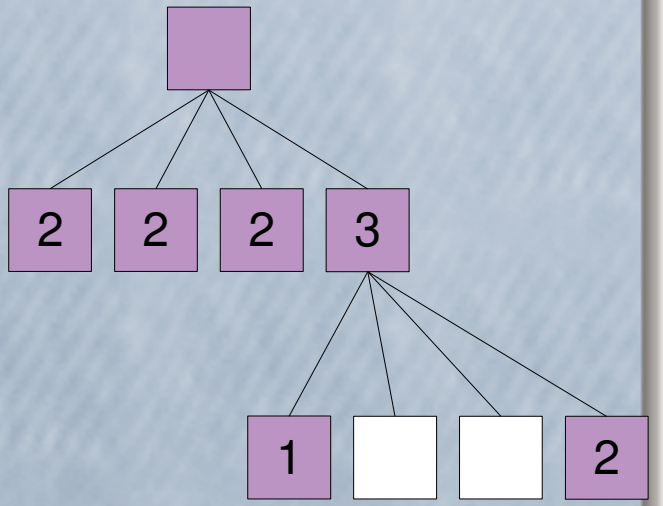
Tree Data Structure



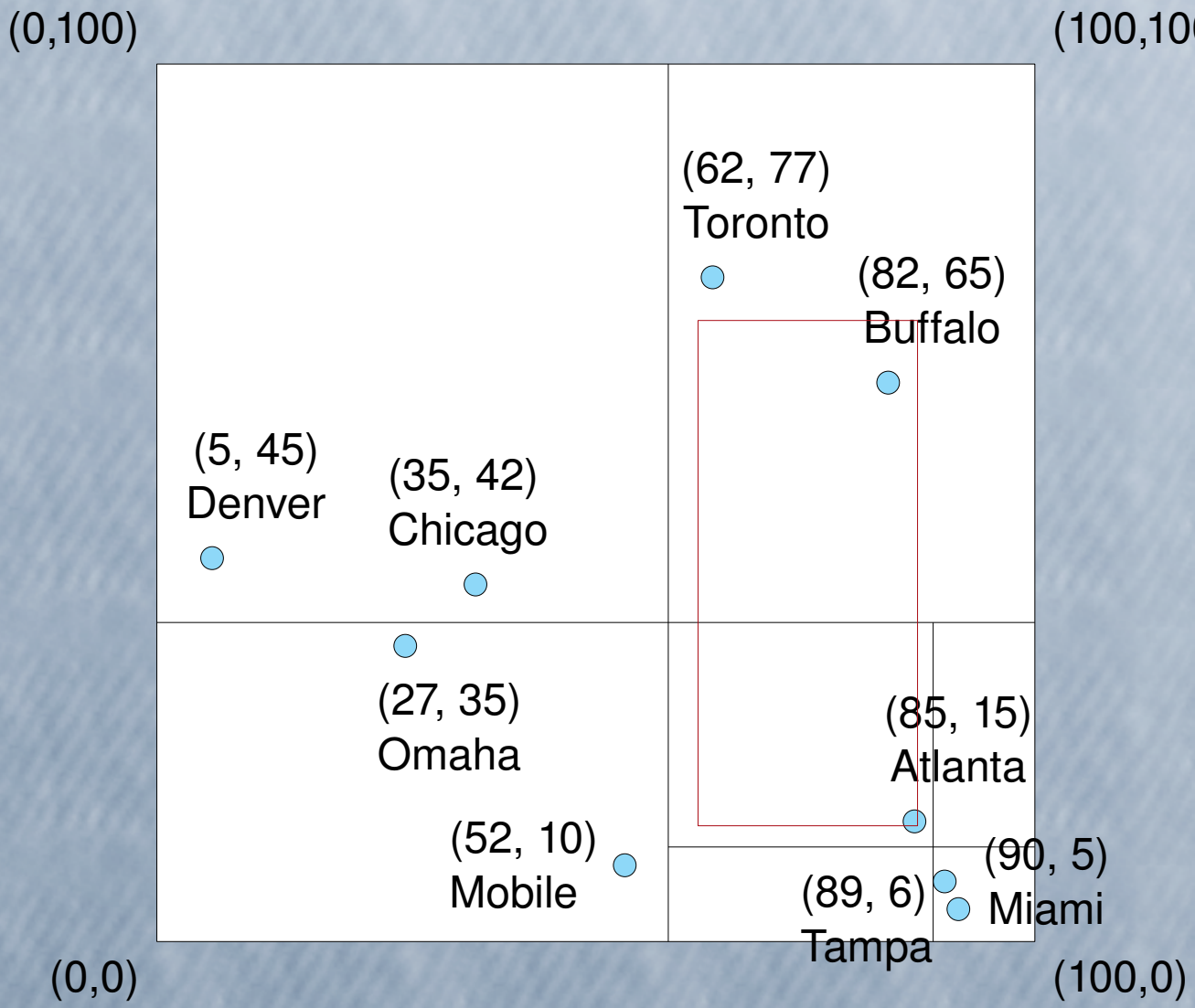
An Object-Space Split Heuristic



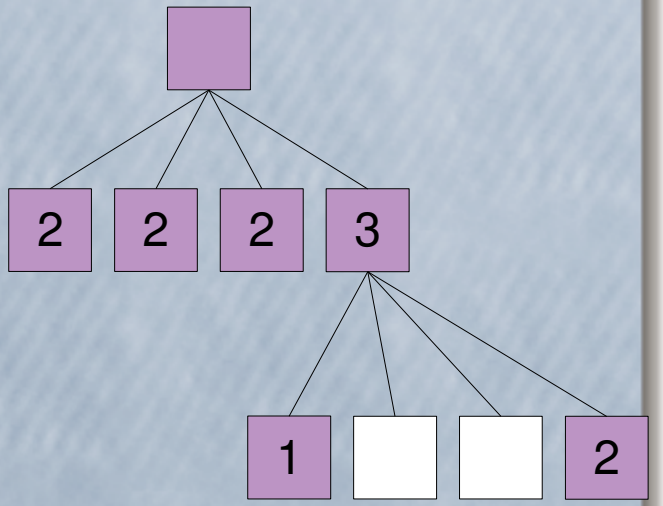
Tree Data Structure



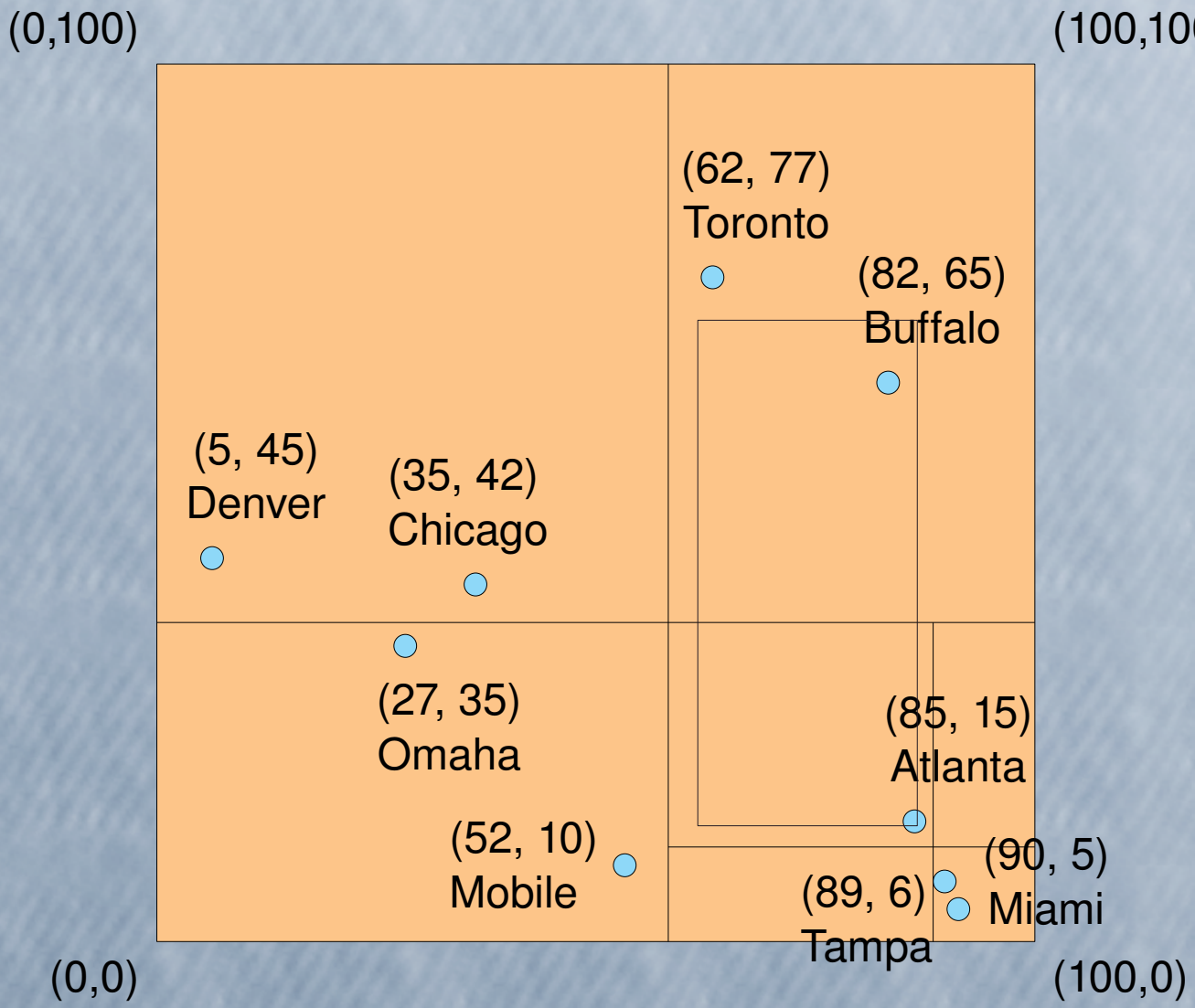
Range Search



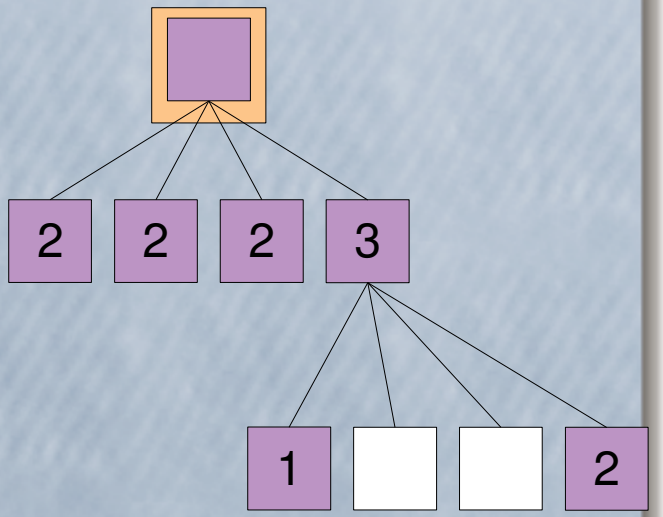
Tree Data Structure



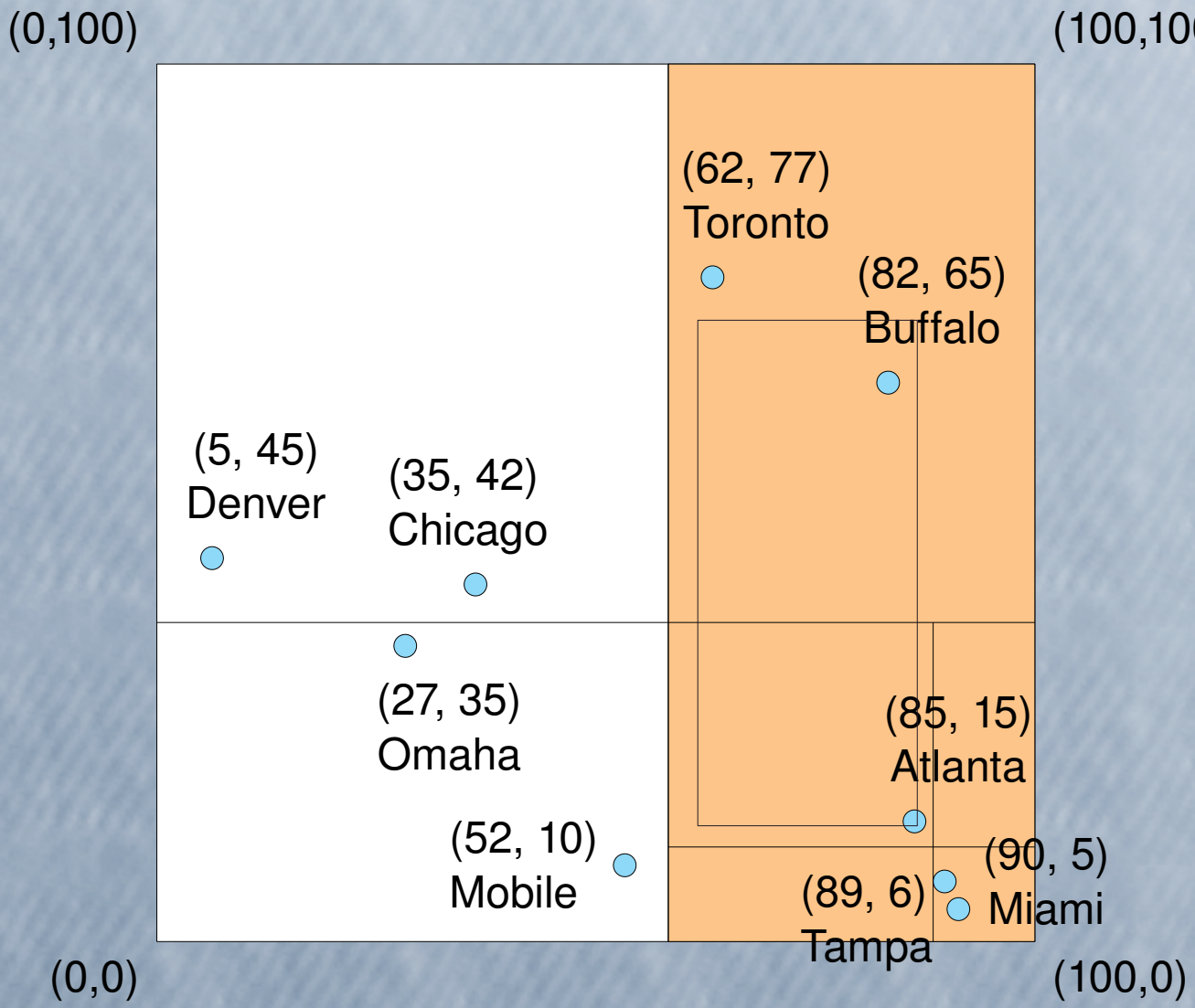
Range Search



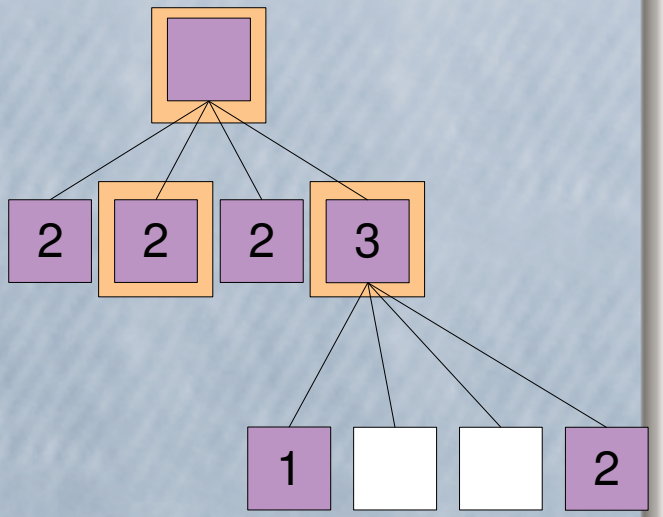
Tree Data Structure



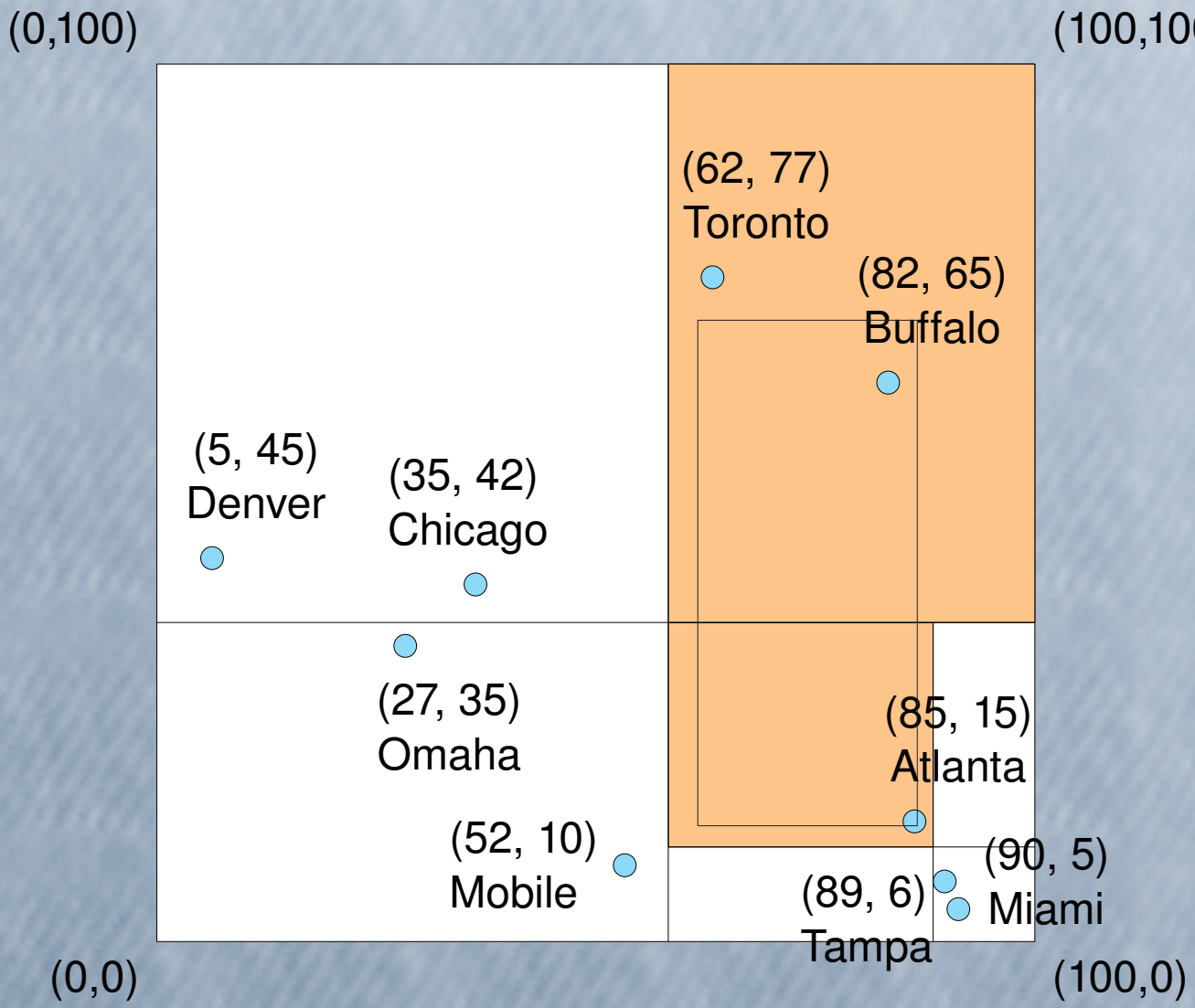
Range Search



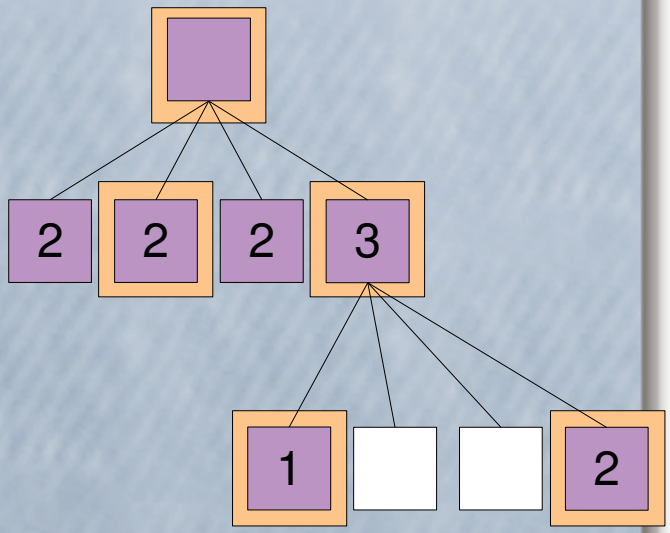
Tree Data Structure



Range Search



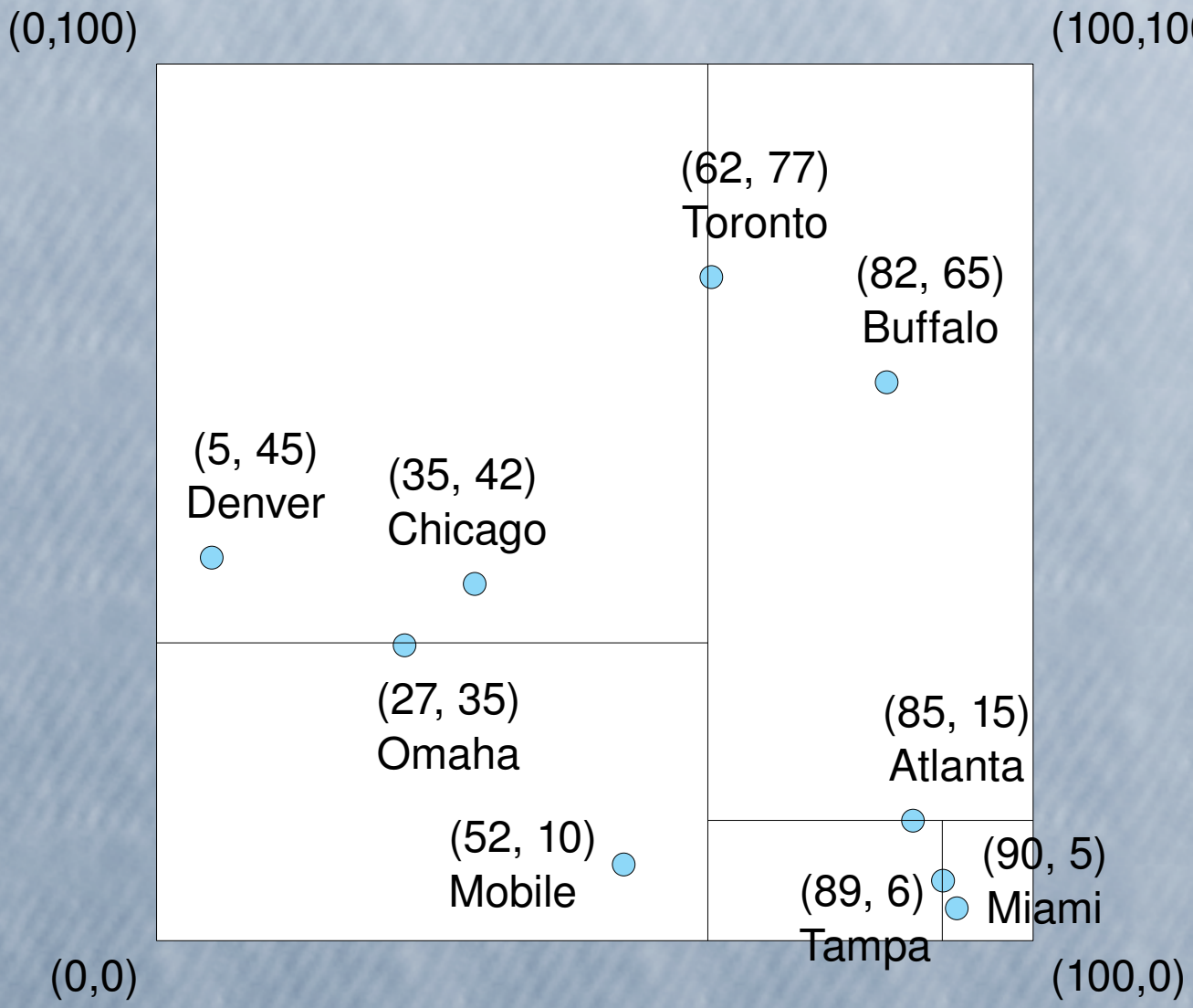
Tree Data Structure



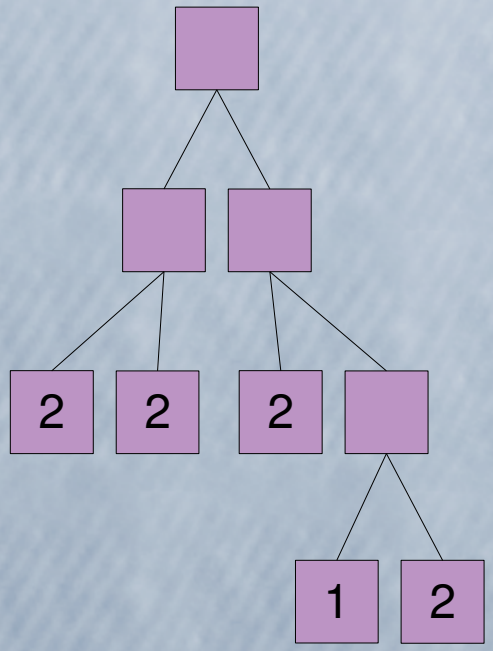
Split Heuristics

- Can make the tree...
  - Shallower
  - Faster to traverse
- But how to compute where to make splits?
  - Extensive discussion in the book

