

Further Mathematics and Algorithms

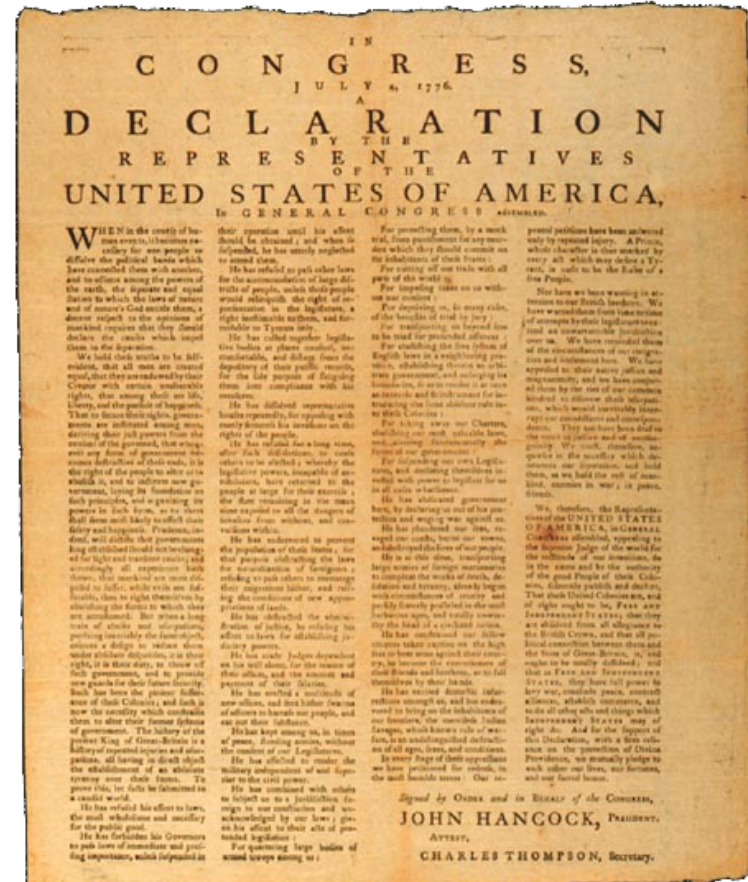
Lesson 3: *Declare your intentions (not your actions)*



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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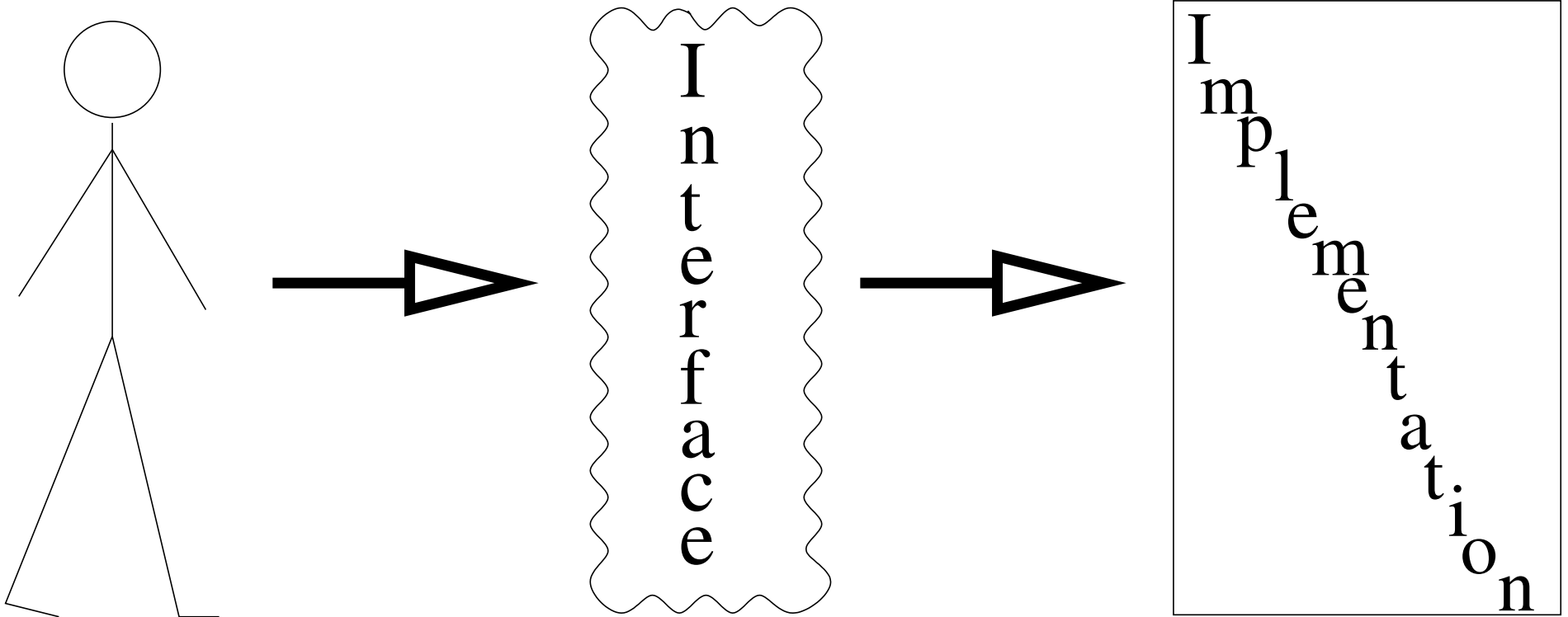
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Object-Oriented Classes



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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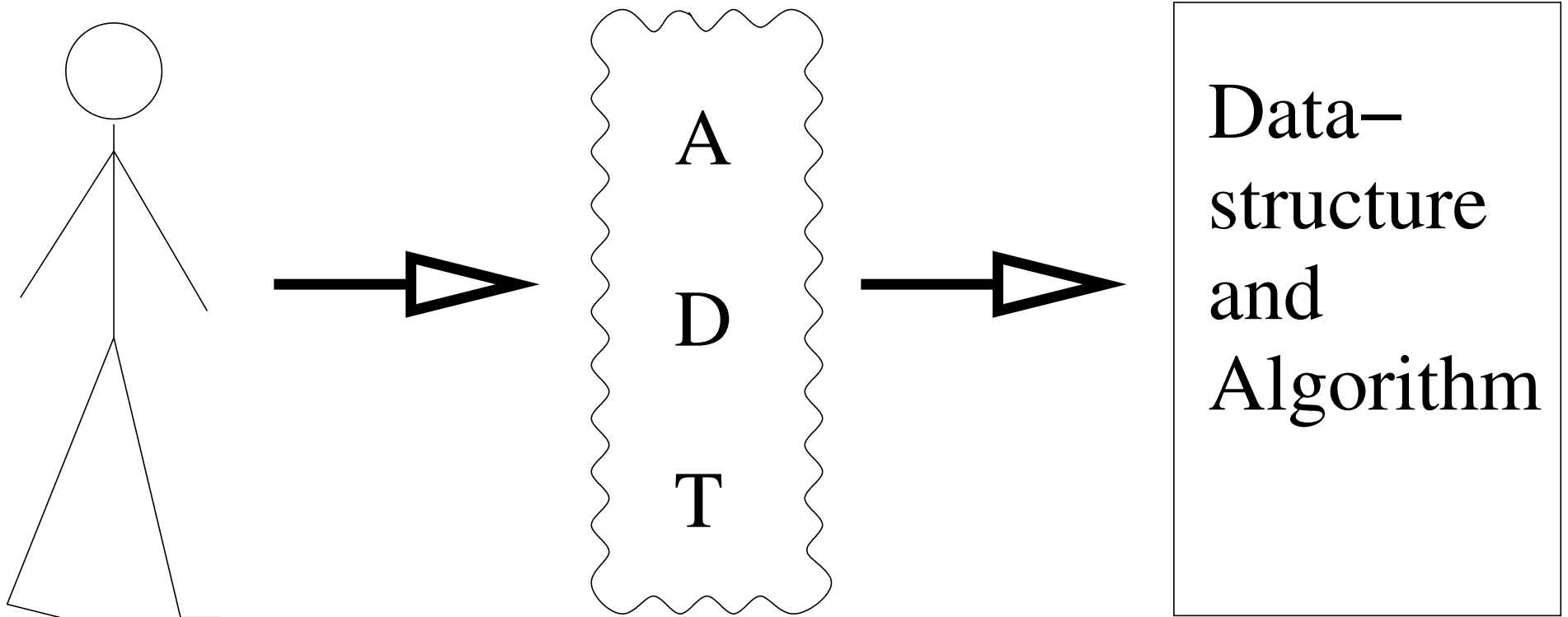
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ADTs



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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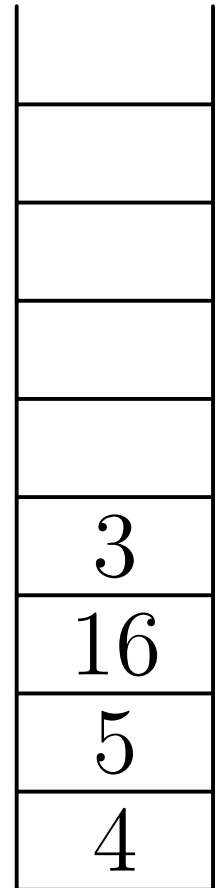
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1. Abstract Data Types (ADTs)
2. **Stacks**
3. Queues and Priority Queues
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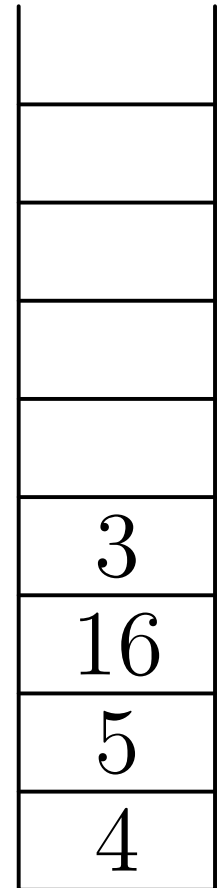
Stacks

- Last In First Out (LIFO) memory



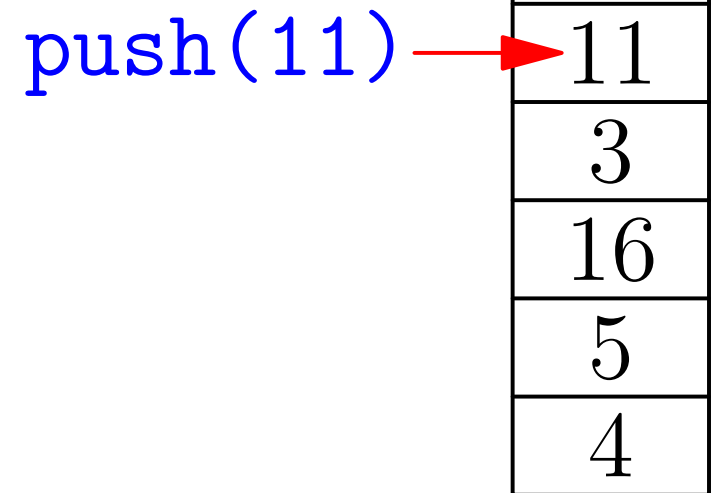
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 - ★ `push(item)`



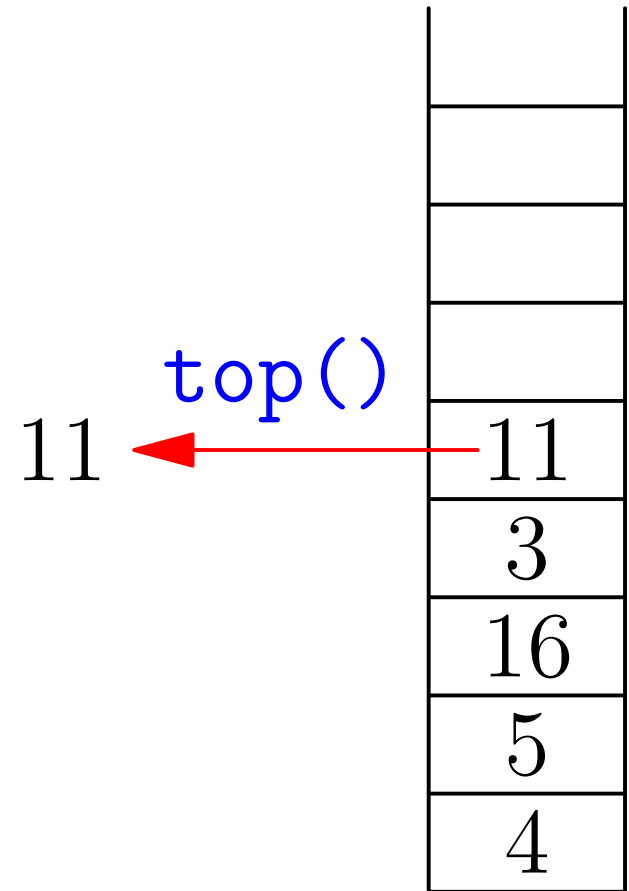
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★ `T top()`



