Data Structures and Algorithms

Lesson 2: *Declare your intentions (not your actions)*

IN
CONGRESS,
JULY 4, 1776.
A
DECLARATION
BY THE
REPRESENTATIVES
OF THE
UNITED STATES OF AMERICA,
In GENERAL CONGRESS assembled.

JOHN HANCOCK, PRESIDENT.
ATTEST,
CHARLES THOMPSON, Secretary.

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


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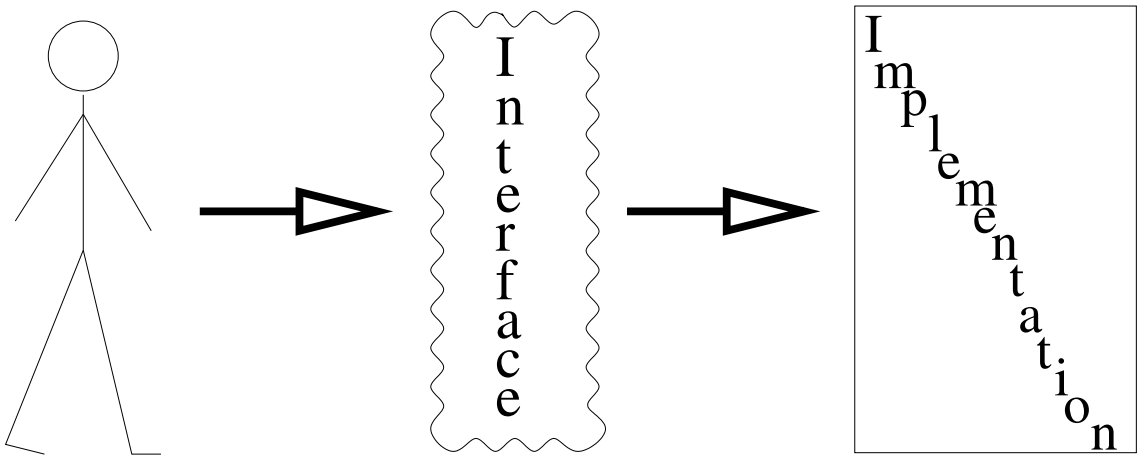
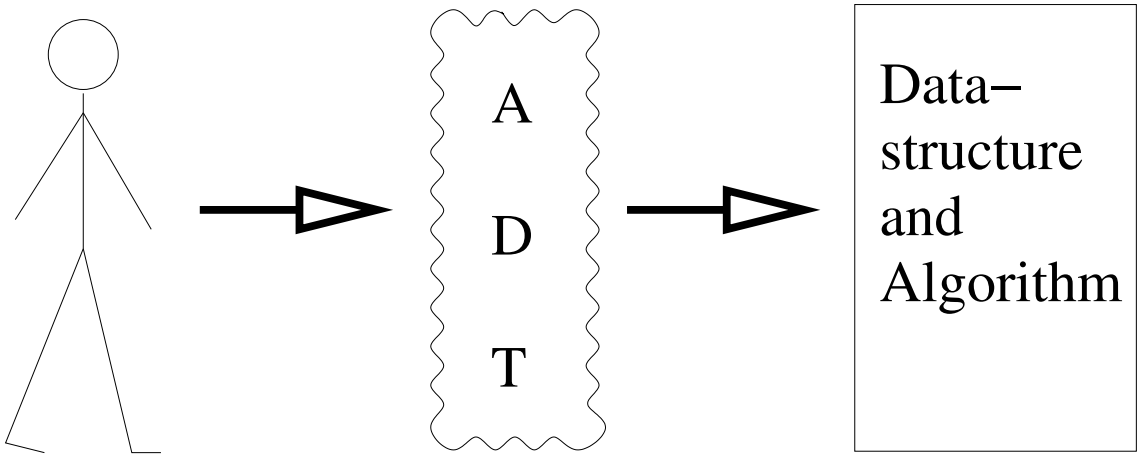
Encapsulation