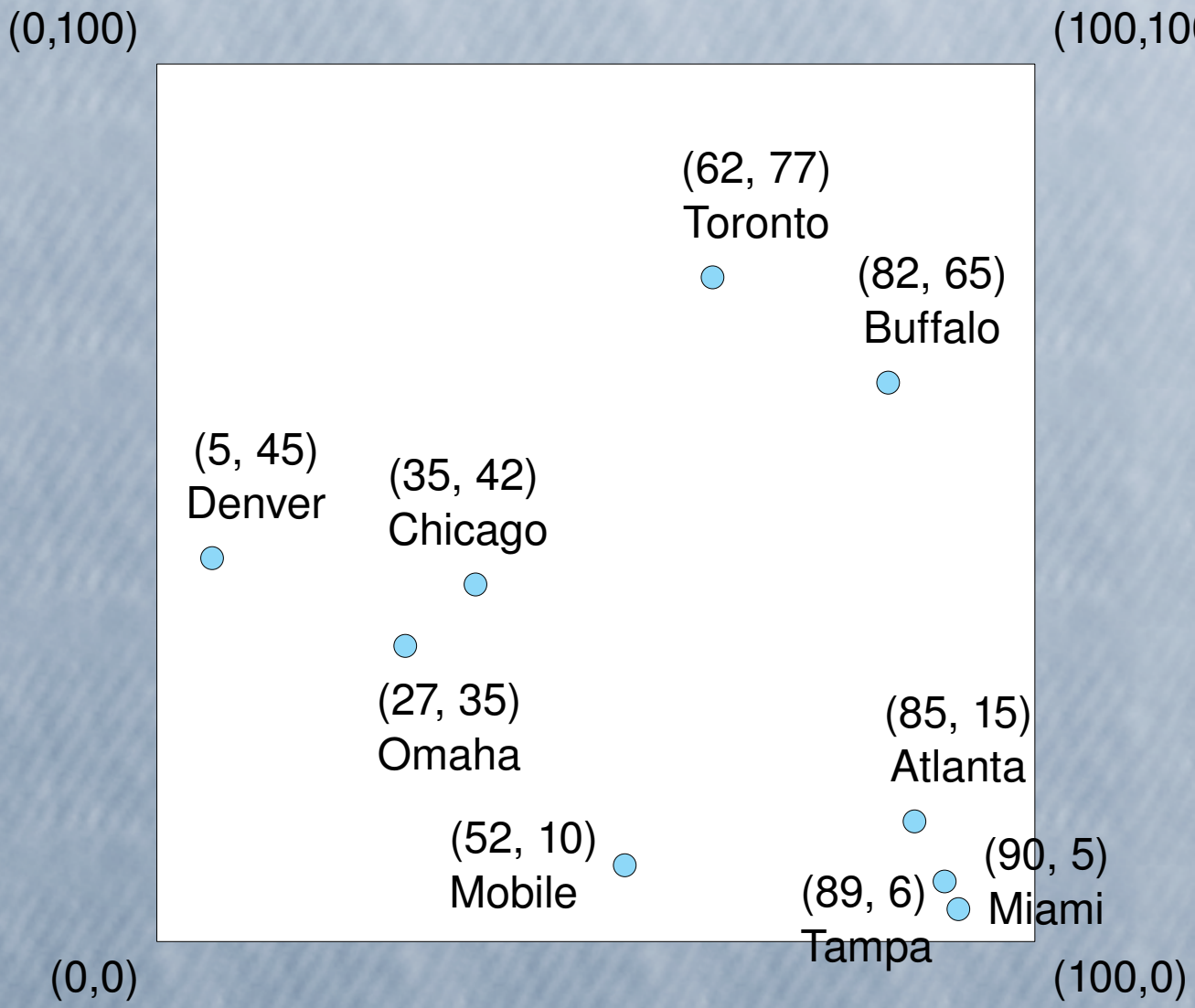
kd-Trees



Tree Data Structure



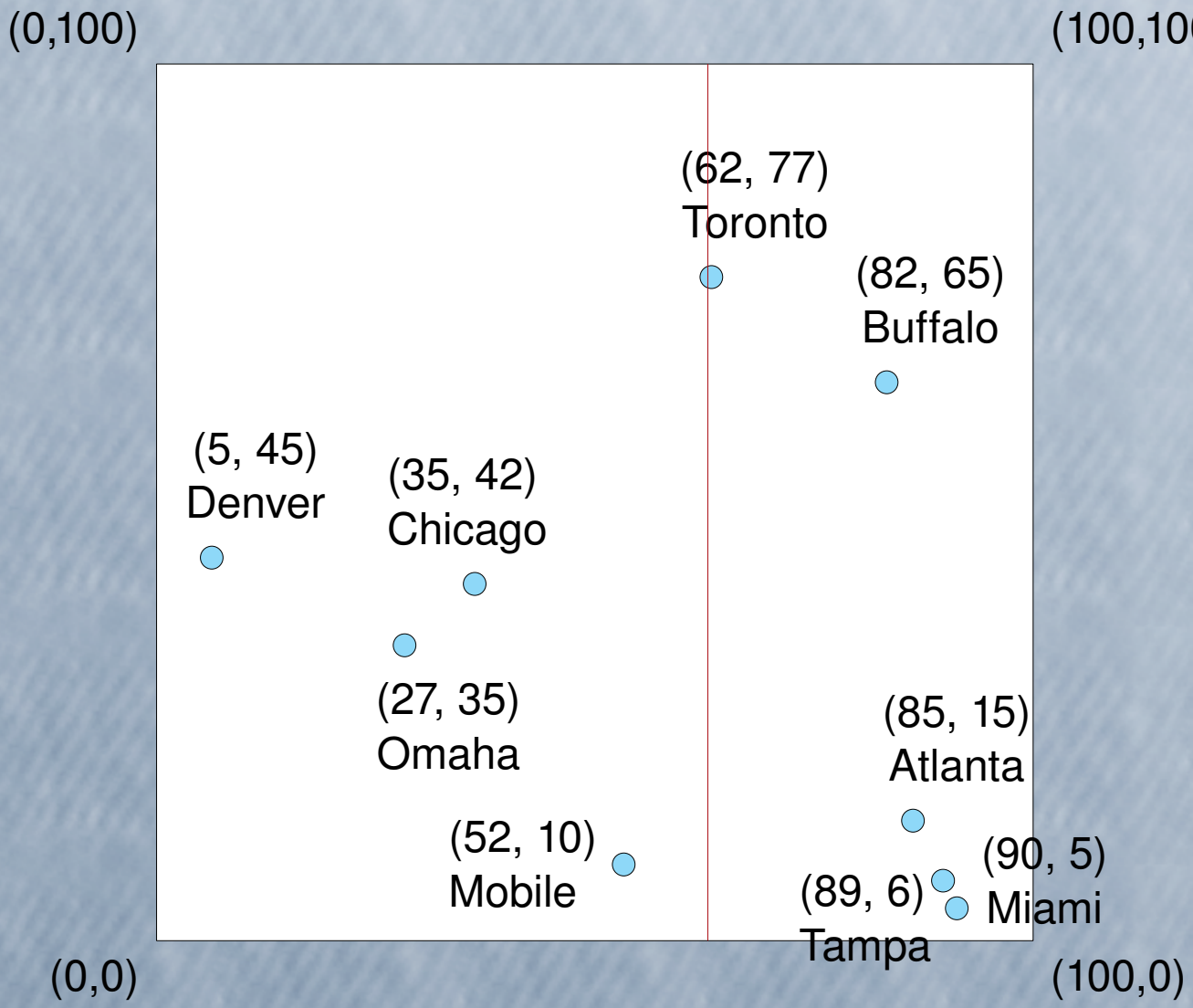
kd-Trees



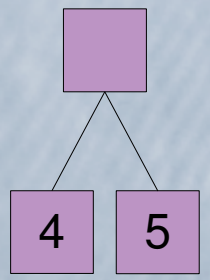
Tree Data Structure

9

kd-Trees

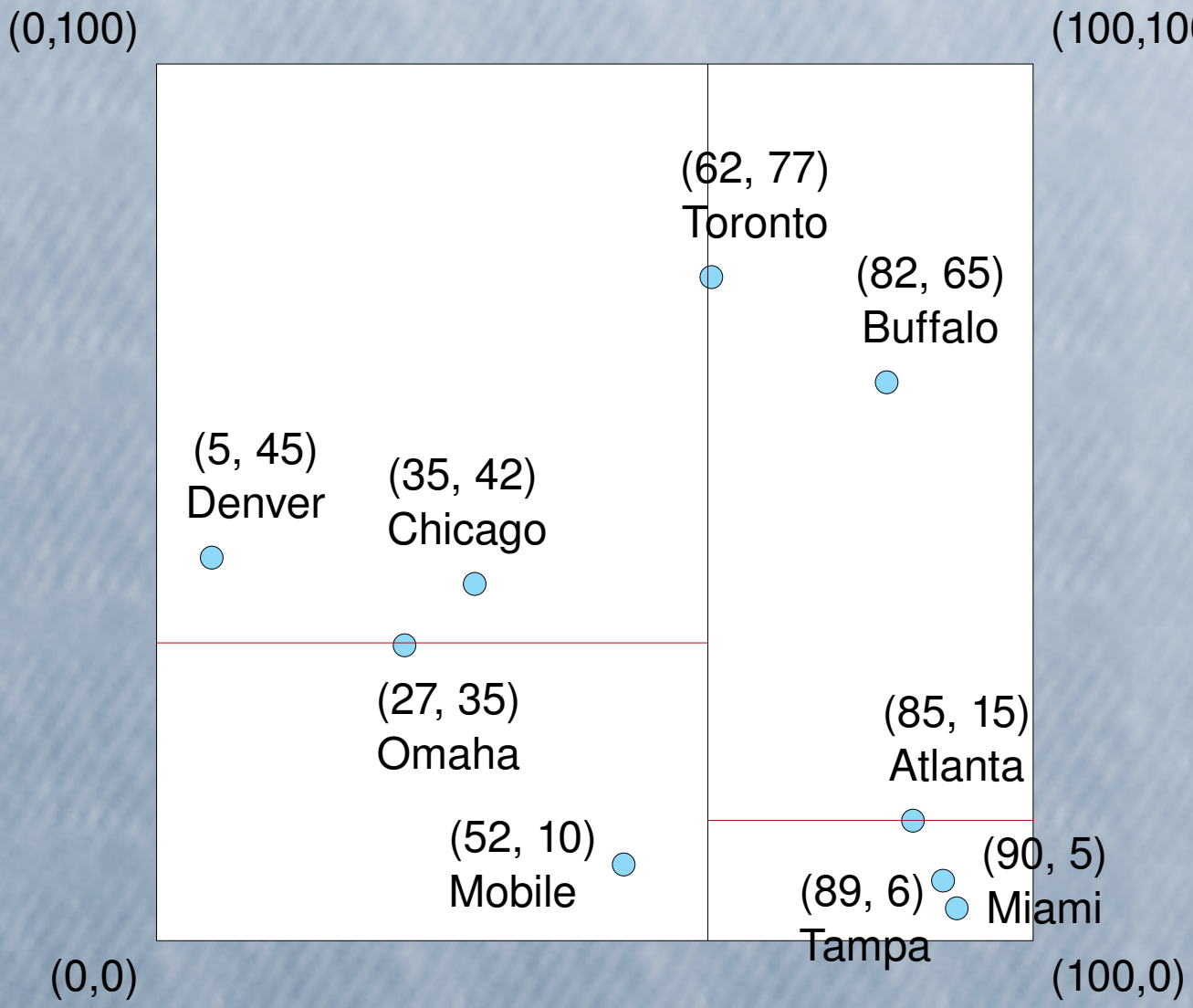


Tree Data Structure

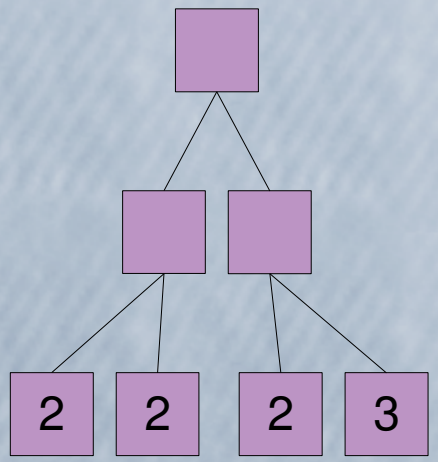


Using median split, alternating directions

kd-Trees

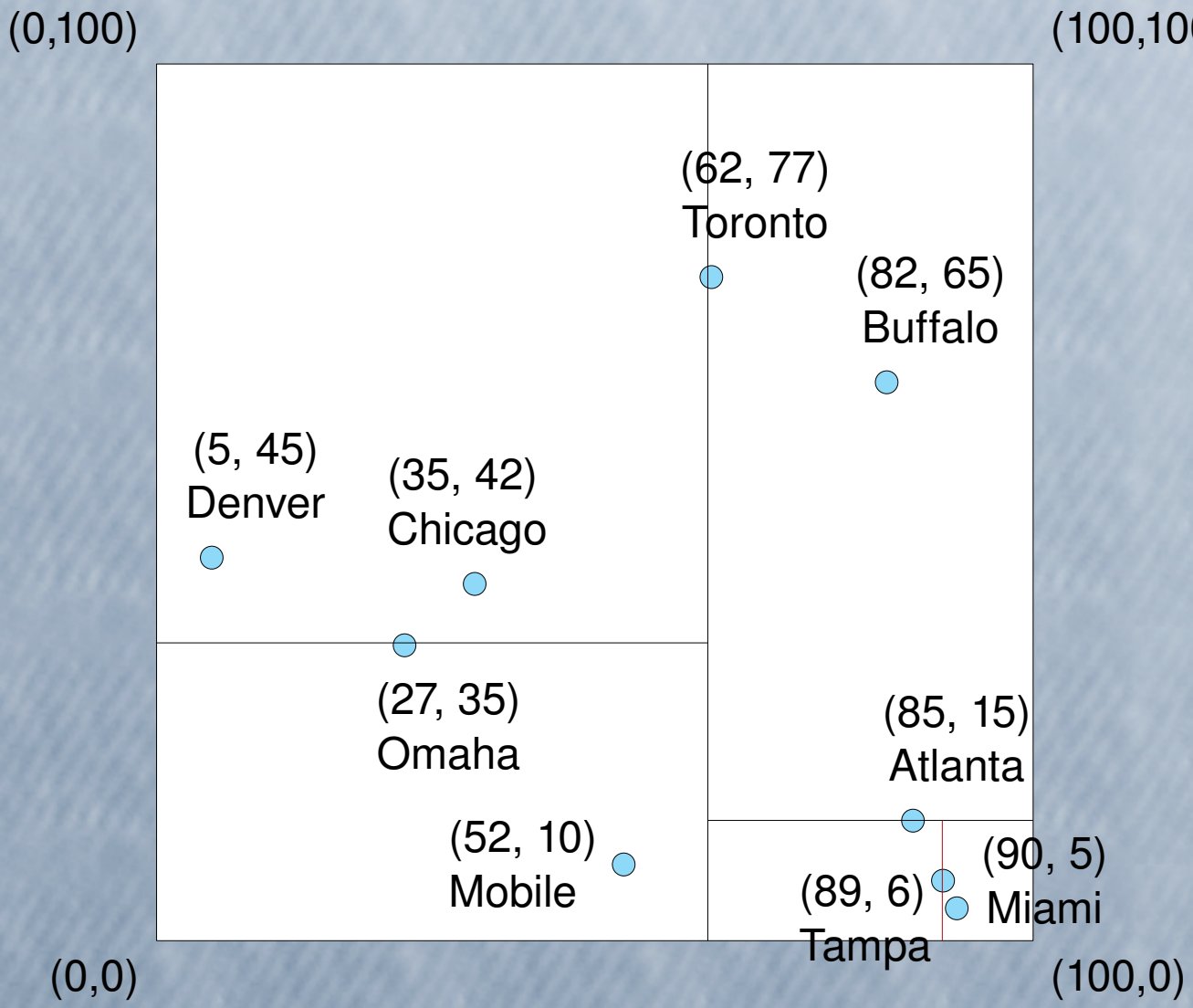


Tree Data Structure

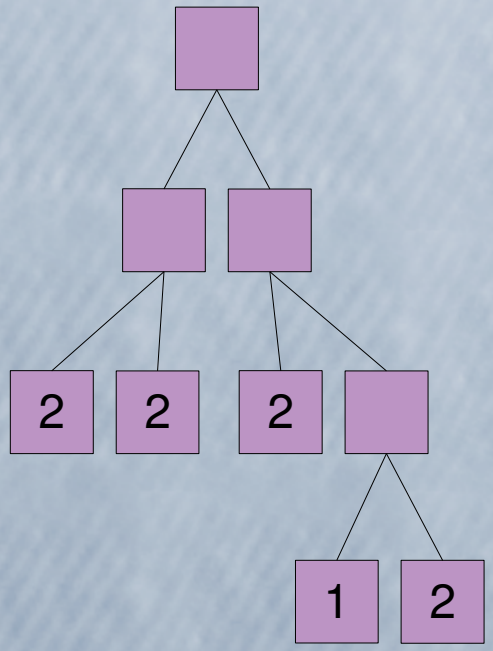


Using median split, alternating directions

kd-Trees

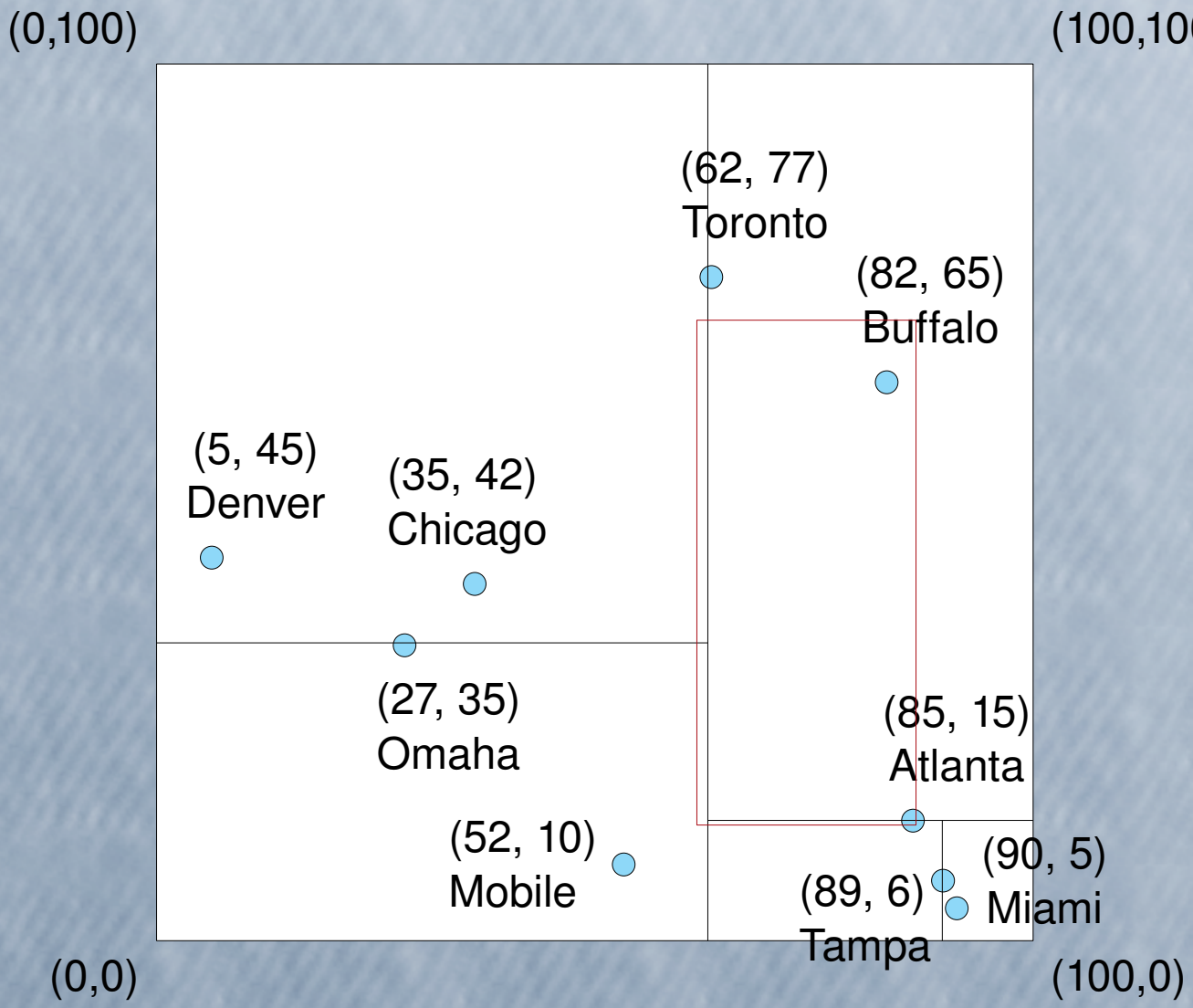


Tree Data Structure

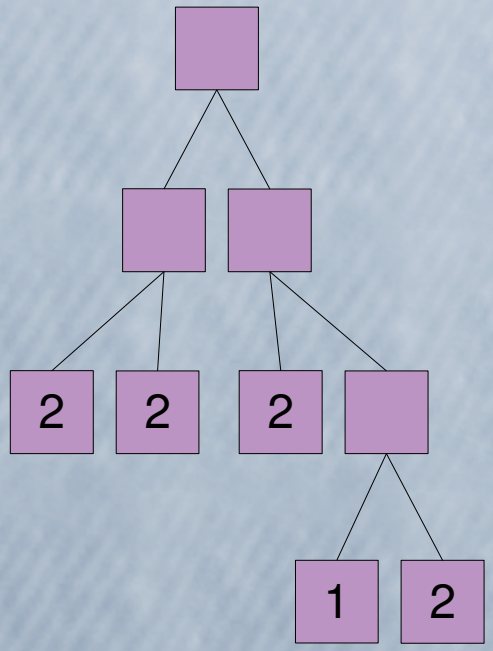


Using median split, alternating directions

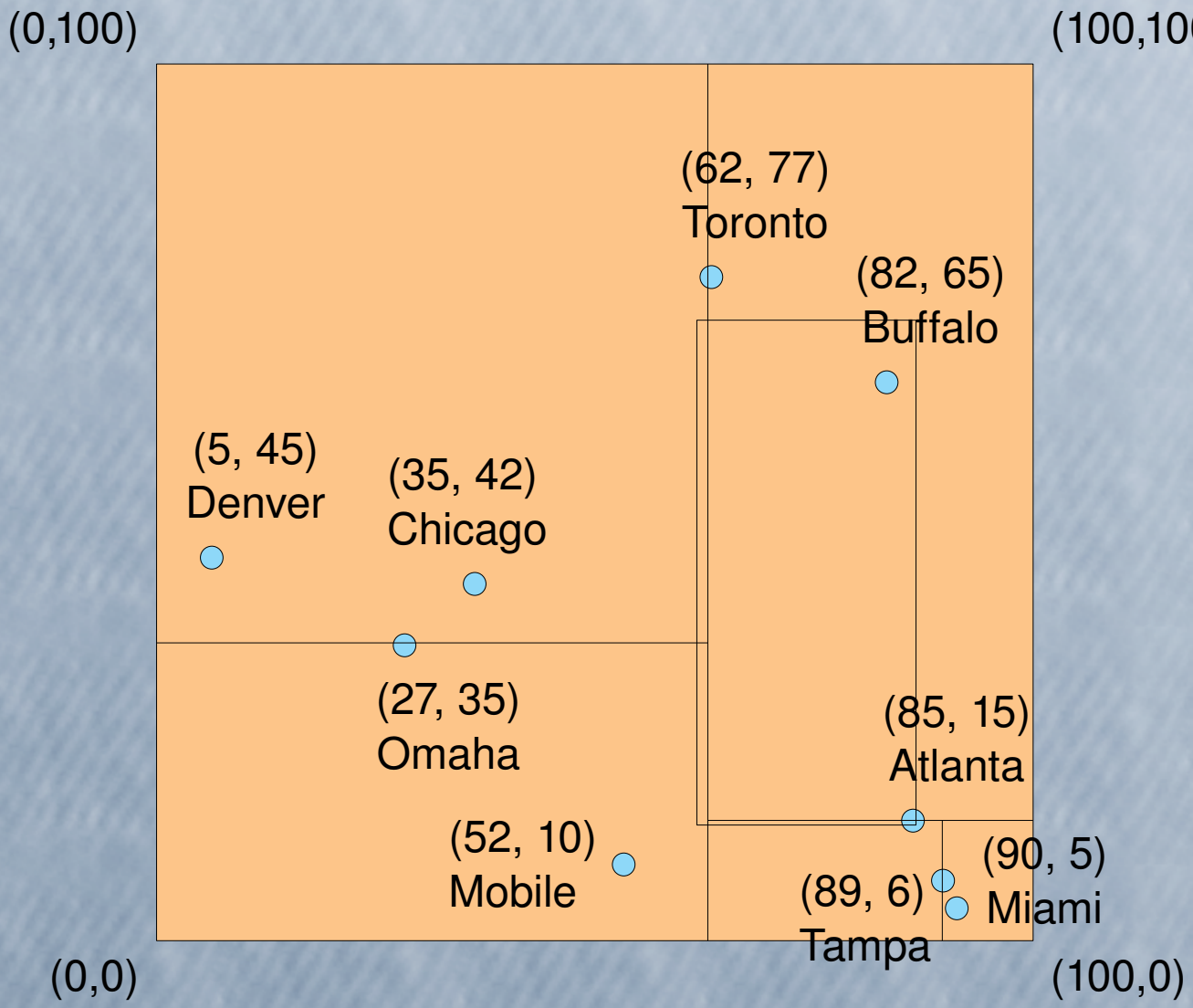
Range Query on kd-Trees



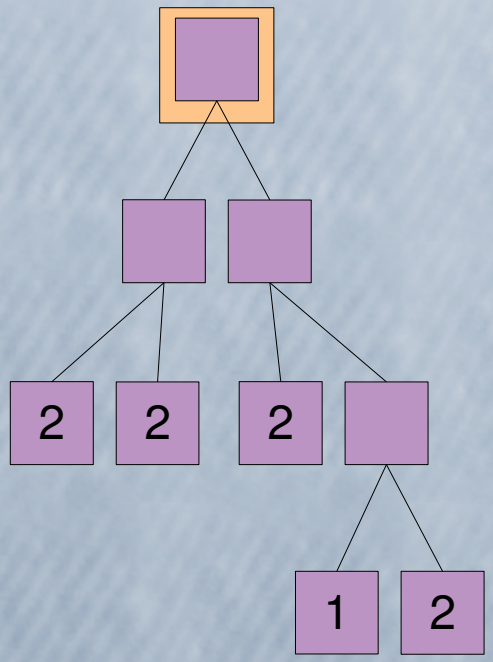