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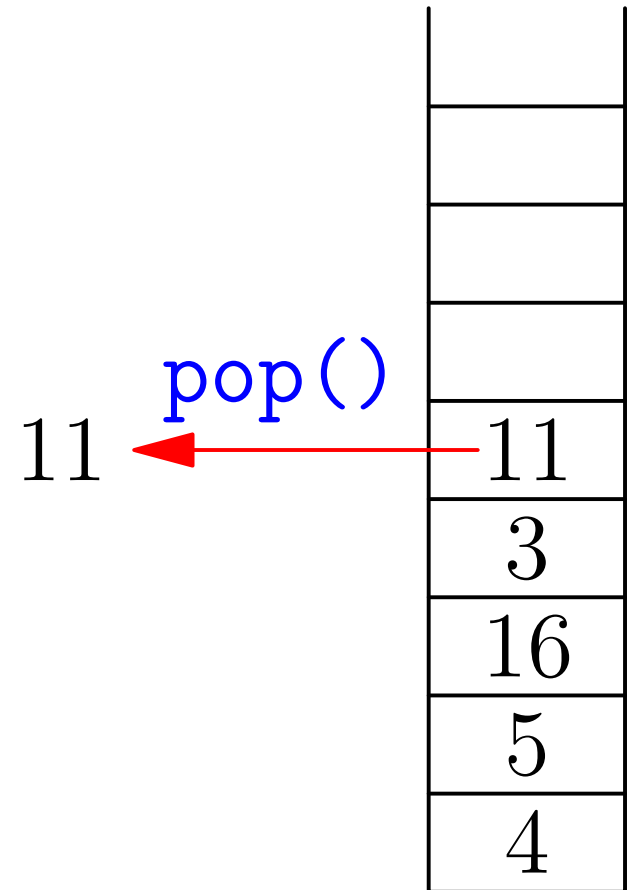
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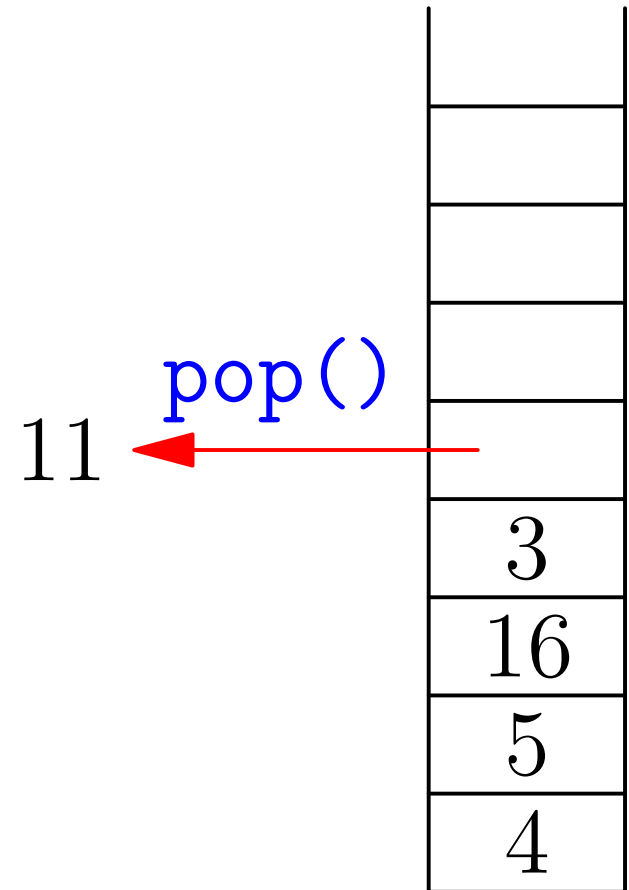
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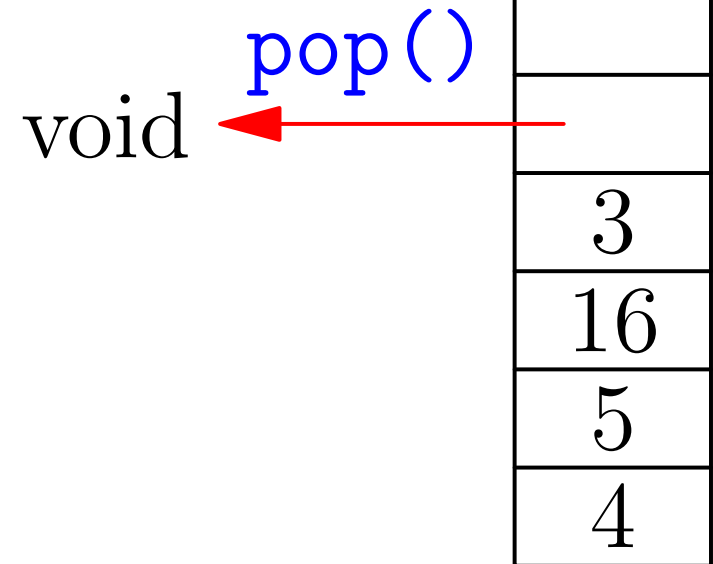
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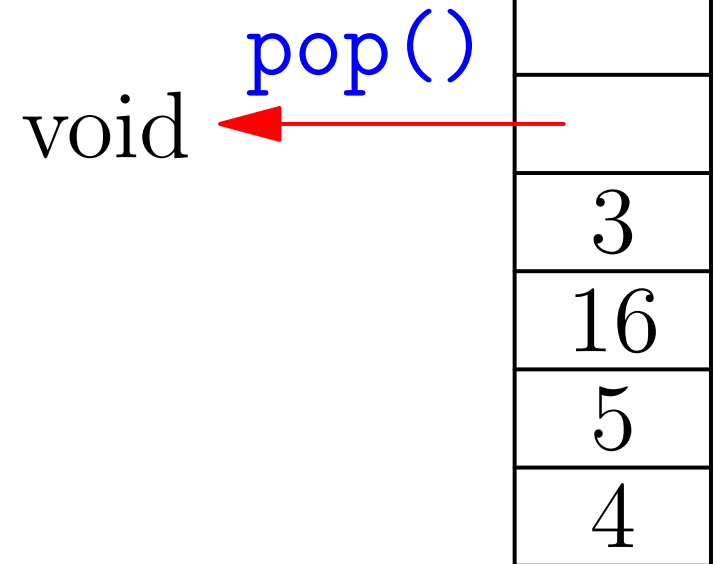
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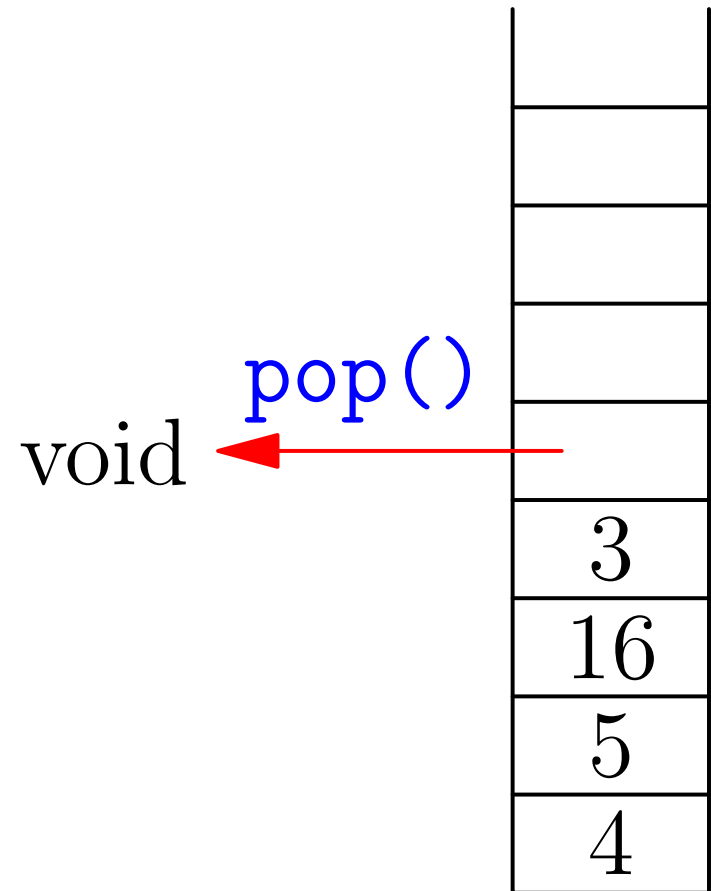
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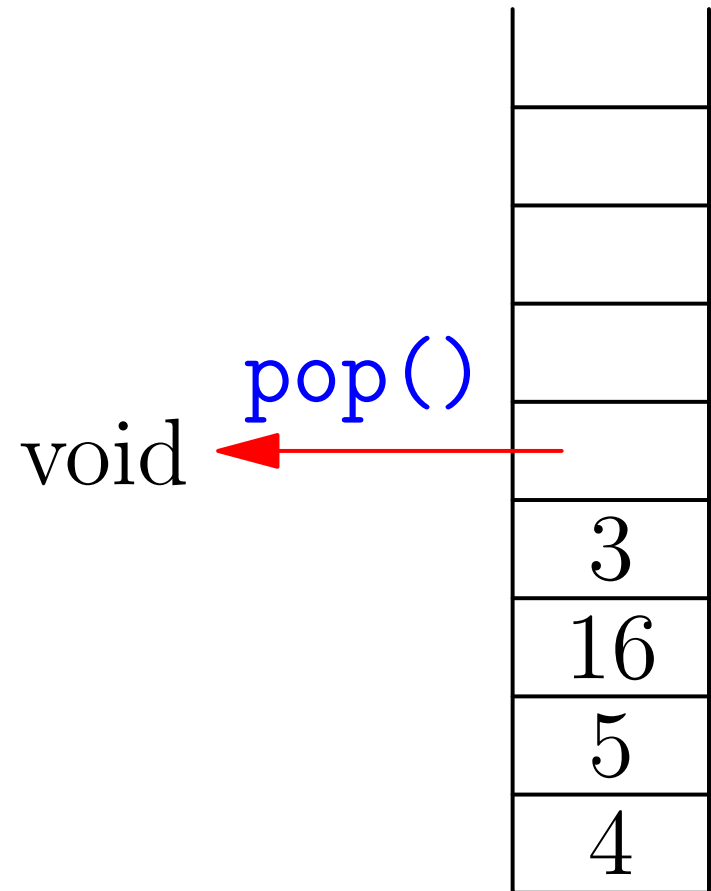
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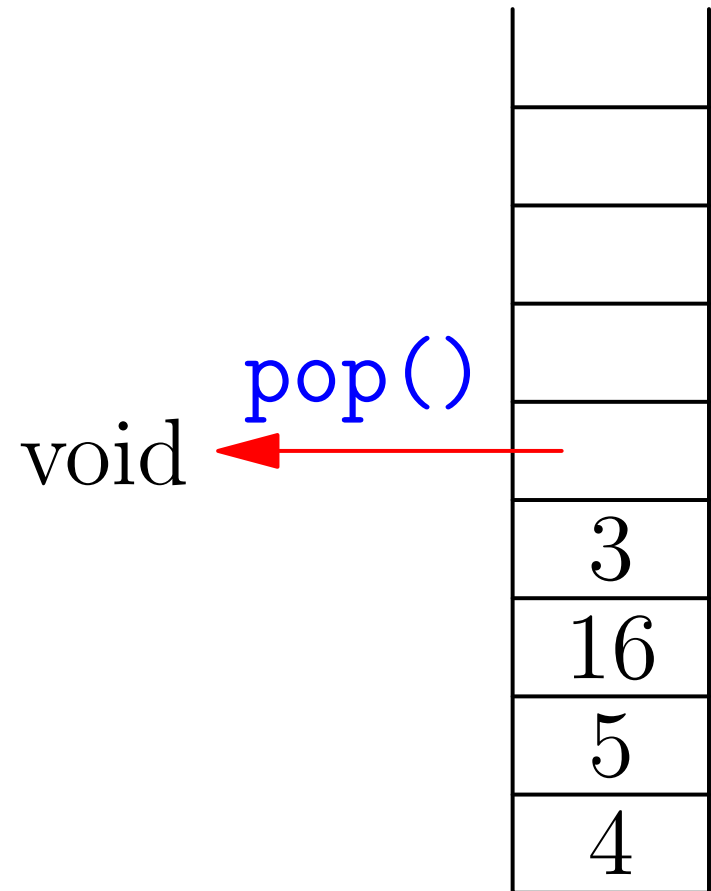
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Why Use a Stack?

- 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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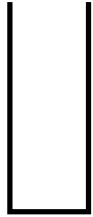
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Evaluating Arithmetic Expressions

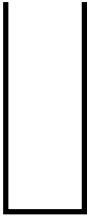
$$(((7+3)/5)*(7-5))$$

Evaluating Arithmetic Expressions

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Number



Operator

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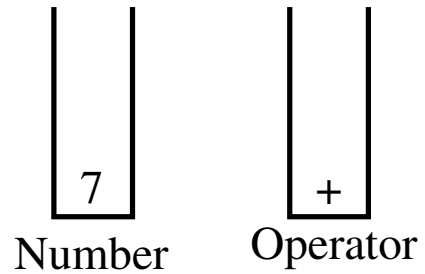
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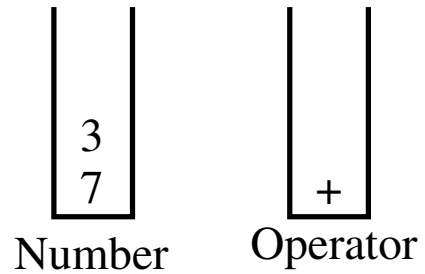
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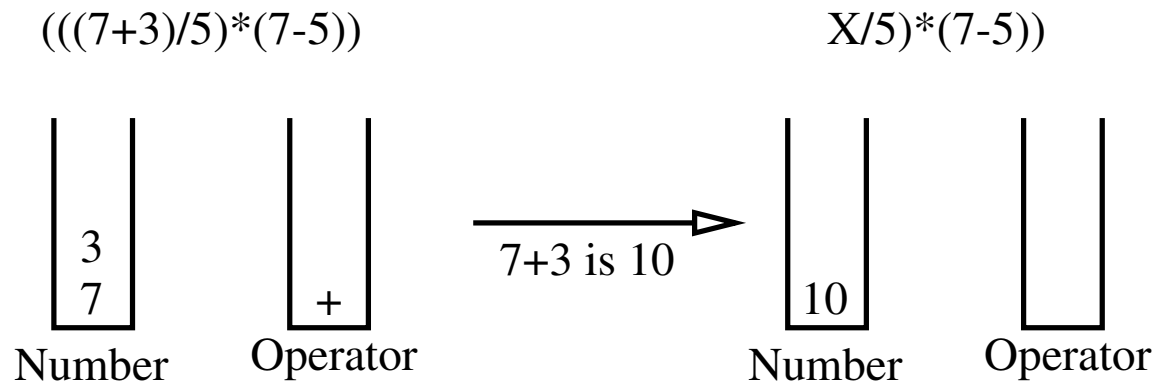


