

Algorithms and Analysis

Lesson 3: *Declare your intentions (not your actions)*



ADTs, stacks, queues, priority queues, sets, maps

Outline

1. Abstract Data Types (ADTs)
2. Stacks
3. Queues and Priority Queues
4. Lists, Sets and Maps
5. Putting it Together



Object Oriented Programming

- OO-programming allows you to build large systems reliably
- In the OO-methodology you separate the interface from the implementation
- The **interface** is the public methods (functions) of a class
- The implementation is hidden (**encapsulated**) and may be changed without affecting how the class is used
- There exist other ways of programming, but C++ is designed to support the OO-methodology

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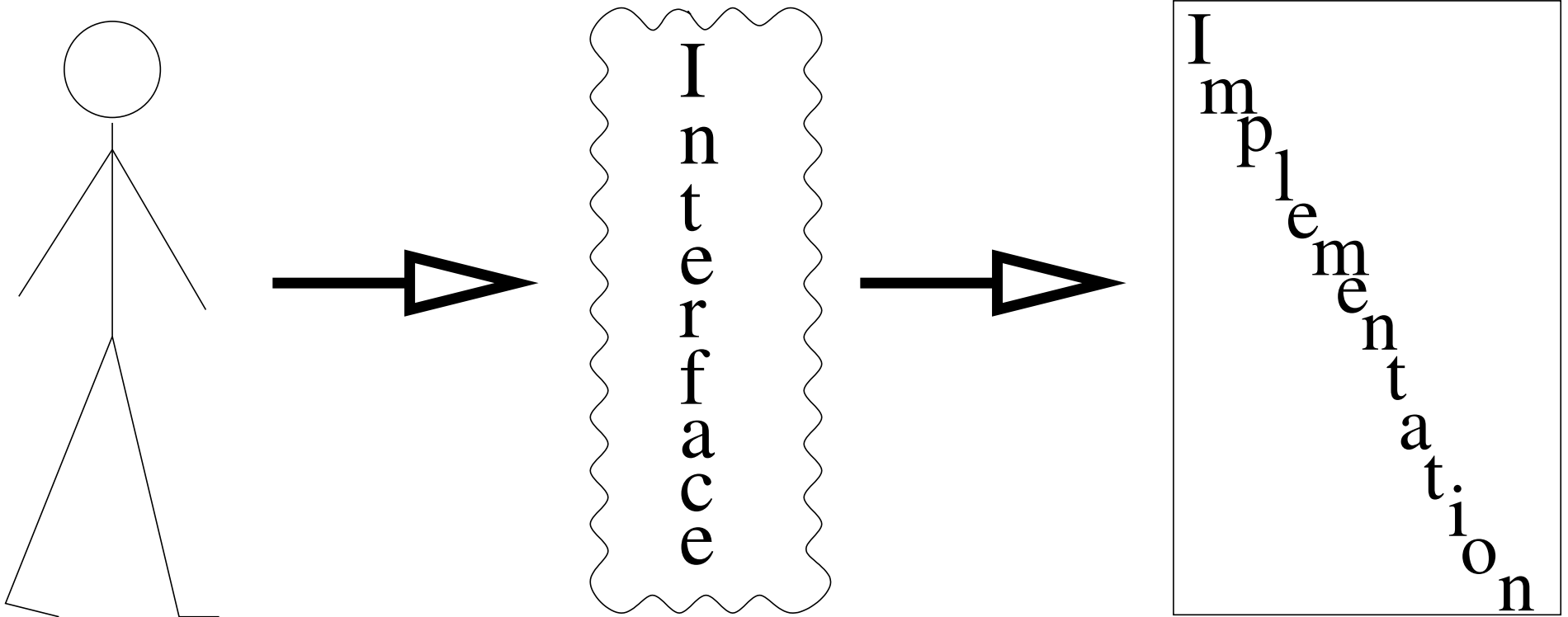
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Object-Oriented Classes



Abstract Data Types

- With data structures there are some traditional interfaces called **Abstract Data Types** or ADTs
- These are implementation free data structures
- They are mathematical abstractions of the data structure
- Their purpose is to allow you to declare your intentions
- You are entering into an agreement that you only intend to use the underlying data structure in the way specified by the interface

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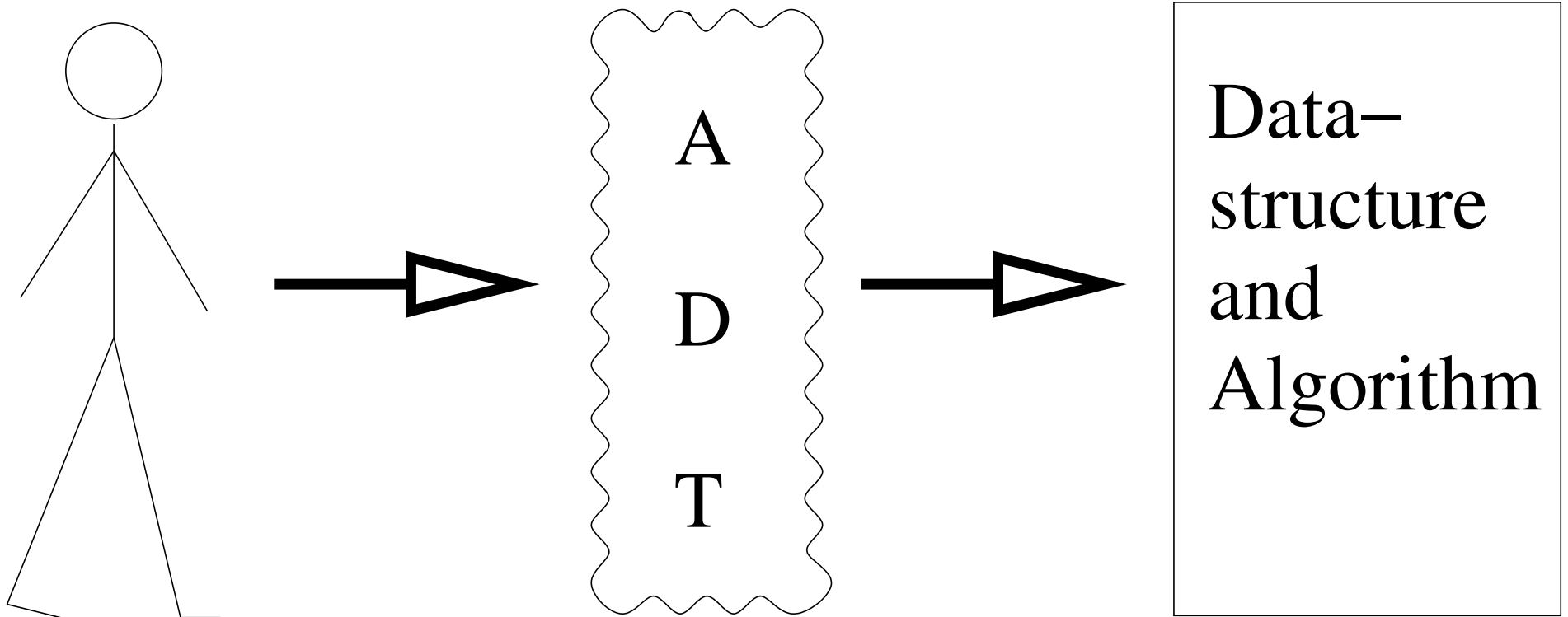
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ADTs



Say it with an ADT

- Common ADTs include stacks, queues, priority queues, sets, multisets and maps
- There are many possible implementations of these ADTs (some far from obvious)
- Each ADT has a limited set of methods associated with it
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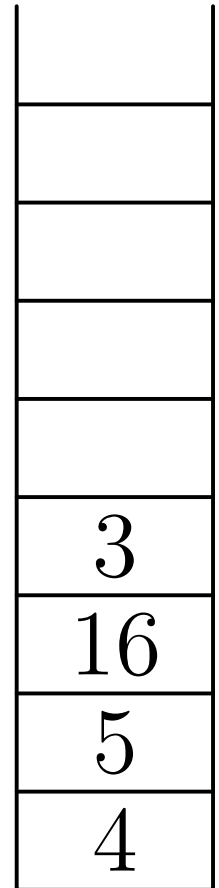
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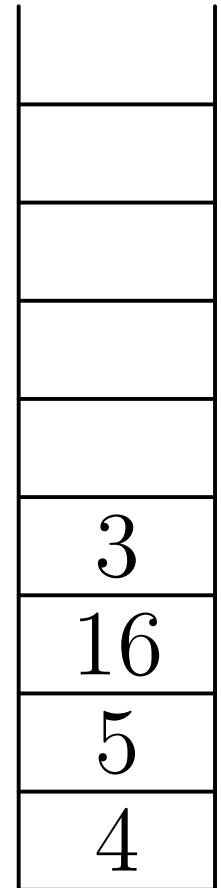
Stacks

- Last In First Out (LIFO) memory



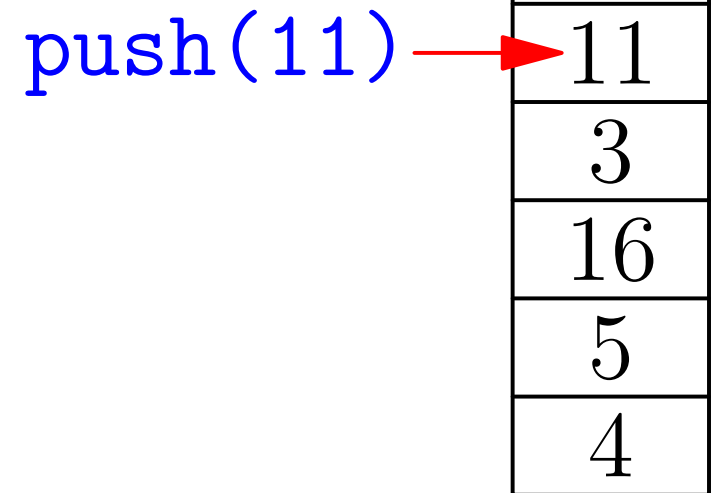
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 - ★ `push(item)`