Tree Data Structure



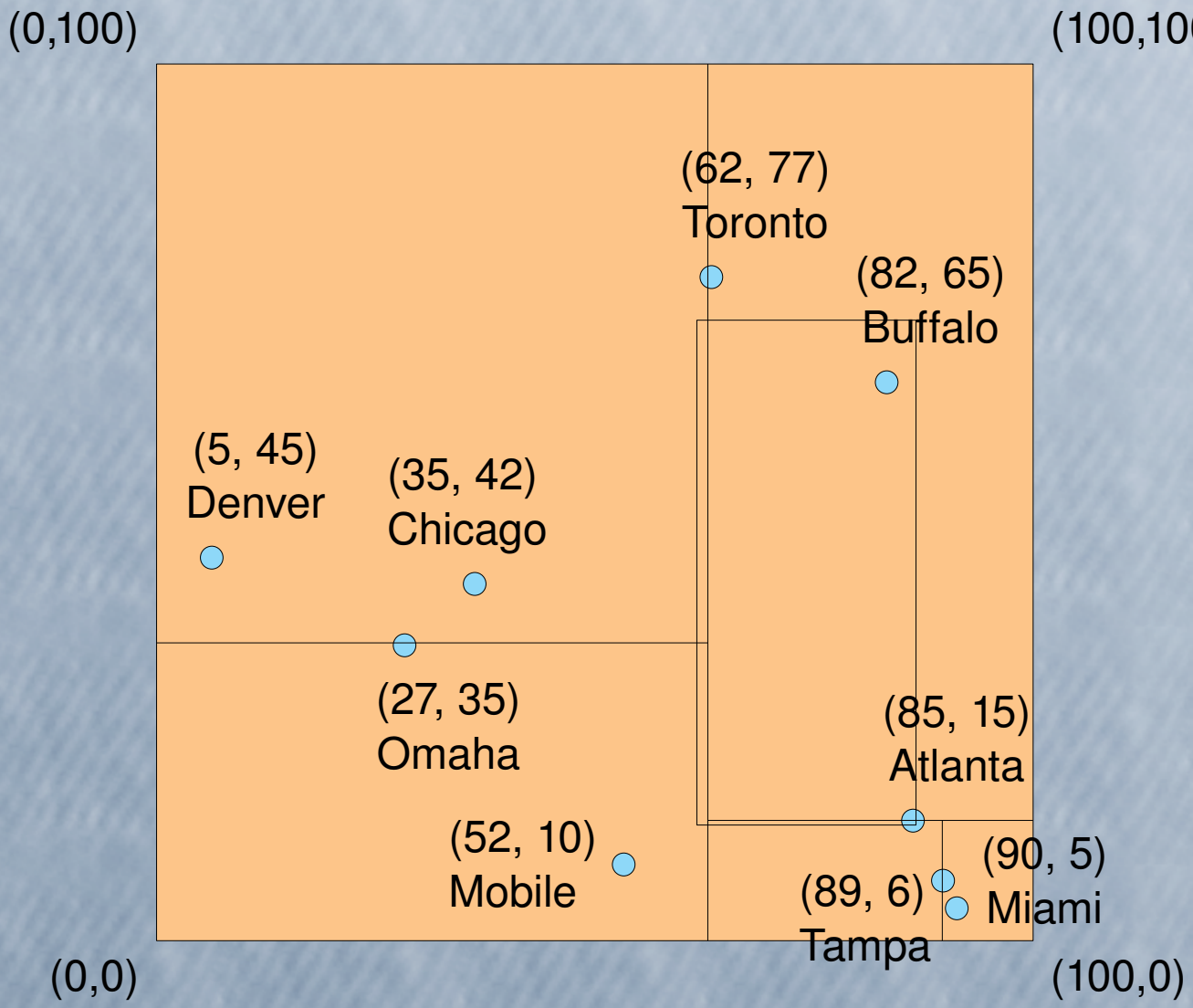
Range Query on kd-Trees



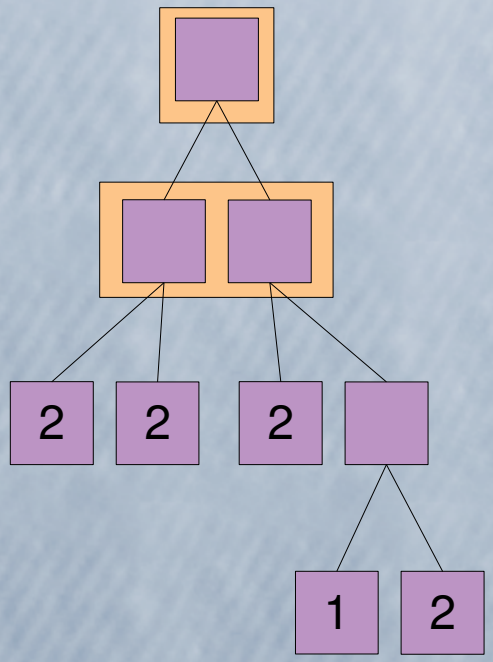
Tree Data Structure



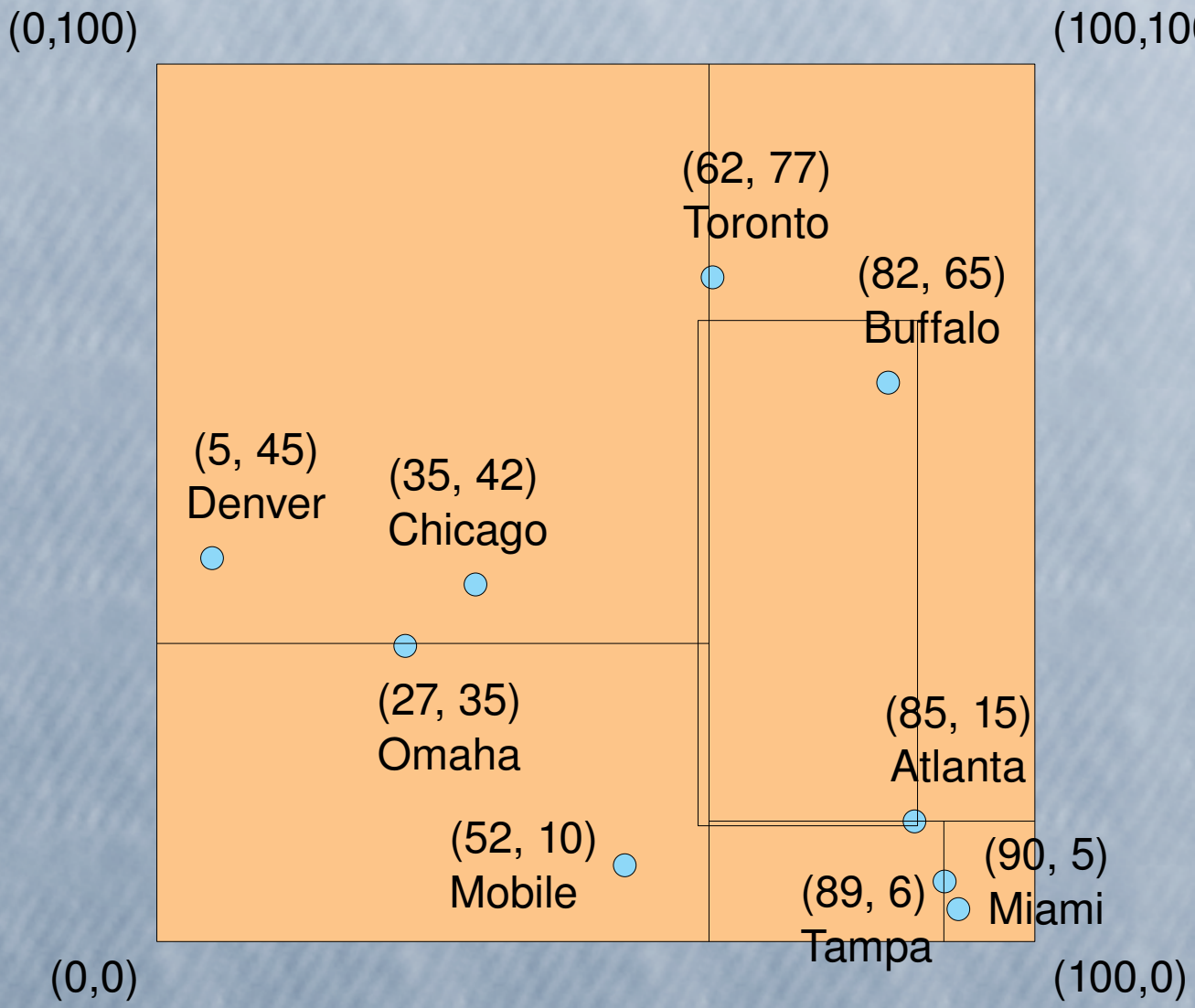
Range Query on kd-Trees



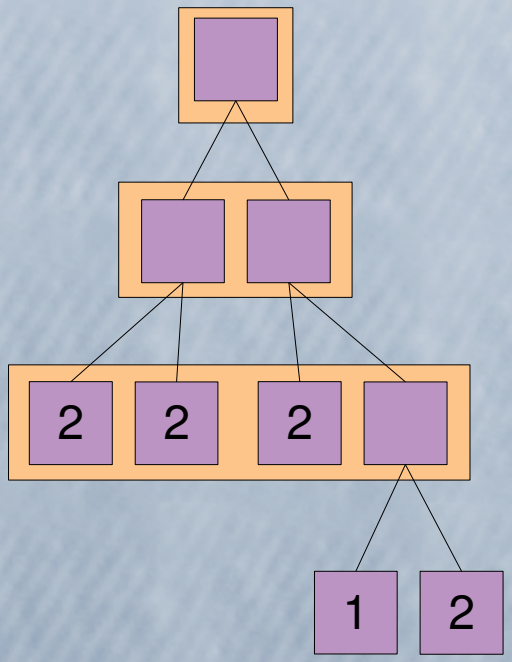
Tree Data Structure



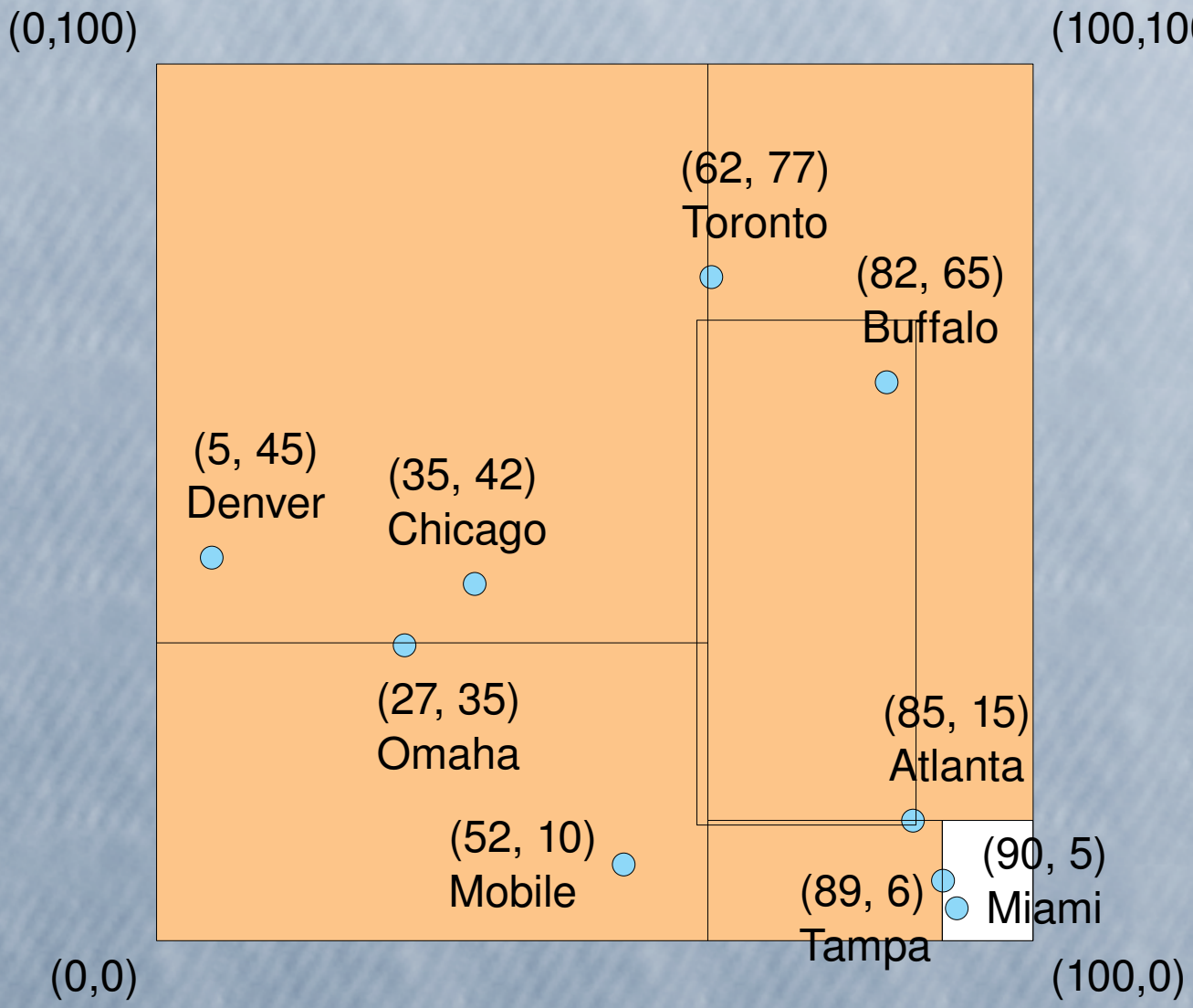
Range Query on kd-Trees



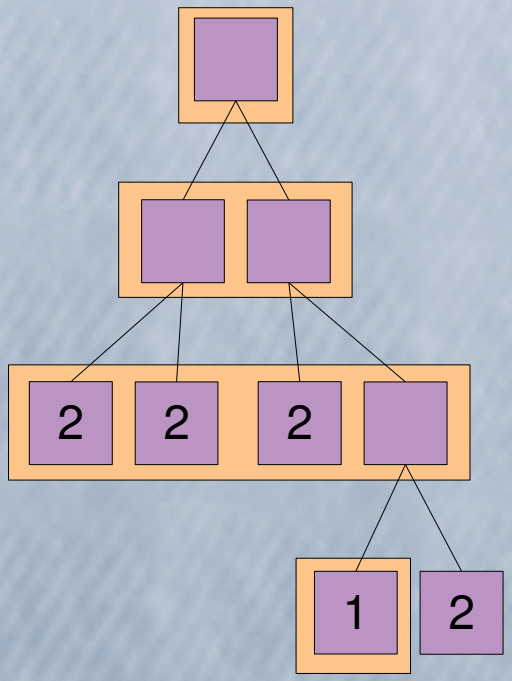
Tree Data Structure



Range Query on kd-Trees

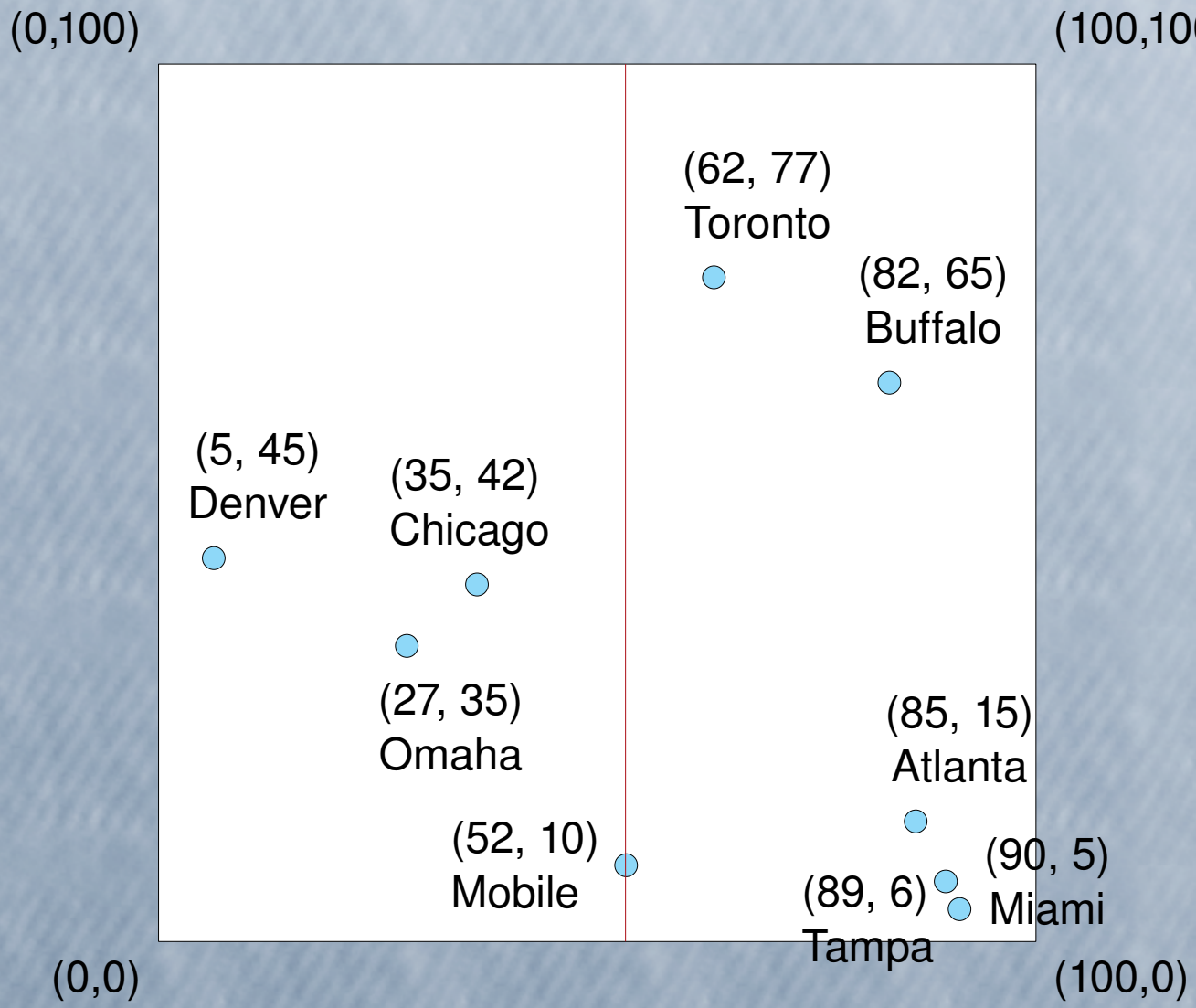


Tree Data Structure

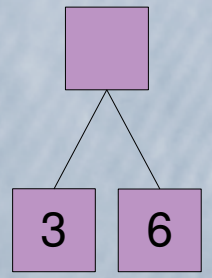


Wow, what went so wrong?

kd-Tree Splitting Heuristic

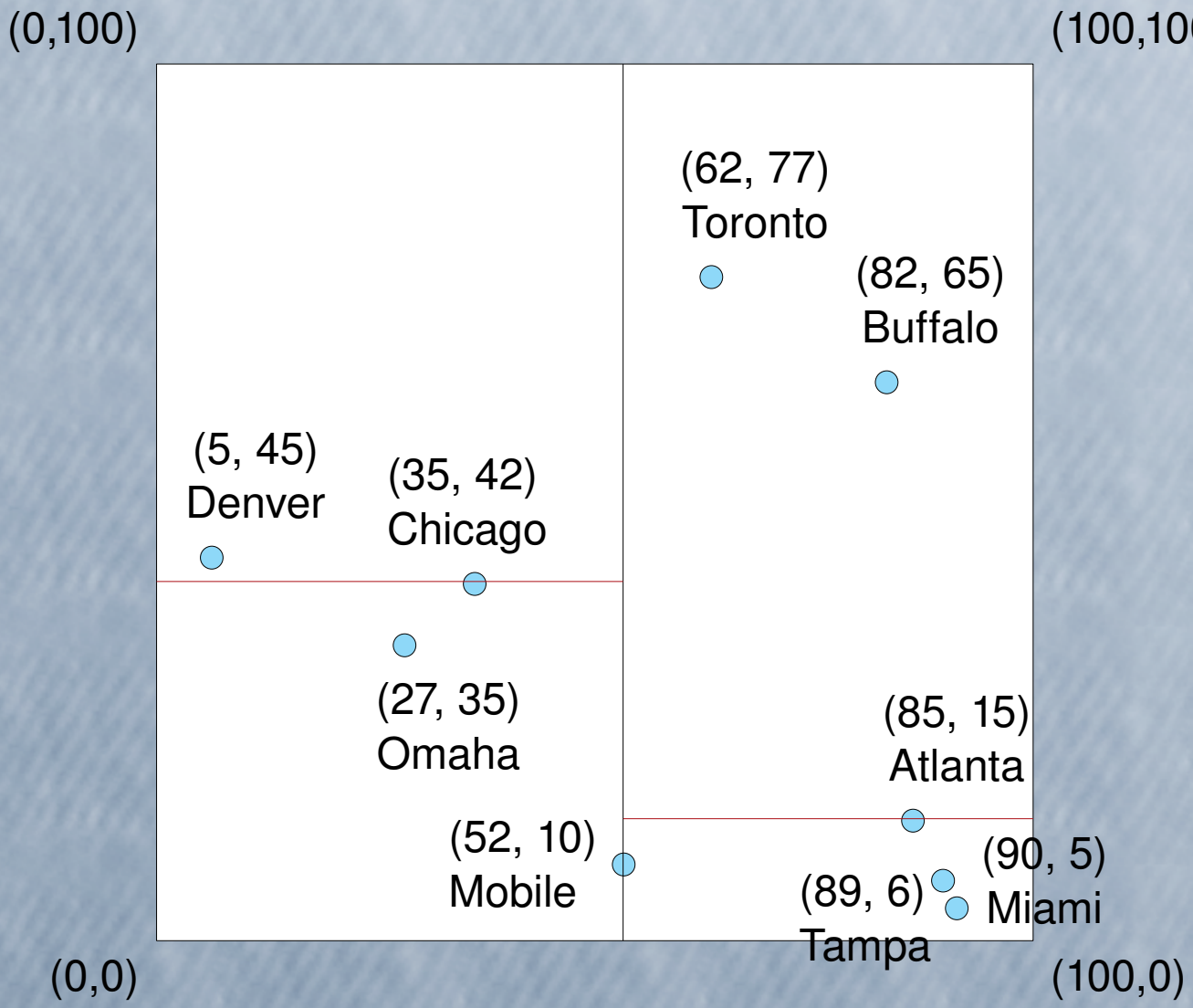


Tree Data Structure

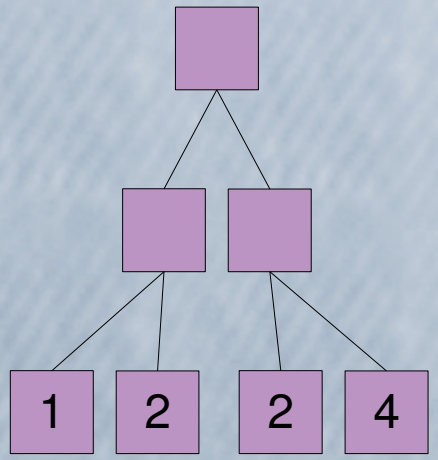


Median split wasn't so good, lets try something else.