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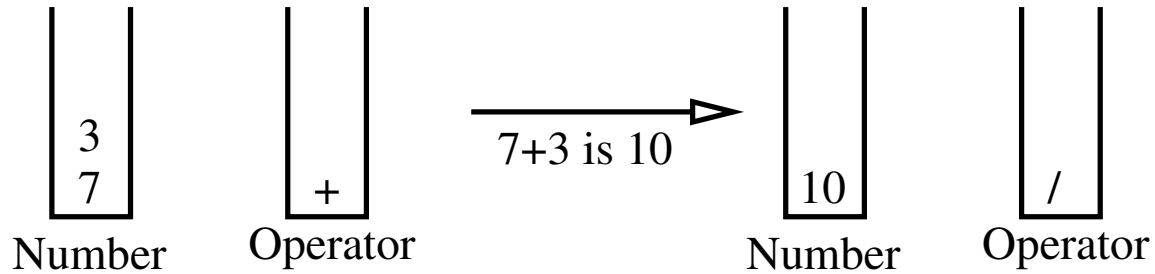
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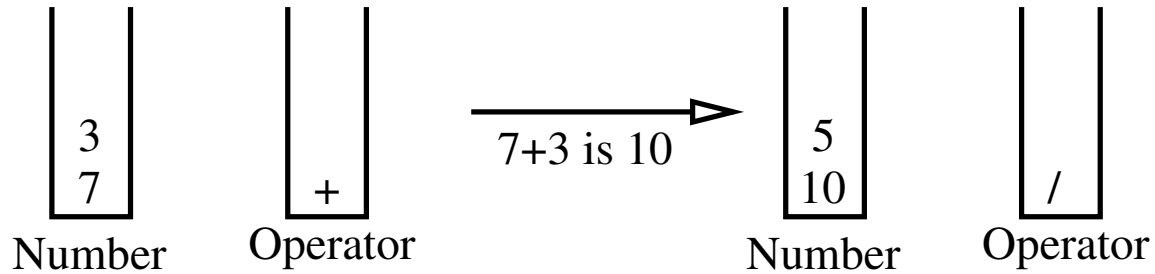
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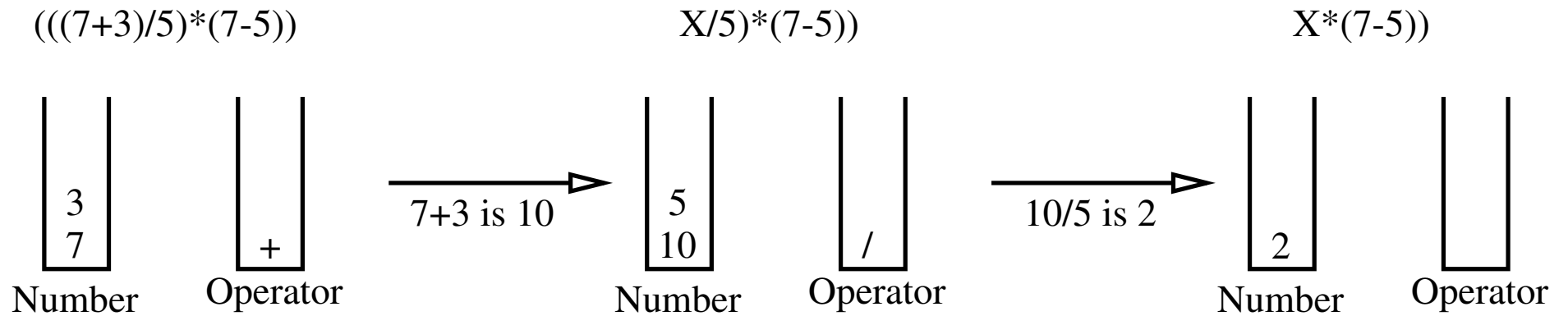
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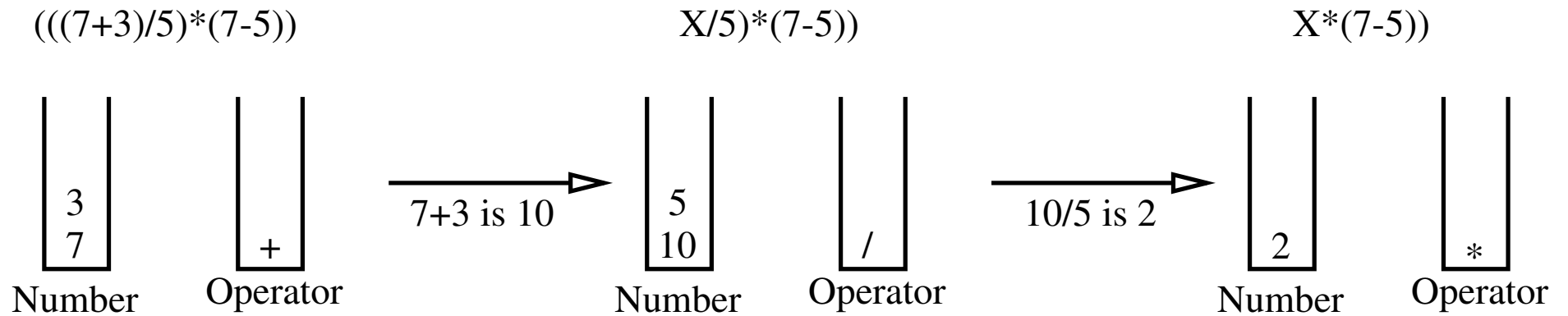
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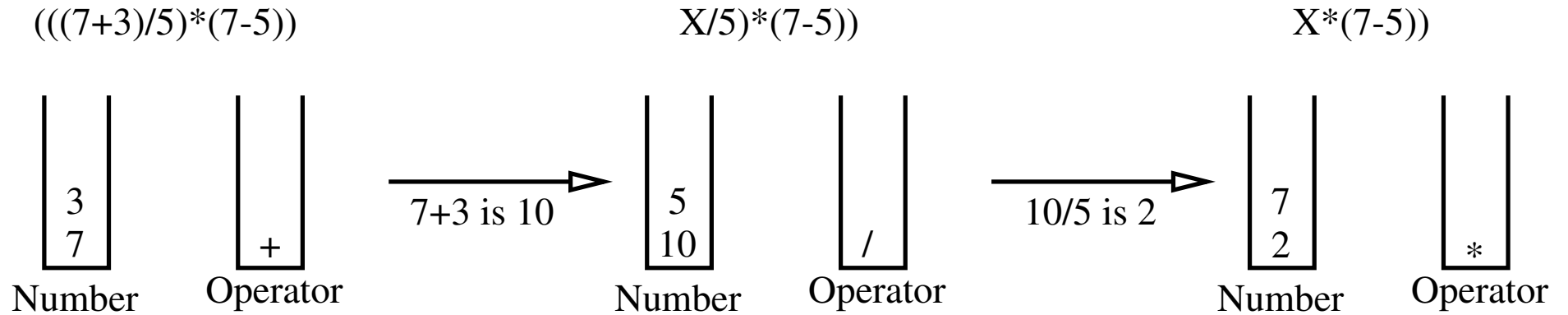
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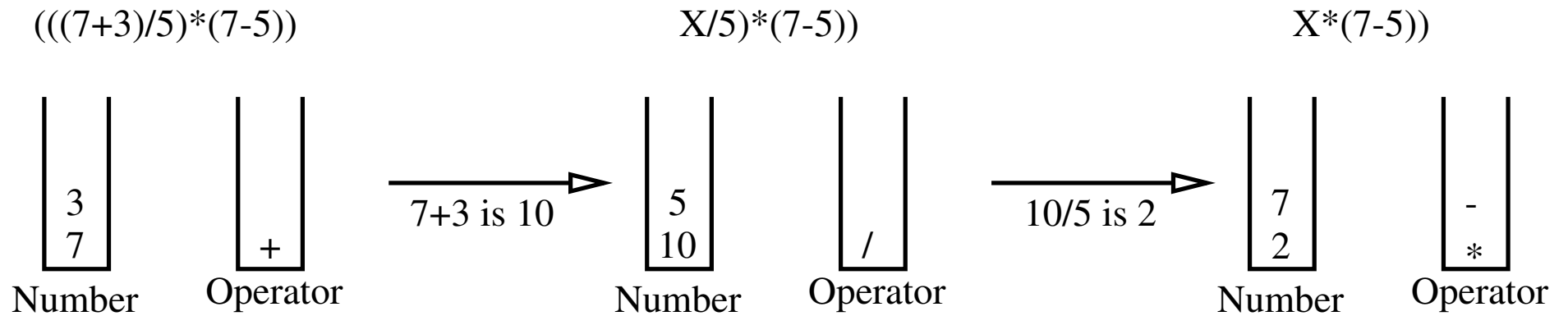
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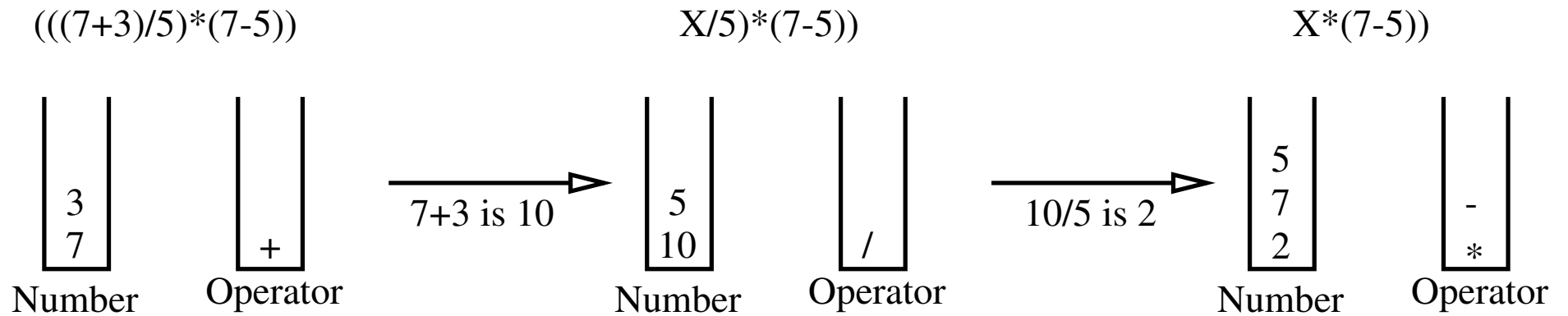
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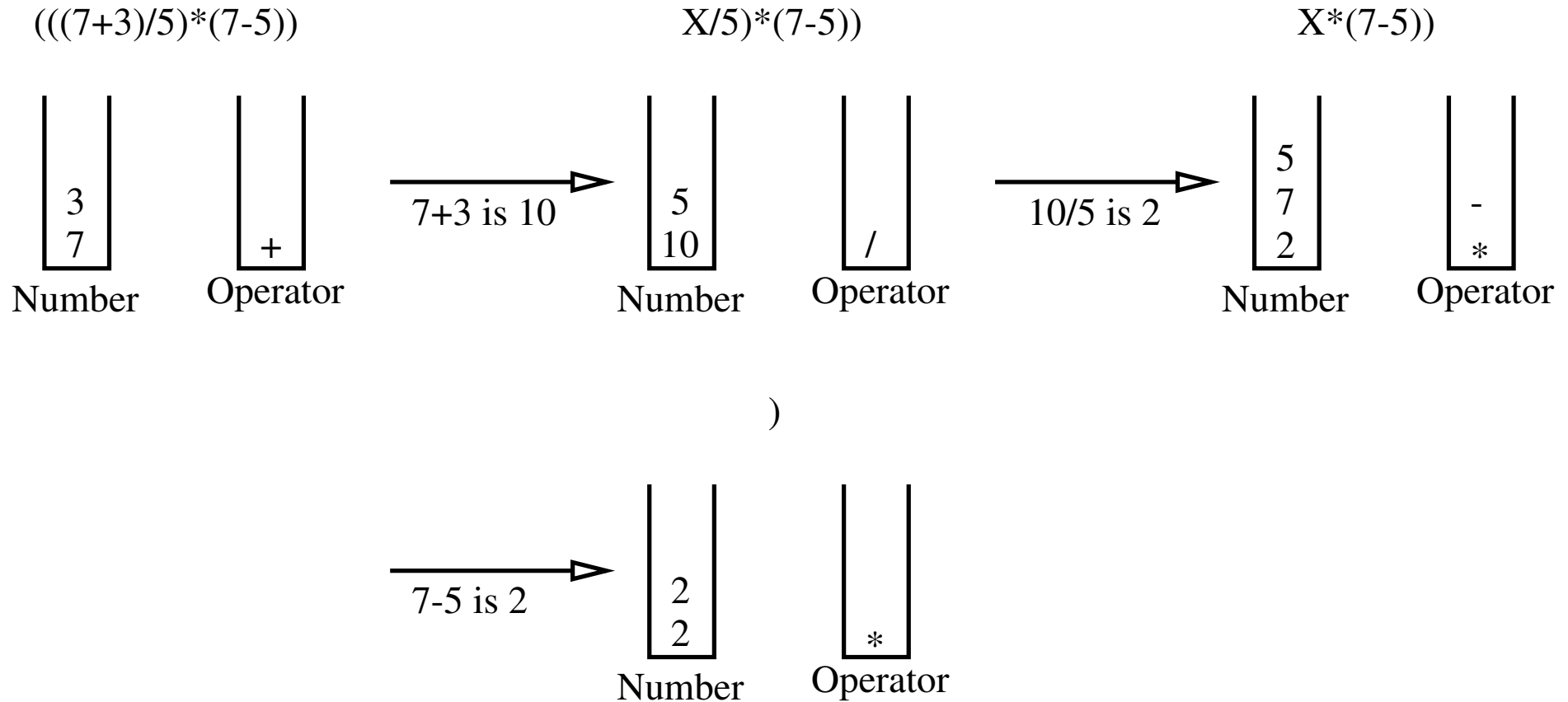
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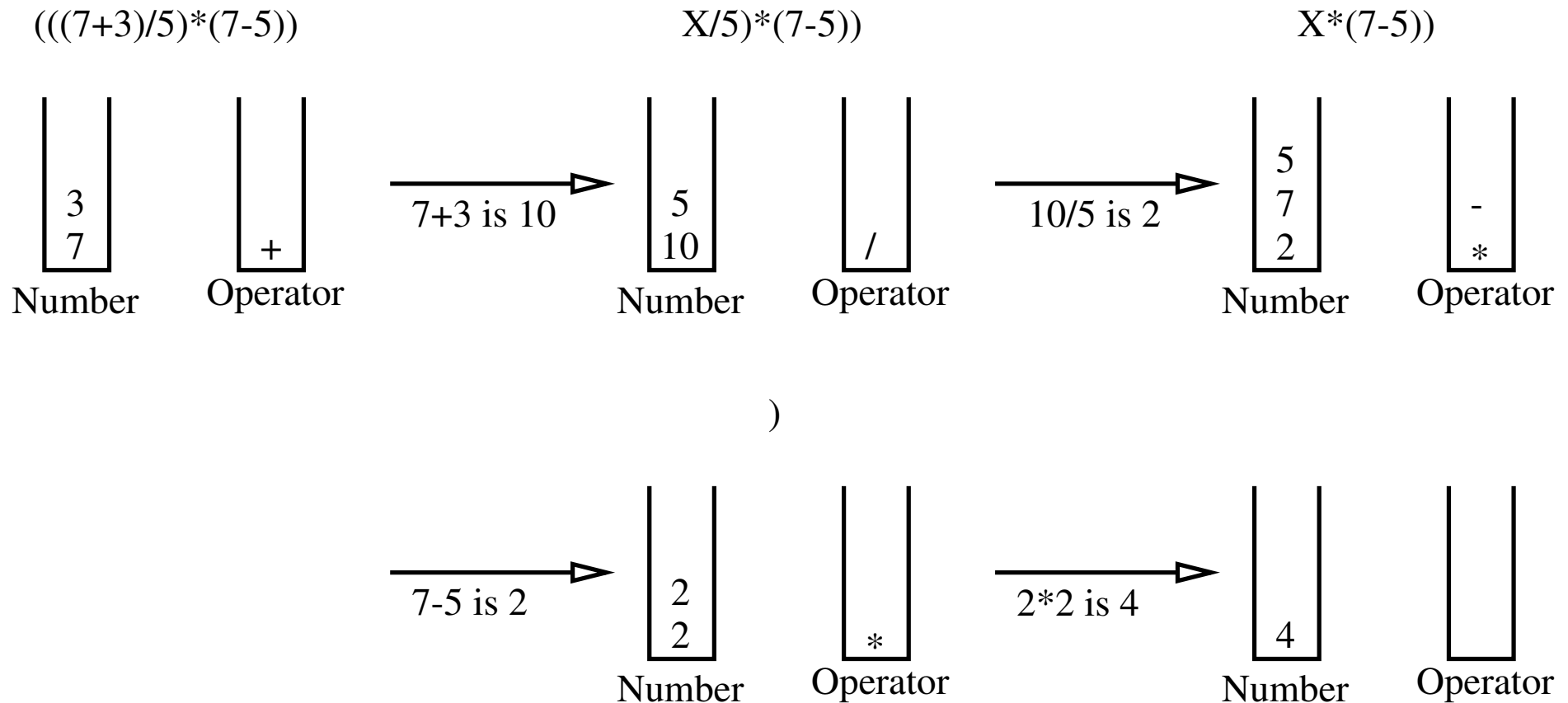
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Queues

- First-in-first-out (FIFO) memory model



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- `enqueue(elem)`



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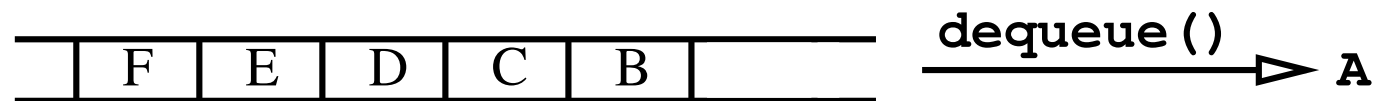
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Queues