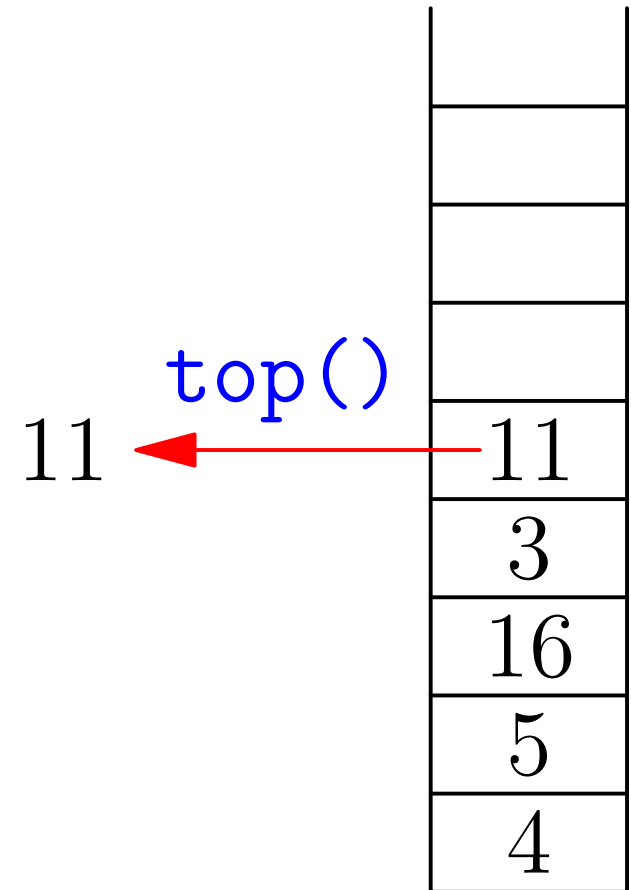
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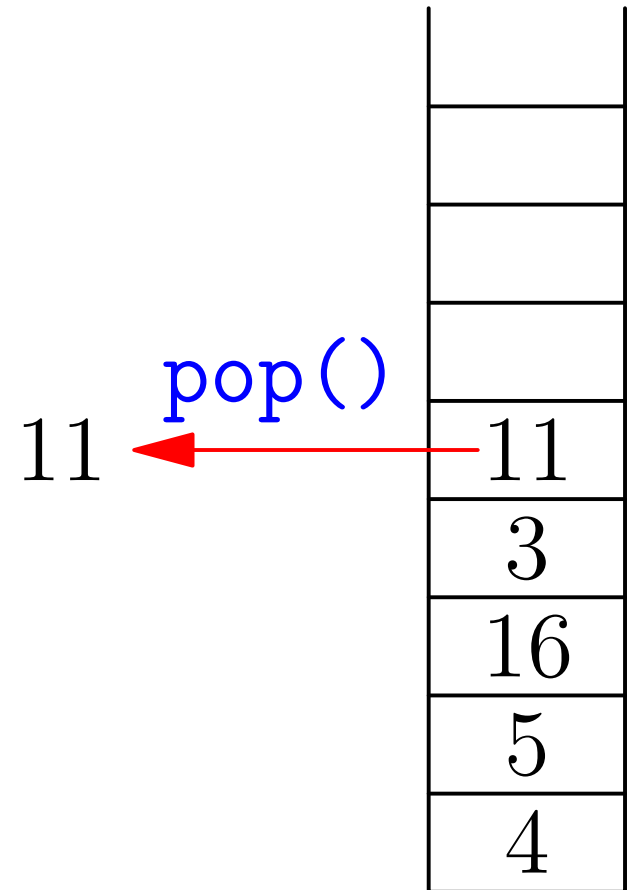
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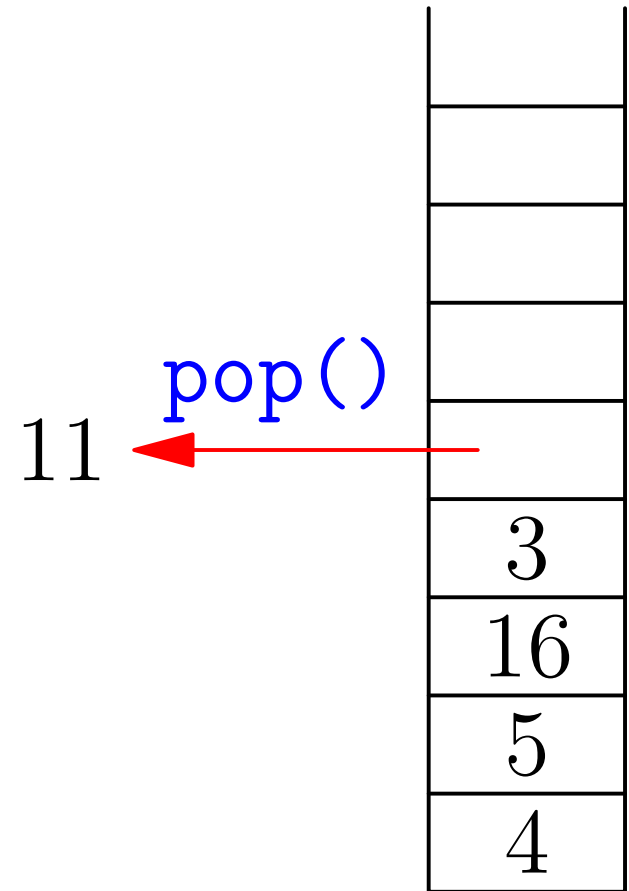
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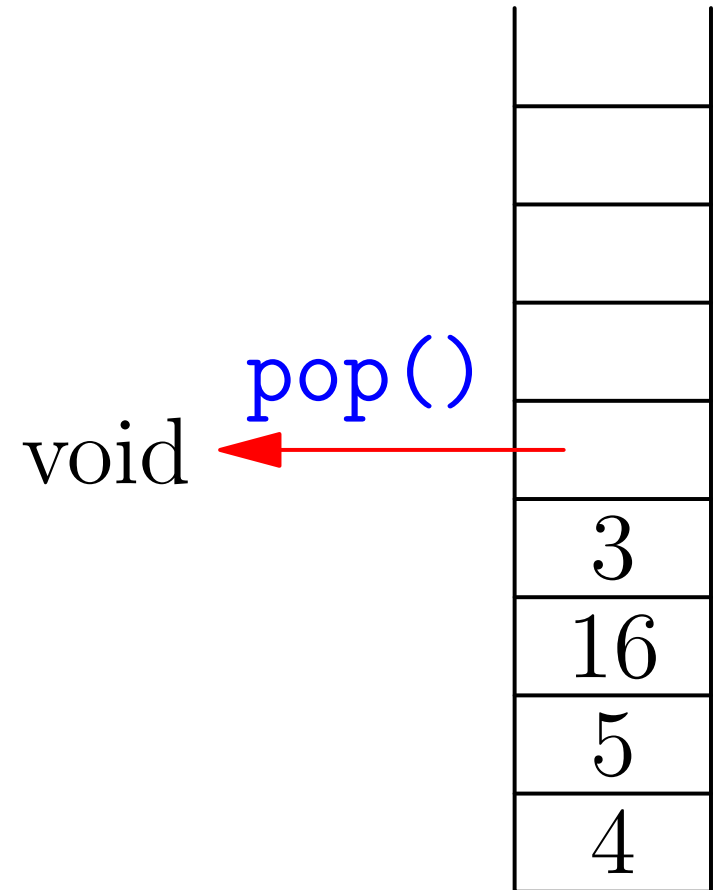
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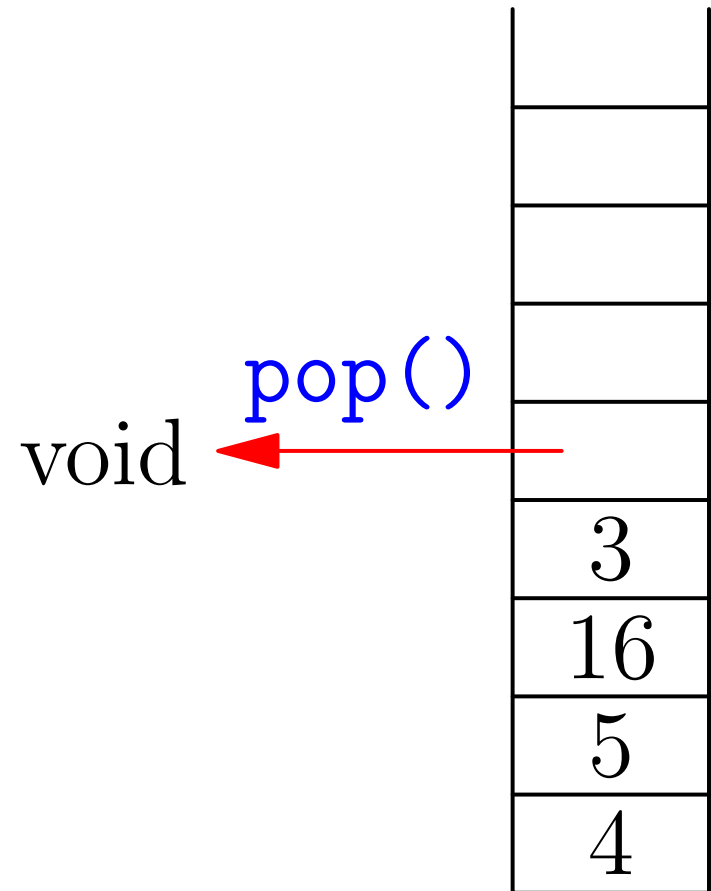
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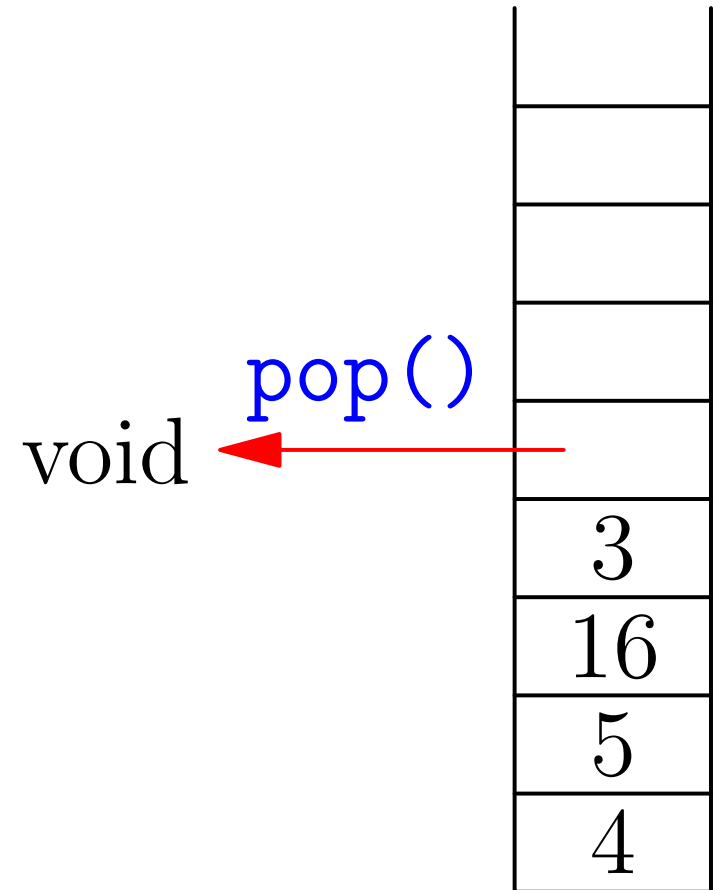
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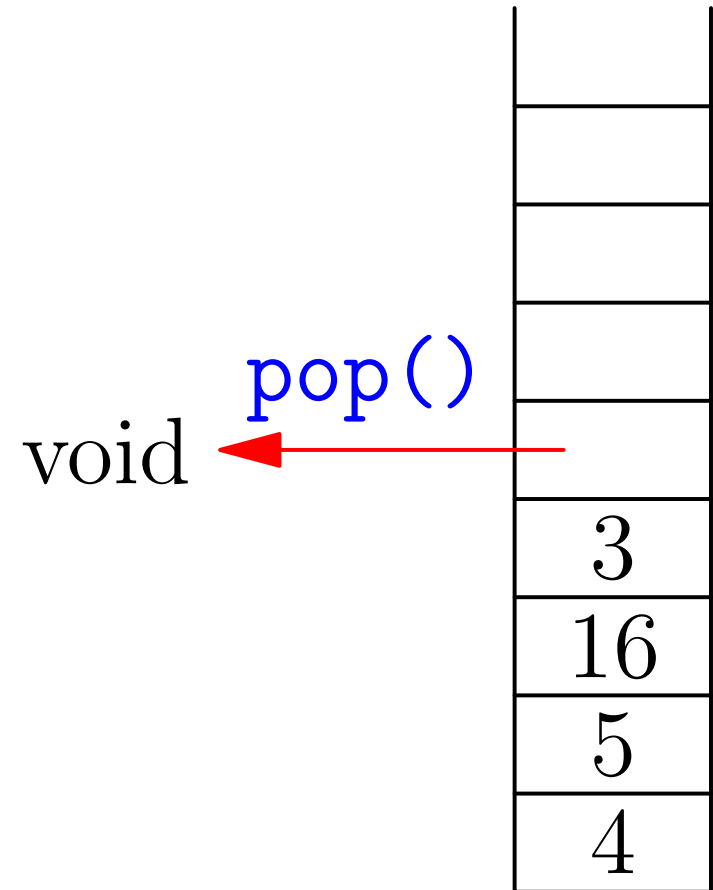
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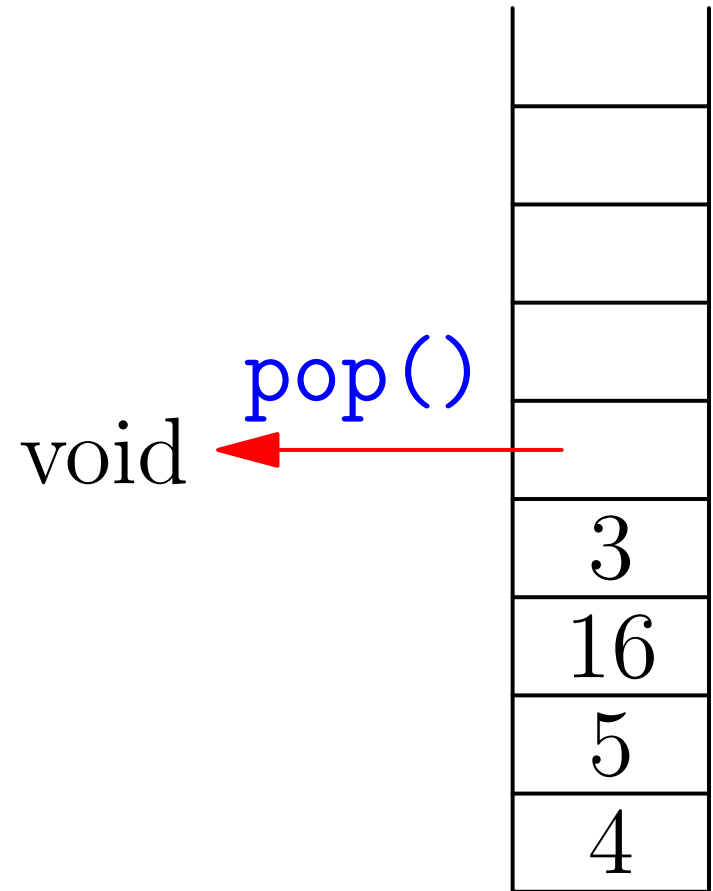
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- Stacks reduces the access to memory—no longer random access
- Seems counter intuitive to reduce what you can do
- Gives you a very simple interface
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- Sufficient for large number of algorithms

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Uses of Stacks

- Reversing an array
- Parsing expression for compilers
 - ★ balancing parentheses
 - ★ matching XML tags
 - ★ evaluating arithmetic expression
- Clustering algorithm

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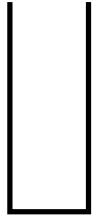
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Evaluating Arithmetic Expressions

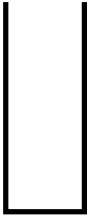
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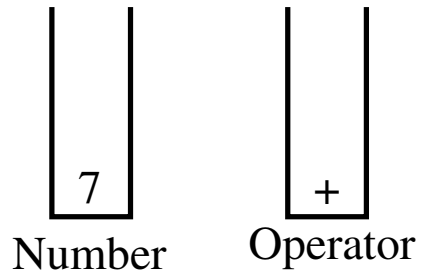
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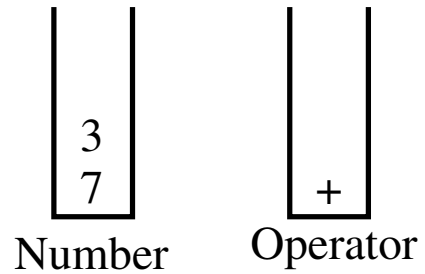
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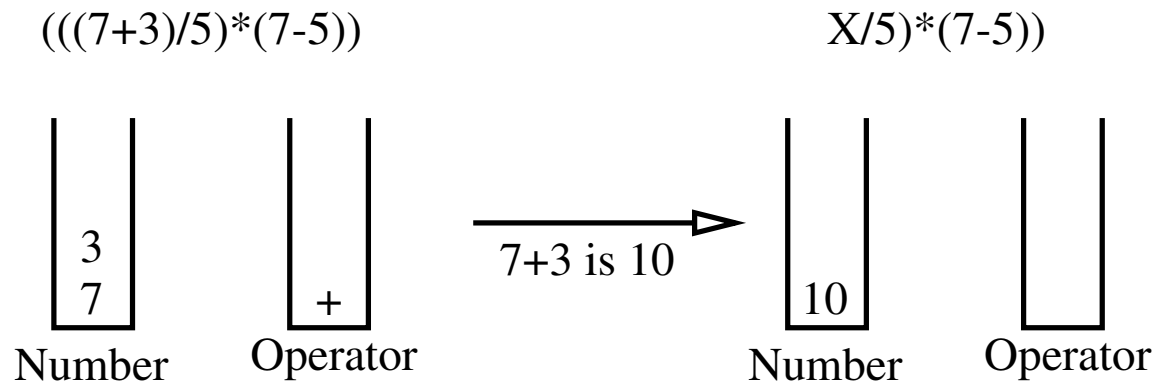