kd-Tree Splitting Heuristic



Tree Data Structure



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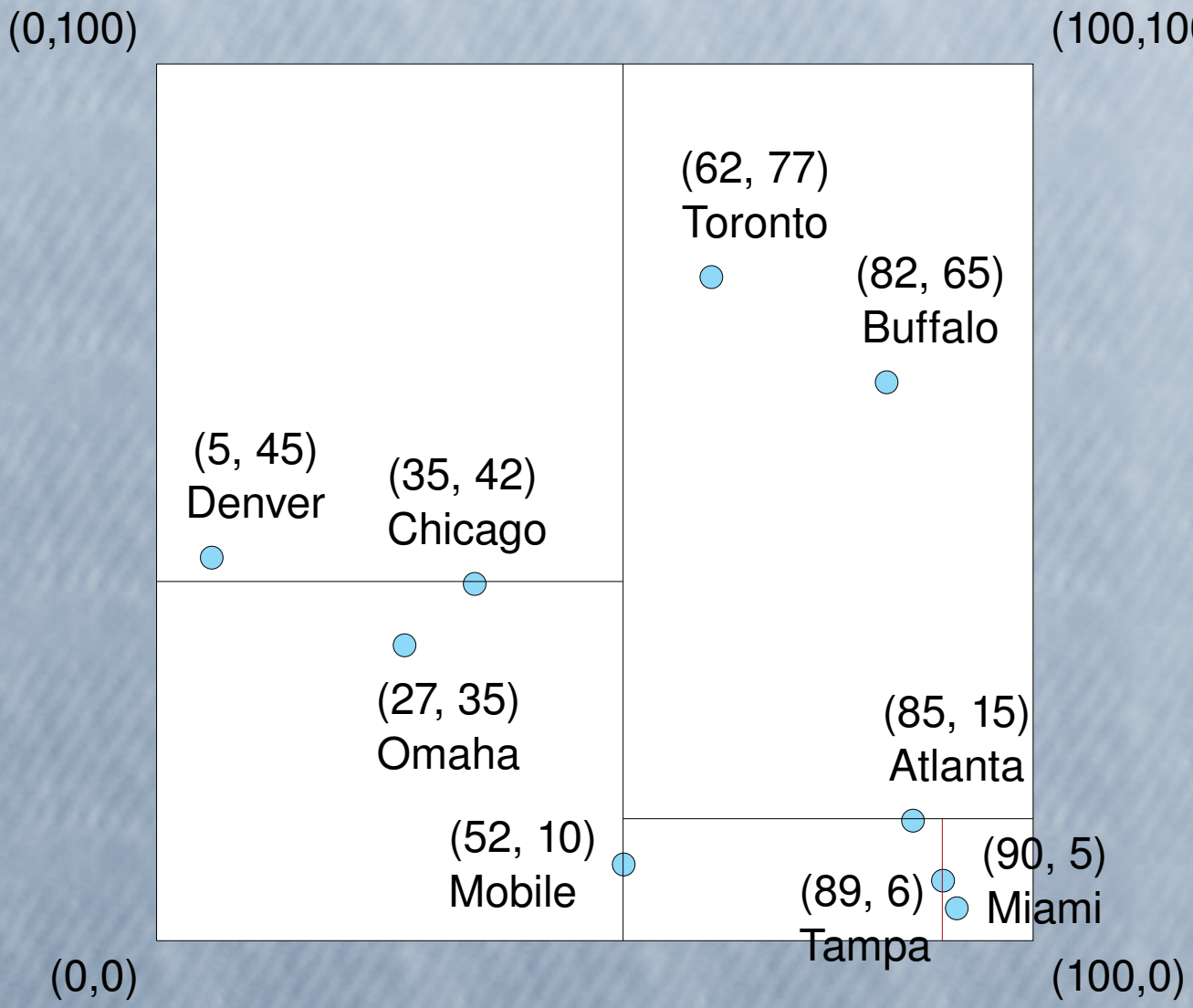
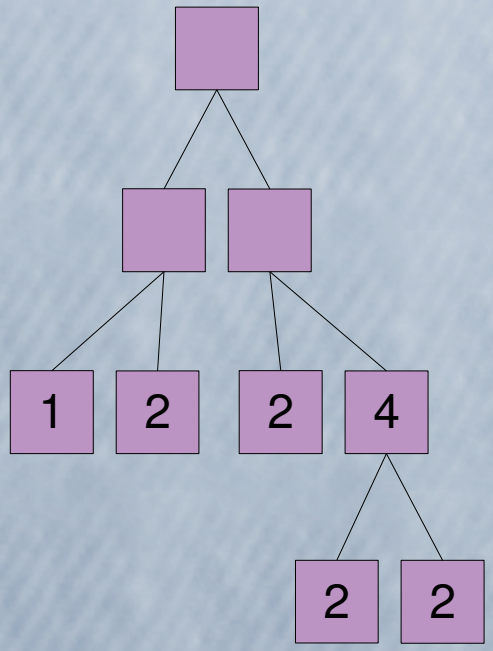
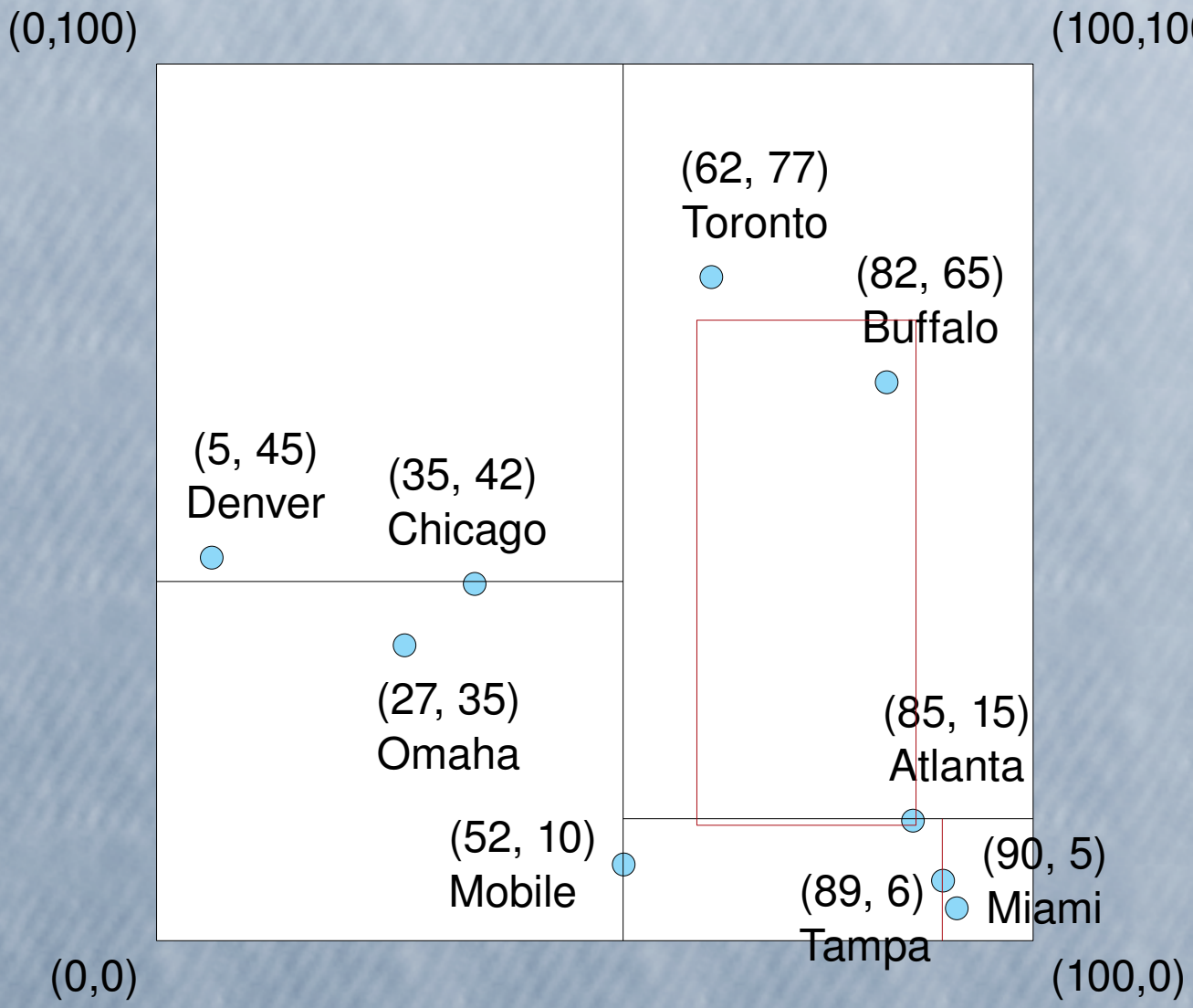


Tree Data Structure

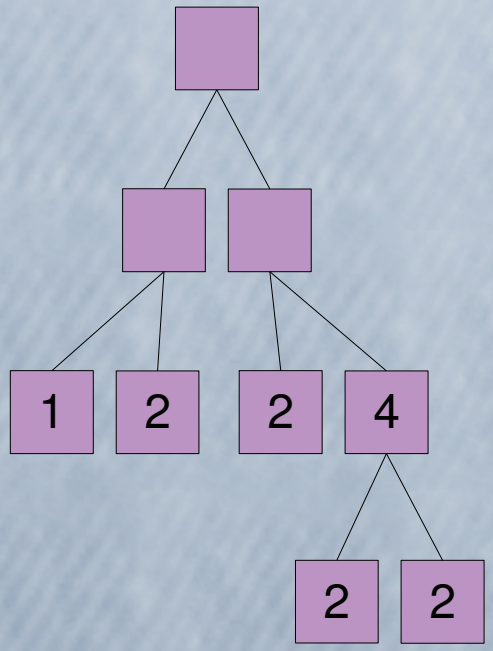


Median split wasn't so good, lets try something else.