- 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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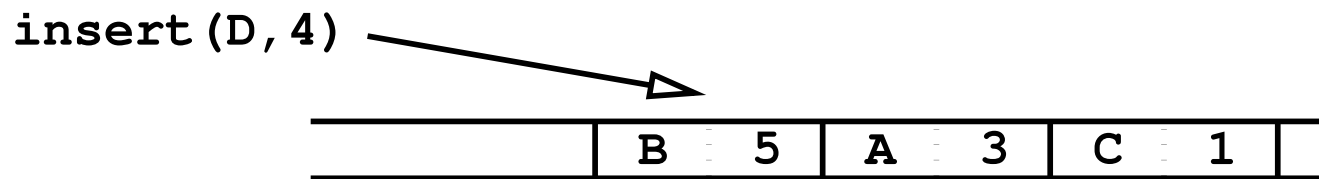
Priority Queues

- Queue with priorities

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Priority Queues

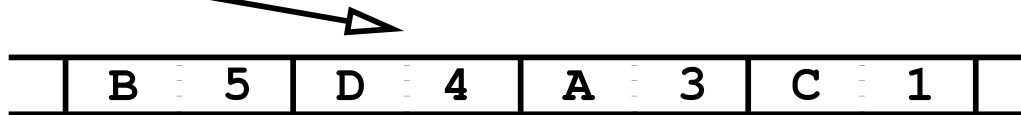
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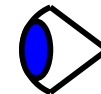
`insert(D, 4)`



Priority Queues

- Queue with priorities
- `insert(elem, priority)` (in C++ `push()`)
- `findMin()` (in C++ `top()`)

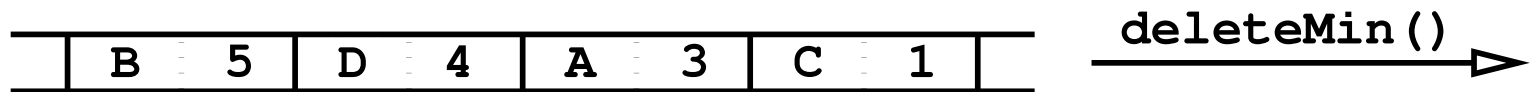
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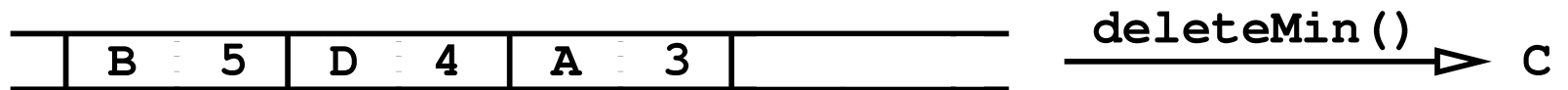
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- Queues with priorities (e.g. which threads should run)
- Real time simulation
- Often used in “greedy algorithms”
 - ★ Huffman encoding
 - ★ Prim’s minimum spanning tree algorithm

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Implementation of Priority Queue

- Could be implemented using a binary tree or linked list
- Most efficient implementation uses a heap
- A heap is a binary tree implemented using an array

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Lists

- 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 counts
- You can have repetitions of elements
- It has random access, e.g. `v[i]`
- You can `push_back(i)`, `insert`, `erase`, etc.
- C++ has a linked list class `List<T>`

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- That is, it is a collection where the order in which you put items into the list counts
- You can have repetitions of elements
- It has random access, e.g. `v[i]`
- You can `push_back(i)`, `insert`, `erase`, etc.
- C++ has a linked list class `List<T>`

Sets

- 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
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Maps

- A map provides a content addressable memory for pairs *keyword: data*
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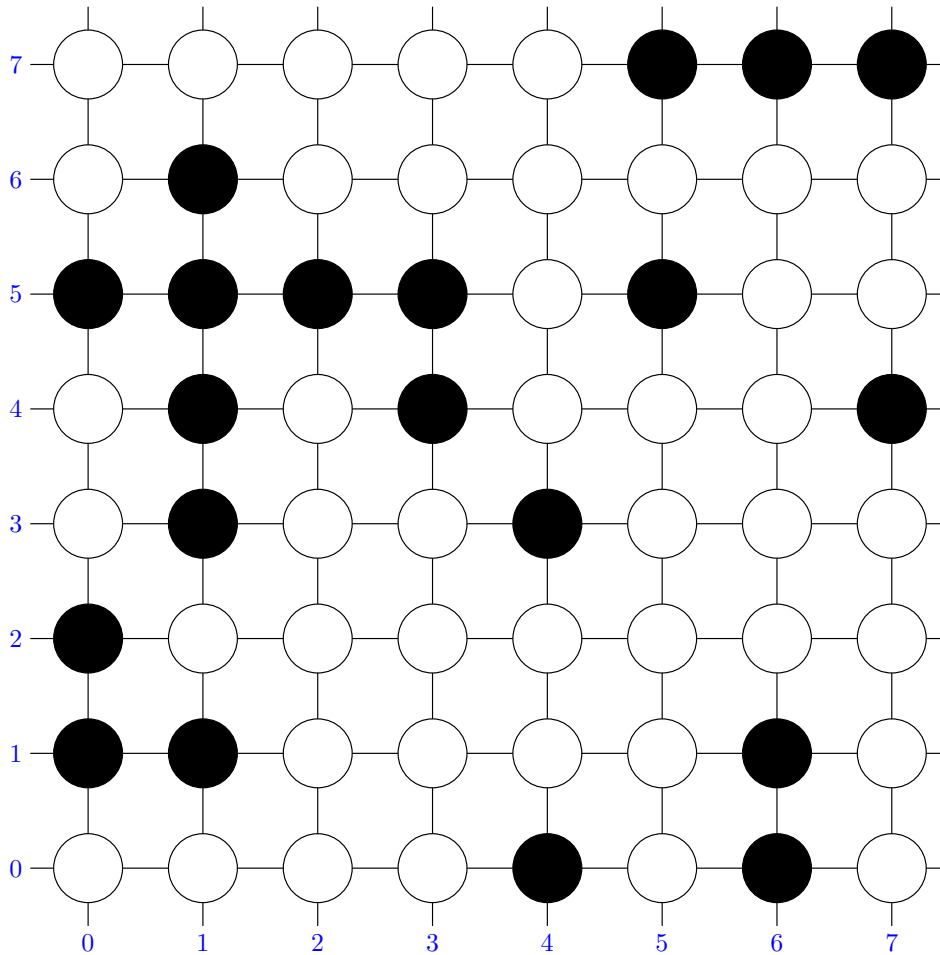
- A map provides a content addressable memory for pairs *keyword: data*
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Outline

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

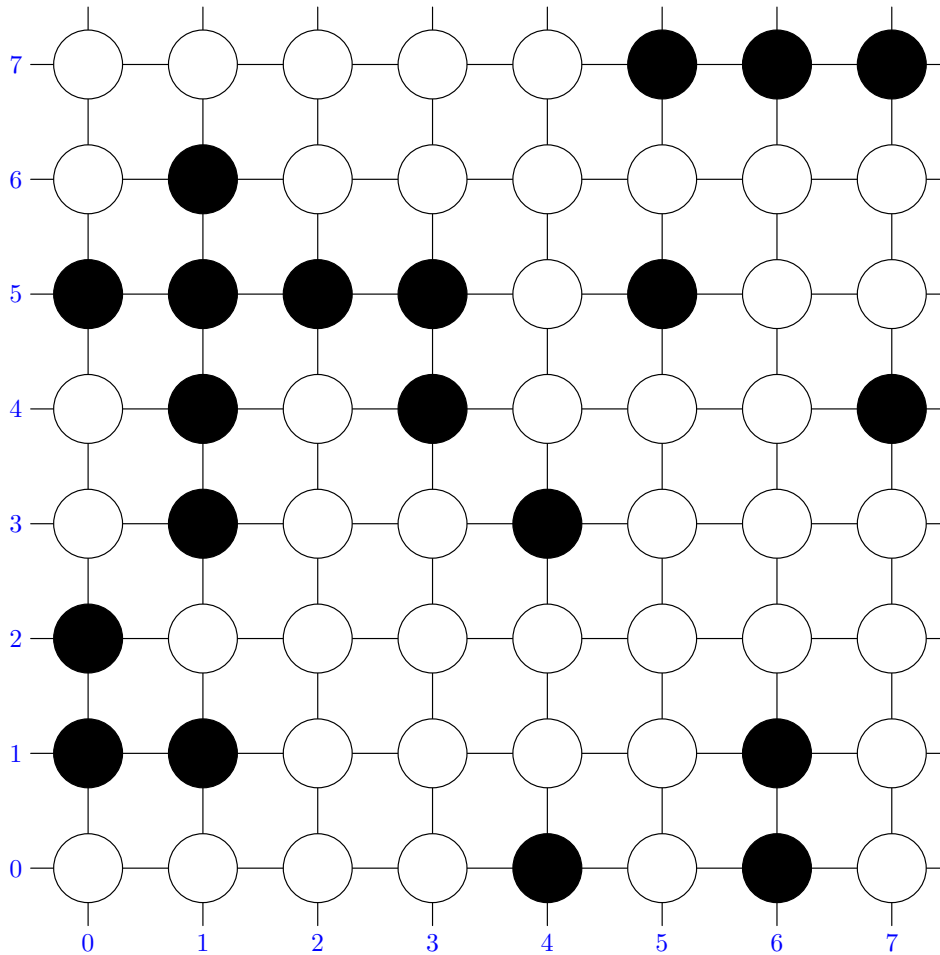


Connected Nodes



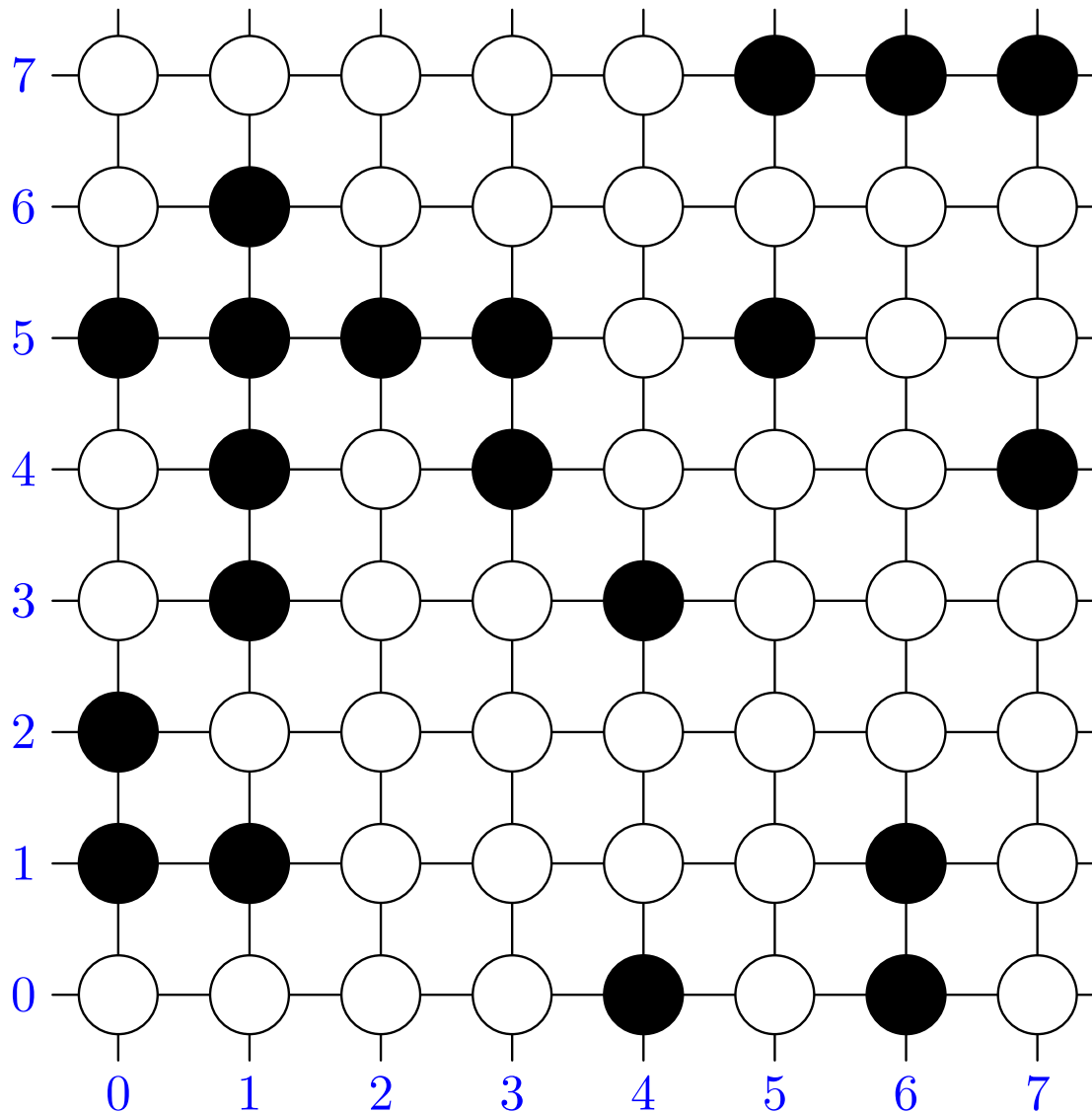
- A frequent problem is to find clusters of connected cells
- Applications in computer vision, computer go, graph connectedness, . . .