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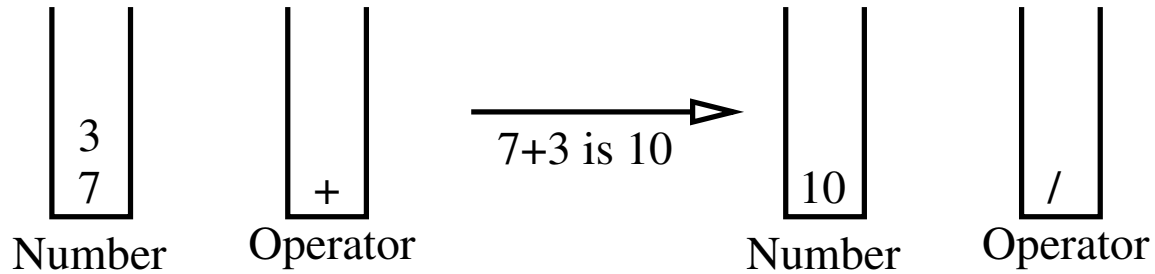
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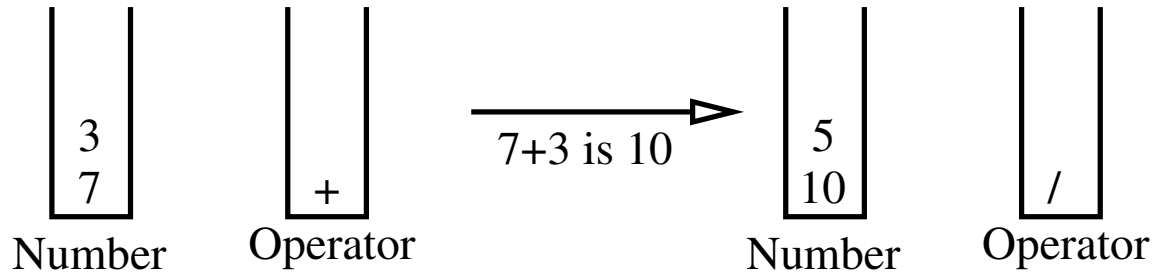
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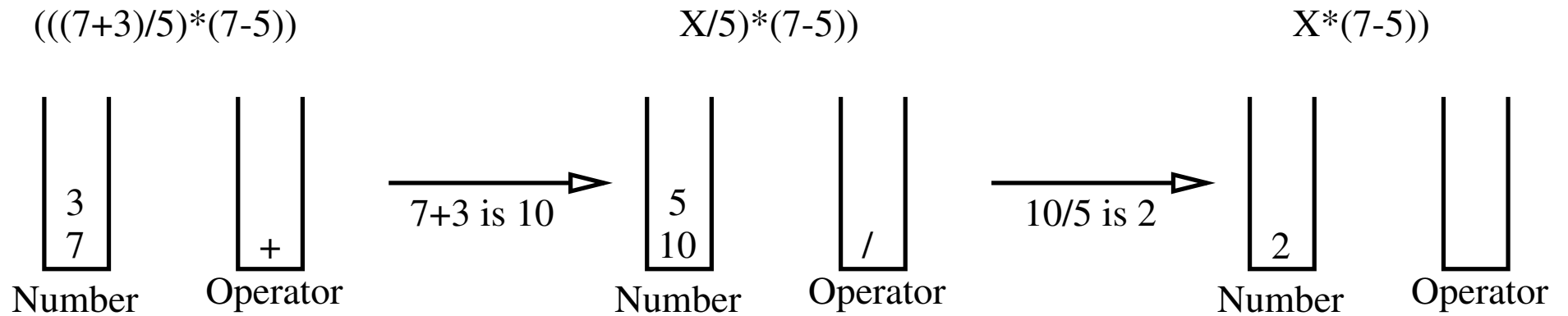
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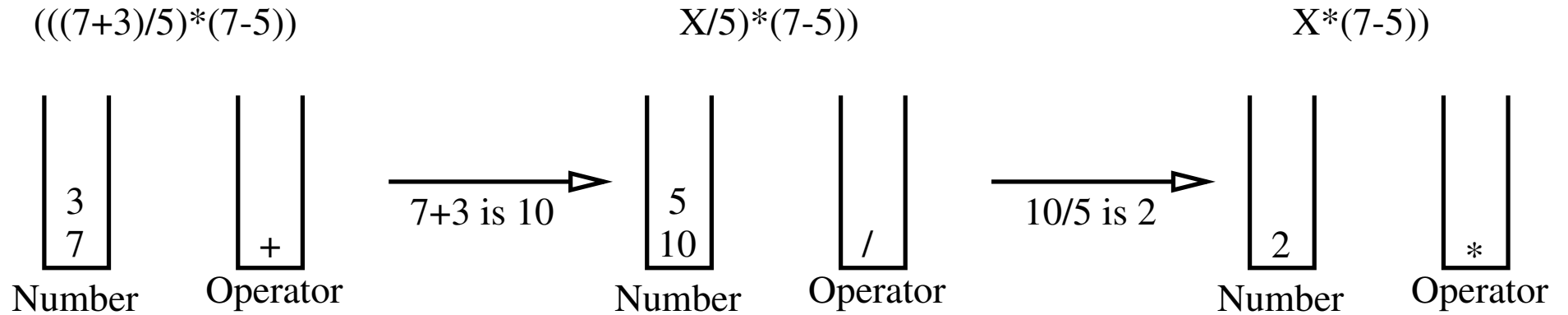
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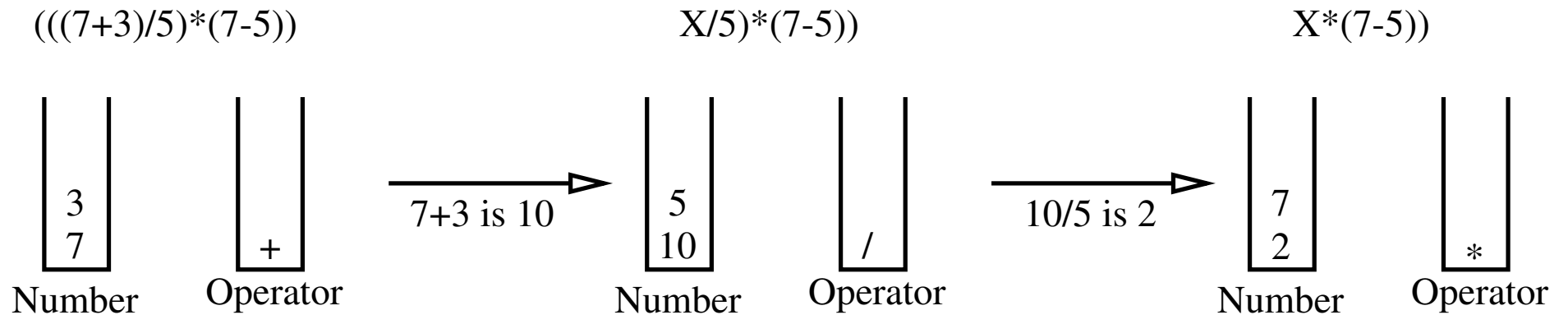
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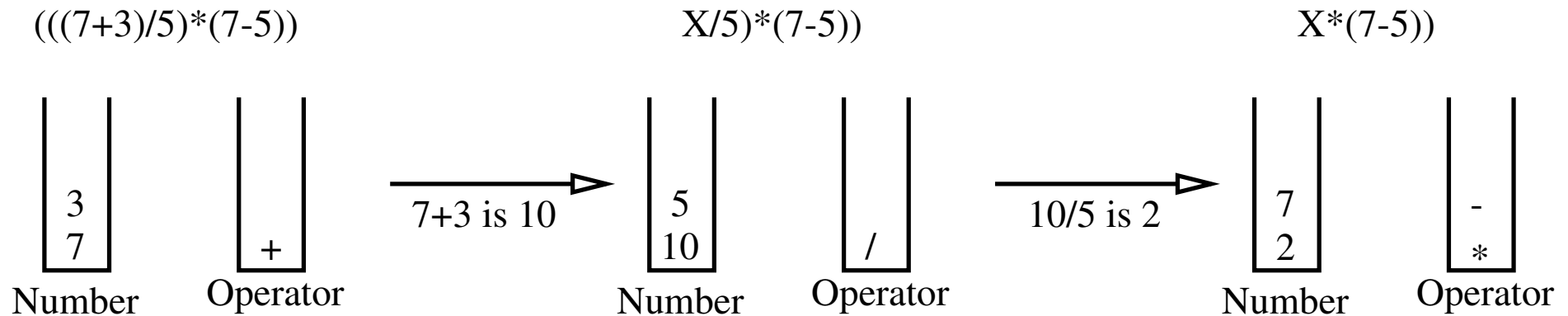
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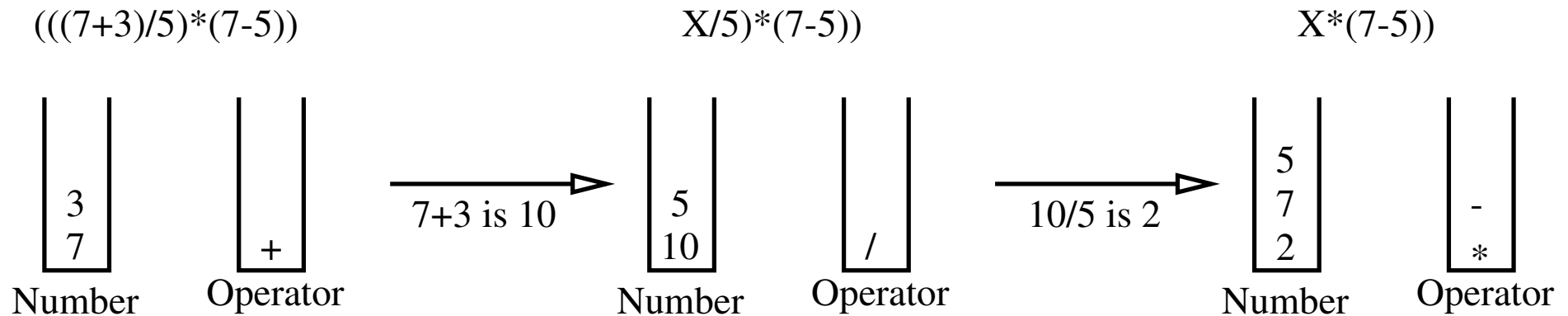
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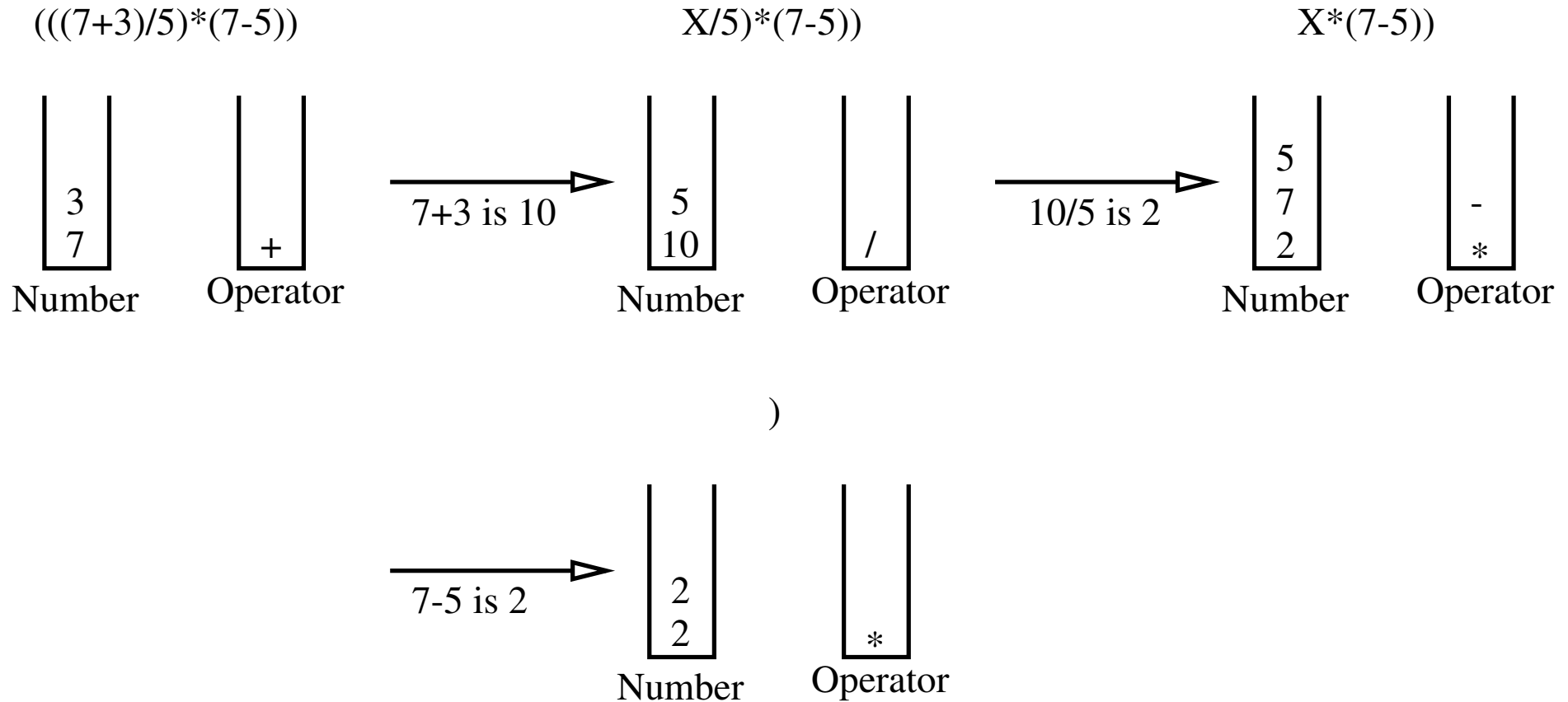
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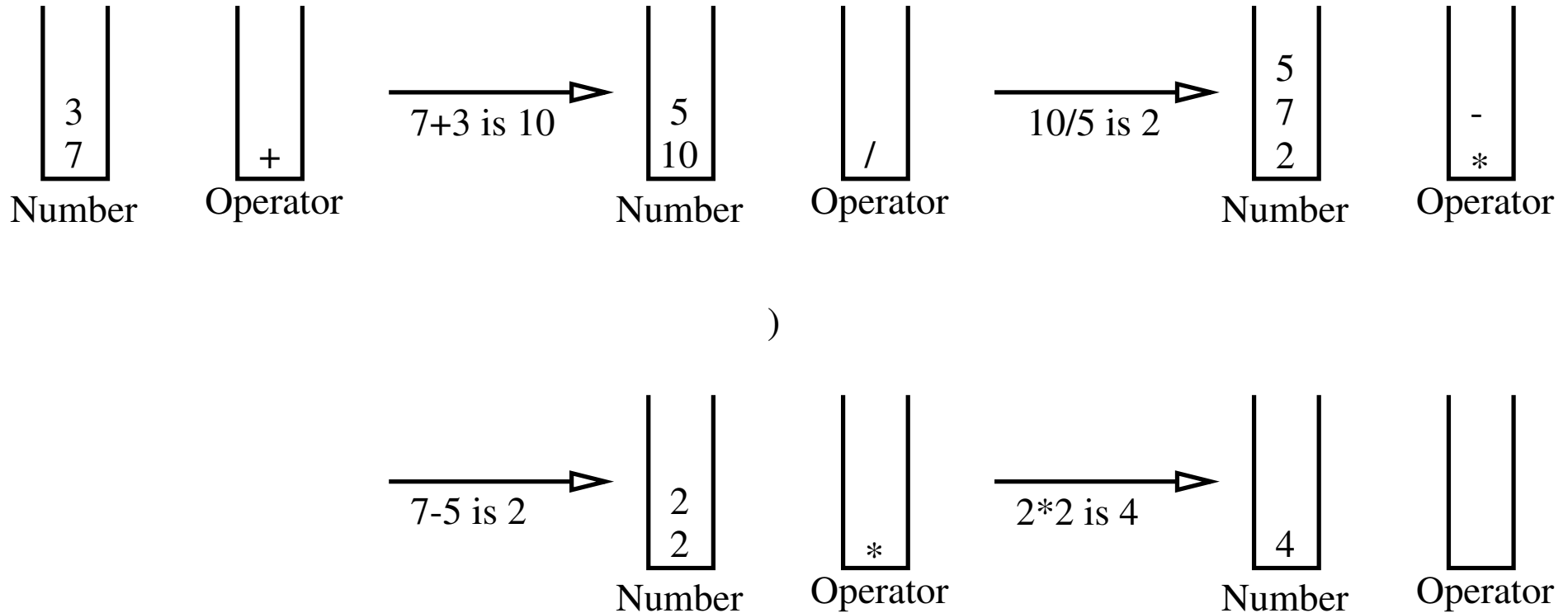


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Queues

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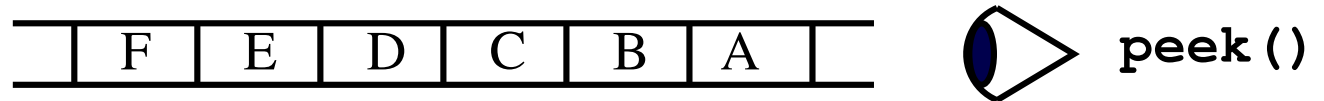
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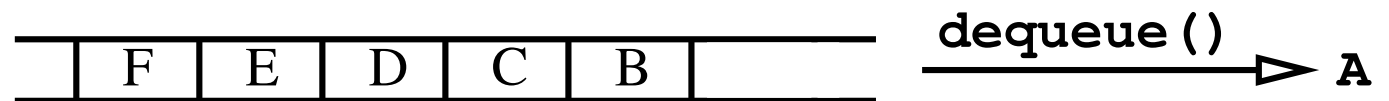
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Queues

- First-in-first-out (FIFO) memory model
- `enqueue(elem)`
- `peek()`
- `dequeue()`
- C++ has a double ended queue (`deque`) with `push_front()`, `push_back()`, etc.