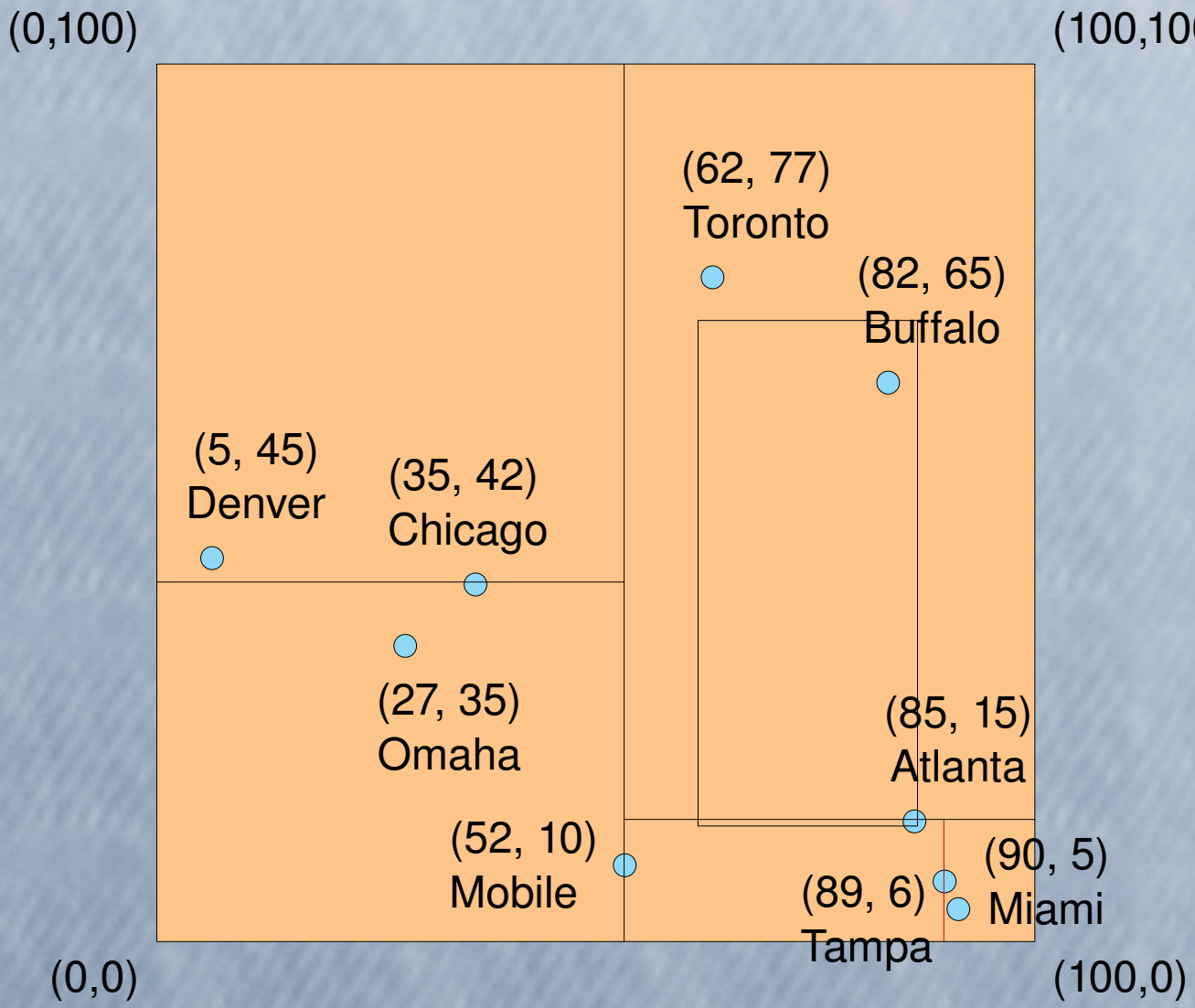
Range Search on the New kd-Tree



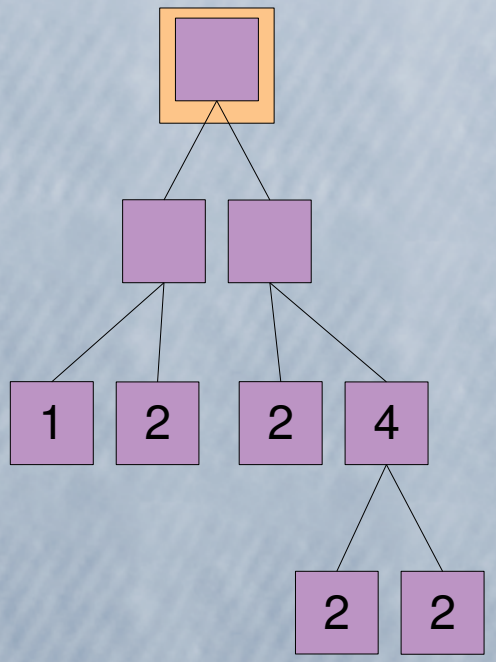
Tree Data Structure



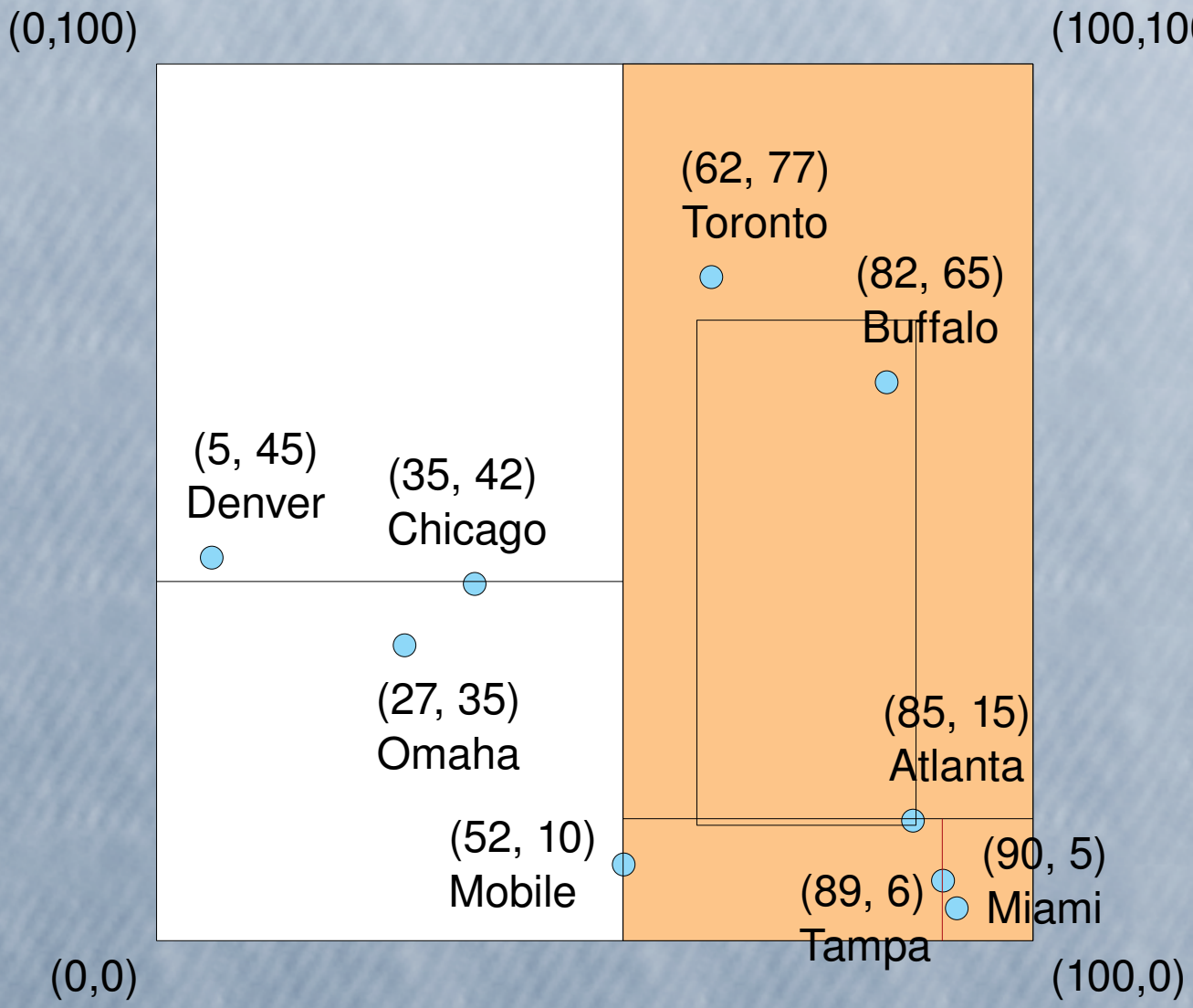
Range Search on the New kd-Tree



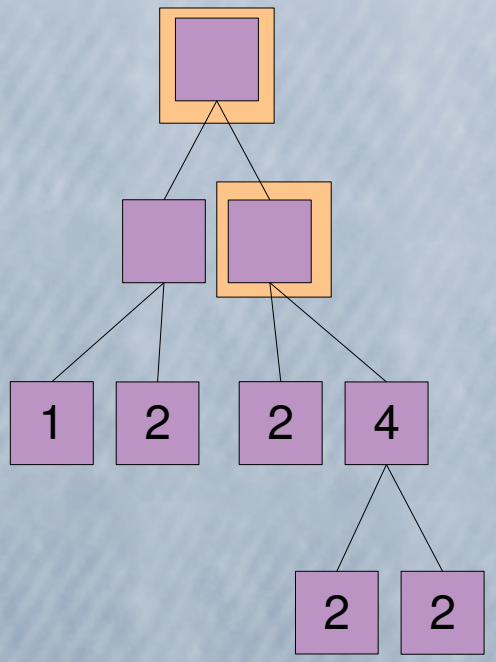
Tree Data Structure



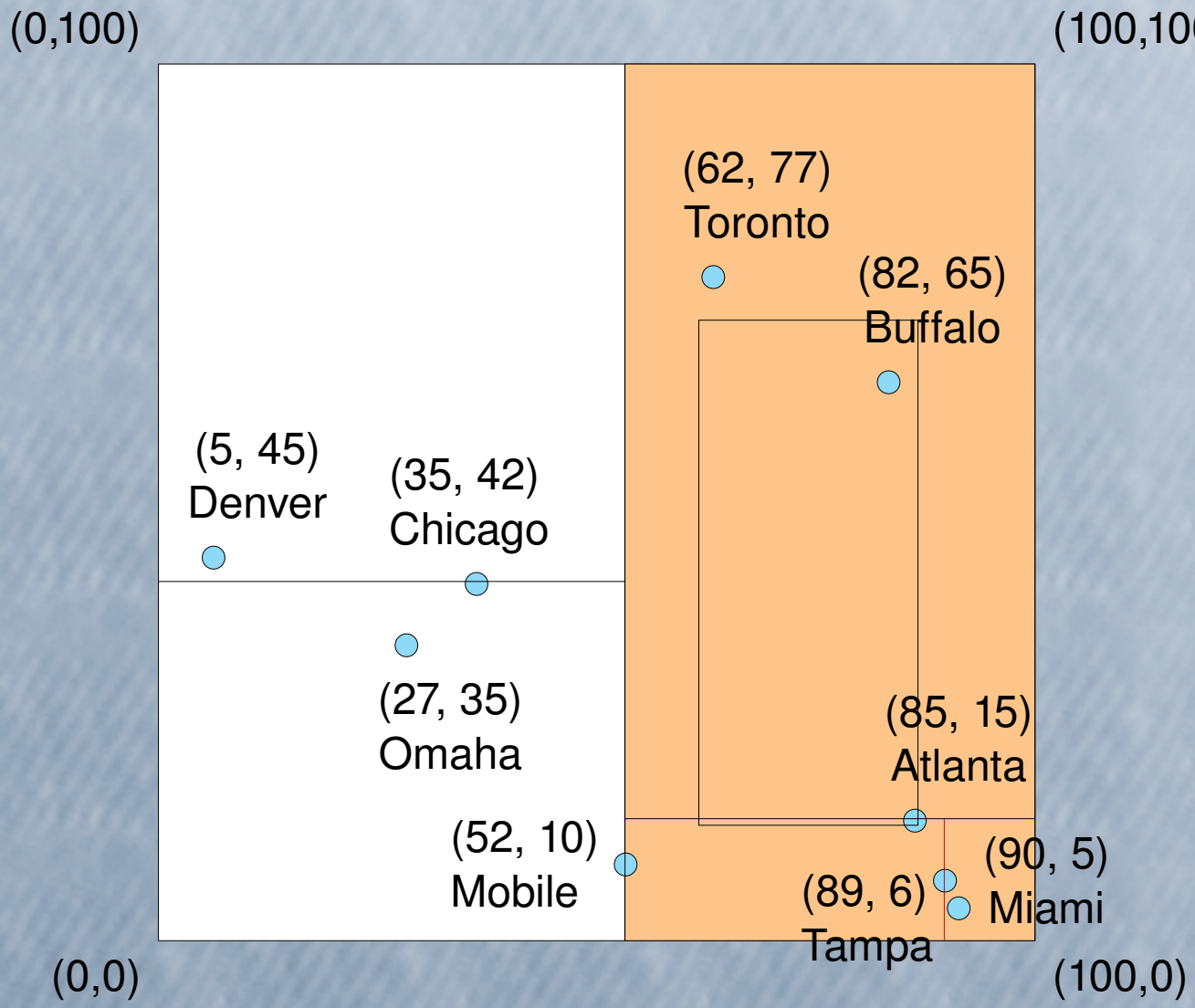
Range Search on the New kd-Tree



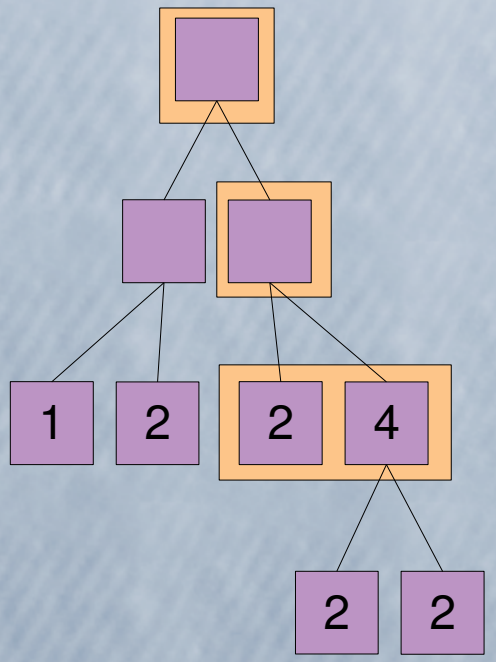
Tree Data Structure



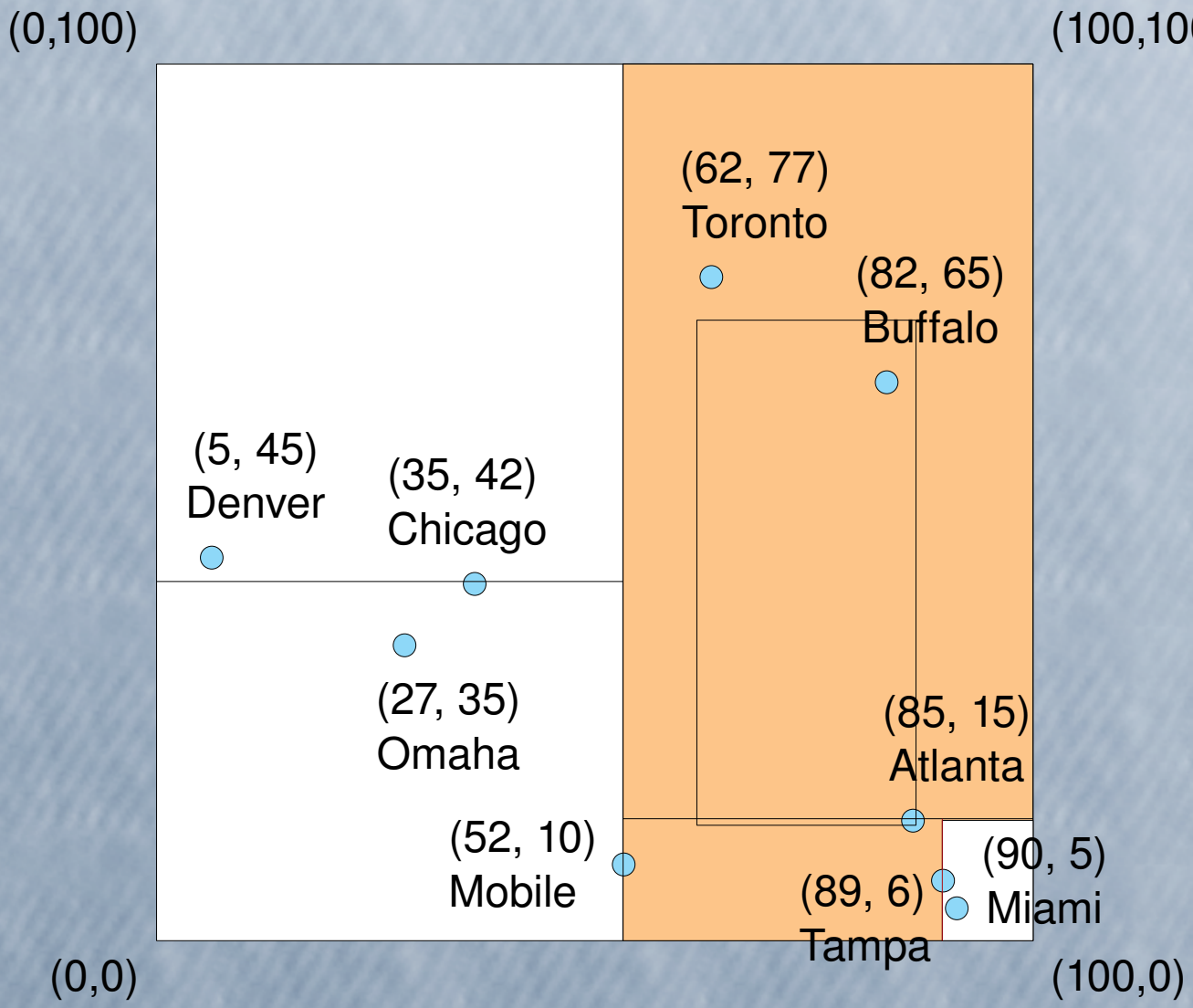
Range Search on the New kd-Tree



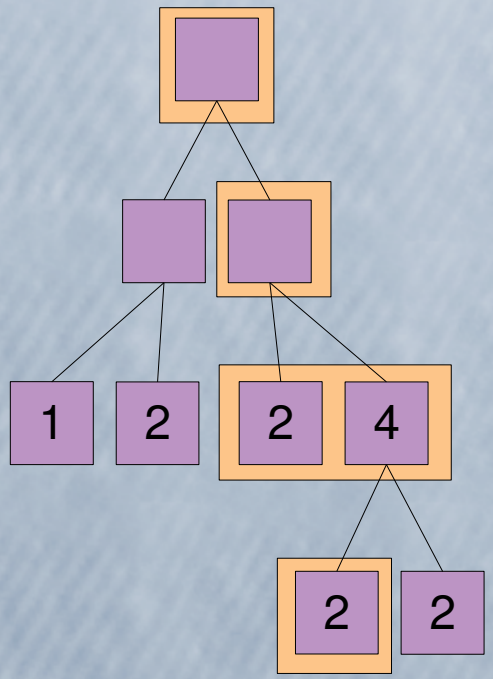
Tree Data Structure



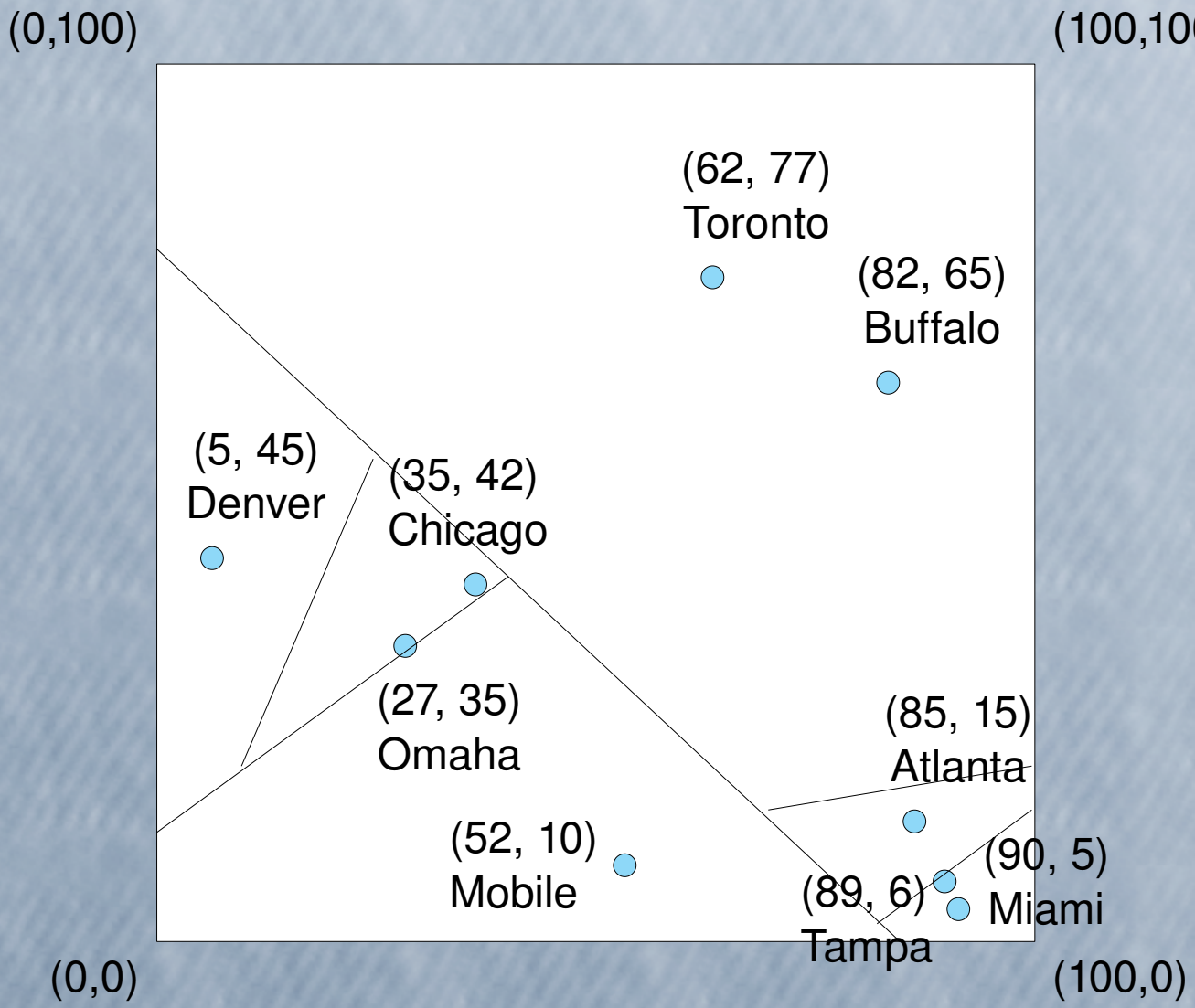
Range Search on the New kd-Tree



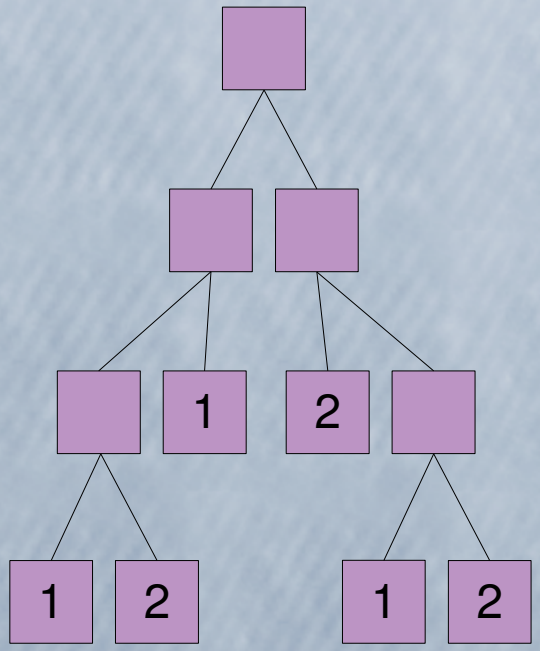
Tree Data Structure



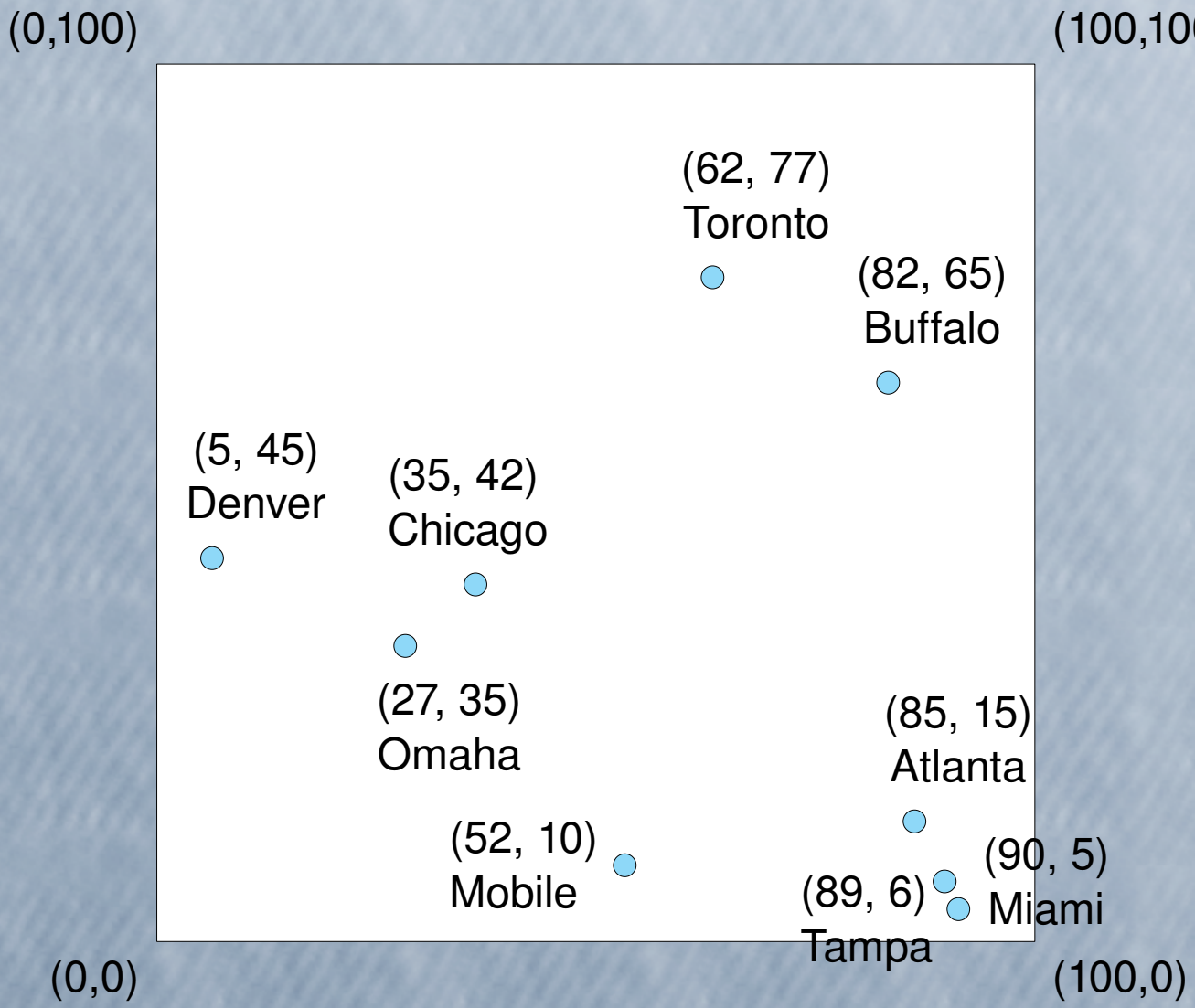
BSP Trees



Tree Data Structure



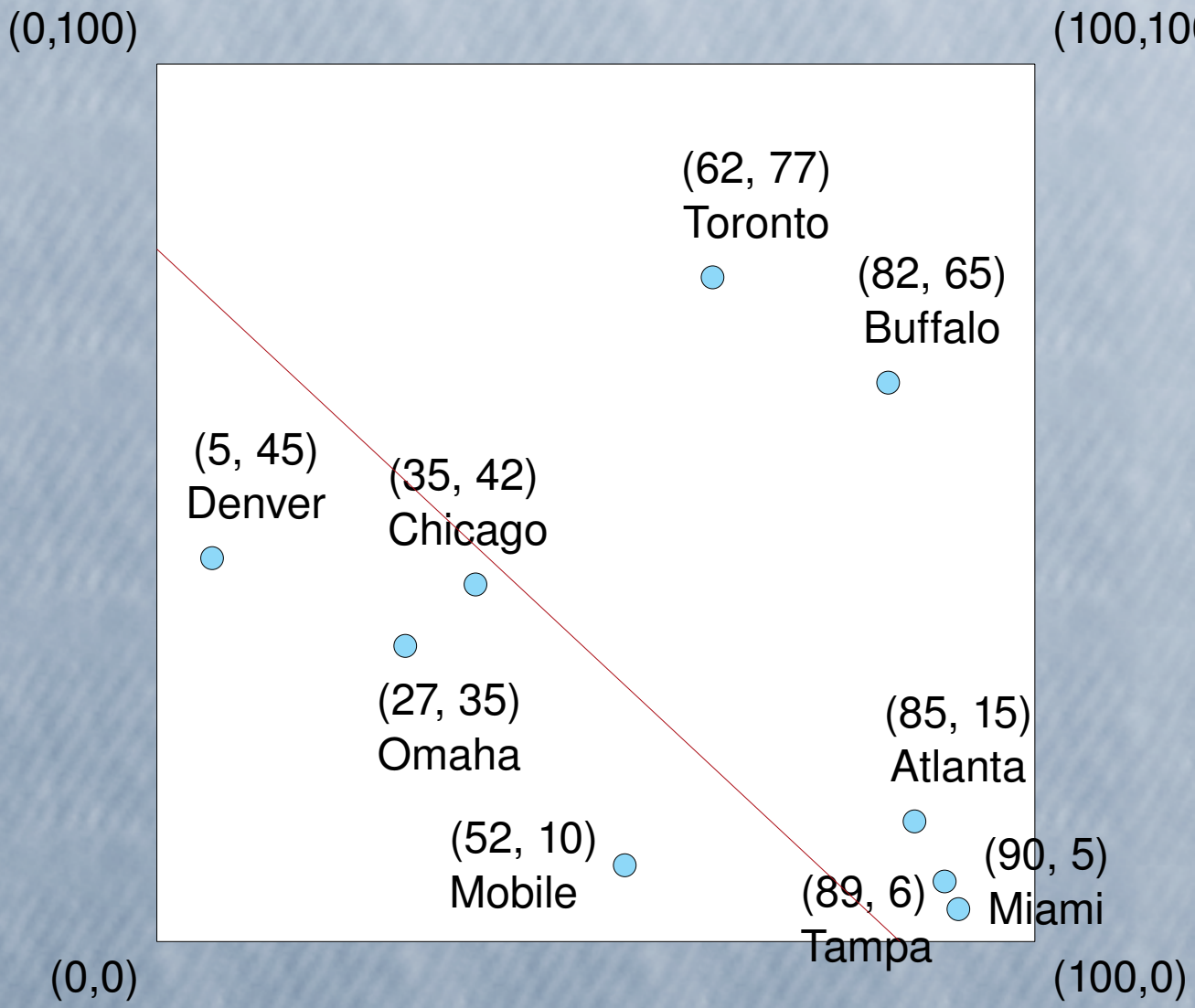