Connected Nodes

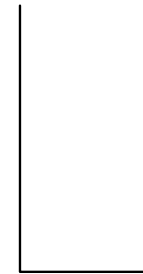


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Connected Nodes

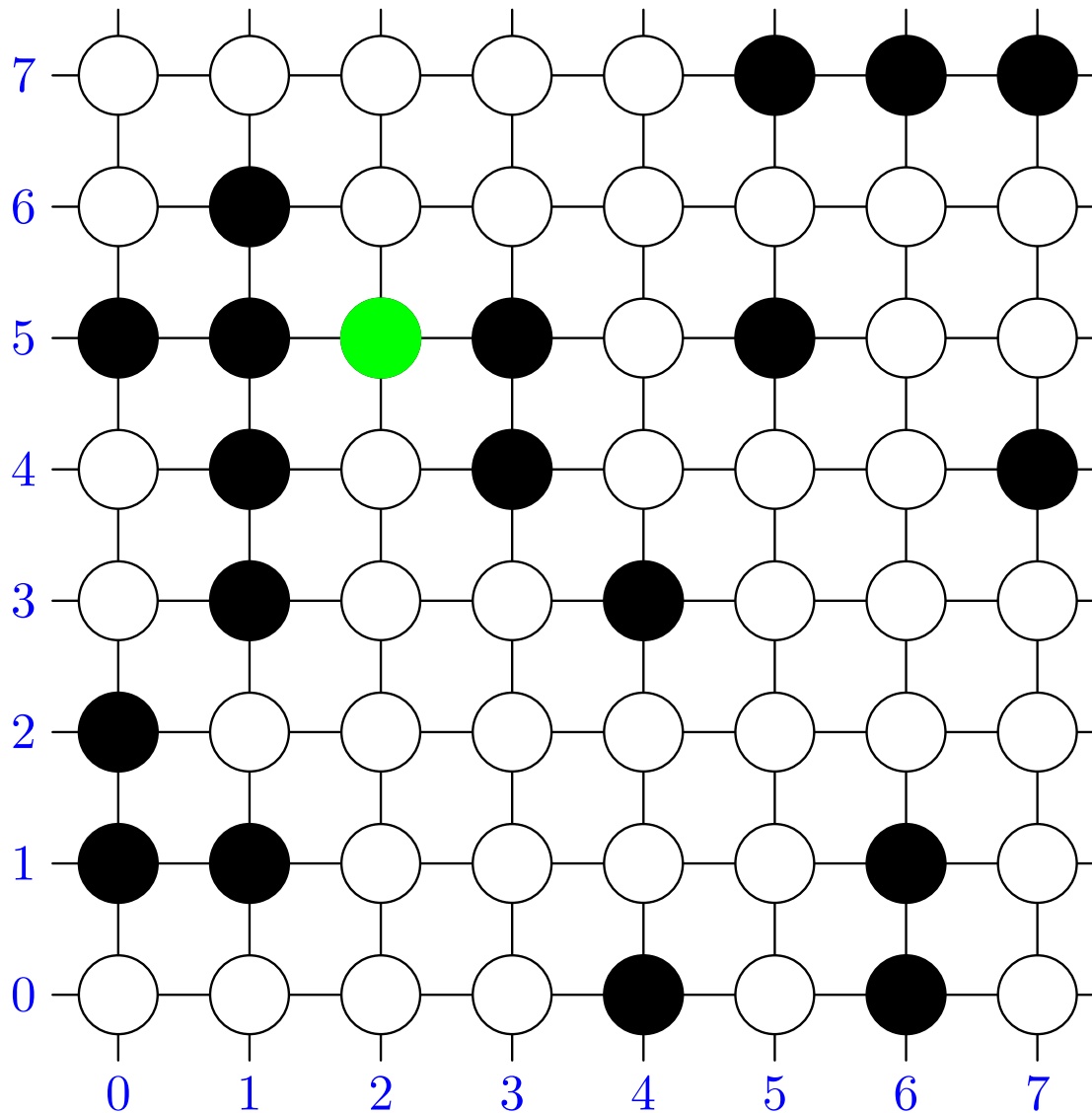


uncheckedNodes =



clusterNodes =
{ }

Connected Nodes



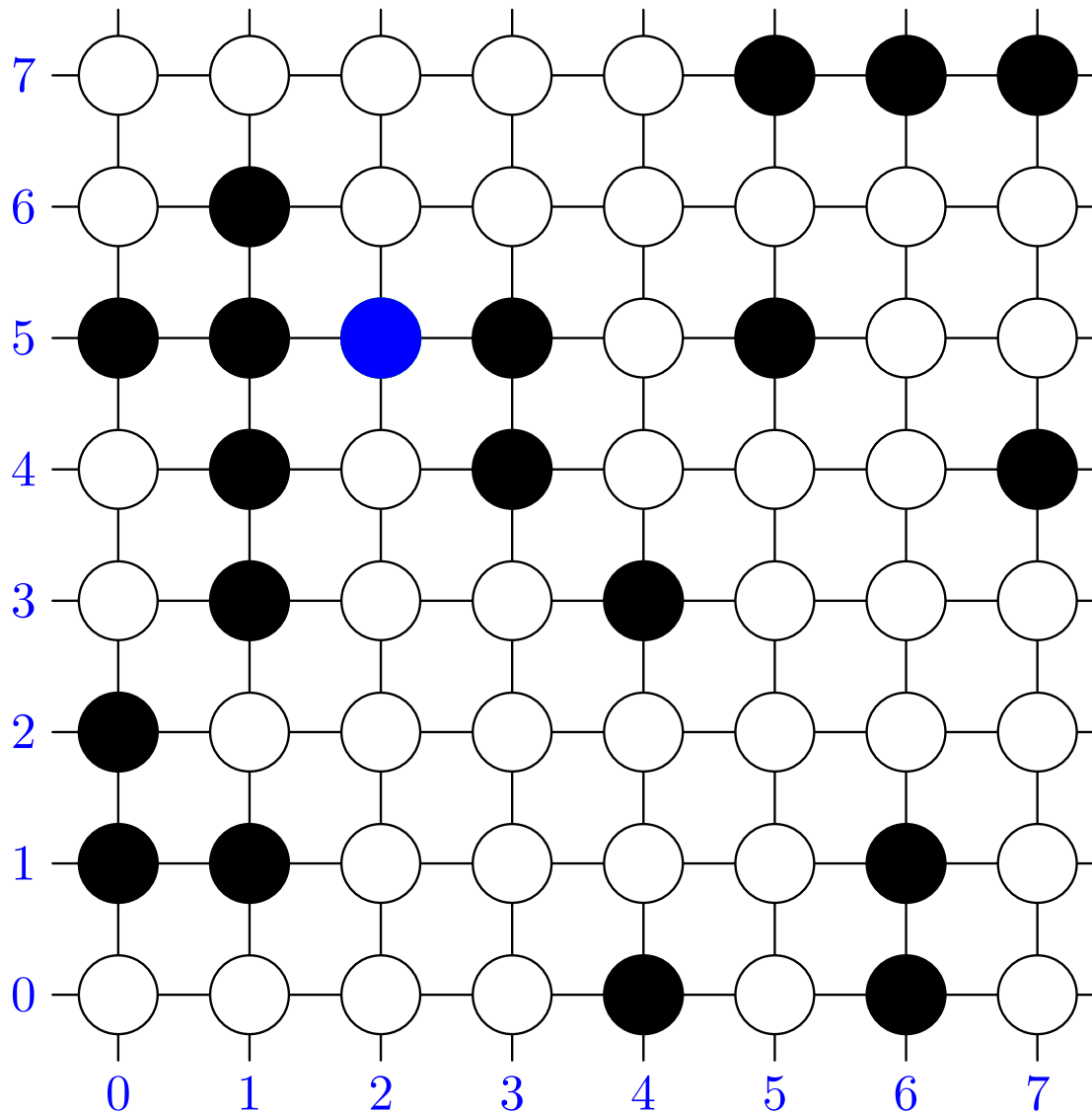
startNode = (2,5)

uncheckedNodes =

(2,5)