Uses of Queues

- Queues are heavily used in multi-threaded applications (e.g. operating systems)
- Multi-threaded applications need to minimise waiting and ensure the integrity of the data structure (for instance when an exception is thrown)
- Because of this they are more complicated than most data structures
- They can be implemented using linked-lists or circular arrays

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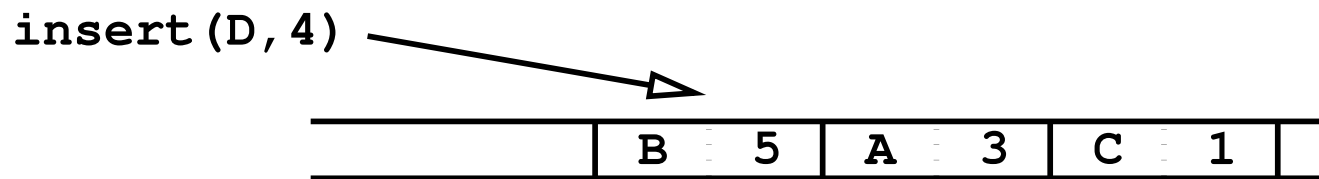
Priority Queues

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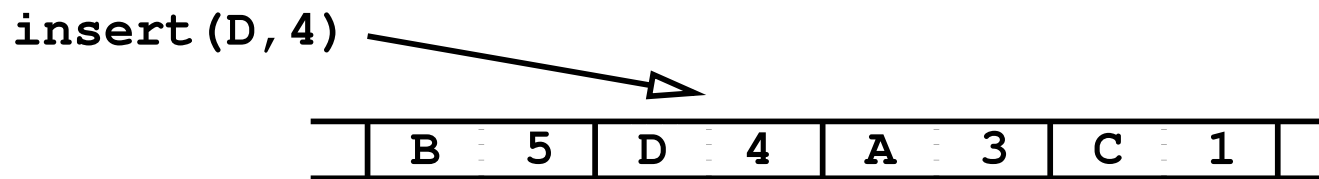
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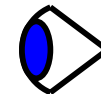
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- `findMin()` (in C++ `top()`)

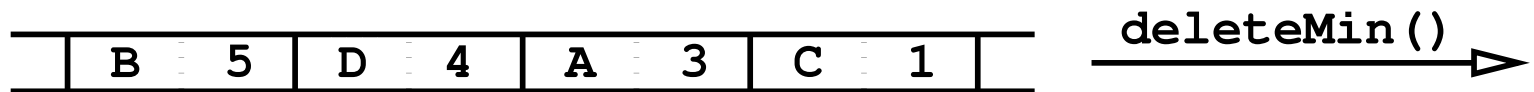
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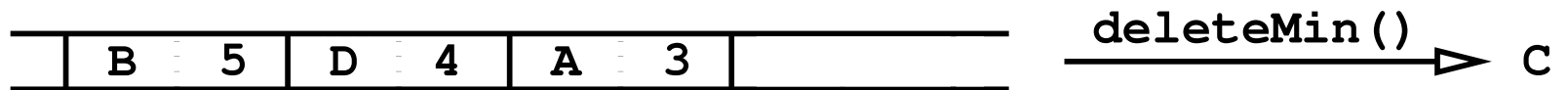
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- Real time simulation
- Often used in “greedy algorithms”
 - ★ Huffman encoding
 - ★ Prim’s minimum spanning tree algorithm

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Implementation of Priority Queue

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- Most efficient implementation uses a heap
- A heap is a binary tree implemented using an array

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- In C++ the standard list is known as `vector<T>`
- That is, it is a collection where the order in which you put items into the list matters
- You can have repetitions of elements
- It has random access, e.g. `v[i]`
- You can `push_back(i)`, `insert`, `erase`, etc.
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- Models mathematical sets
- Container with no ordering or repetitions
- Methods include `insert`, `find`, `size`, `erase`
- Provides fast search (`find`)
- This is the class to use when you have to rapidly find whether an object is in the set or not