BSP Trees



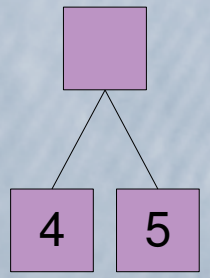
Tree Data Structure

9

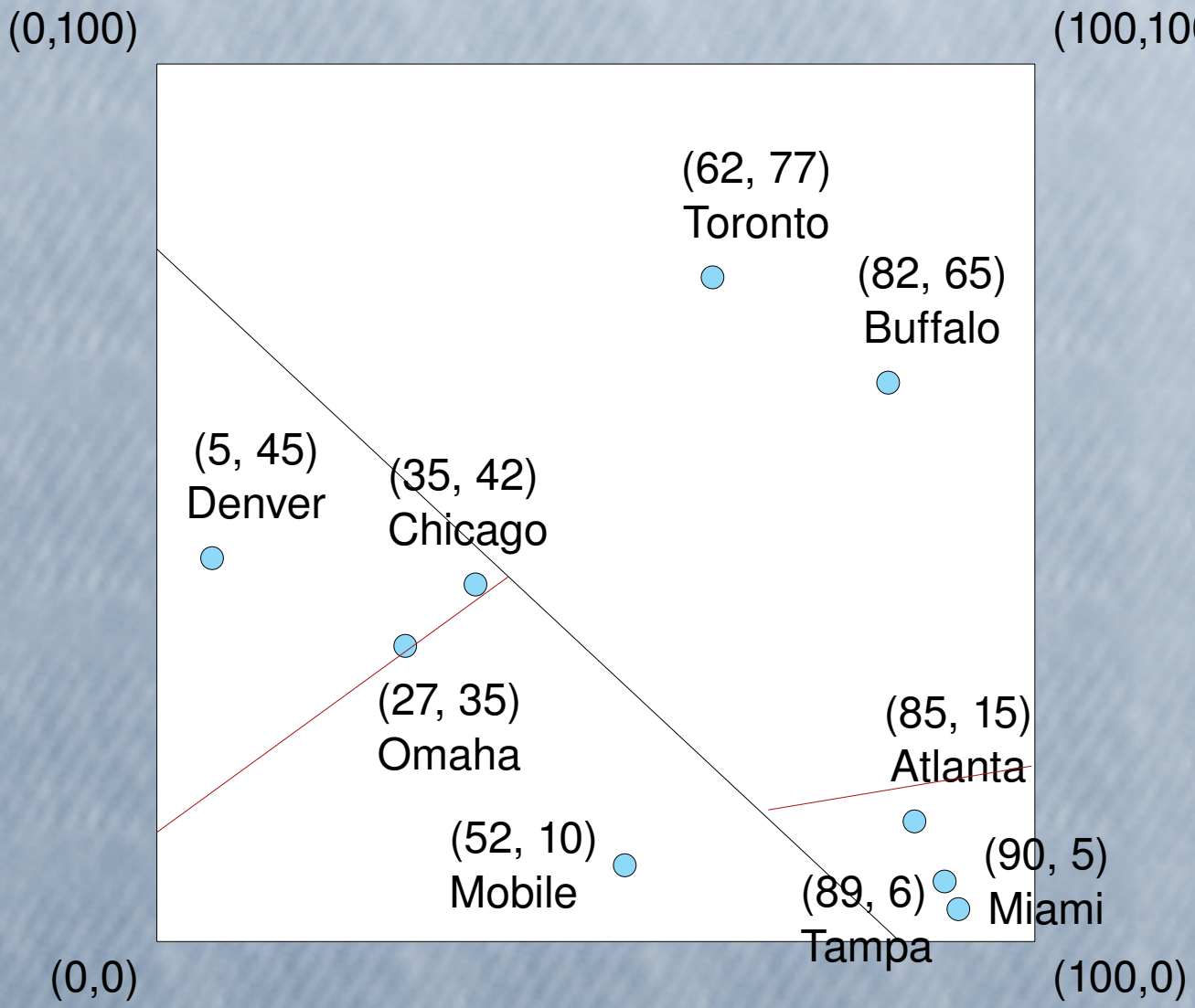
BSP Trees



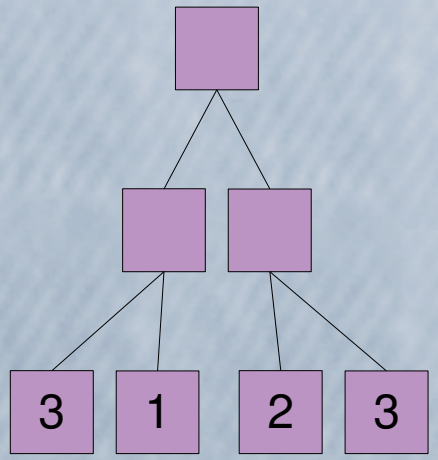
Tree Data Structure



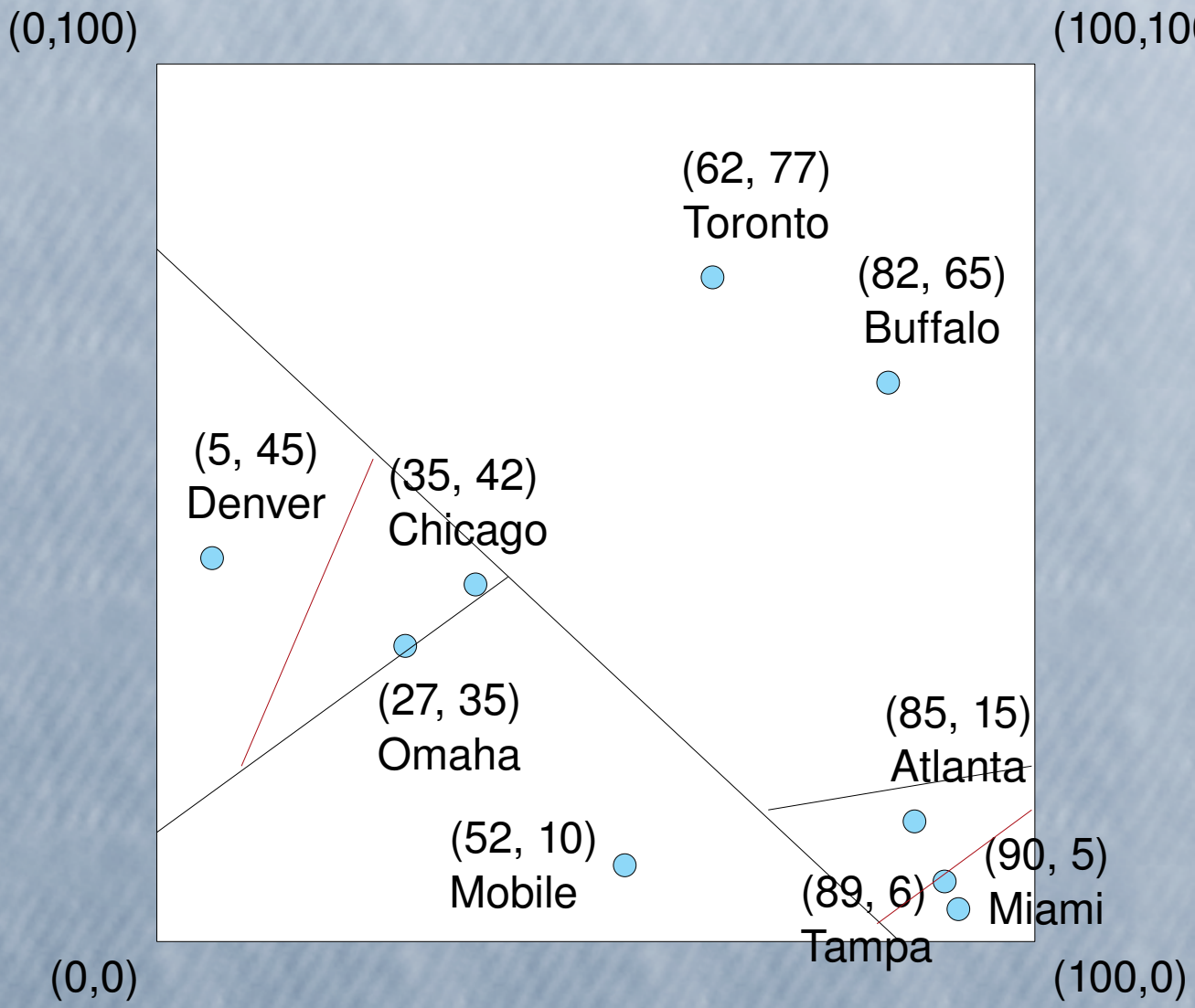
BSP Trees



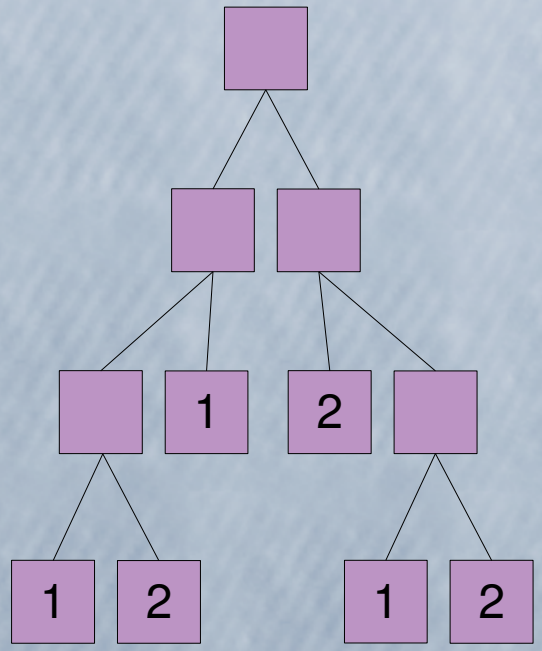
Tree Data Structure



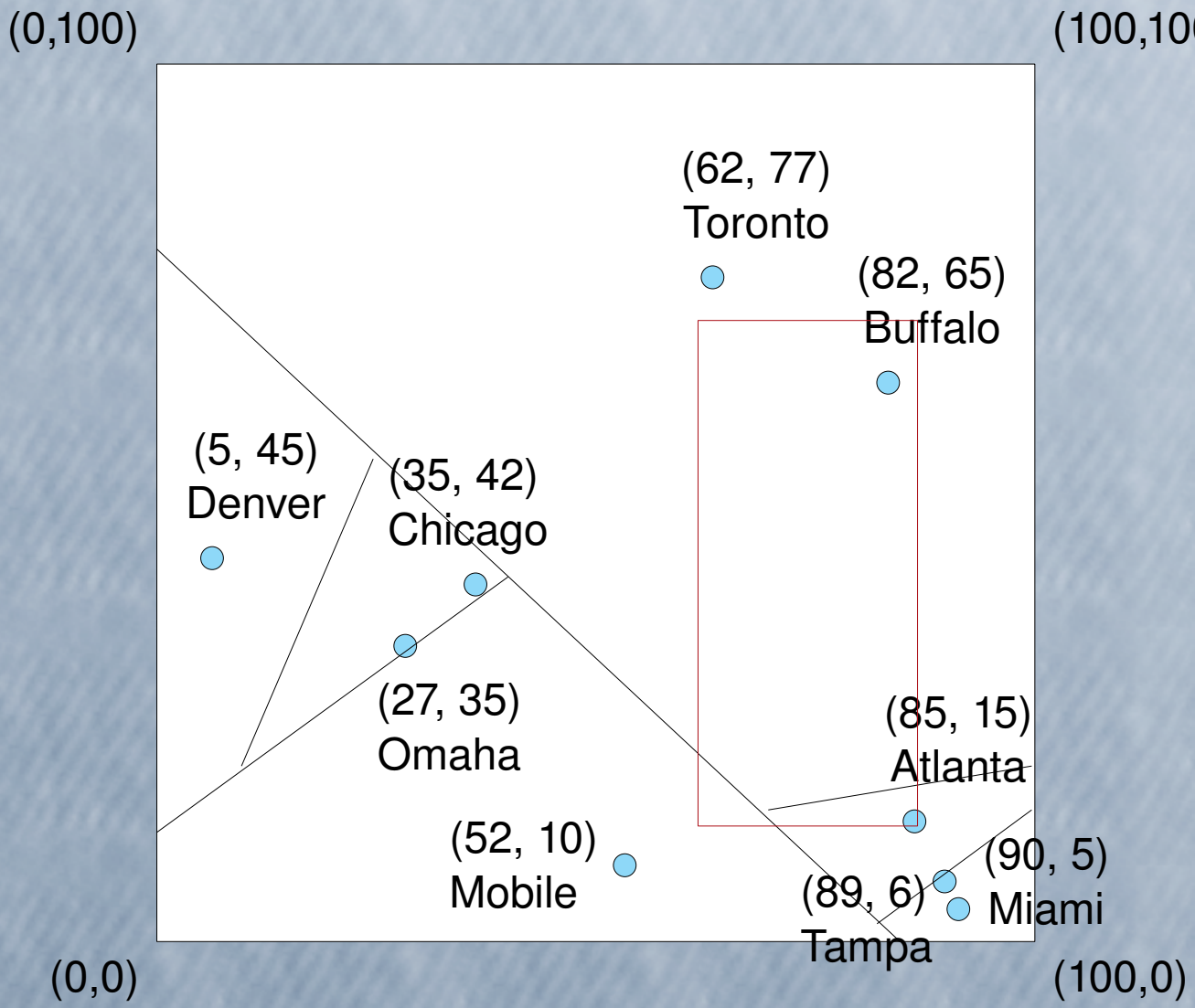
BSP Trees



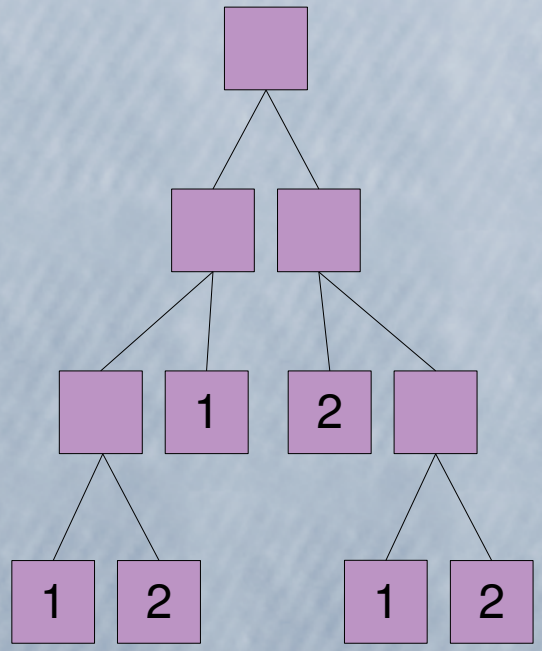
Tree Data Structure



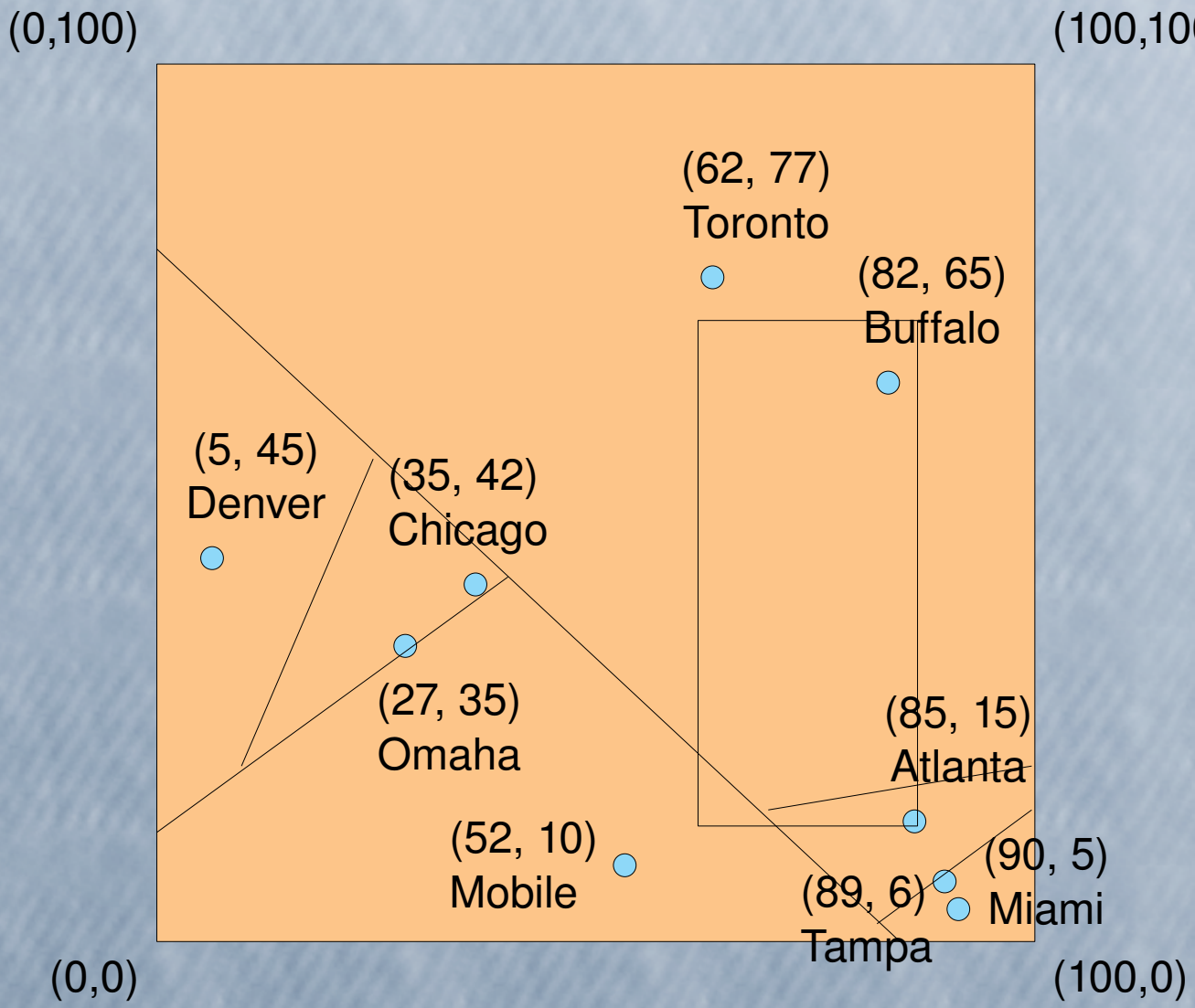
Range Search on BSP Trees



Tree Data Structure



Range Search on BSP Trees



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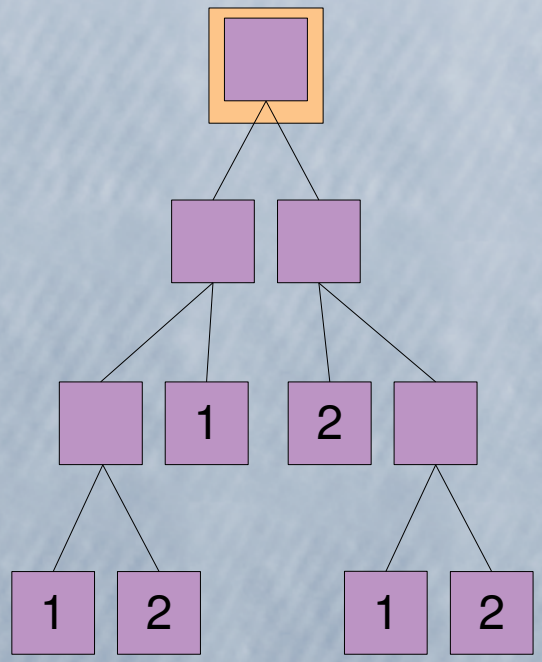

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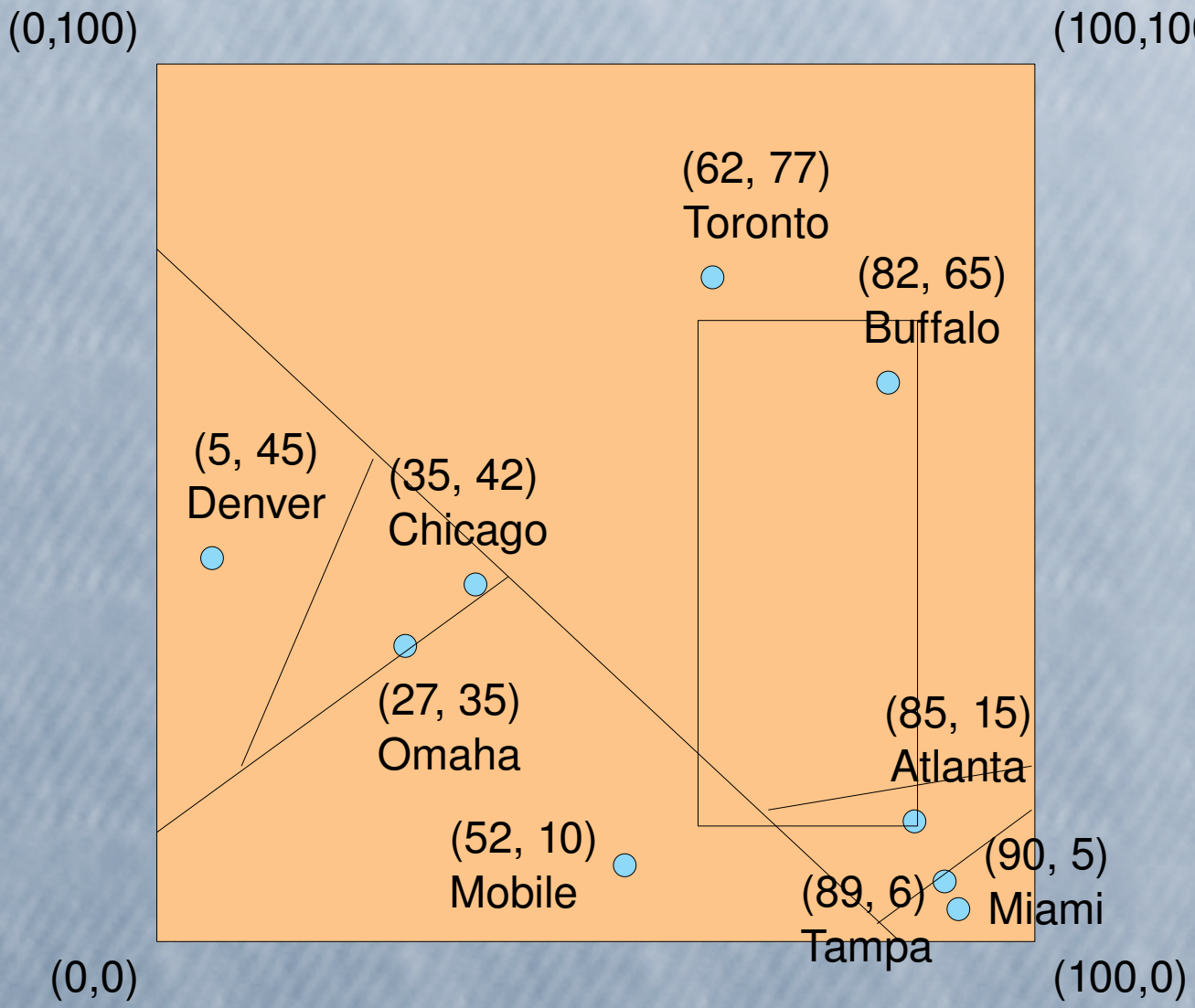
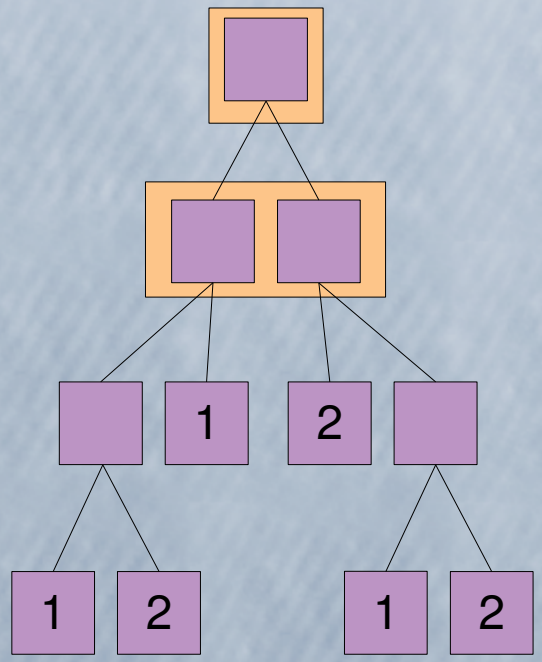
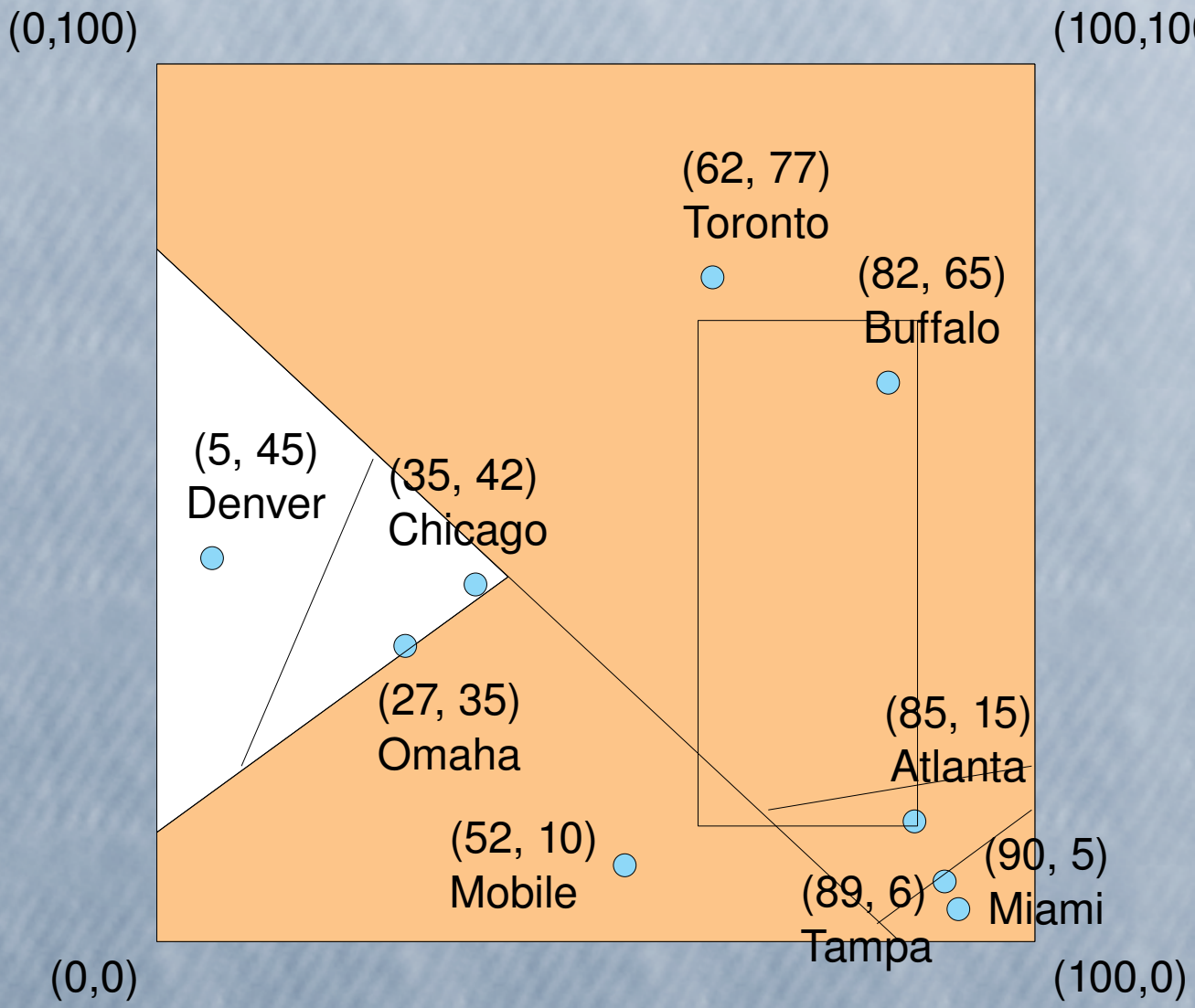