- In the OO-methodology you separate the **interface** from the implementation
- The implementation is hidden (encapsulated) and may be changed without affecting how the class is used
- This is done in classes with the set of public methods being the interface



Abstract Data Types

- An **Abstract Data Type** (ADT) specifies a set of operations through which a certain data structure (e.g. arrays, lists, trees, graphs) can be accessed
- ADTs are mathematical abstractions (implementation-free)
- 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 ADT



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 operations associated with it
- They are an abstraction away from implementation
- By declaring your intentions you are making your code easier to understand and maintain

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We hold these truths to be self-evident, that all men are created equal, that they are endowed by their Creator with certain unalienable rights, that among these are life, liberty, and the pursuit of happiness. That to secure these rights, governments are instituted among men, deriving their just powers from the consent of the governed, that whenever any form of government becomes destructive of these ends, it is the right of the people to alter or to abolish it, and to institute new government, laying its foundation on such principles, and organizing its powers in such form, as to them shall seem most likely to effect their safety and happiness. Prudence, indeed, will dictate that governments long established should not be changed for light and transient causes; and accordingly all experience hath shewn, that mankind are more disposed to suffer, while evils are sufferable, than to right themselves by abolishing the forms to which they are accustomed. But when a long train of abuses and usurpations, pursuing invariably the same object, evinces a design to reduce them under absolute despotism, it is their right, it is their duty, to throw off such government, and to provide new guards for their future security. Such has been the patient sufferance of these Colonies; and such is now the necessity which constrains them to alter their former systems of government. The history of the present King of Great-Britain is a history of repeated injuries and usurpations, all having in direct object the establishment of an absolute tyranny over these states. To prove this, let facts be submitted to a candid world.

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We, therefore, the Representatives of the UNITED STATES OF AMERICA, in GENERAL CONGRESS assembled, appealing to the Supreme Judge of the world for the rectitude of our intentions, do in the name and by the authority of the good People of these Colonies, solemnly publish and declare, That these United Colonies are, and of right ought to be, FREE AND INDEPENDENT STATES; that they are absolved from all allegiance to the British Crown, and that all political connection between them and the State of Great-Britain, is, and ought to be totally dissolved; and that as FREE AND INDEPENDENT STATES, they have full power to levy war, conclude peace, contract alliances, establish commerce, and to do all other acts and things which INDEPENDENT STATES may of right do. And for the support of this Declaration, with a firm reliance on the protection of Divine Providence, we mutually pledge to each other our lives, our fortunes, and our sacred honor.

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Stacks

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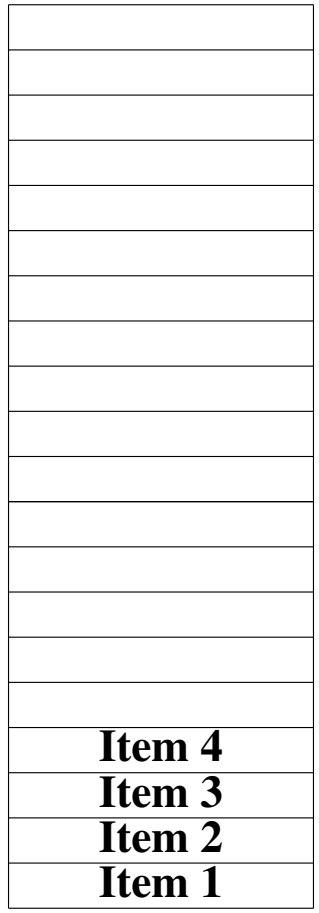