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Iterators

- Wish to act on all members of the set
- Performed using an `iterator`
- Iterators are used by many collections
- In C++ iterators follow the pointer convention

```
set<string> words;
```

```
words.insert("hello");
```

```
words.insert("world");
```

```
for(auto iter = words.begin(); iter != words.end(); ++iter) {  
    cout << *iter << endl;  
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Implementation of Sets

- Sets are very important and there are many implementations depending on their usage
- Two common implementations of sets are
 - ★ hash tables: `unordered_set<T>`
 - ★ binary trees: `set<T>`
- Which is most efficient depends on the application
- Binary trees allow you to iterate in order
- `multiset<T>` are sets with repetition

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Maps

- A map provides a content addressable memory for pairs *key: value*
- It provides fast access to the *value* through the *key*
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Maps

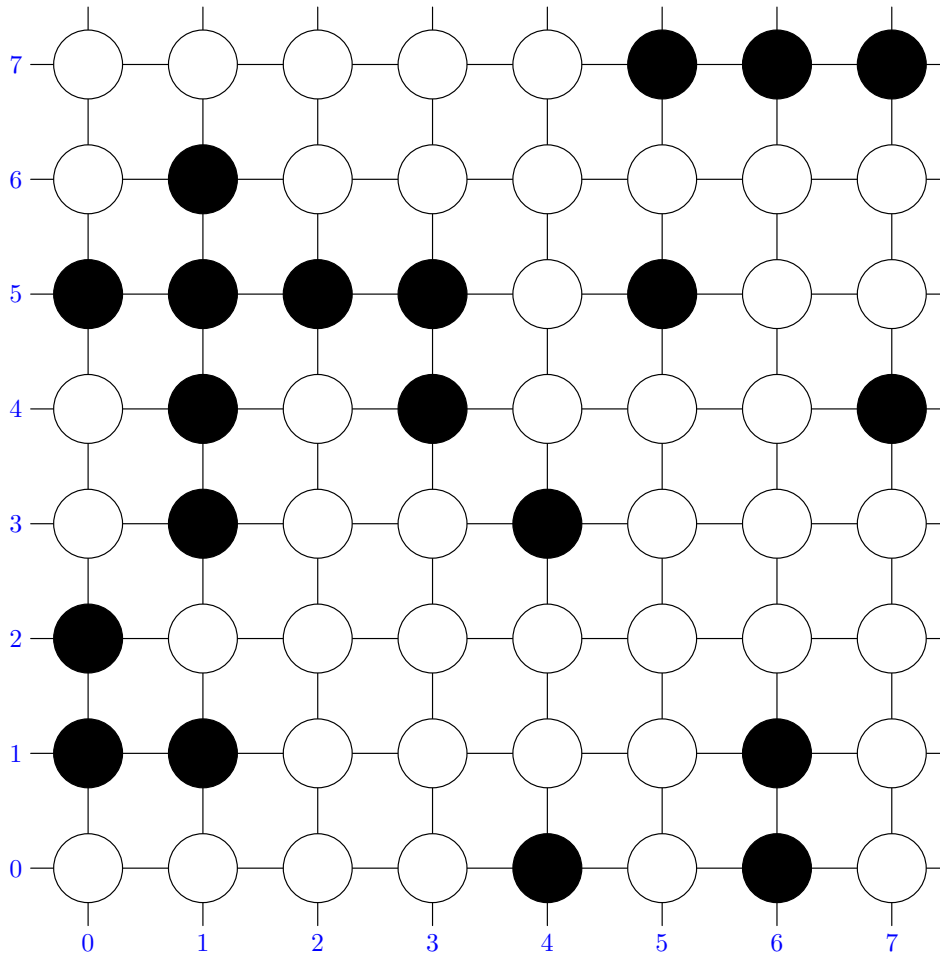
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Outline

1. Abstract Data Types (ADTs)
2. Stacks
3. Queues and Priority Queues
4. Lists, Sets and Maps
5. **Putting it Together**

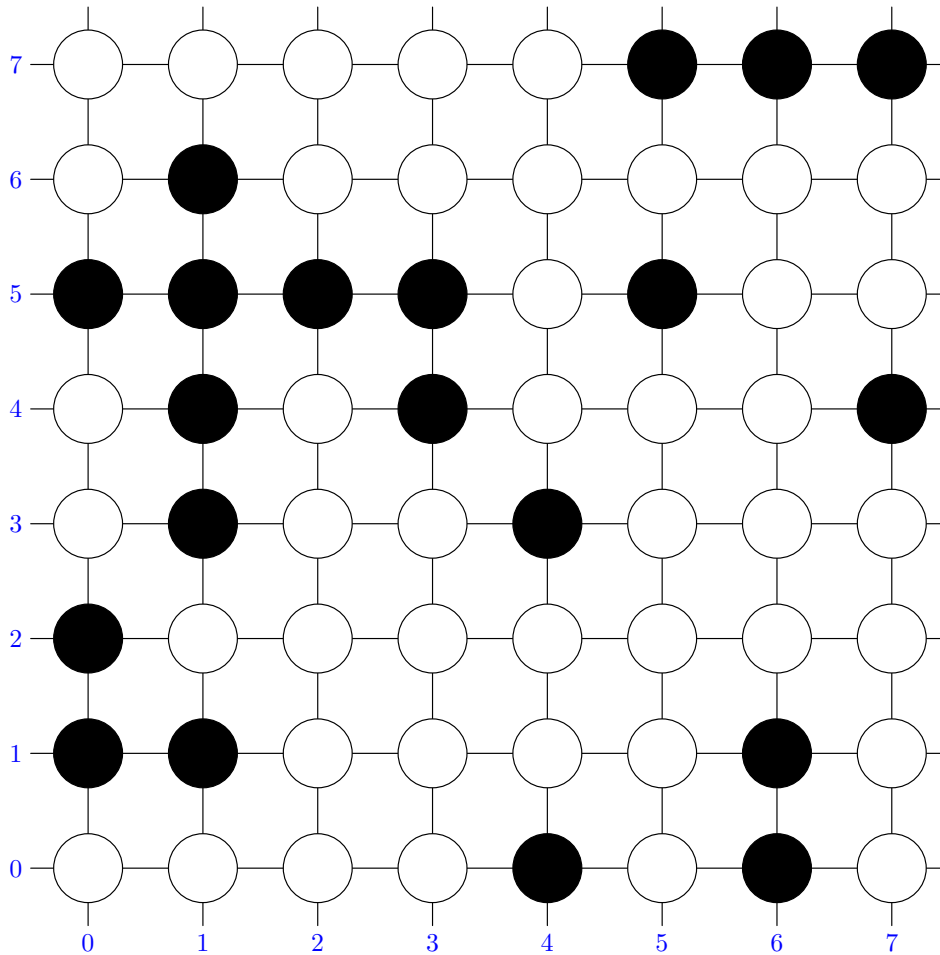


Connected Nodes



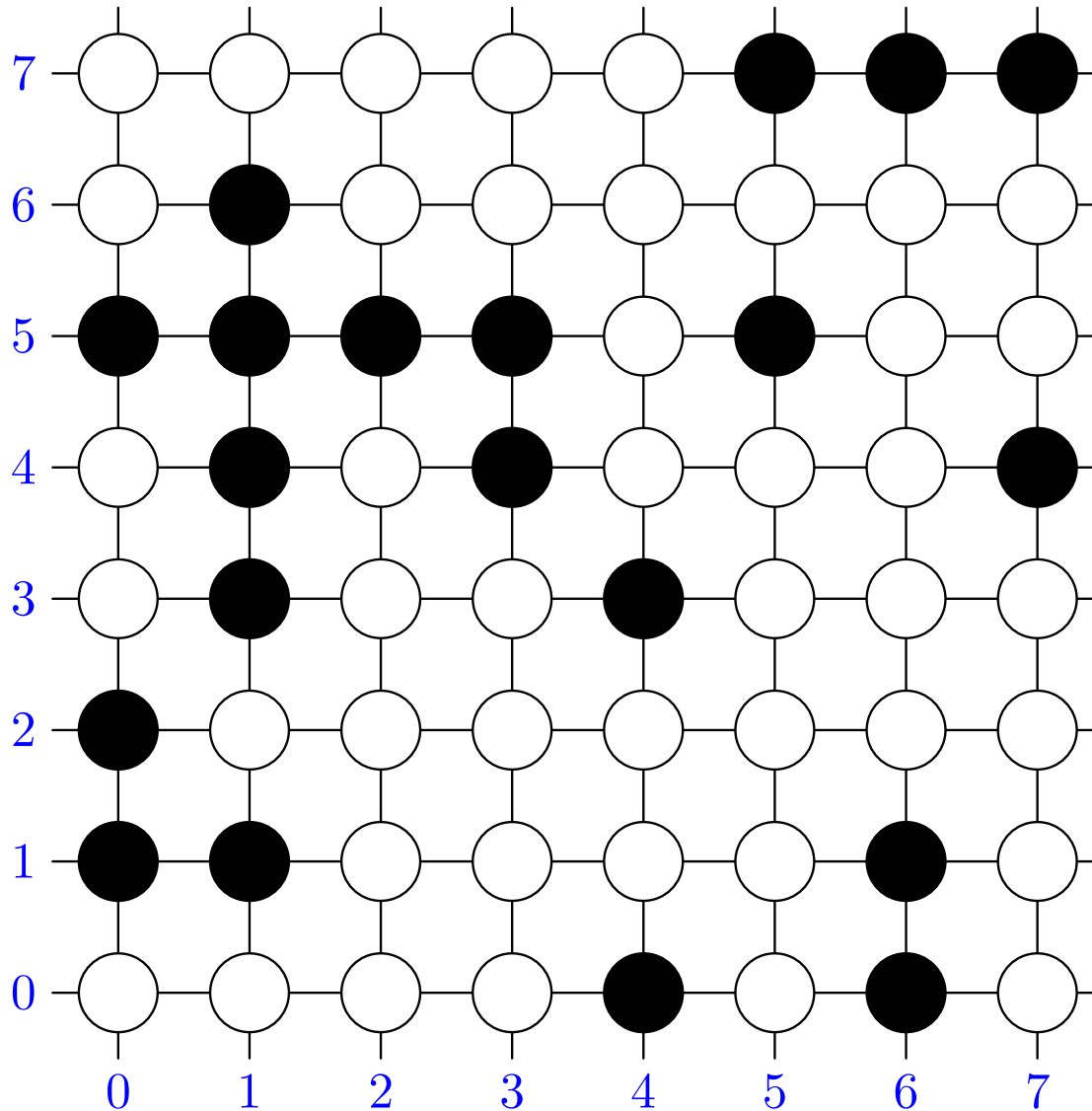
- A frequent problem is to find clusters of connected cells
- Applications in computer vision, computer go, graph connectedness, . . .