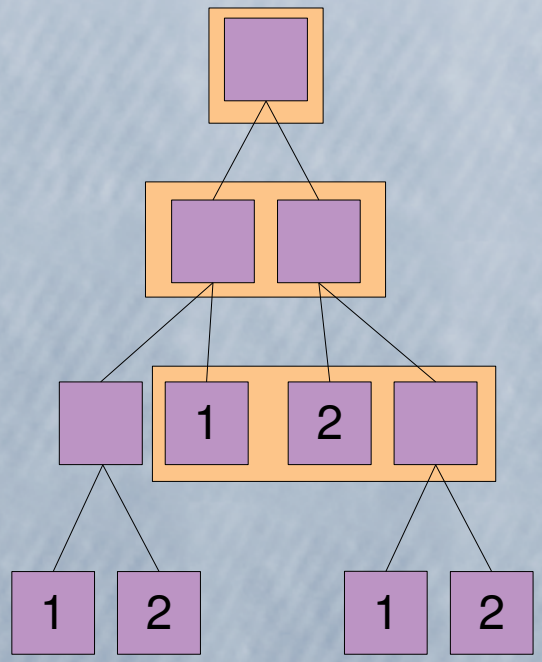
Tree Data Structure



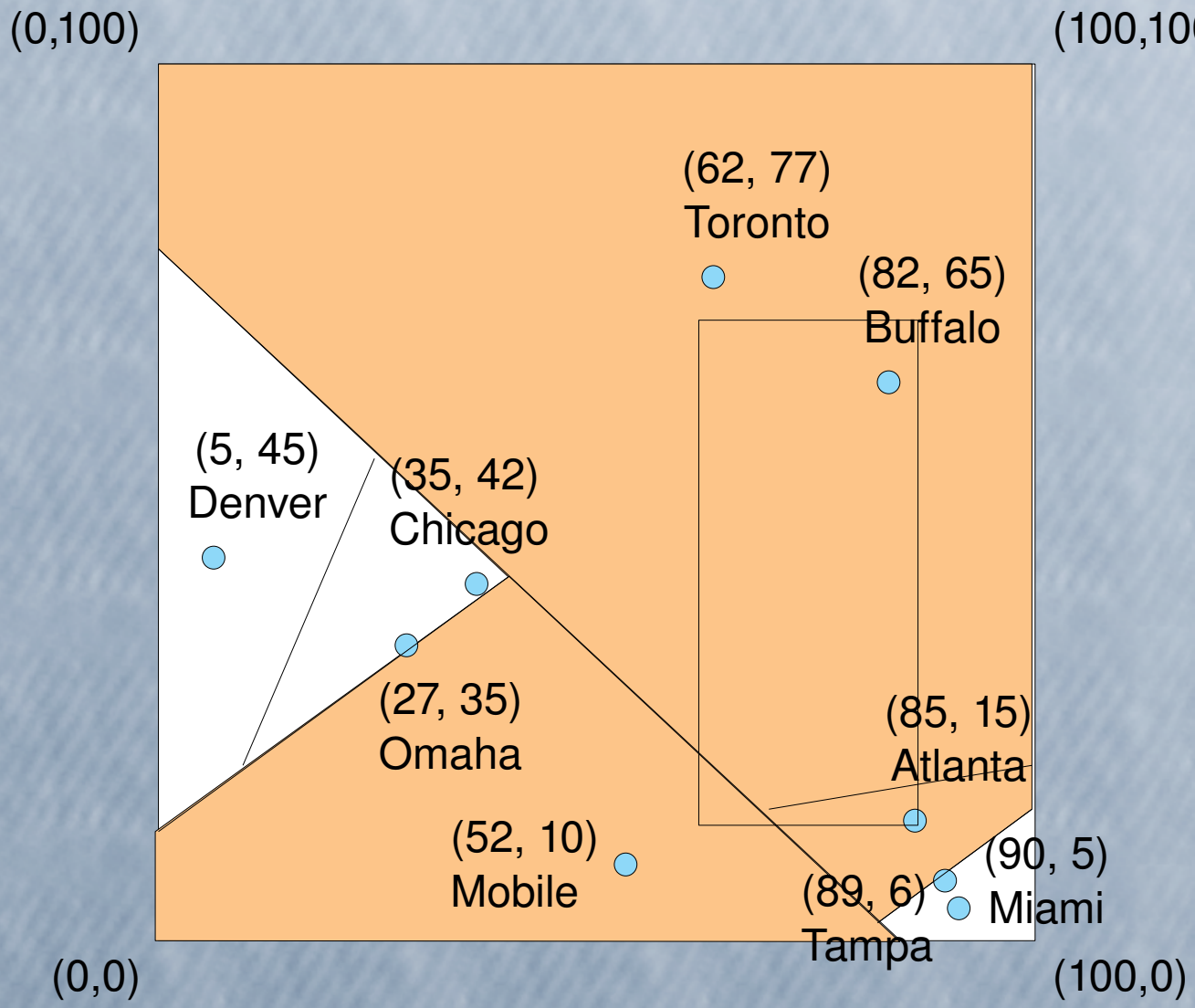
Range Search on BSP Trees



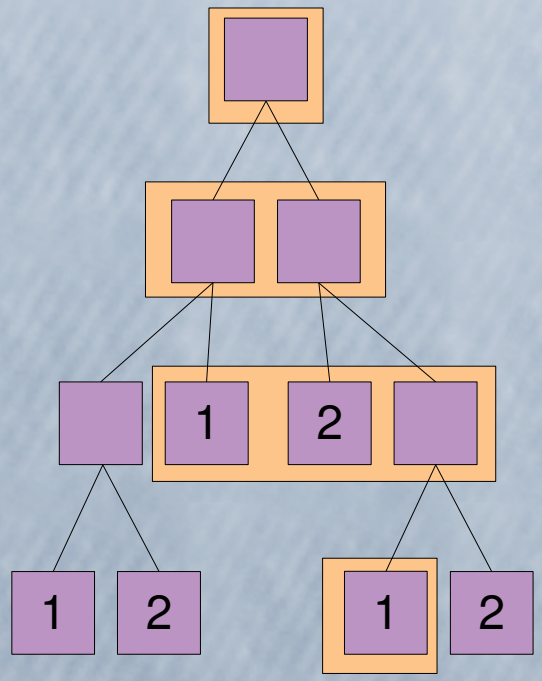
Tree Data Structure



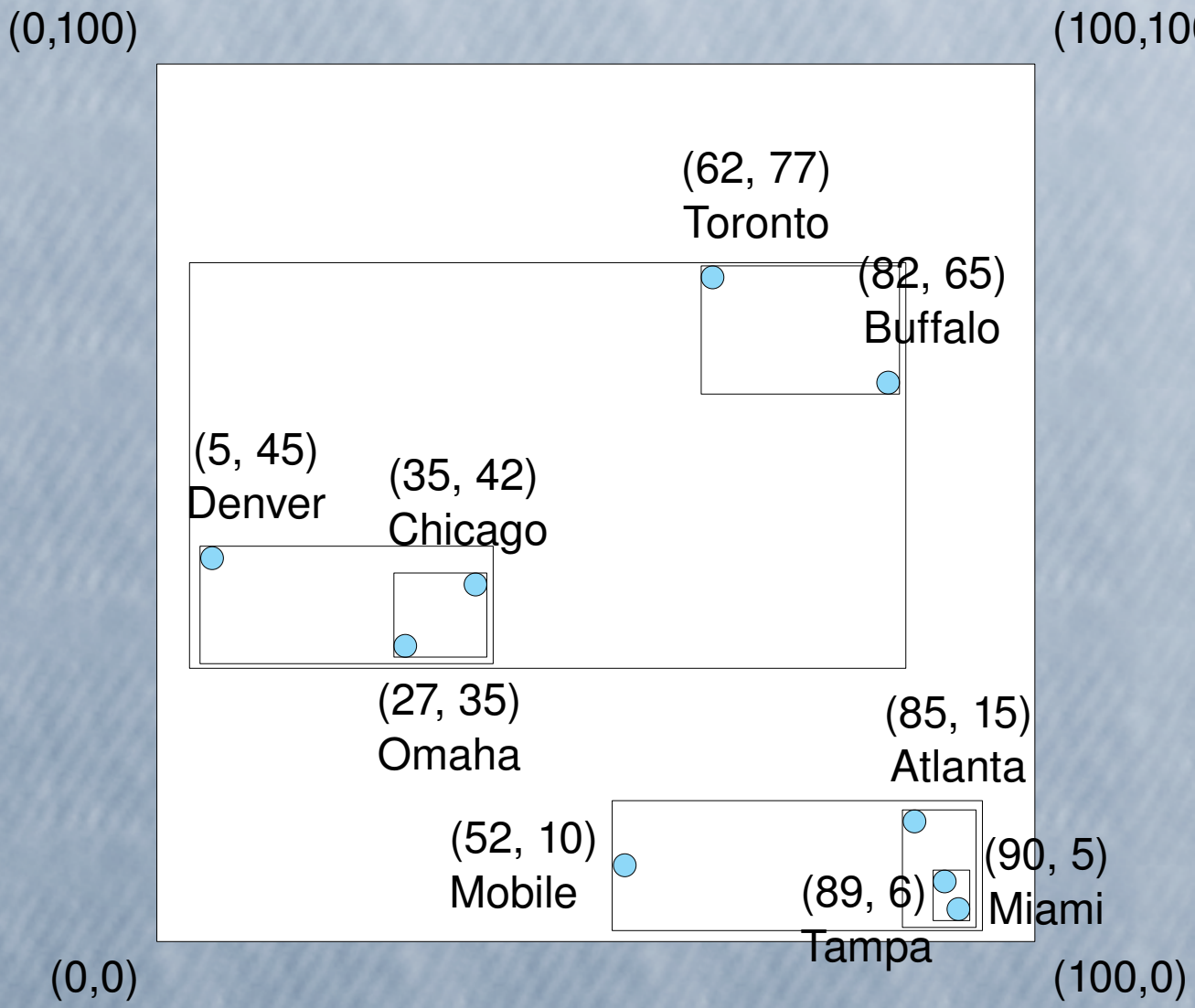
Range Search on BSP Trees



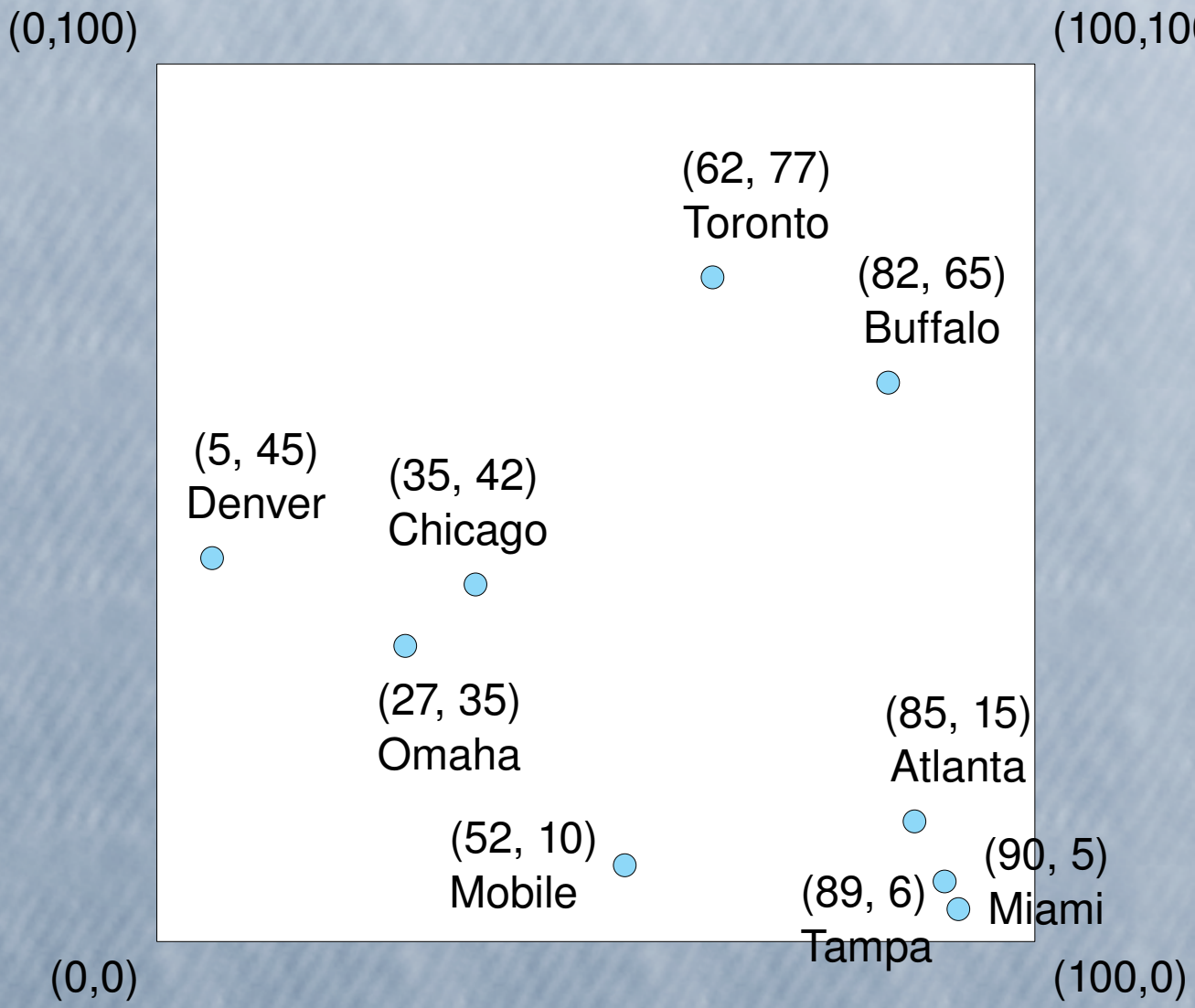
Tree Data Structure



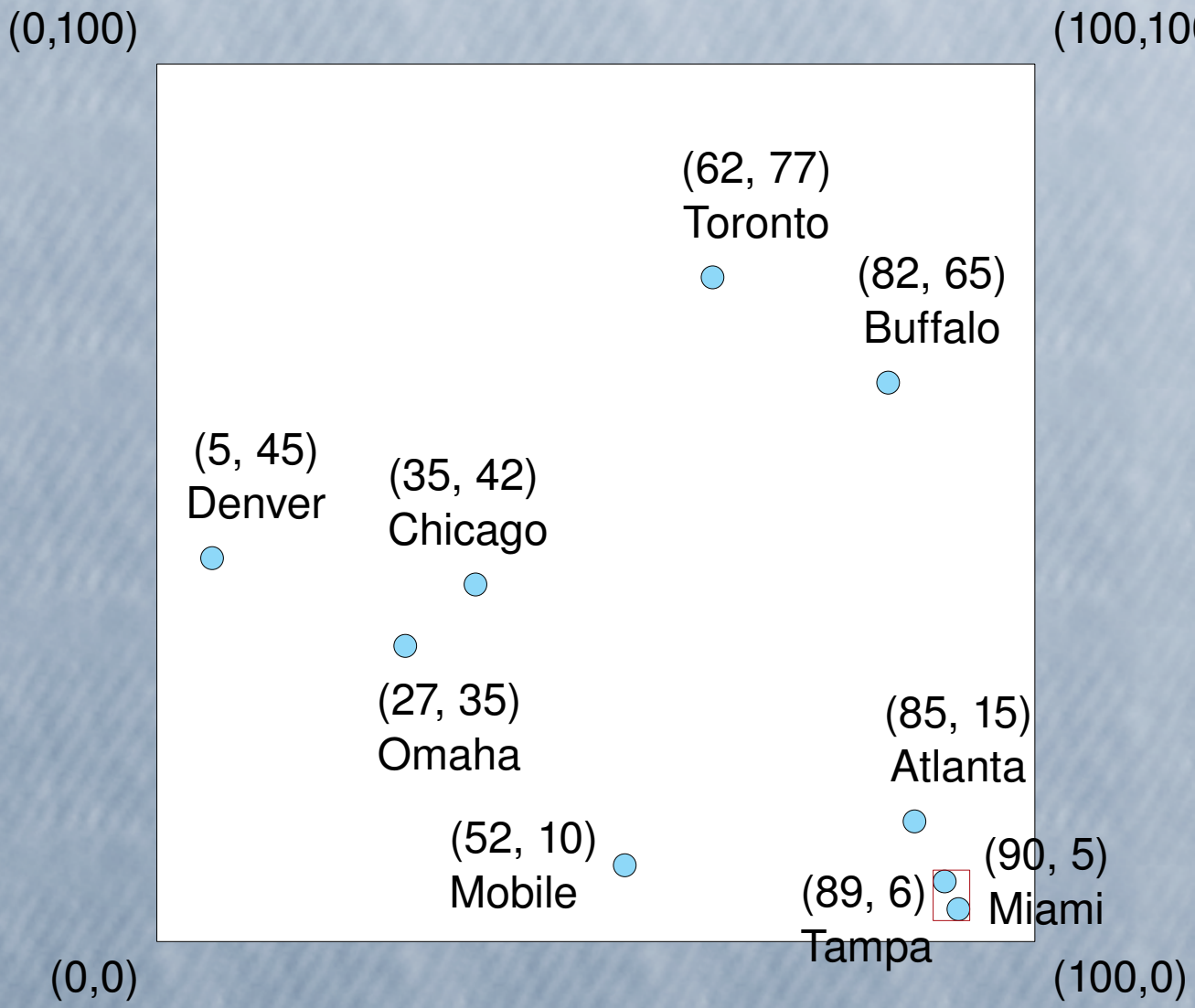
Bounding Volume Hierarchies



Bounding Volume Hierarchies



Bounding Volume Hierarchies



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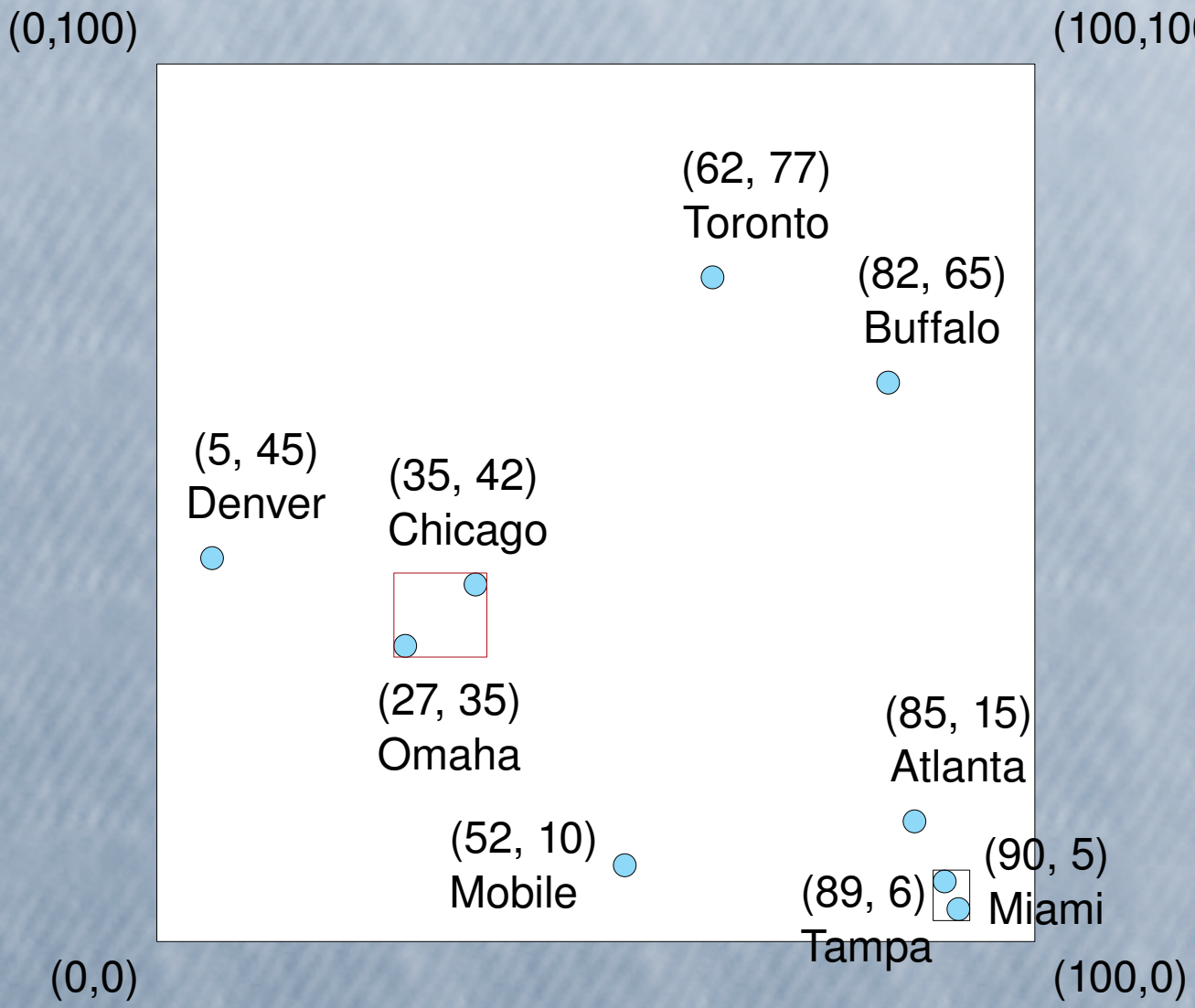

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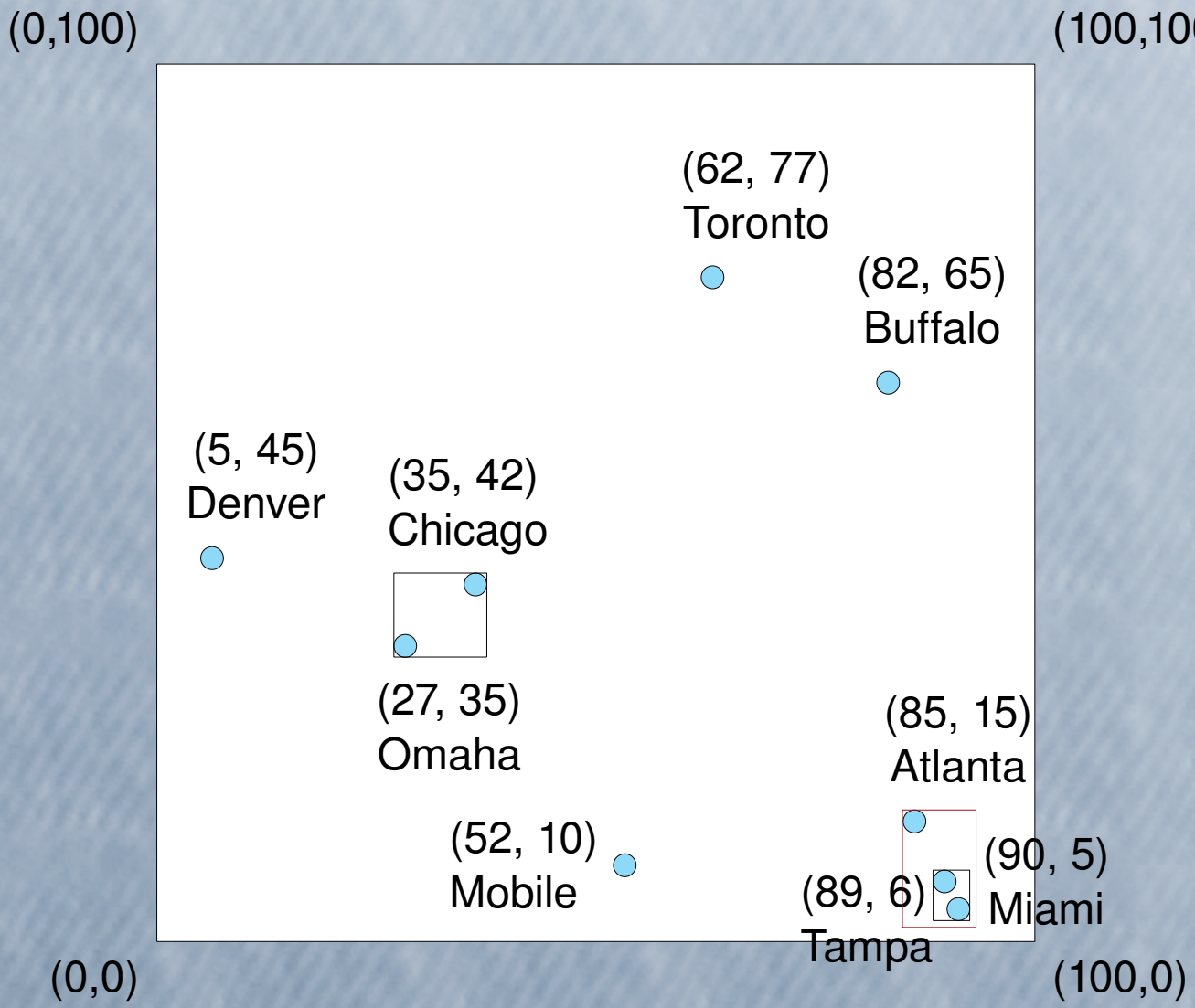

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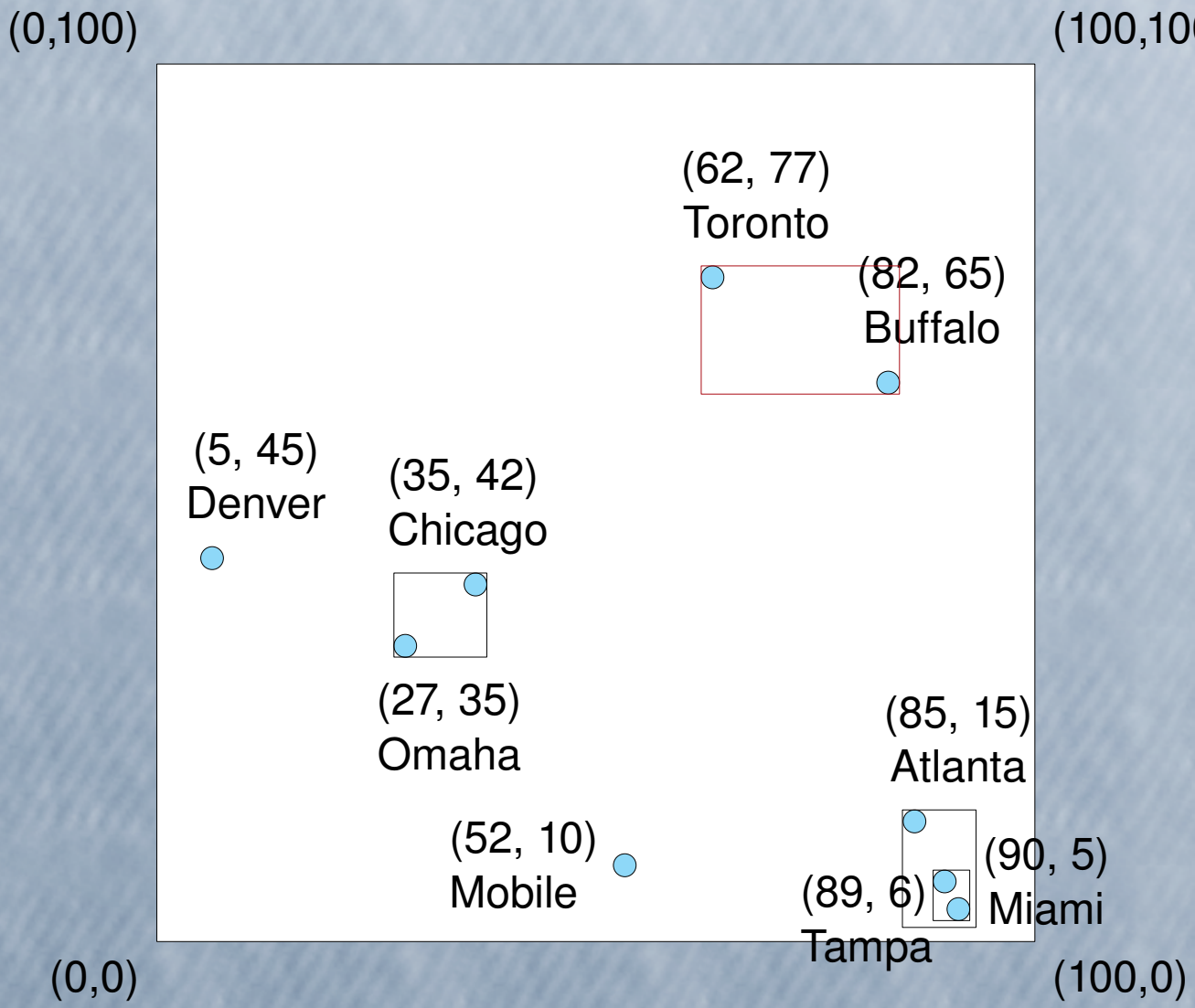

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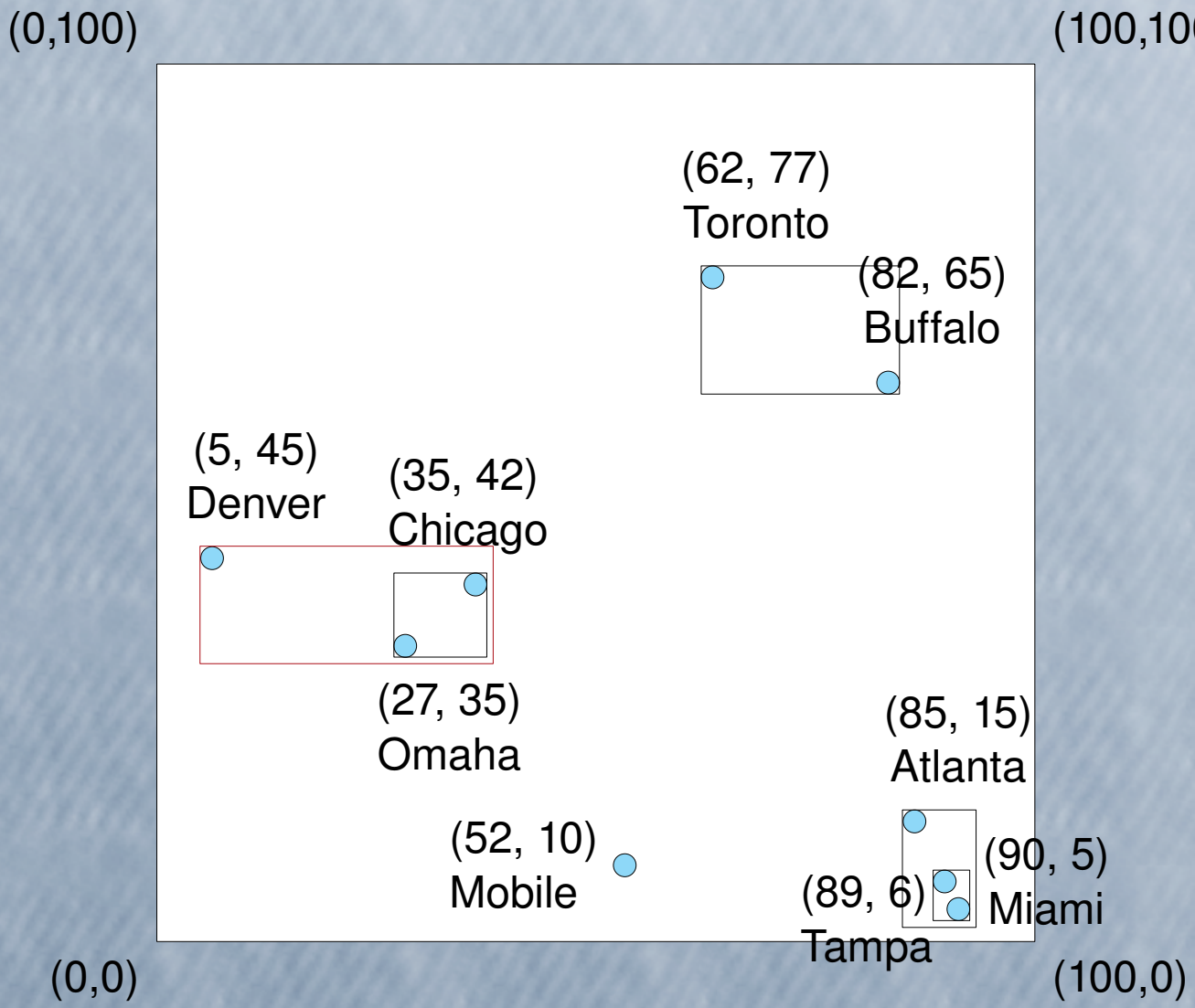