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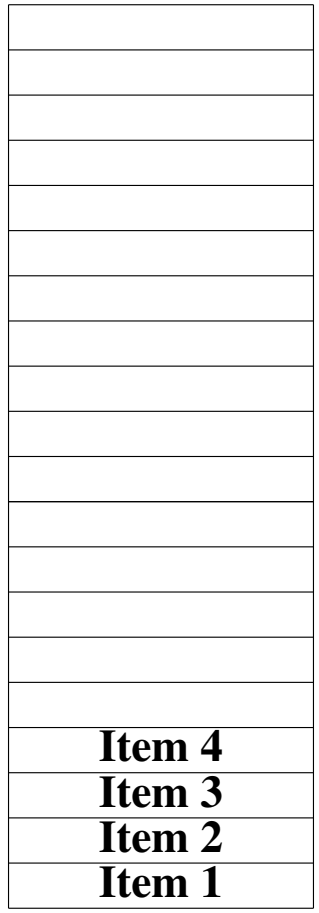
- Standard operations



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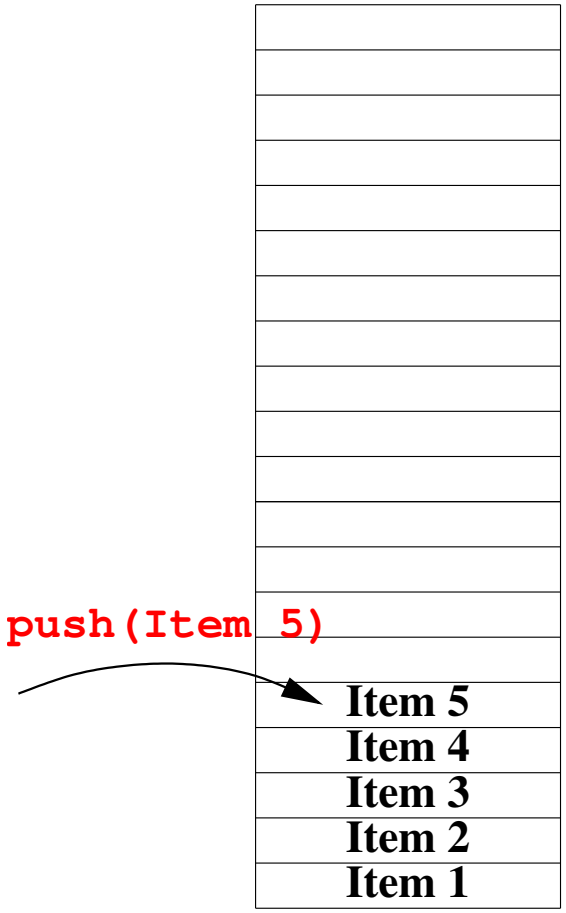
  - ⋆ `push(item)`



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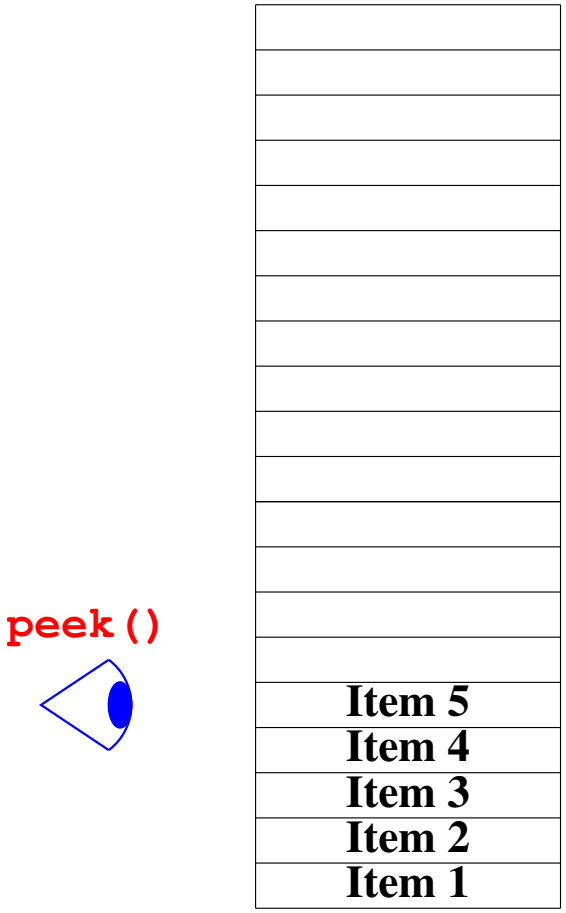
  - `push(item)`
  - `T peek()`