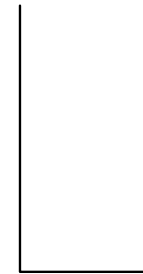
clusterNodes =
{ (2,5) }

Connected Nodes



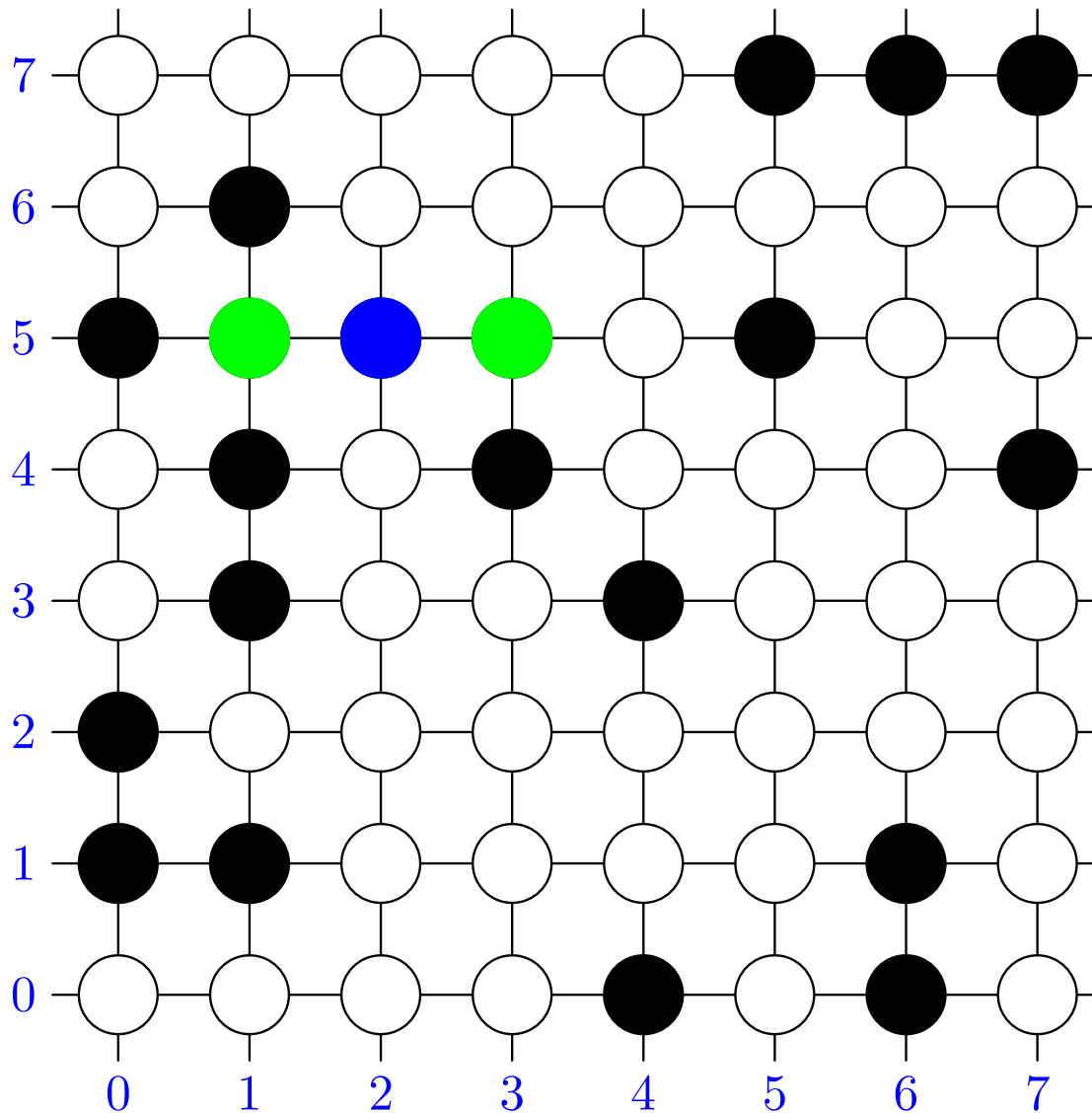
$\text{next} = (2, 5)$

$\text{uncheckedNodes} =$



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

Connected Nodes



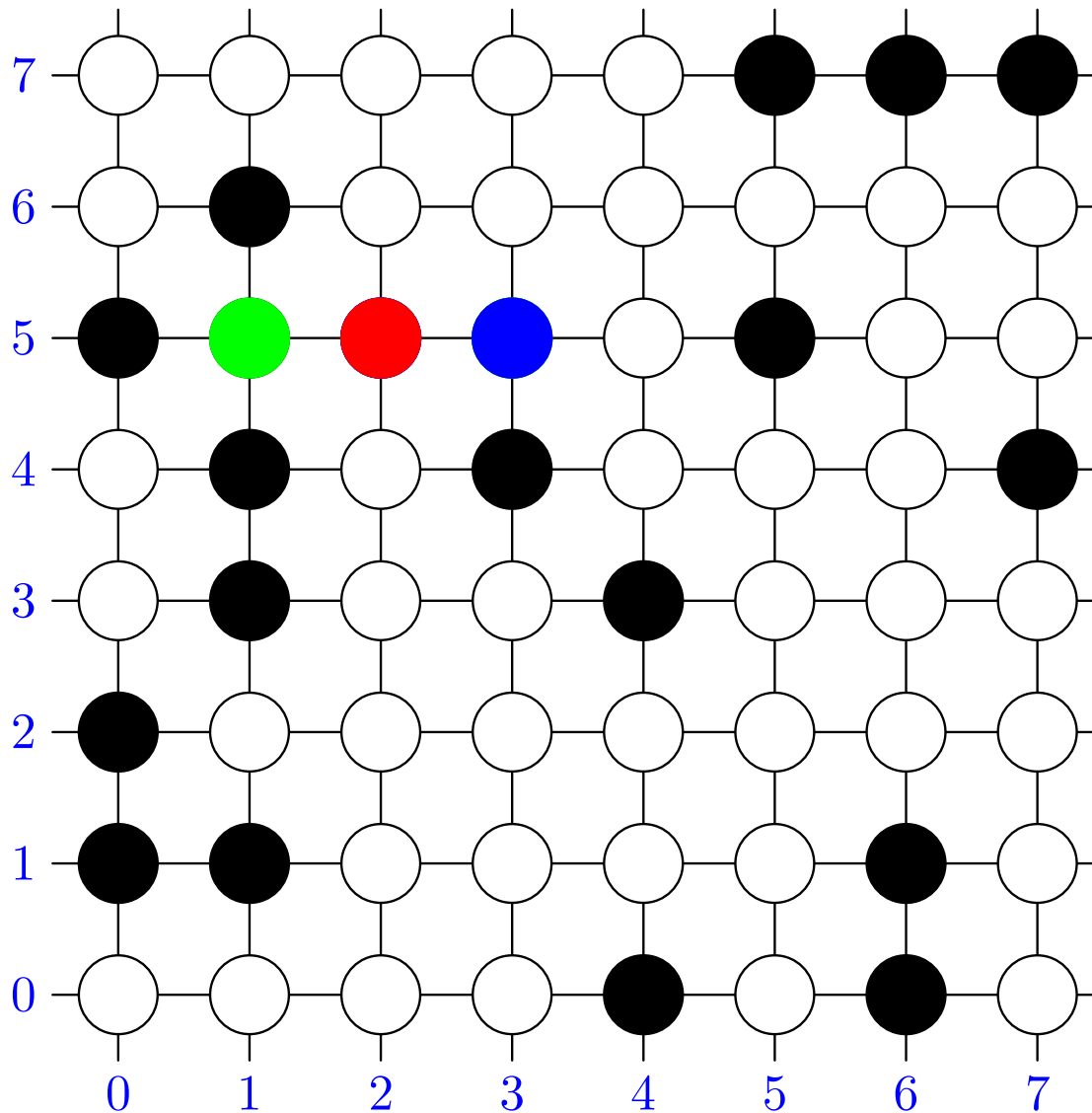
$\text{next} = (2, 5)$

$\text{uncheckedNodes} =$

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

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

Connected Nodes



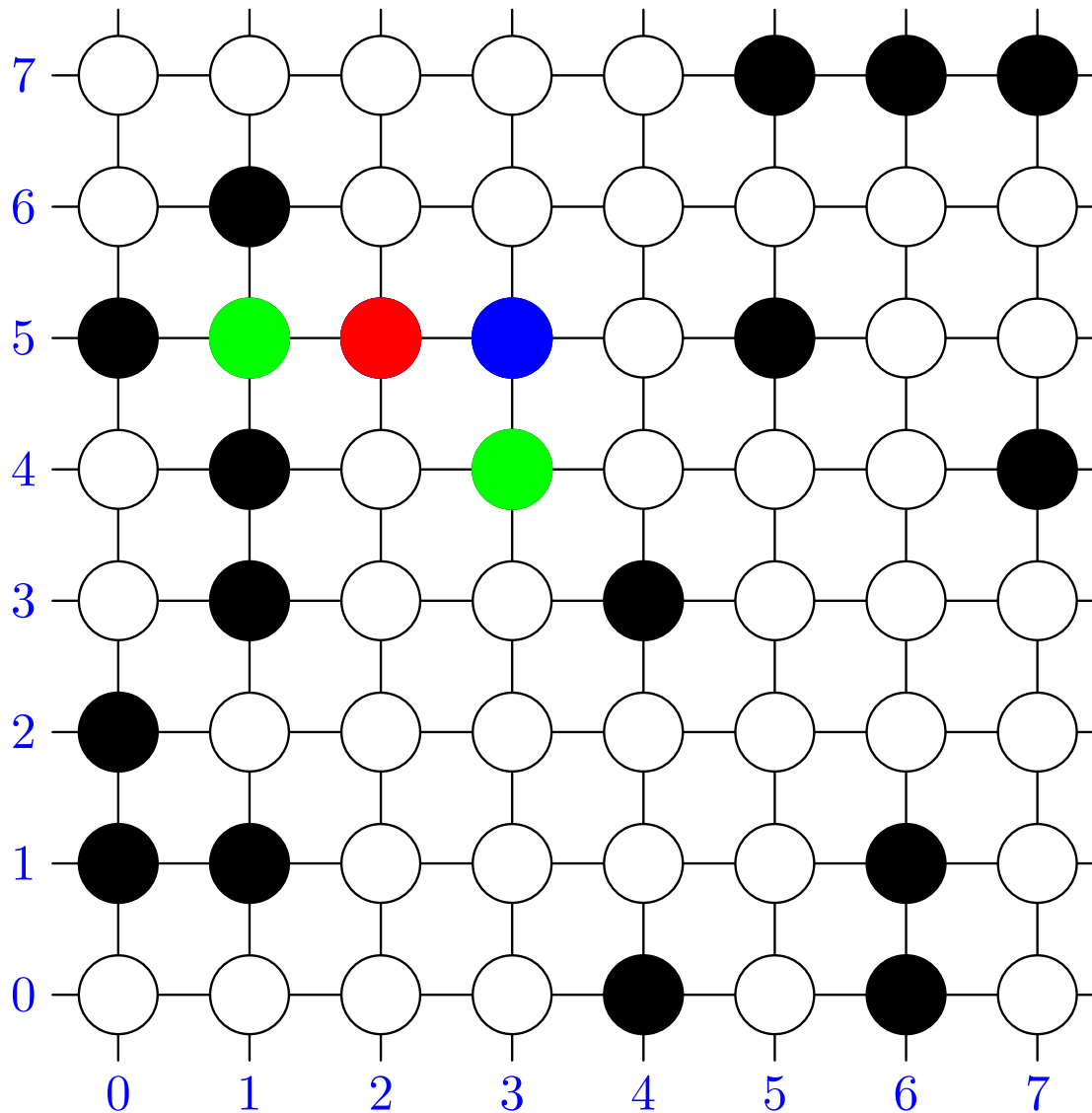
$\text{next} = (3, 5)$

$\text{uncheckedNodes} =$

$(1, 5)$

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

Connected Nodes



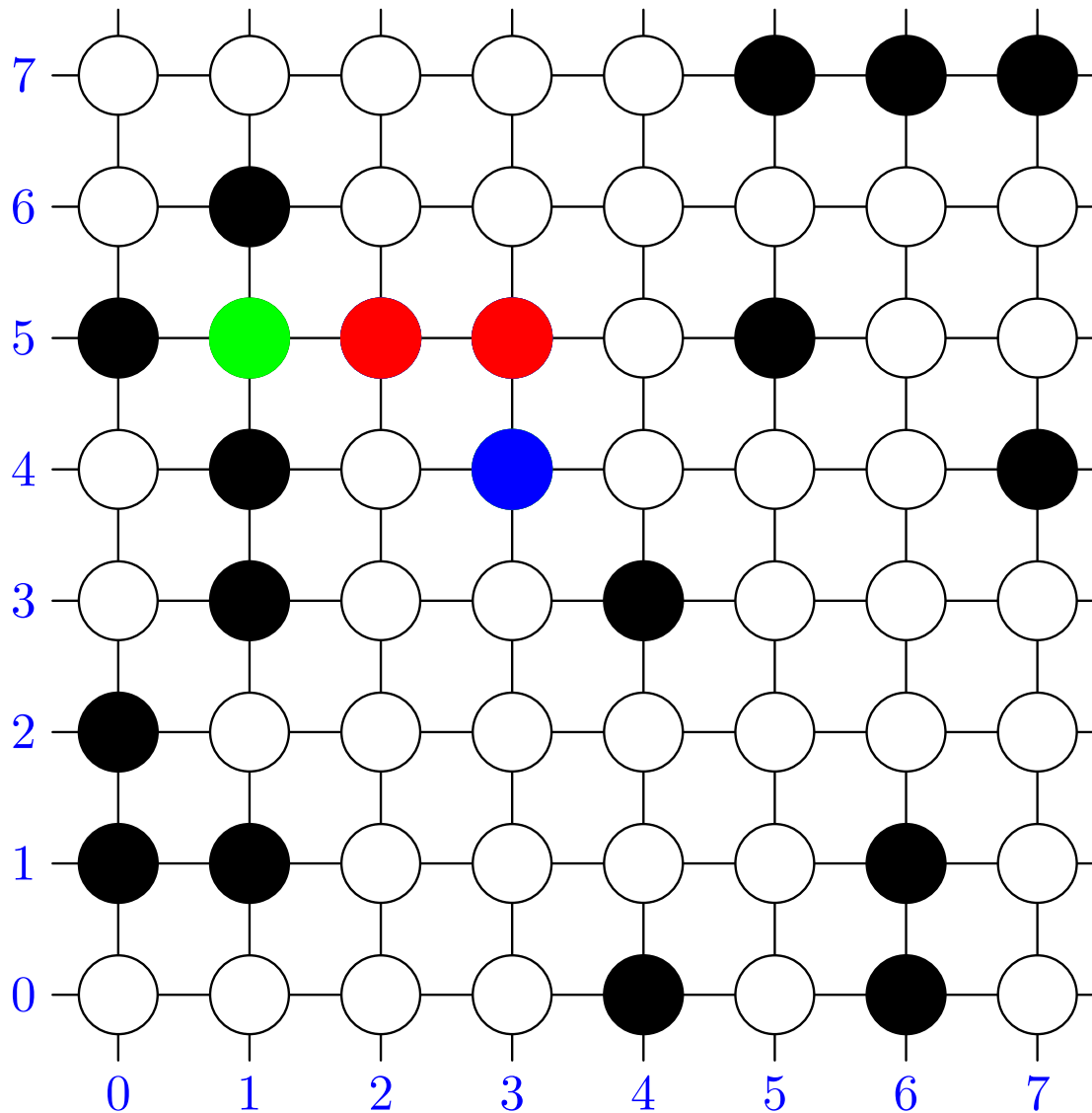
$\text{next} = (3, 5)$

$\text{uncheckedNodes} =$

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

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

Connected Nodes



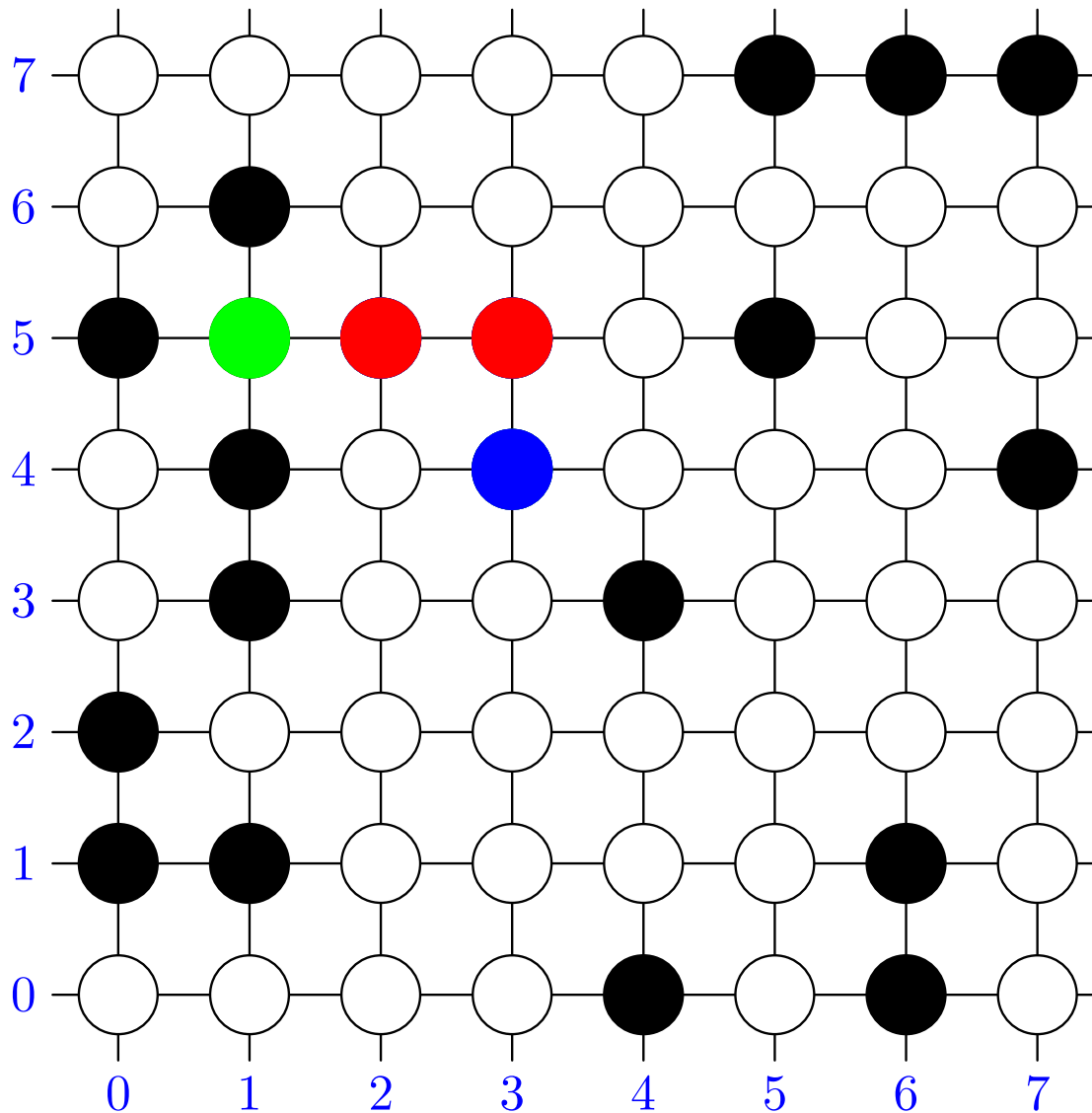
$\text{next} = (3, 4)$

$\text{uncheckedNodes} =$

$(1, 5)$

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

Connected Nodes



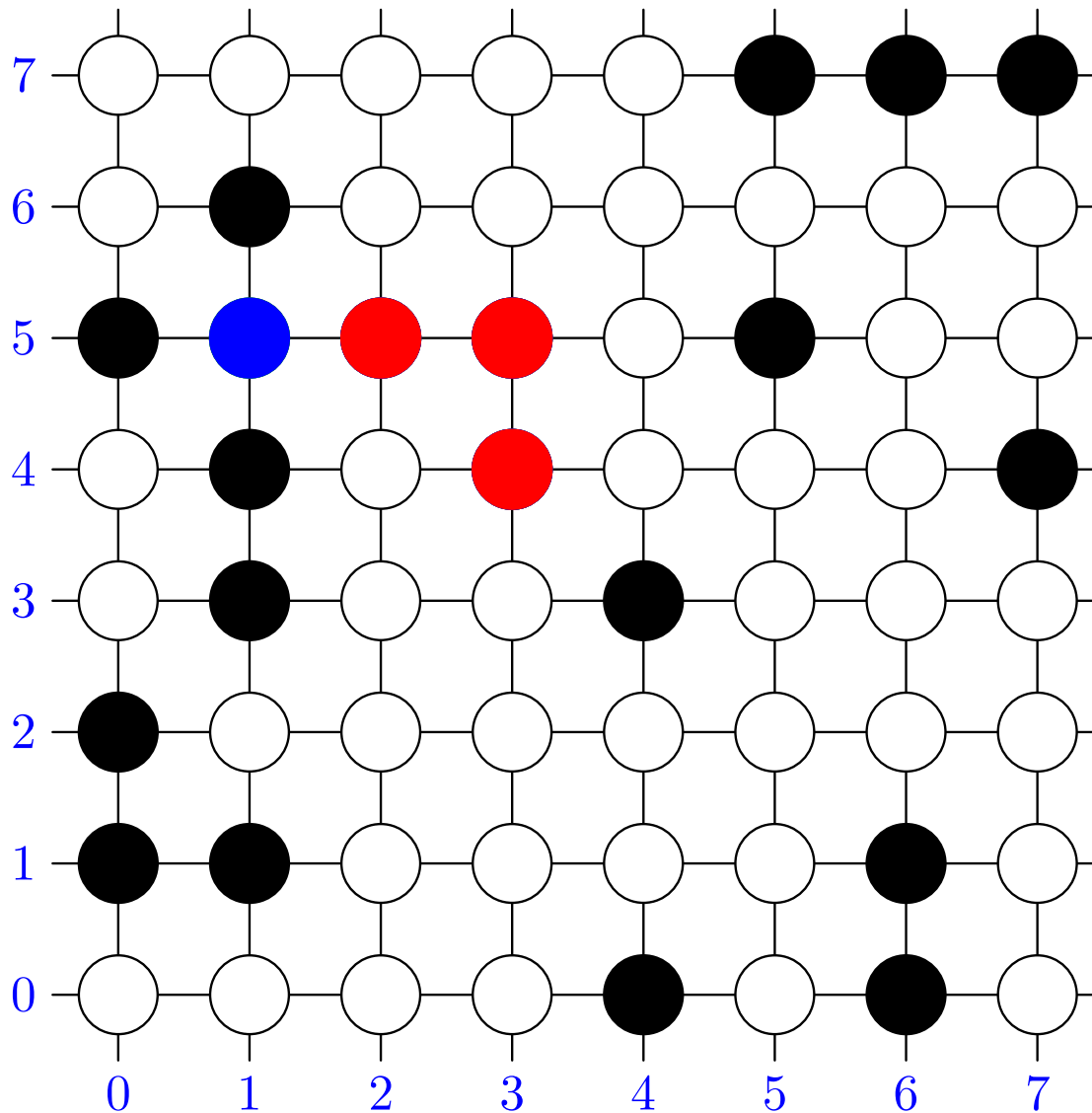
$\text{next} = (3, 4)$

$\text{uncheckedNodes} =$

$(1, 5)$

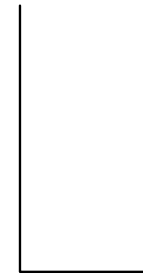
$\text{clusterNodes} =$
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Connected Nodes