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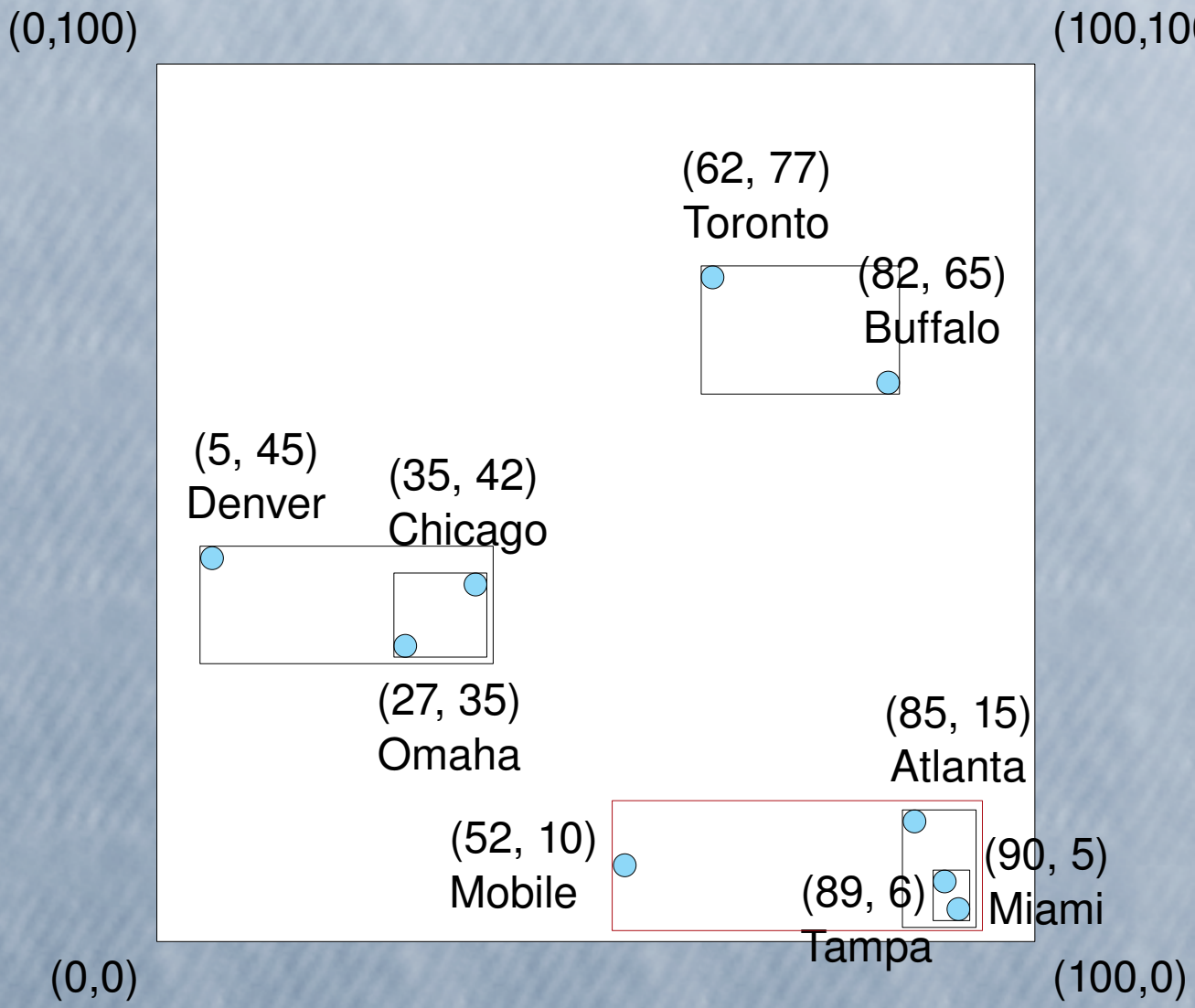
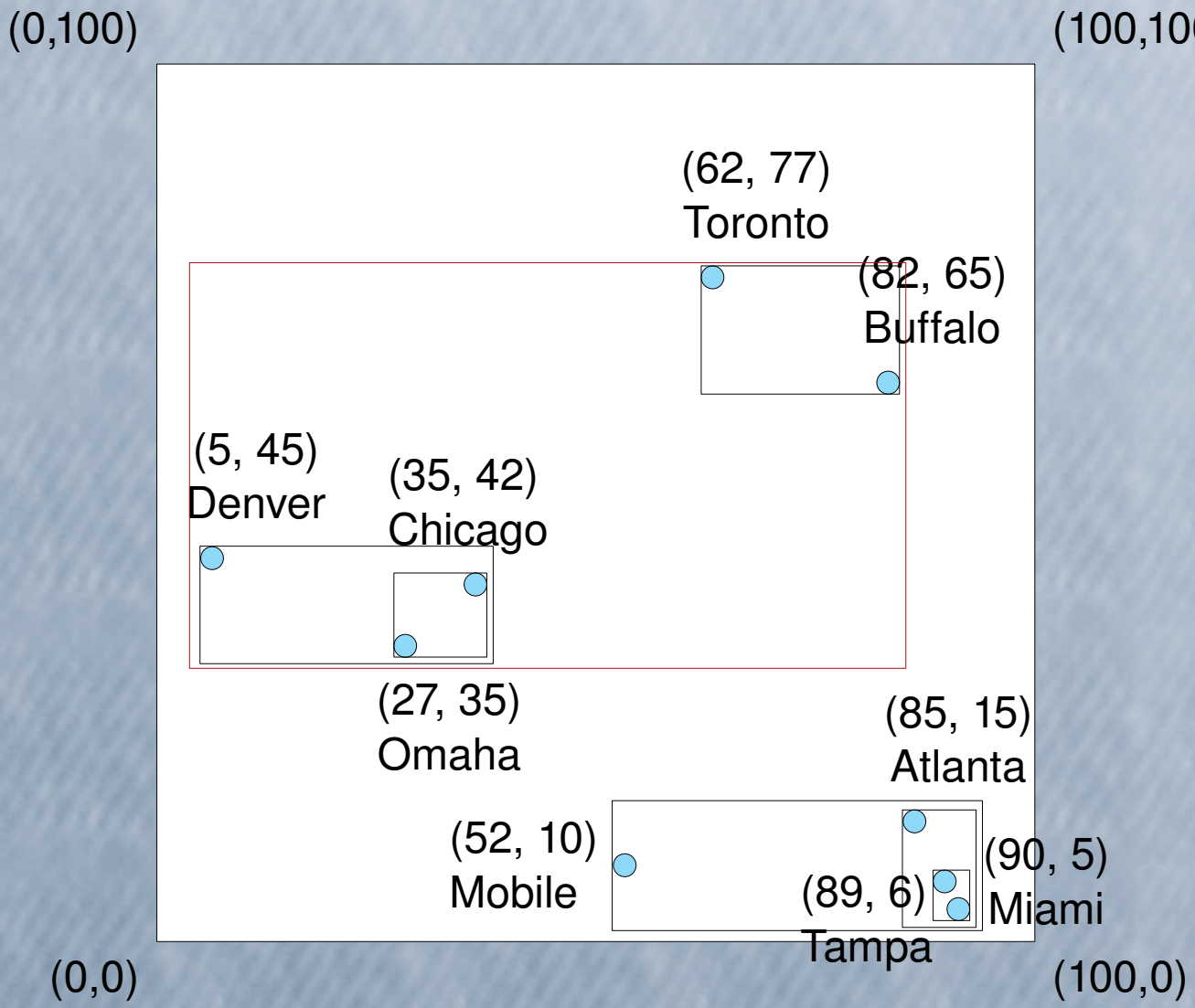
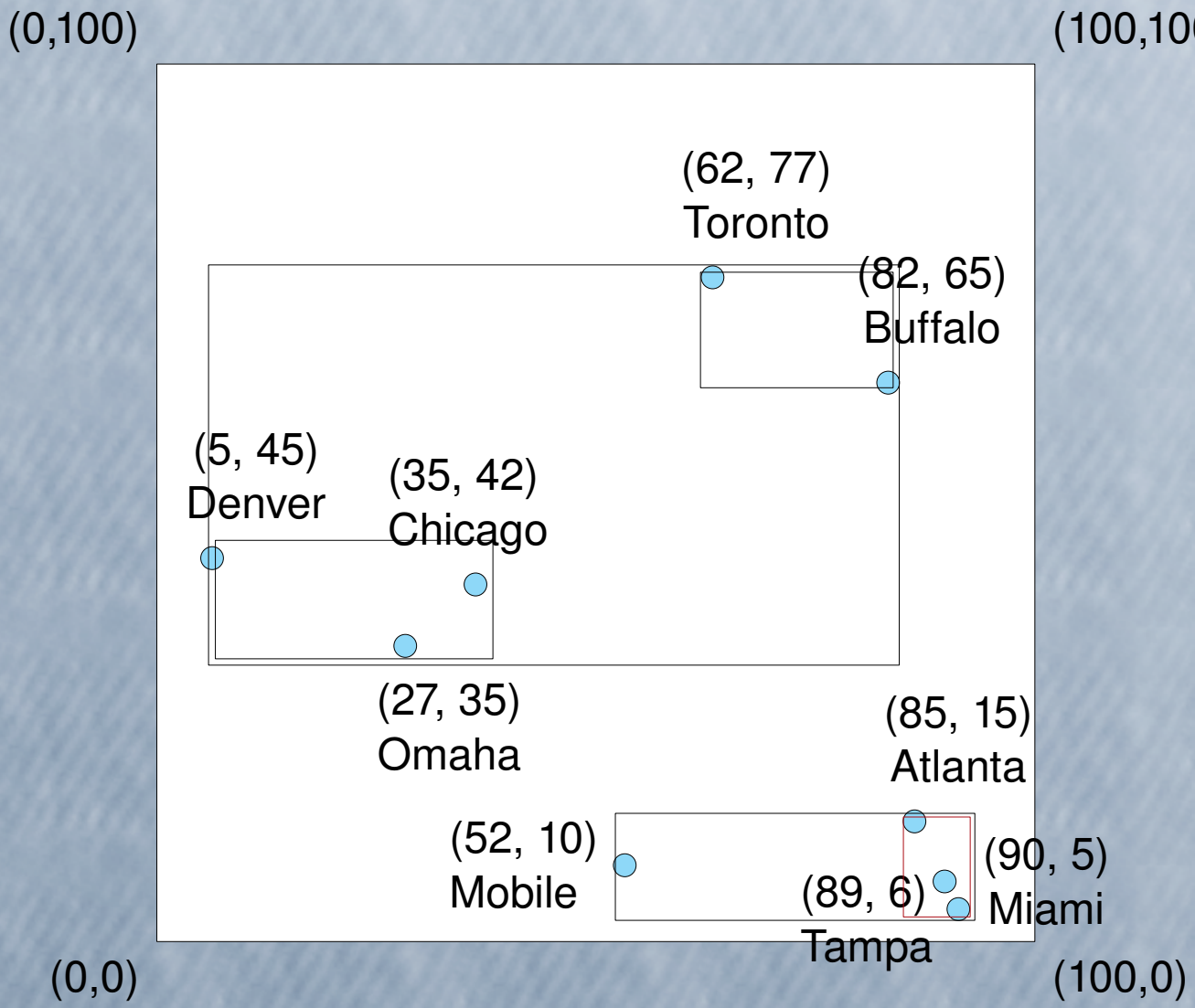


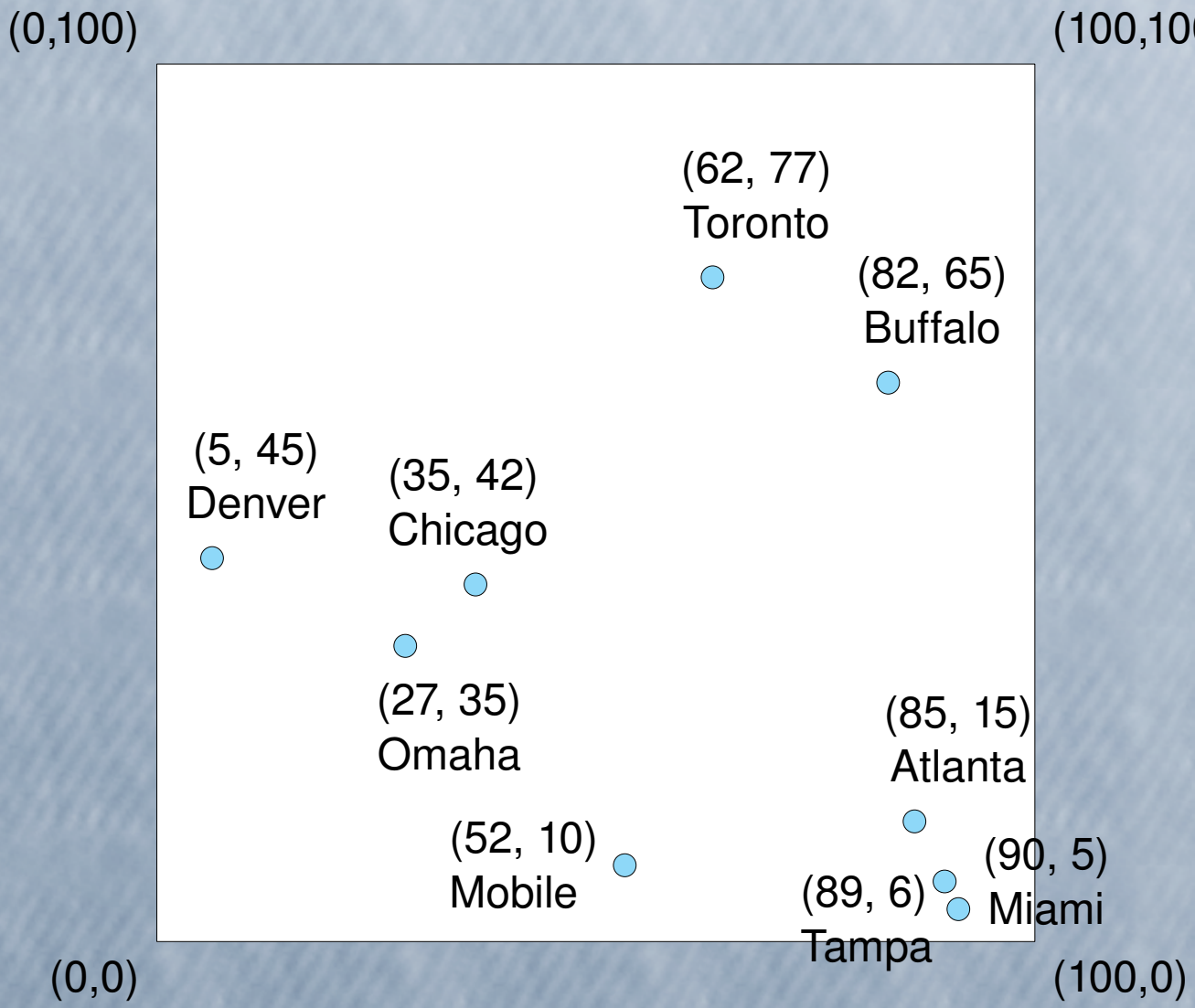
Bounding Volume Hierarchies



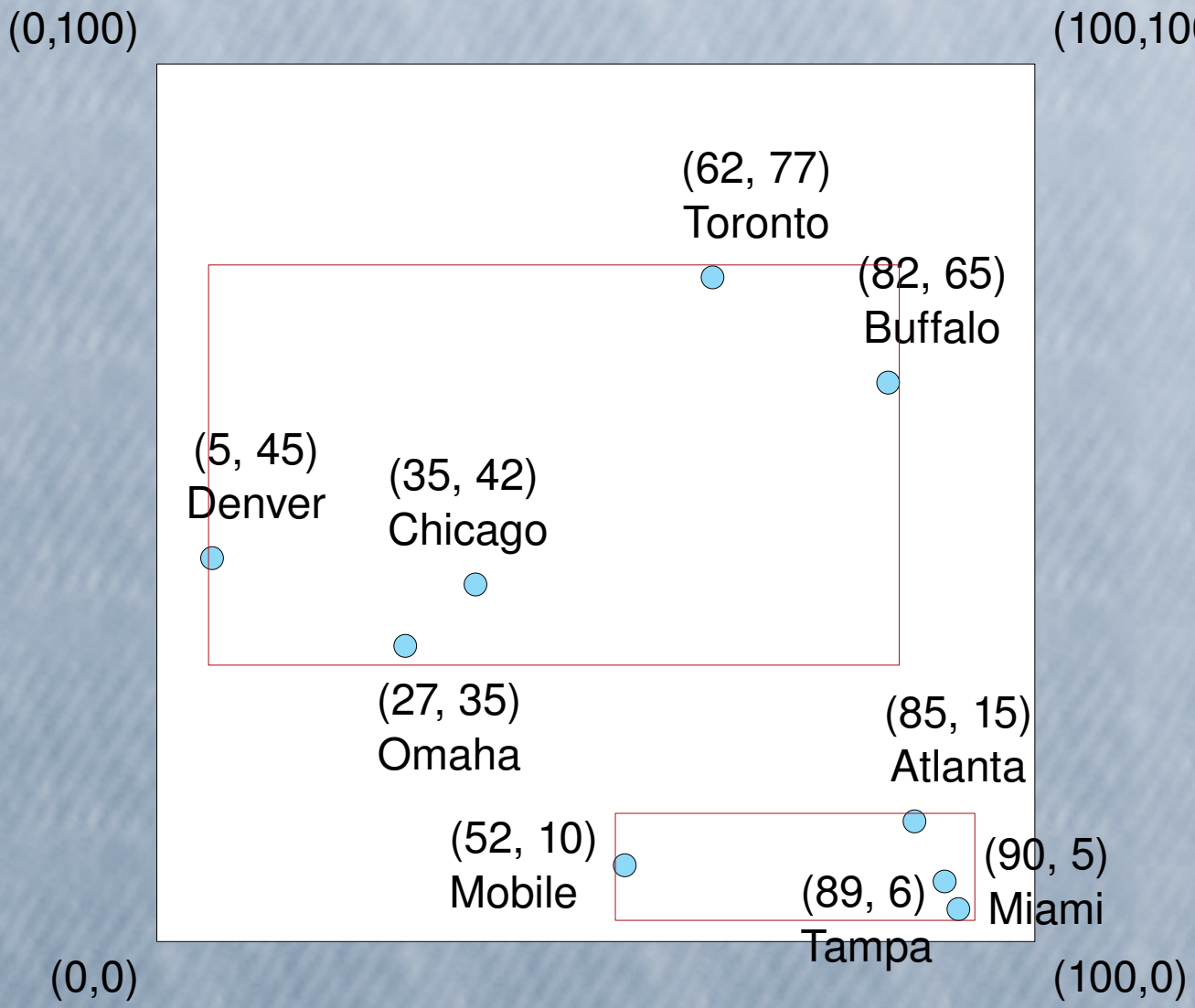
Alternate Build Order



Alternate Build Order



Bounding Volume Hierarchies



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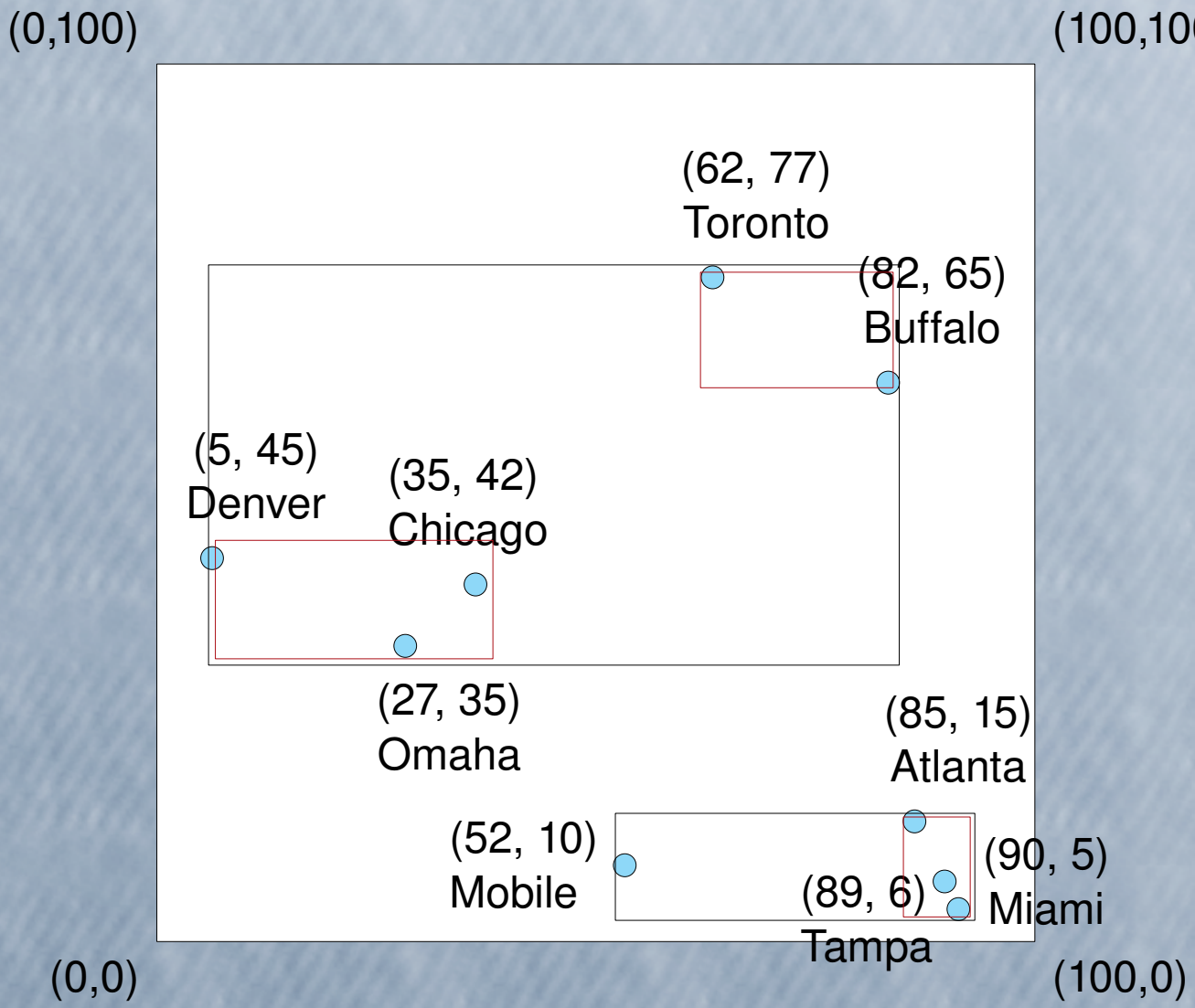
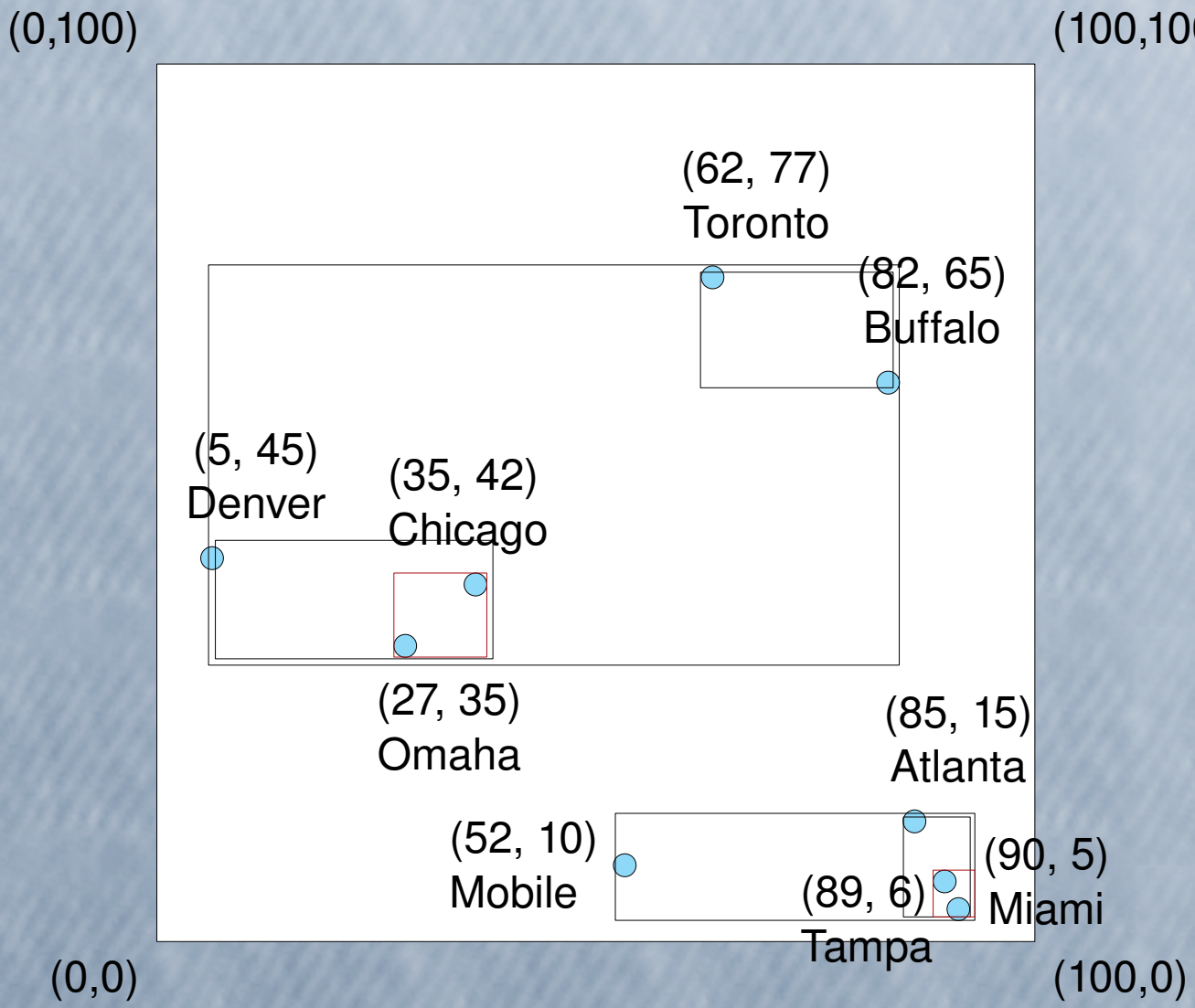


Bounding Volume Hierarchies



Paper Presentation Order?
Week 5-13
Joe, Matt, Ray, Mark, Scott, Cody,
James, Steve, Roger

Spatial Data Structures for Project 1

- Range Tree – Joe and Ray
- Regular / Irregular Grid – Roger and Steve
- Quadtree / Octree – Mark and Scott
- kd-tree / Binary Space Partition (BSP)-Tree – Cody and Matt
- Bounding Volume Hierarchy - James

Next time

- Additional operations on spatial data structures
- Reading – skim research papers
- Select paper to present
- Presentation on UnitTest++
- Meeting time changed: 4:00-6:45 SEM 257