Connected Nodes

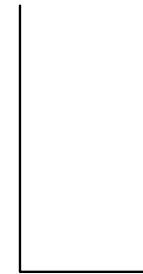


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Connected Nodes

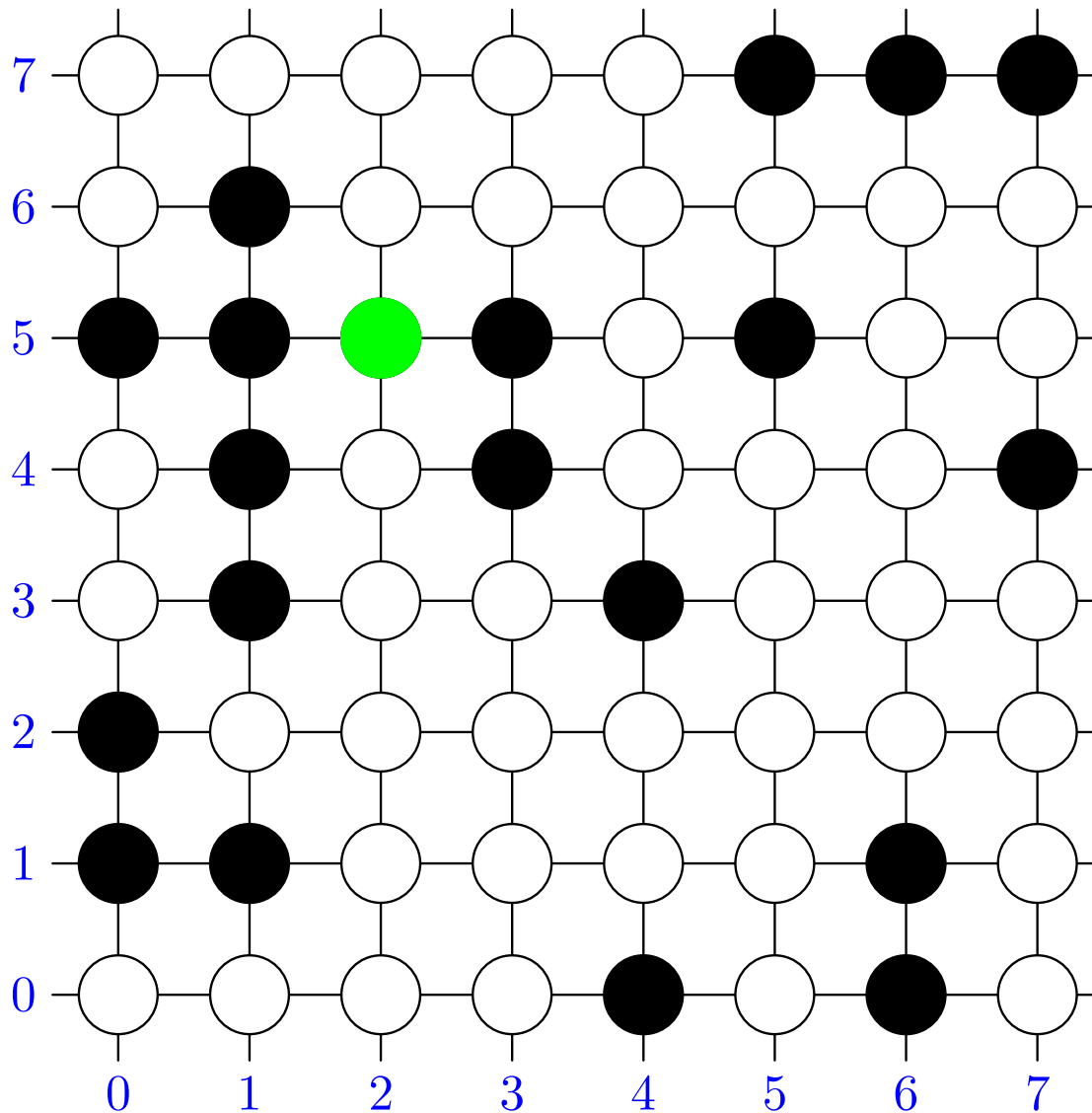


uncheckedNodes =



clusterNodes =
{ }

Connected Nodes



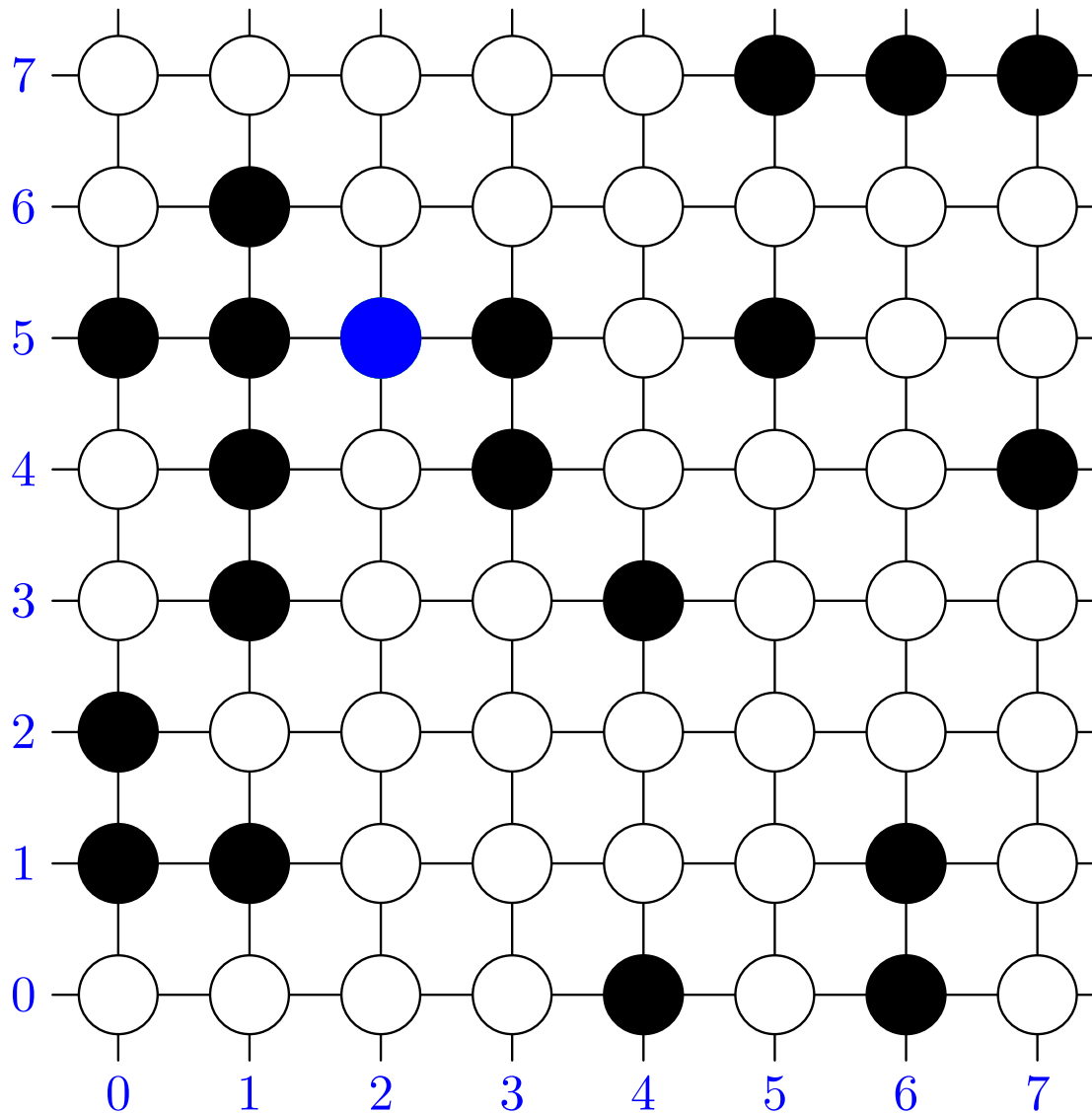
startNode = (2,5)

uncheckedNodes =

(2,5)

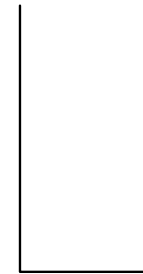
clusterNodes =
{ (2,5) }

Connected Nodes



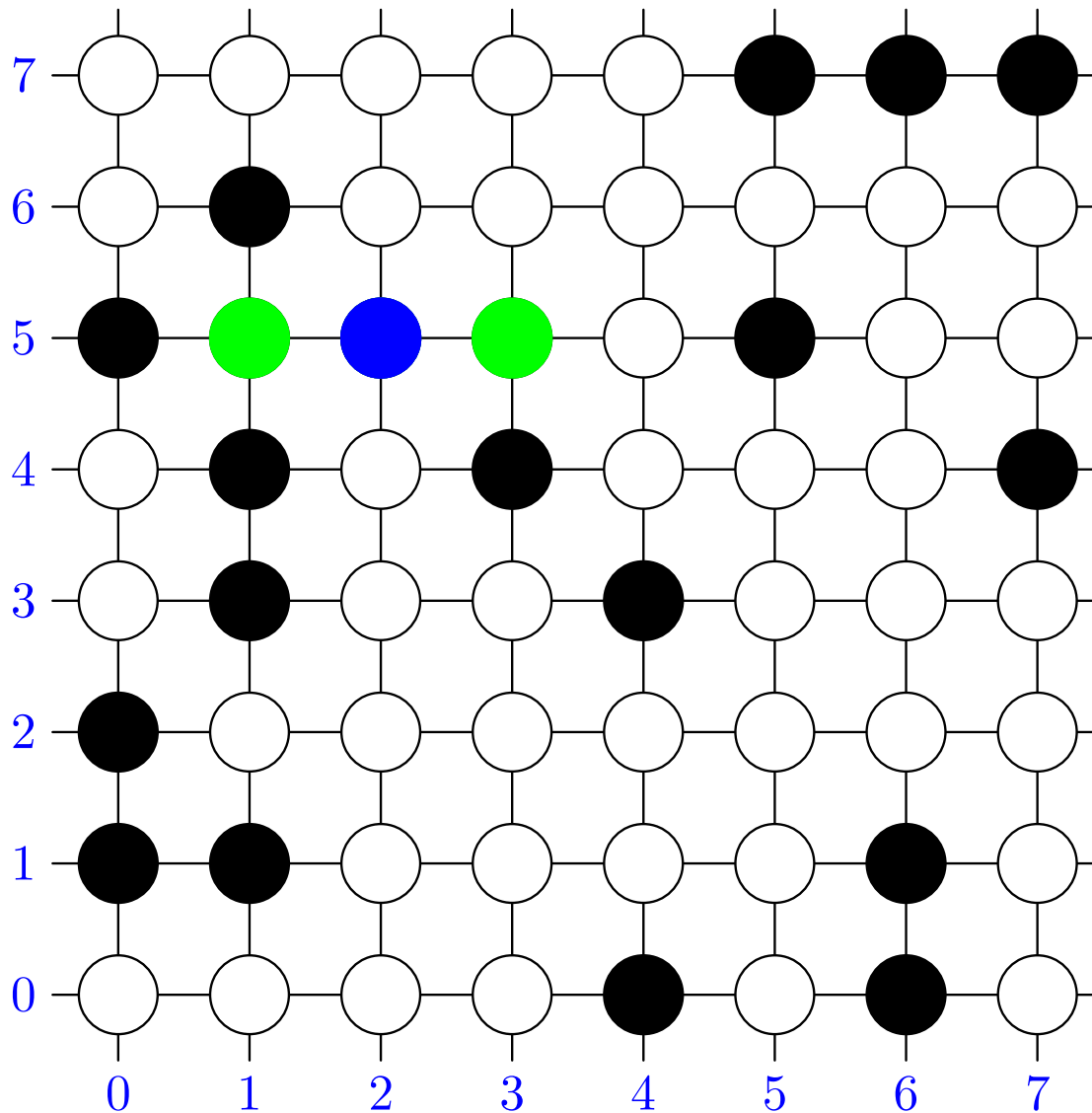
$\text{next} = (2, 5)$

$\text{uncheckedNodes} =$



$\text{clusterNodes} =$
 $\{ (2, 5) \}$

Connected Nodes



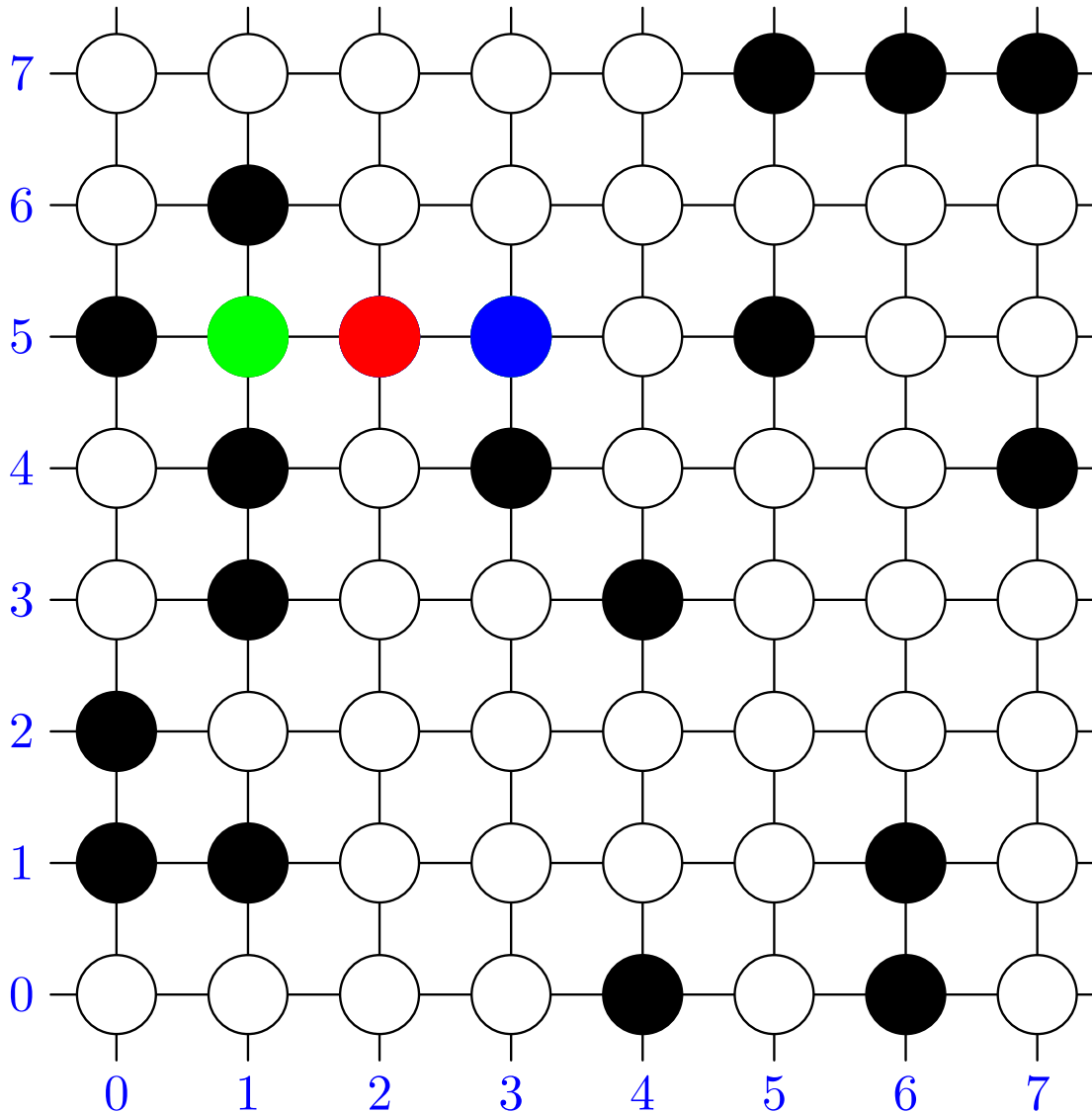
$\text{next} = (2, 5)$

$\text{uncheckedNodes} =$

$\begin{matrix} (3, 5) \\ (1, 5) \end{matrix}$

$\text{clusterNodes} =$
 $\{ (2, 5), (1, 5), (3, 5) \}$

Connected Nodes



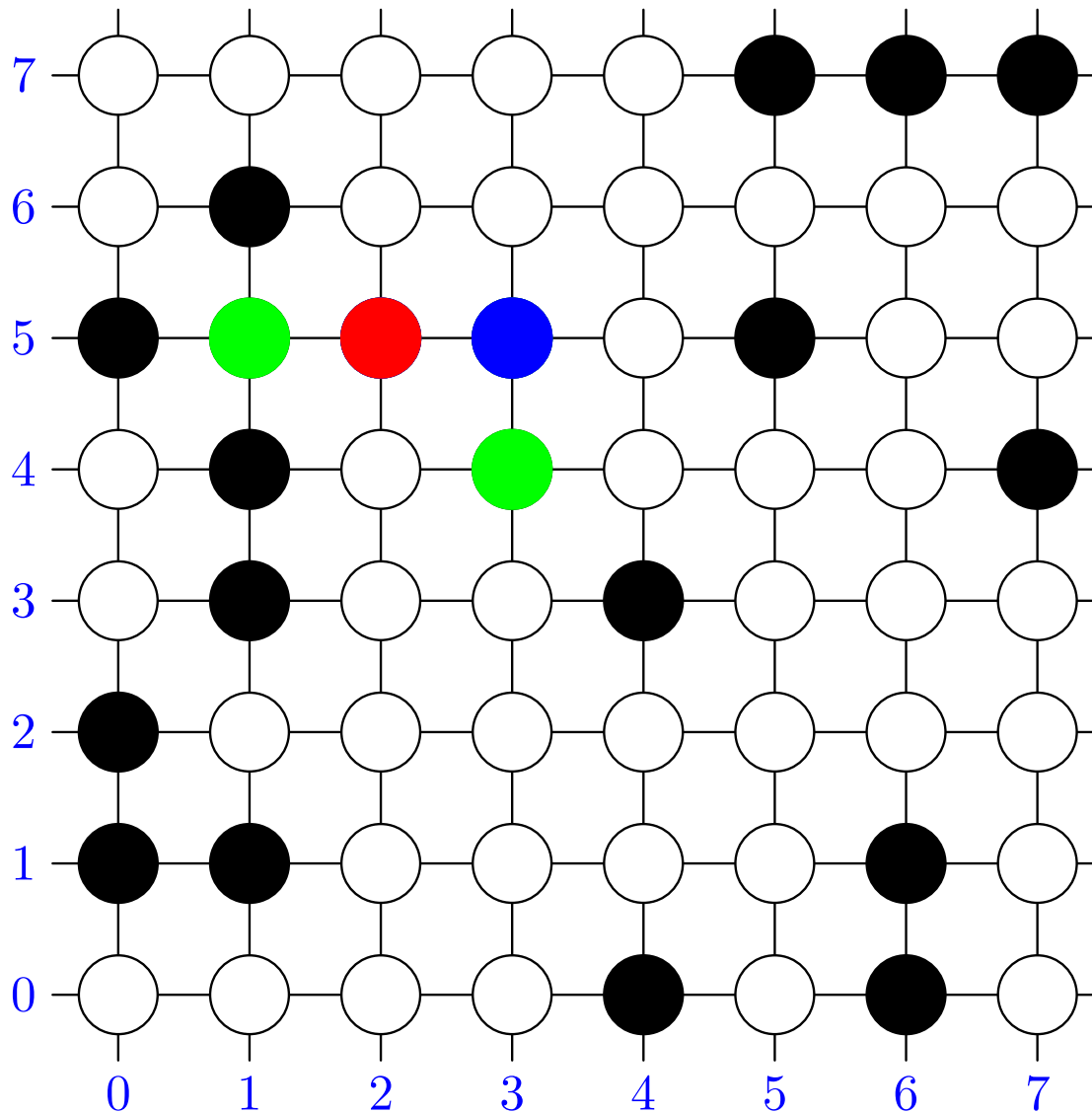
$\text{next} = (3, 5)$

$\text{uncheckedNodes} =$

$(1, 5)$

$\text{clusterNodes} =$
 $\{ (2, 5), (1, 5), (3, 5) \}$

Connected Nodes



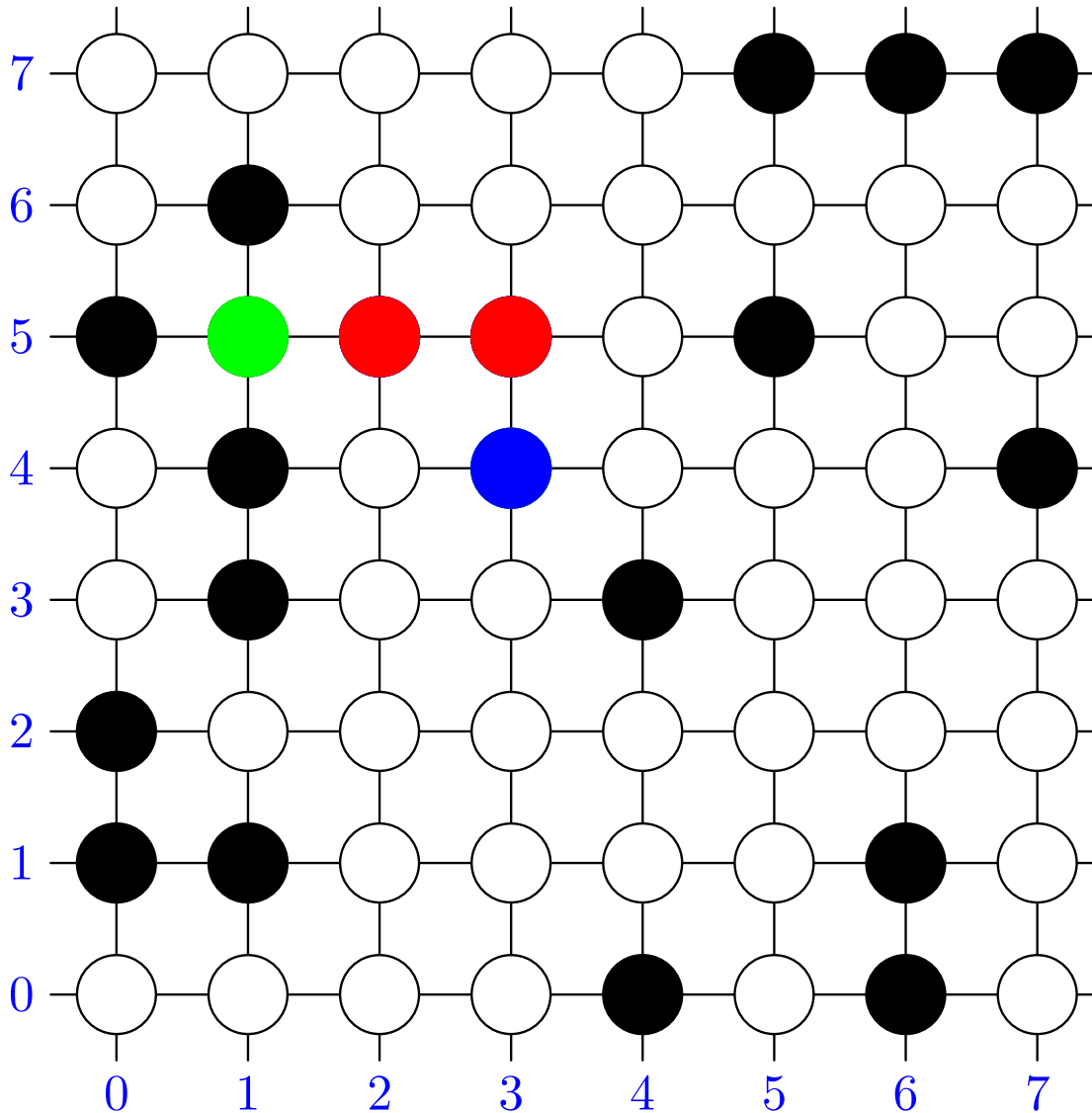
$\text{next} = (3, 5)$

$\text{uncheckedNodes} =$

$\begin{matrix} (3, 4) \\ (1, 5) \end{matrix}$

$\text{clusterNodes} =$
 $\{ (2, 5), (1, 5), (3, 5),$
 $(3, 4) \}$

Connected Nodes



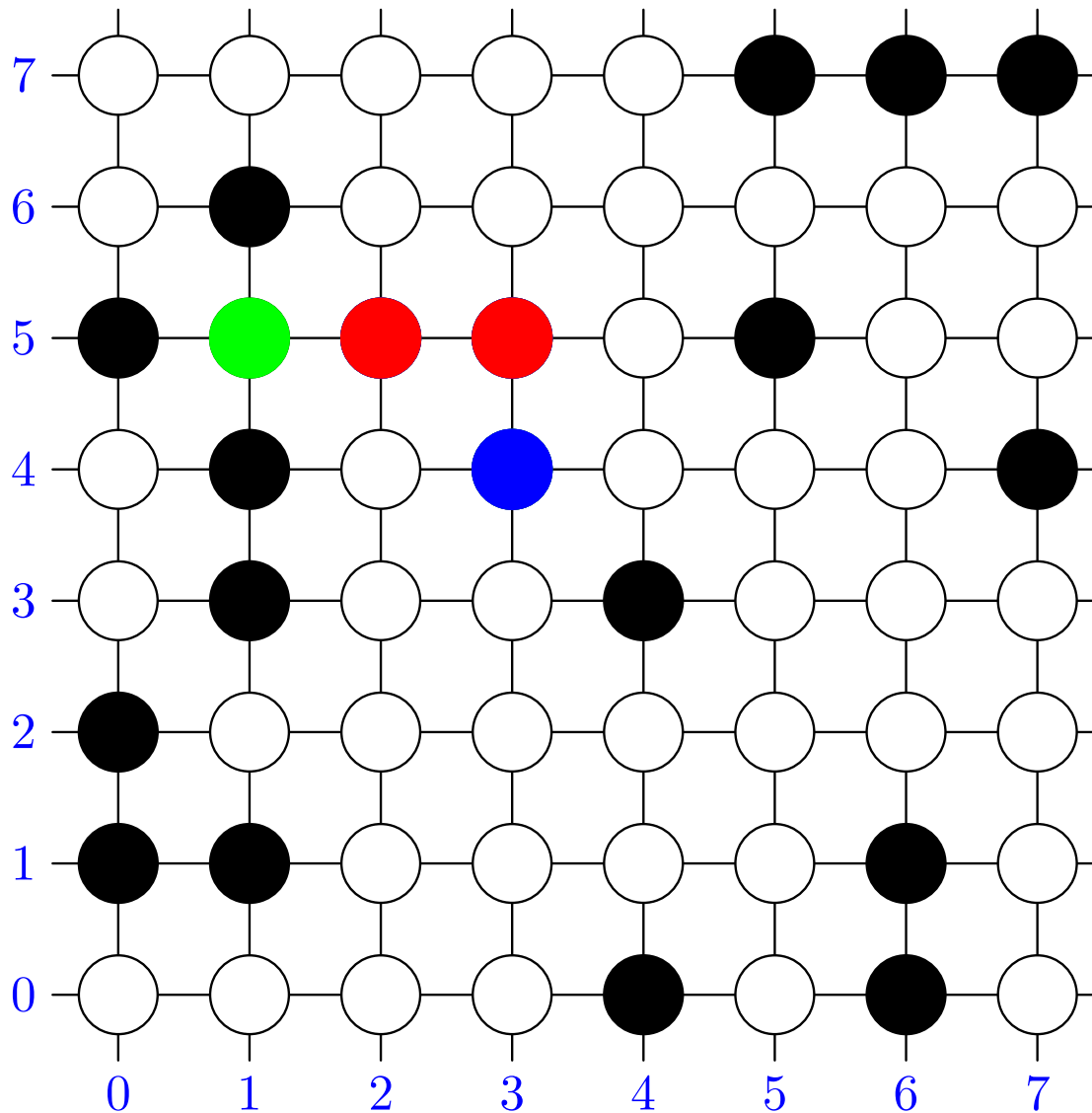
$\text{next} = (3, 4)$

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$(1, 5)$

$\text{clusterNodes} =$
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Connected Nodes



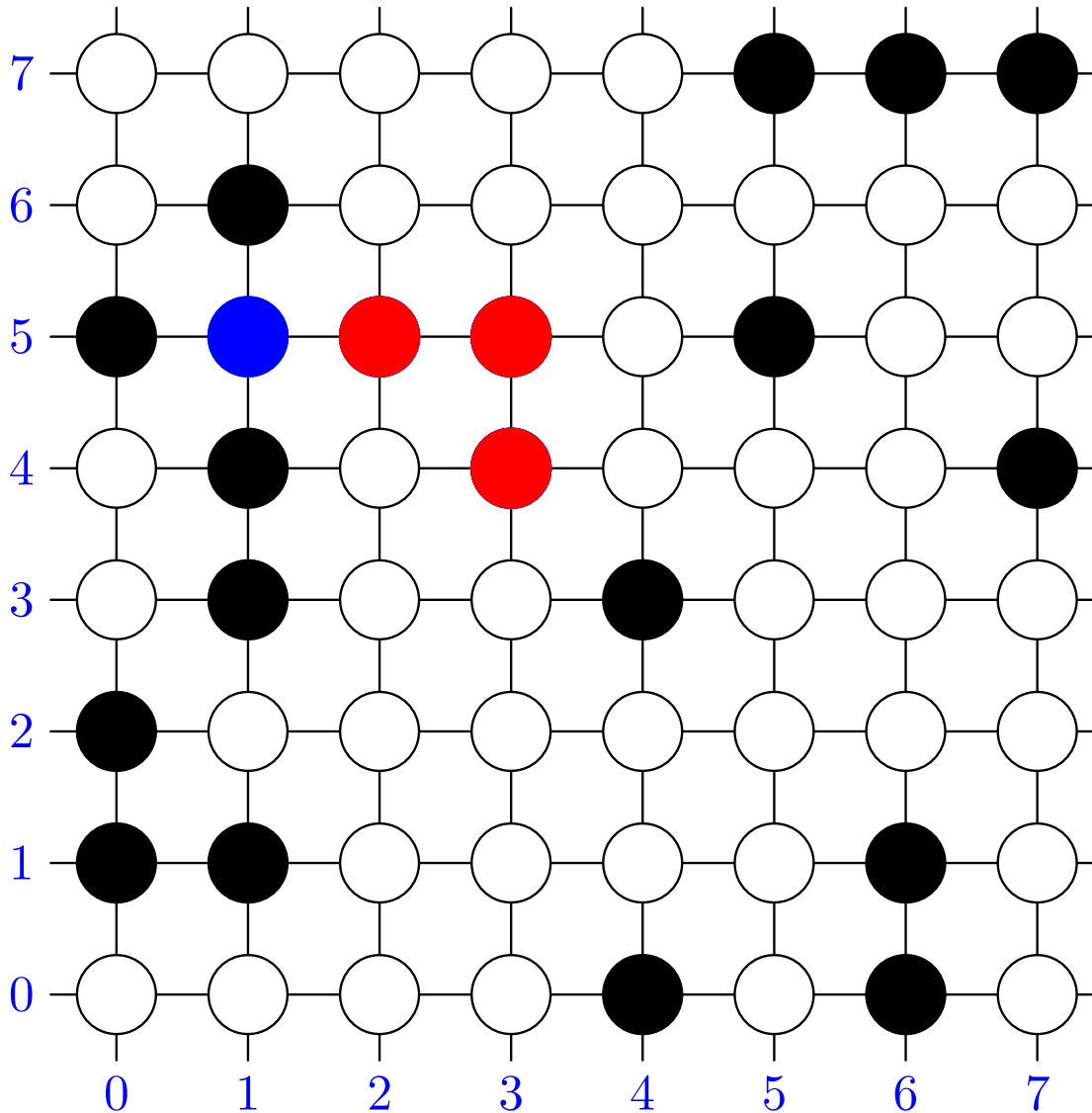
$\text{next} = (3, 4)$

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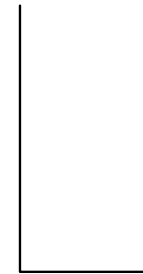