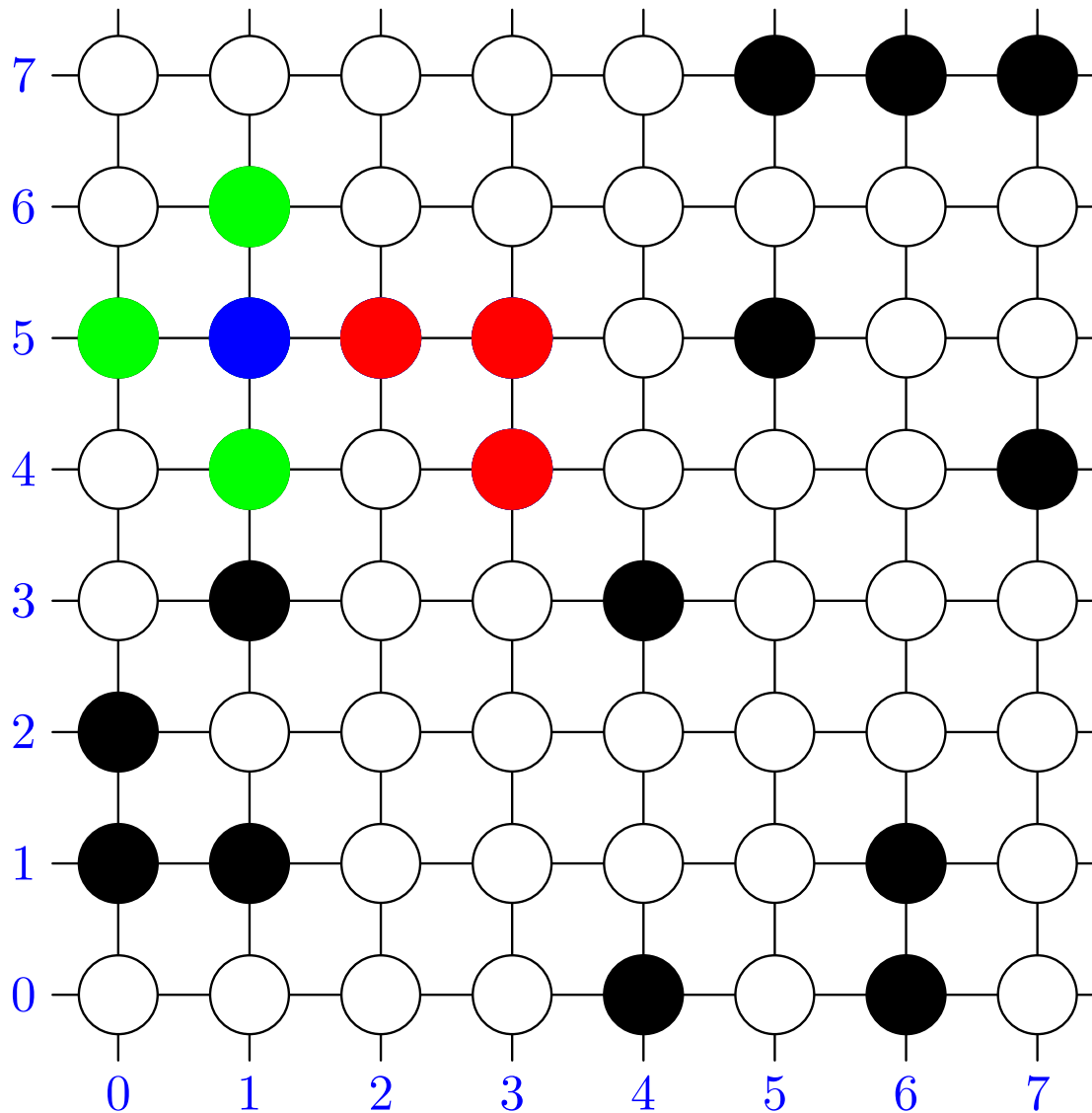
$\text{next} = (1, 5)$

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

Connected Nodes



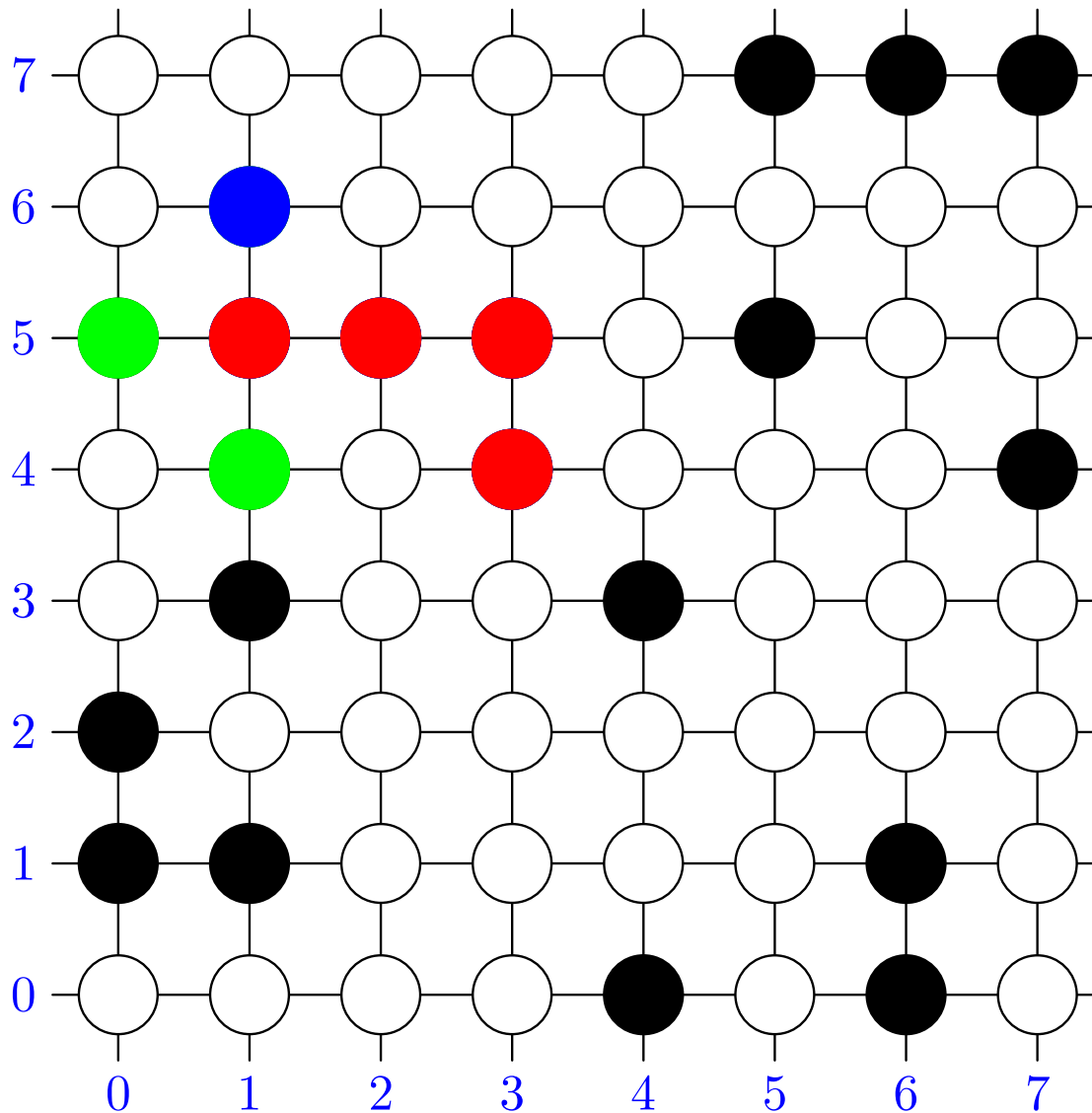
$\text{next} = (1, 5)$

$\text{uncheckedNodes} =$

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

$\text{clusterNodes} =$
 $\{ (2, 5), (1, 5), (3, 5),$
 $(3, 4), (0, 5), (1, 4),$
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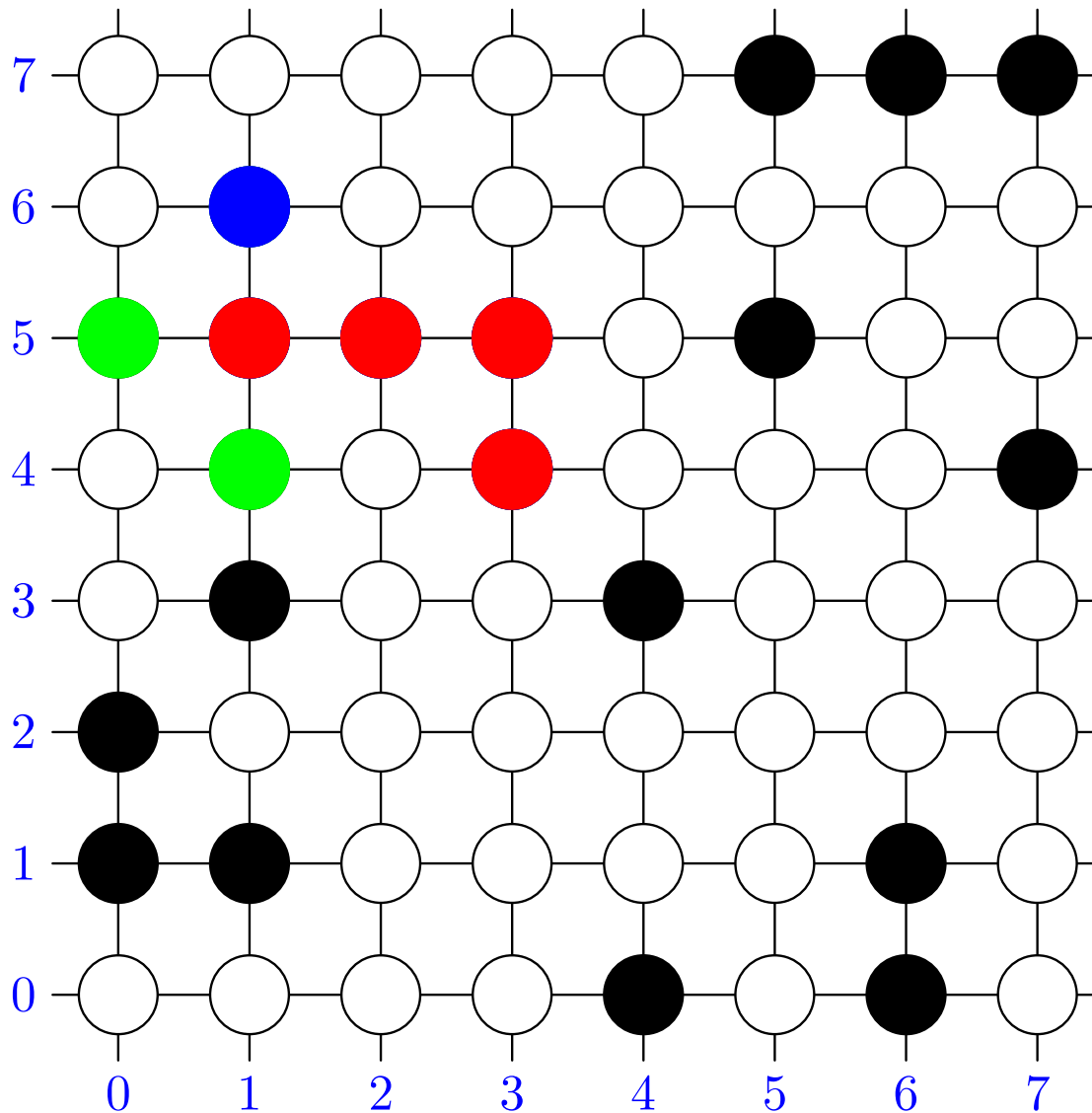
$\text{next} = (1, 6)$

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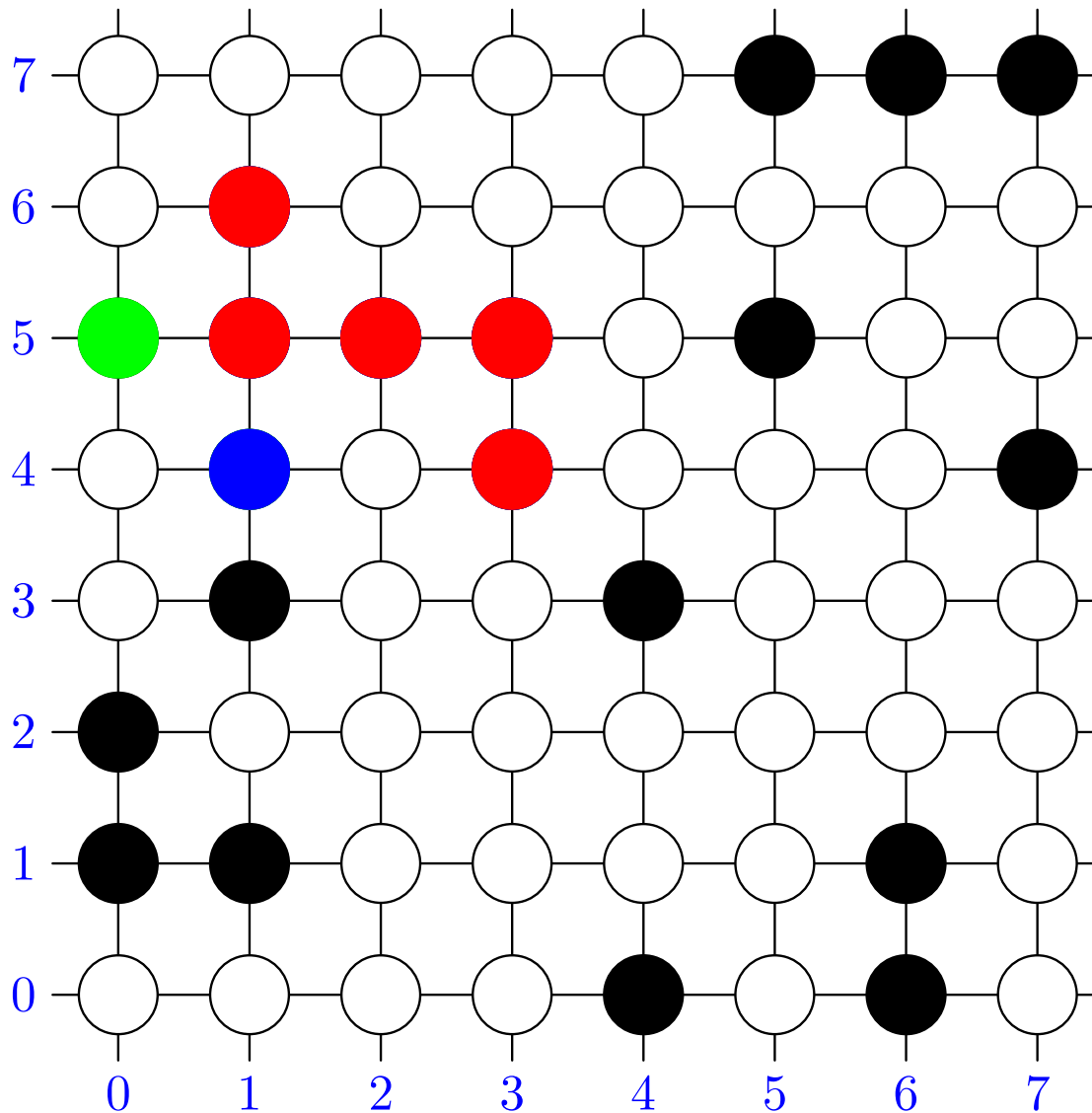
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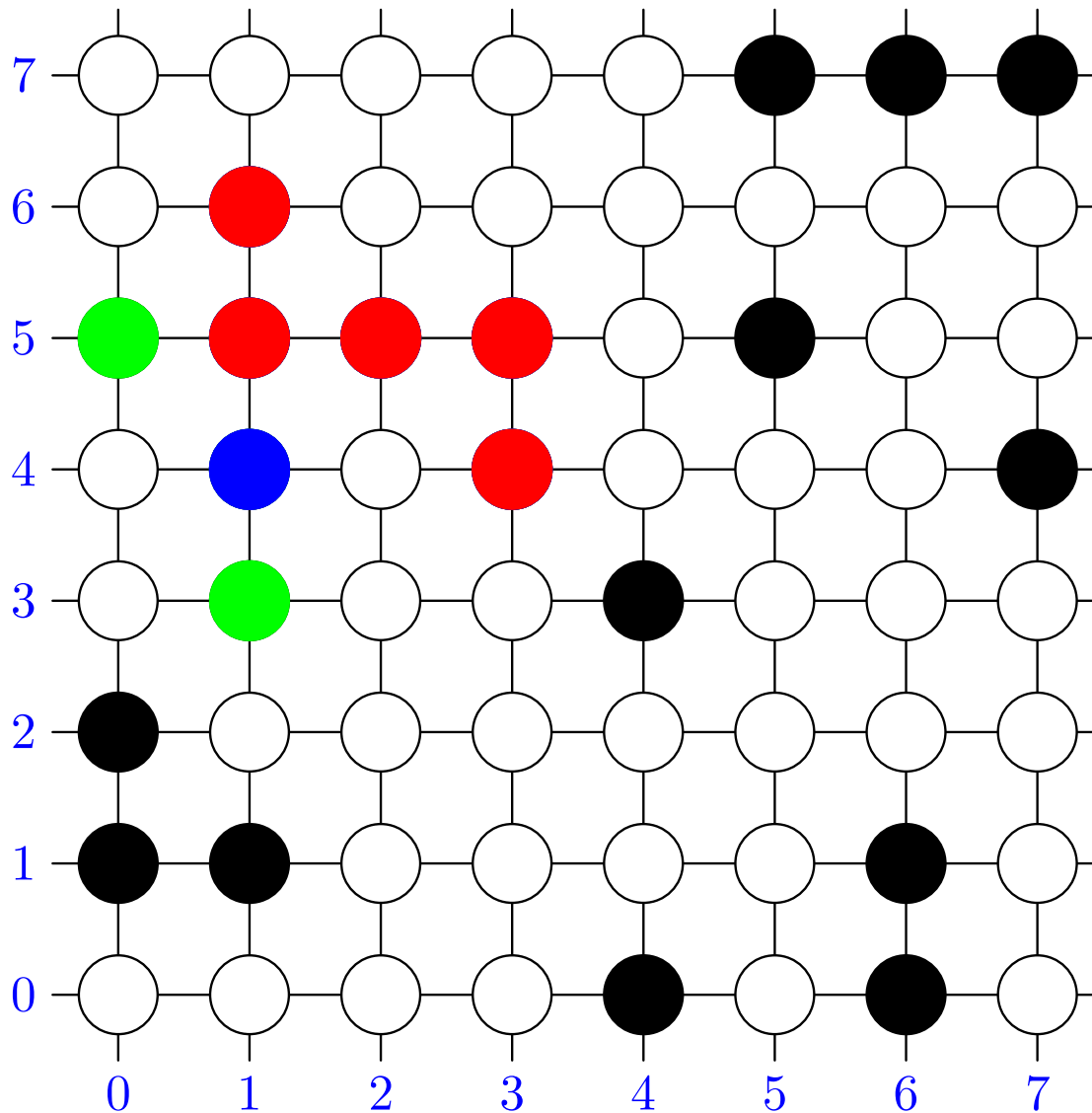
$\text{next} = (1, 4)$