$\text{clusterNodes} =$
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Connected Nodes



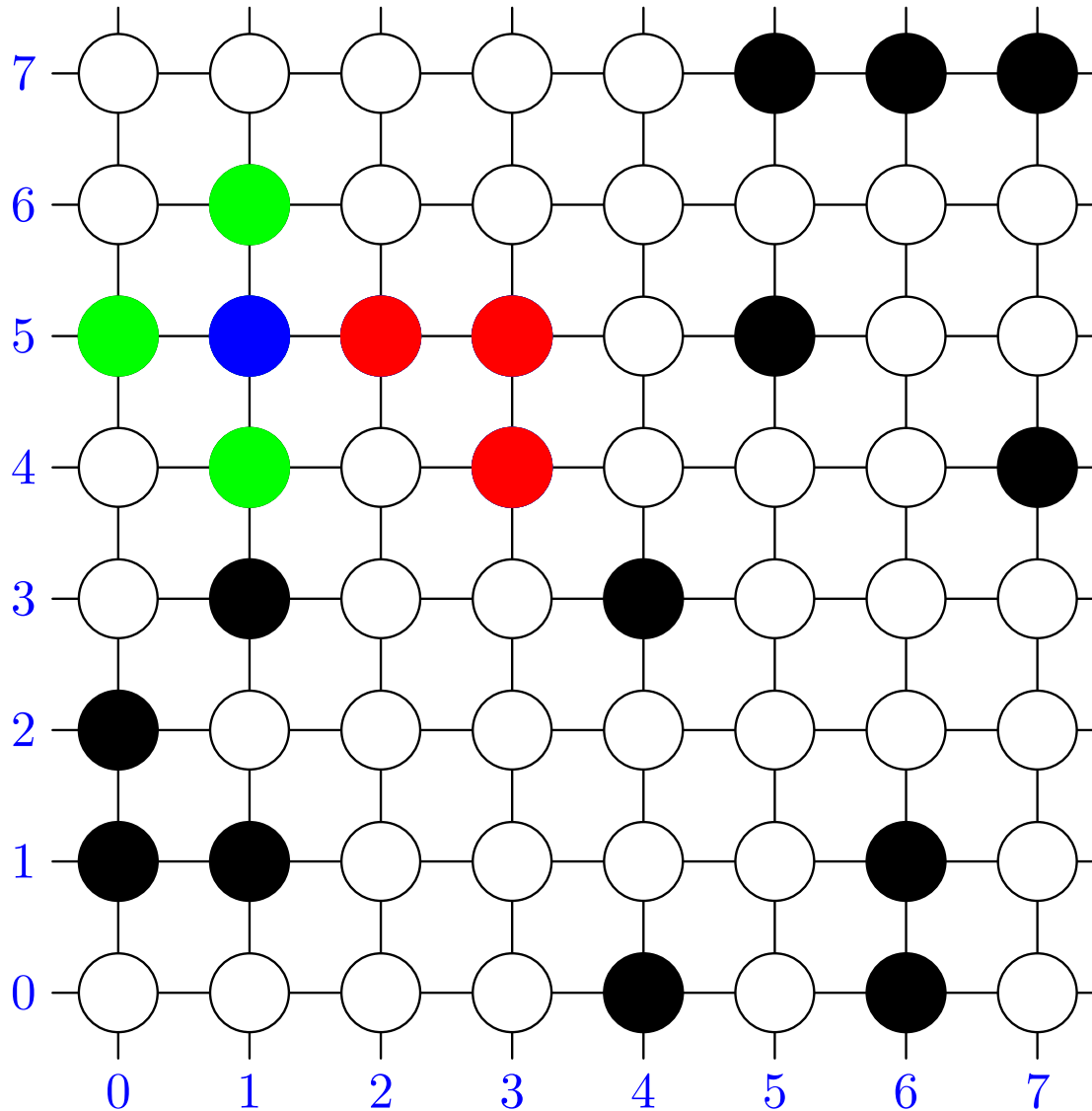
$\text{next} = (1, 5)$

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$\text{clusterNodes} =$
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Connected Nodes



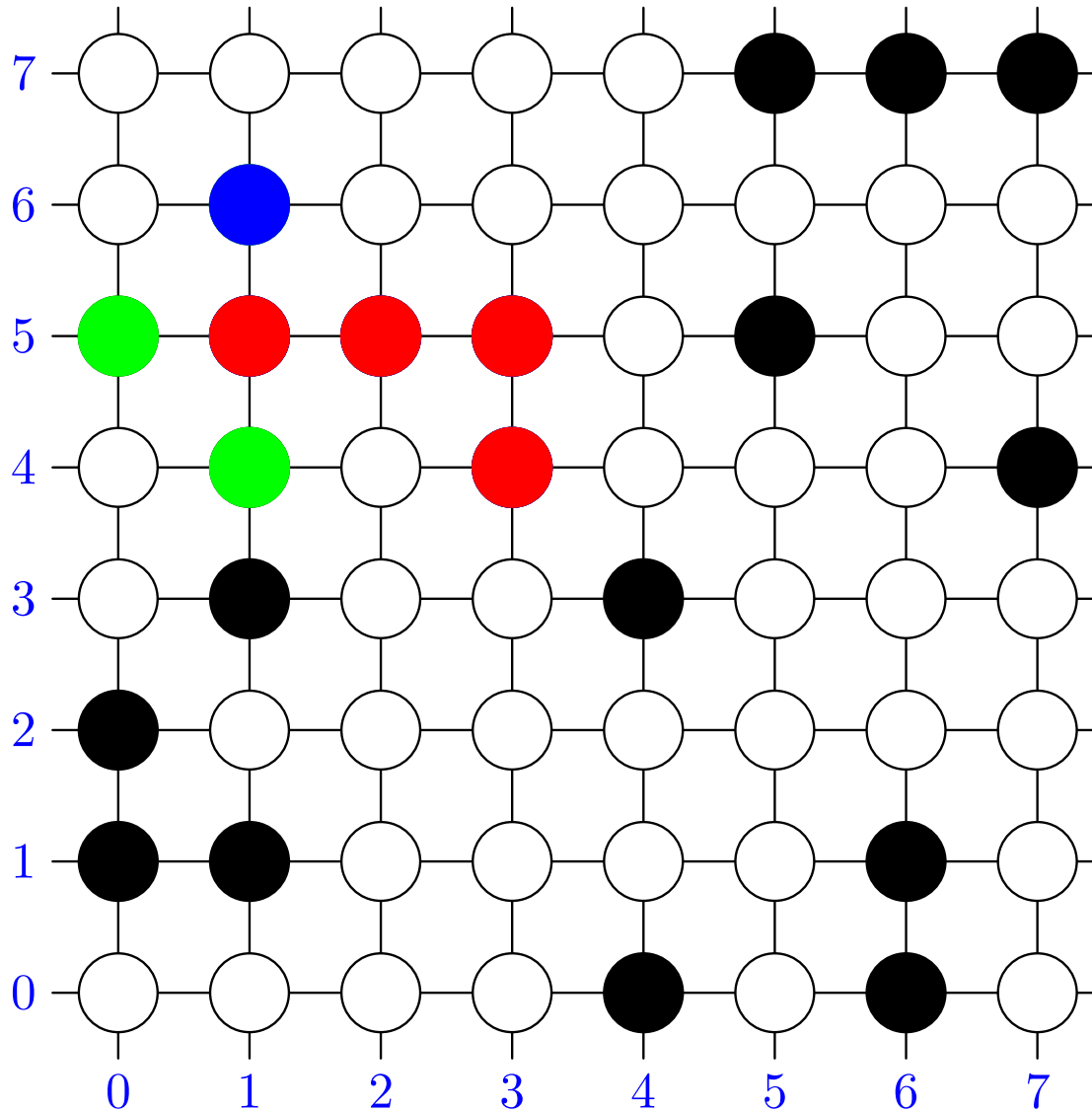
$\text{next} = (1, 5)$

$\text{uncheckedNodes} =$

$\begin{bmatrix} (1, 6) \\ (1, 4) \\ (0, 5) \end{bmatrix}$

$\text{clusterNodes} =$
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 $(3, 4), (0, 5), (1, 4),$
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Connected Nodes



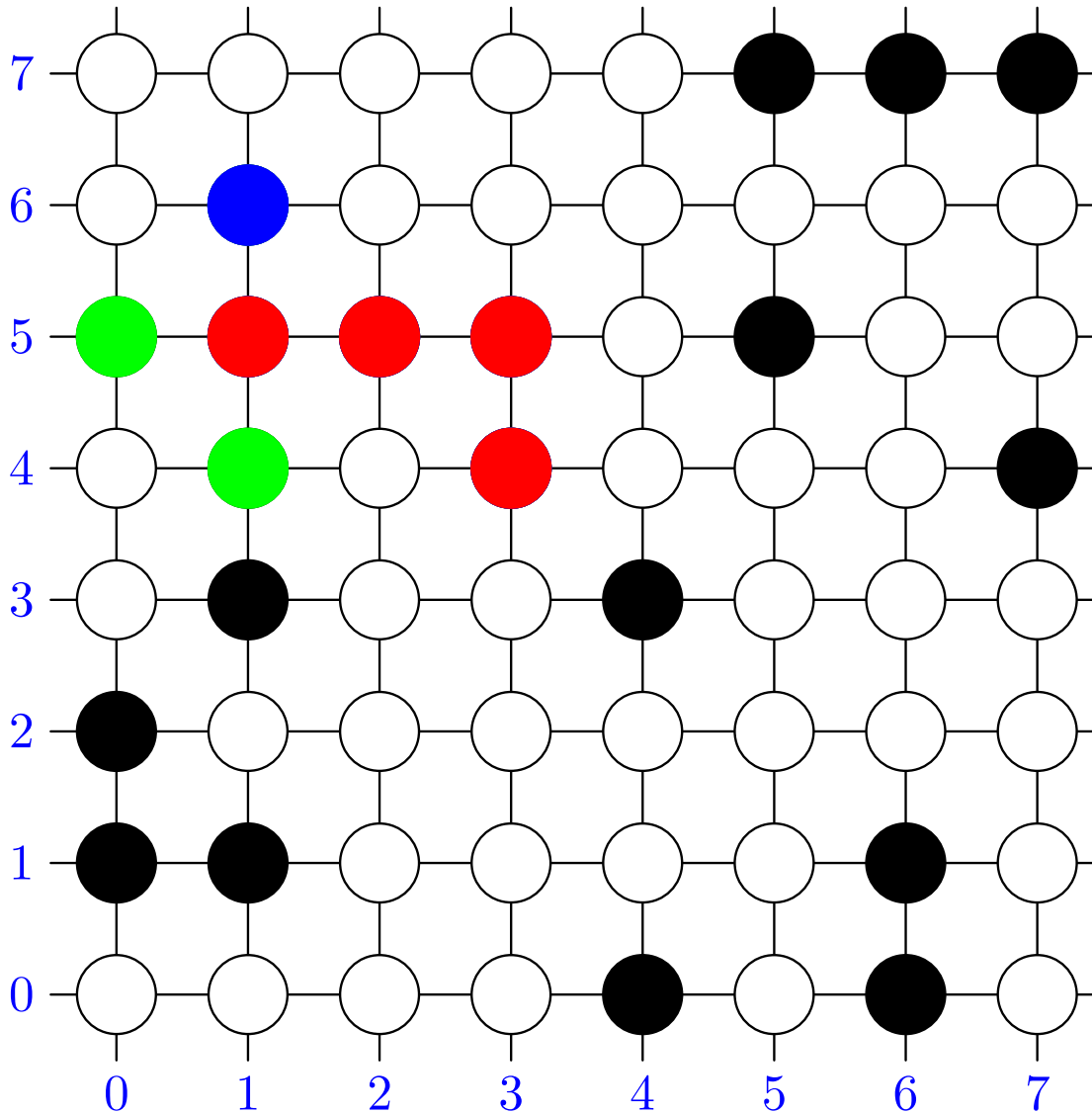
$\text{next} = (1, 6)$

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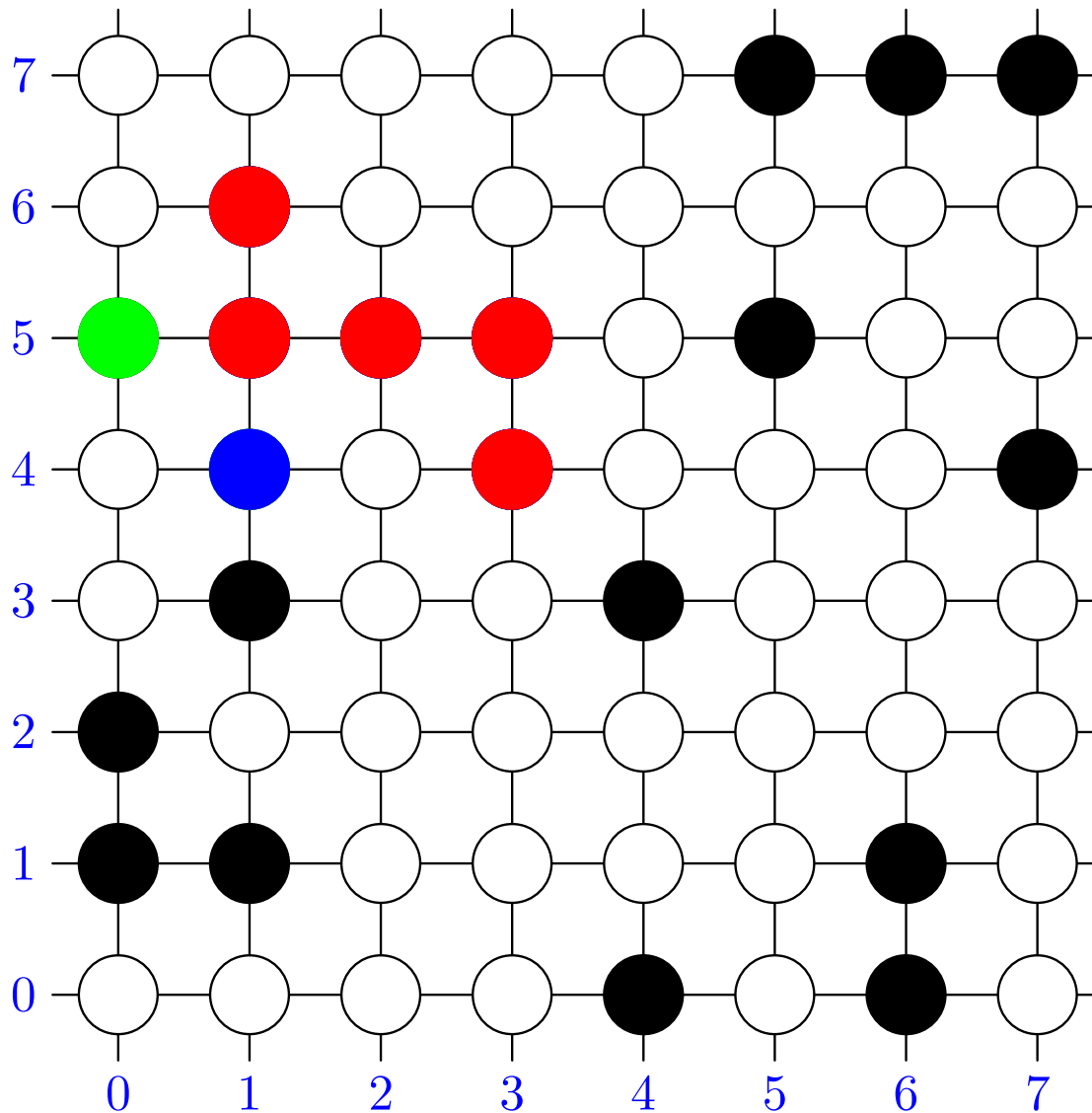
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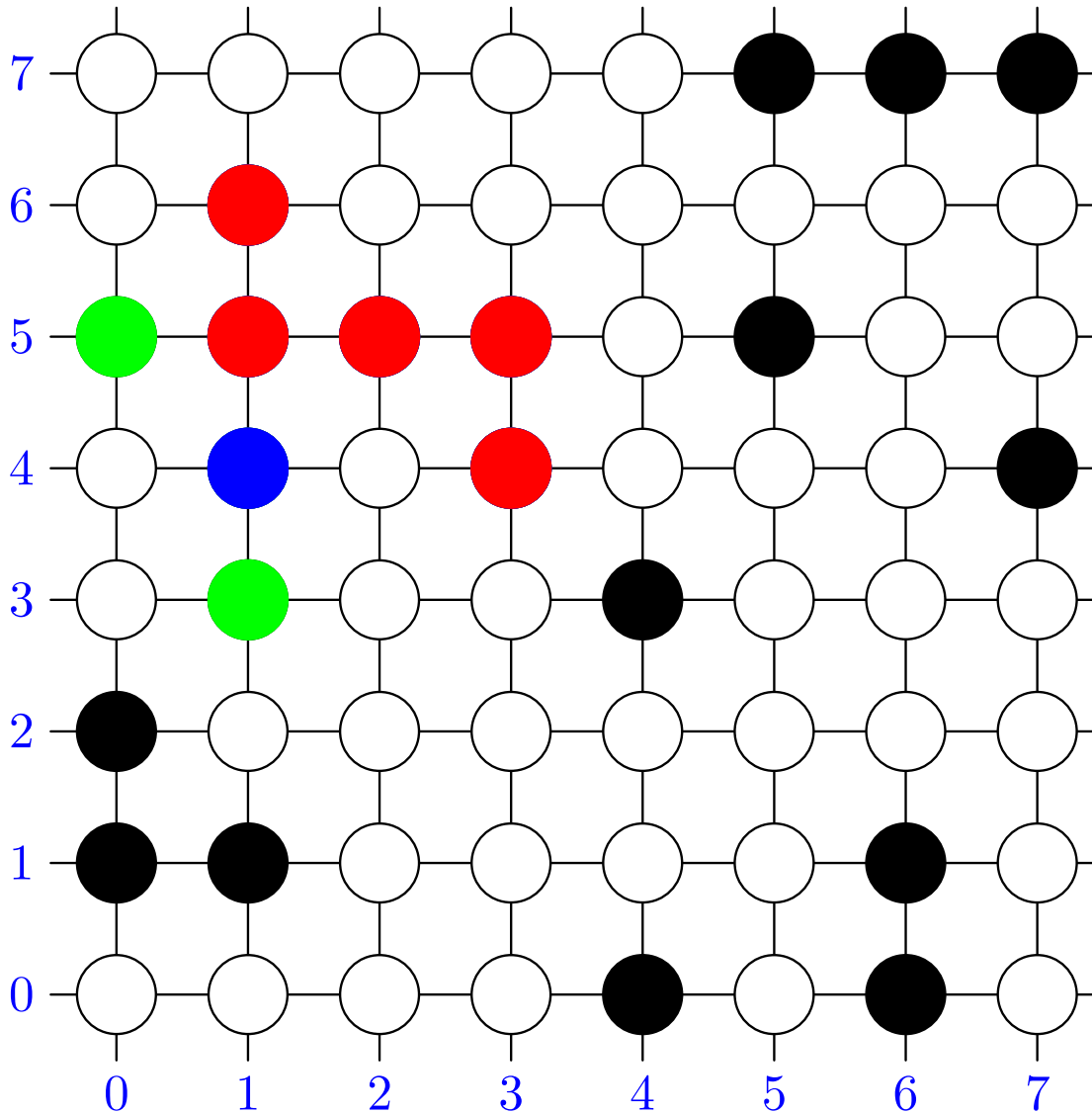
$\text{next} = (1, 4)$

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$\text{next} = (1, 4)$

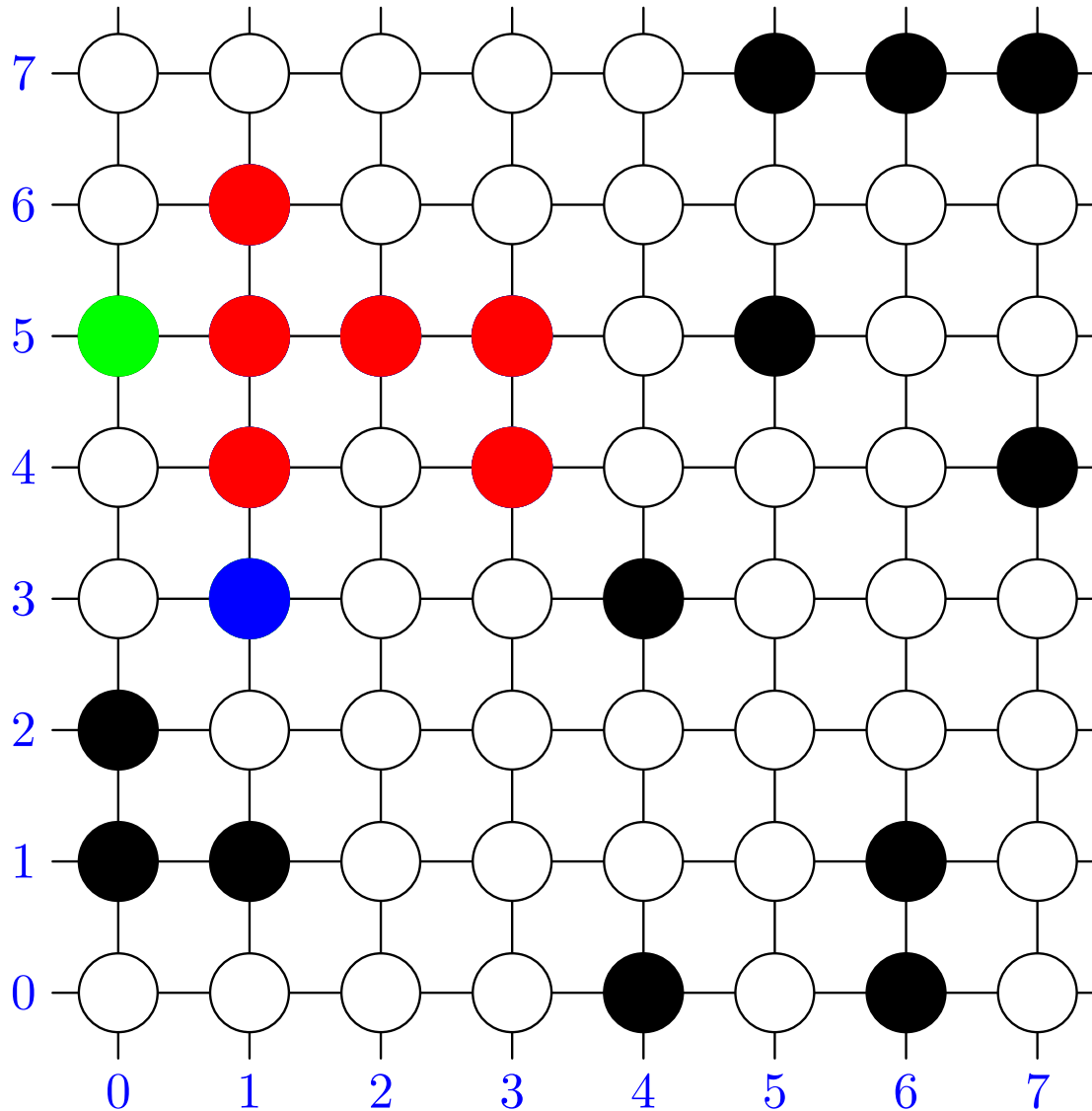
$\text{uncheckedNodes} =$

$\begin{pmatrix} (1, 3) \\ (0, 5) \end{pmatrix}$

$\text{clusterNodes} =$

$\{ (2, 5), (1, 5), (3, 5), \\ (3, 4), (0, 5), (1, 4), \\ (1, 6), (1, 3) \}$

Connected Nodes



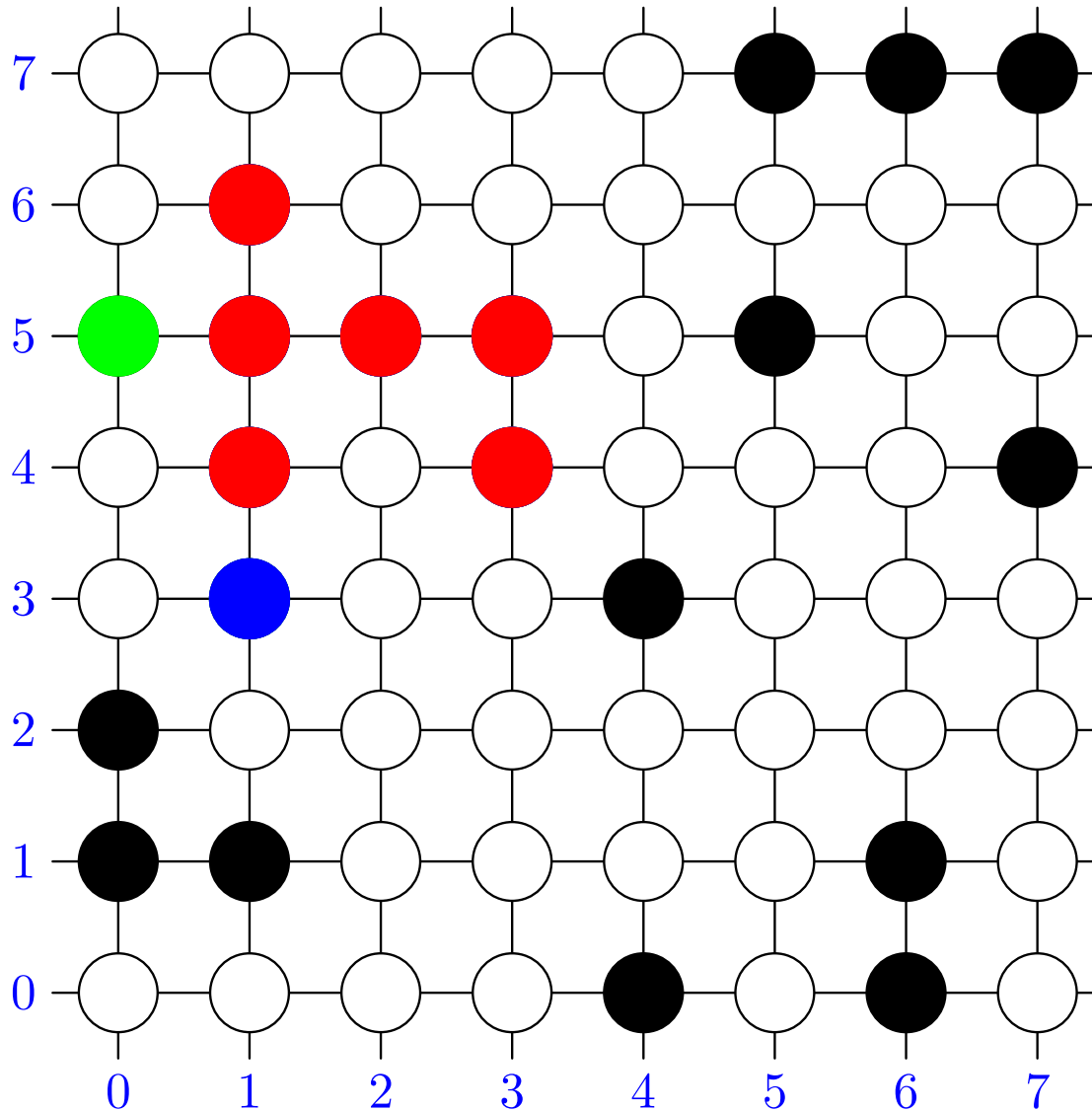
$\text{next} = (1, 3)$

$\text{uncheckedNodes} =$

$(0, 5)$

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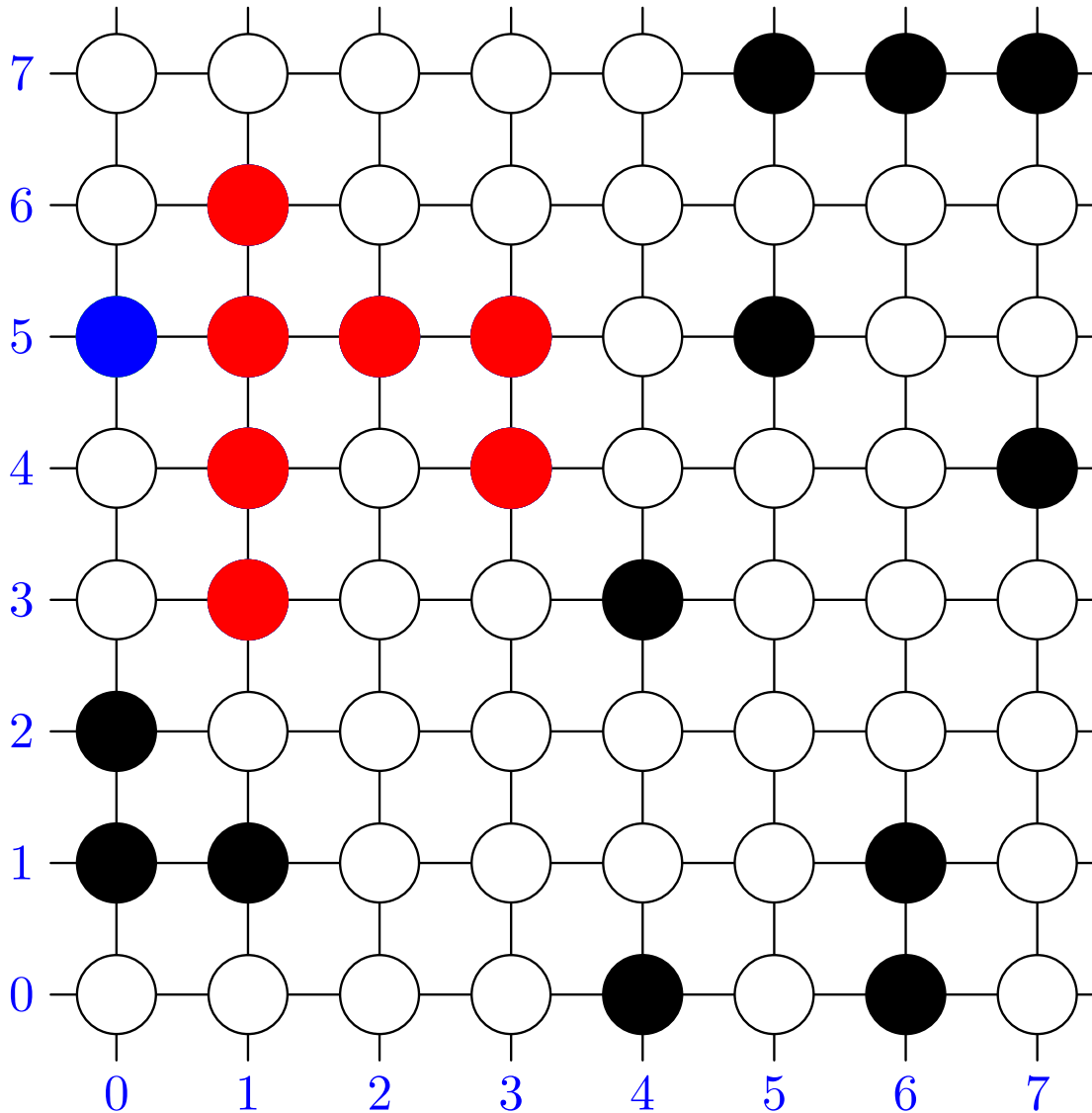
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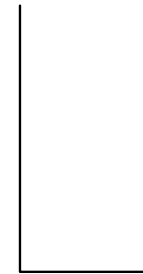
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Connected Node Algorithm

```
set<Node> findCluster(Node startNode, Graph graph)
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Connected Node Algorithm

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{
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set<Node> findCluster(Node startNode, Graph graph)
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    stack<Node> uncheckedNodes;
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    uncheckedNodes.push(startNode);
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    while (!uncheckedNodes.empty()) {
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        Node next = uncheckedNodes.top();    uncheckedNodes.pop();
        vector<Node> neighbours = graph.getNeighbours(next);
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        }
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            }
        }
    }

    return clusterNodes;
}
```

Lessons

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- Their purpose is to allow the programmer to declare their intentions
- They often have different implementations with different properties
- The most efficient implementation is not always obvious—we will see many of these implementations as we go through this course
- You need to know the common ADTs (e.g. Stack, Queue, List, Set, Map) and how and when to use them

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