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Connected Nodes



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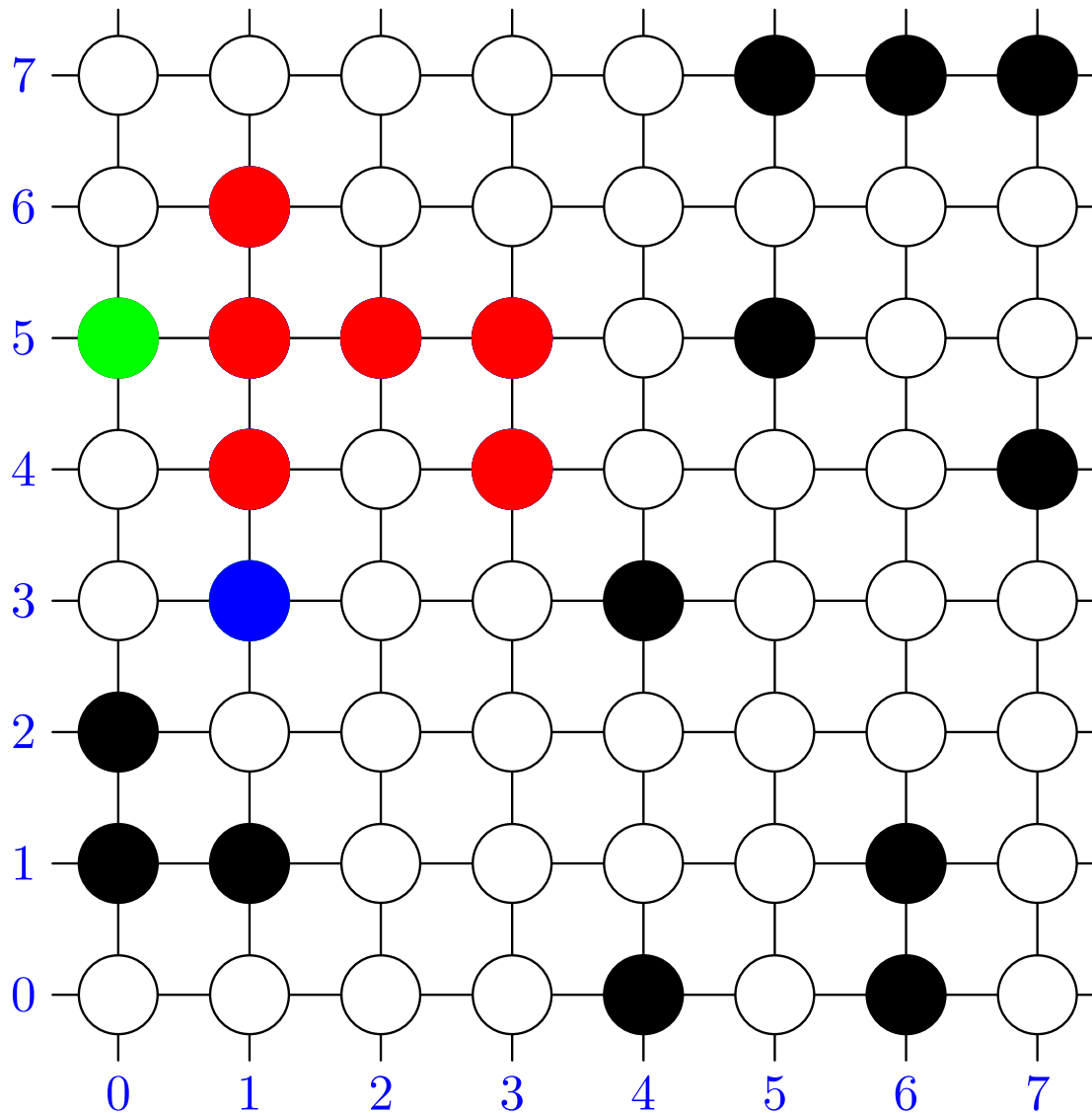
$\text{uncheckedNodes} =$

$(1, 3)$
$(0, 5)$

$\text{clusterNodes} =$

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 $(3, 4), (0, 5), (1, 4),$
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Connected Nodes



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

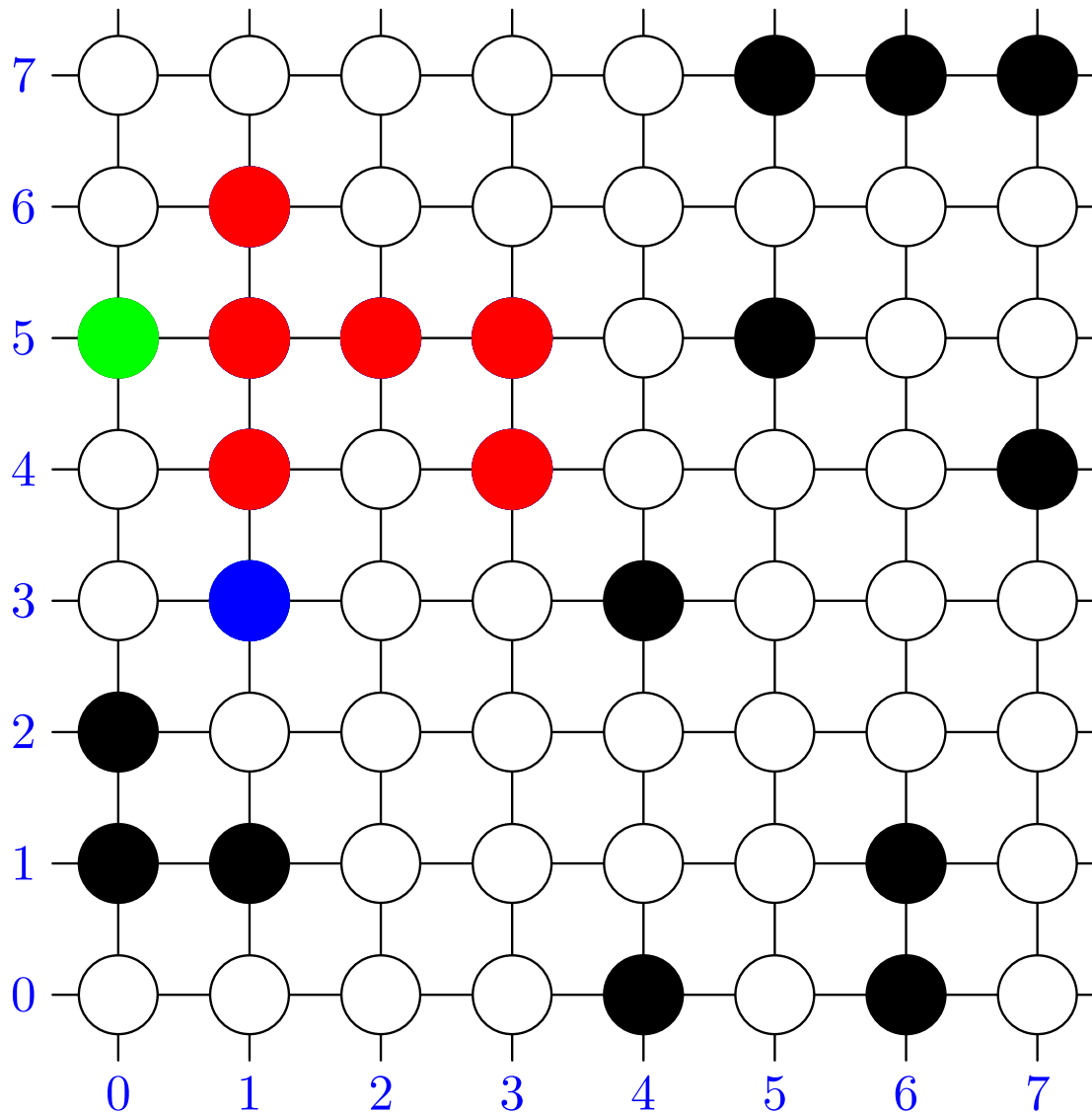
$\text{uncheckedNodes} =$

$(0, 5)$

$\text{clusterNodes} =$

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 $(3, 4), (0, 5), (1, 4),$
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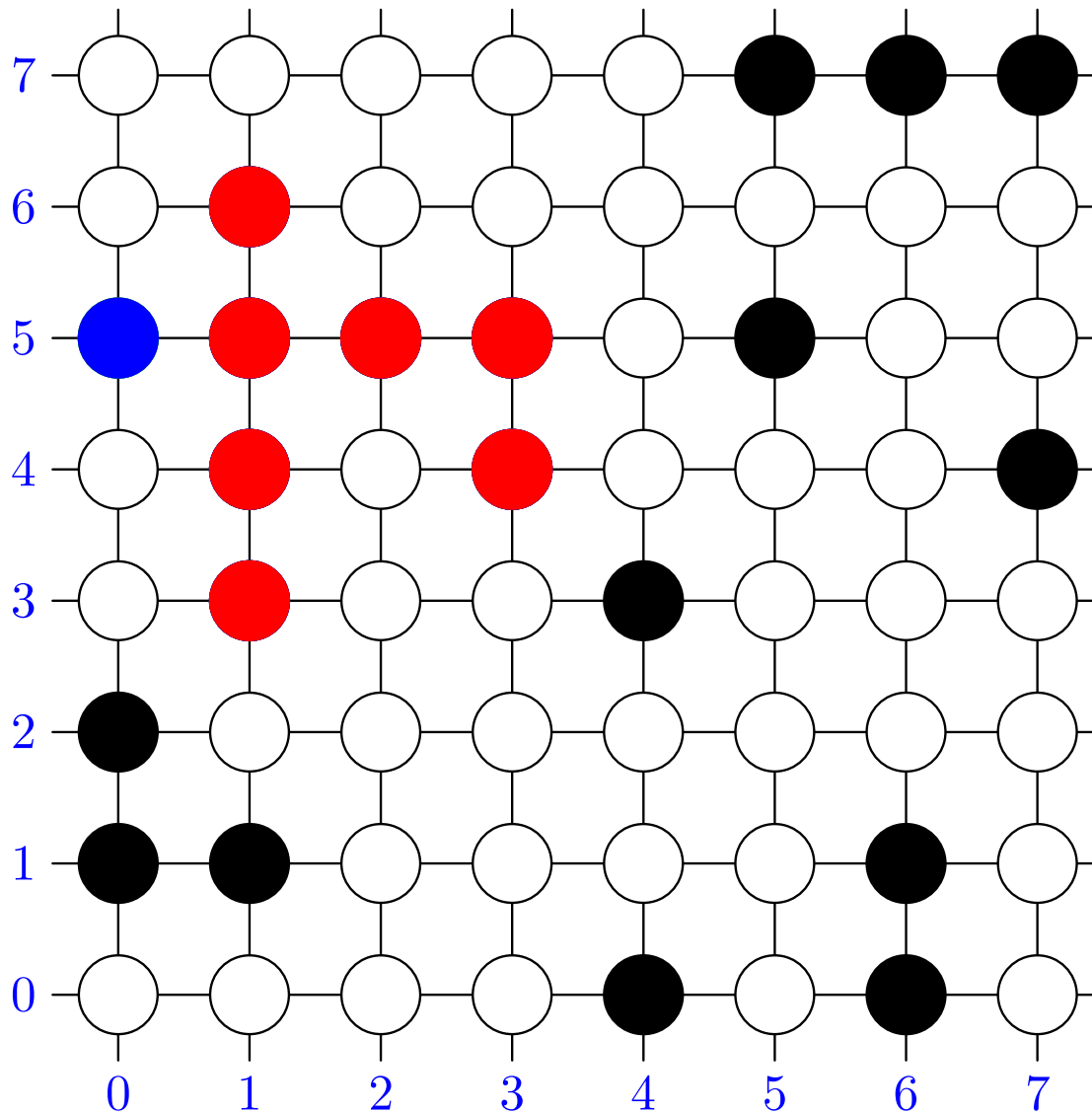
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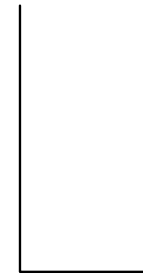
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$\text{next} = (0, 5)$

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    while (!uncheckedNodes.empty()) {
        Node next = uncheckedNodes.top();    uncheckedNodes.pop();
        vector<Node> neighbours = graph.getNeighbours(next);
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            }
        }
    }

    return clusterNodes;
}
```

Lessons

- Abstract Data Types (ADT) are interfaces to data
- 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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