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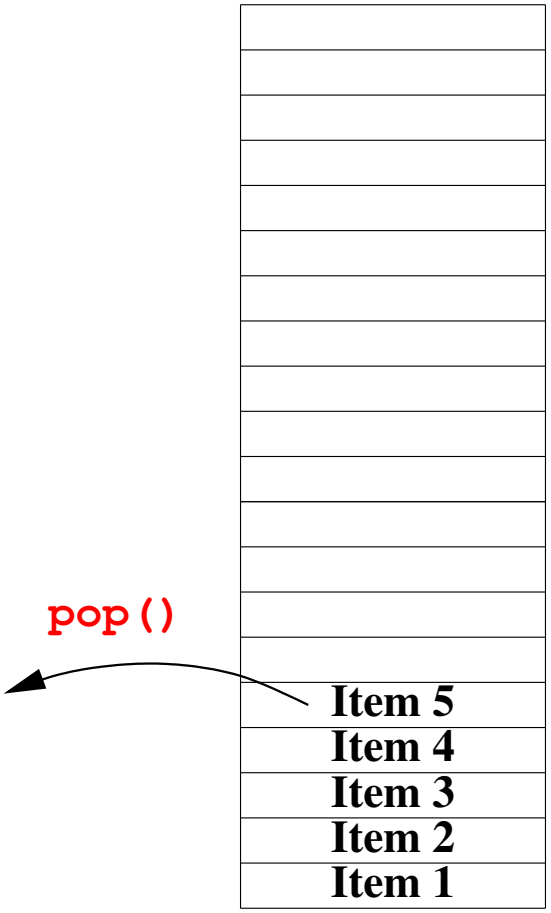

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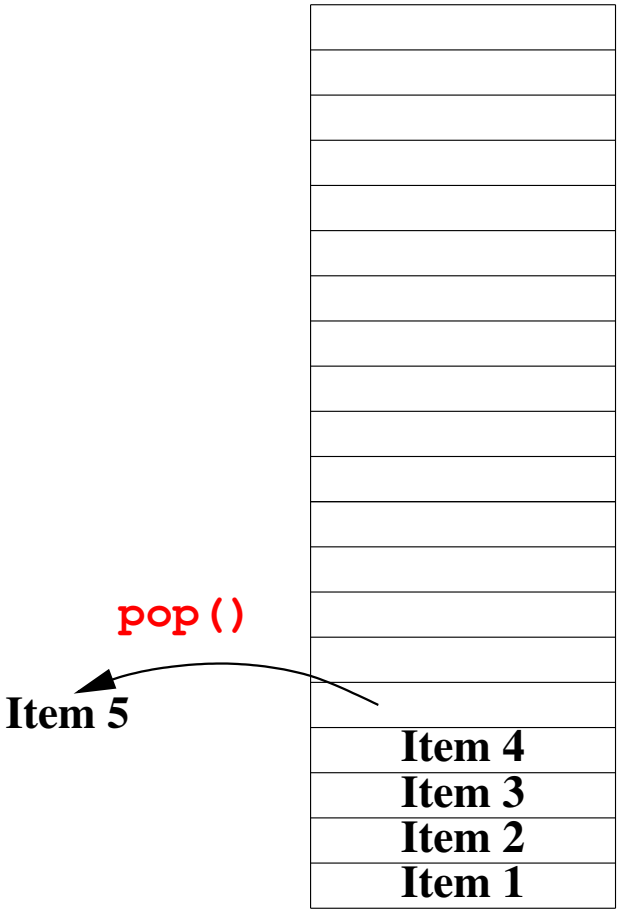

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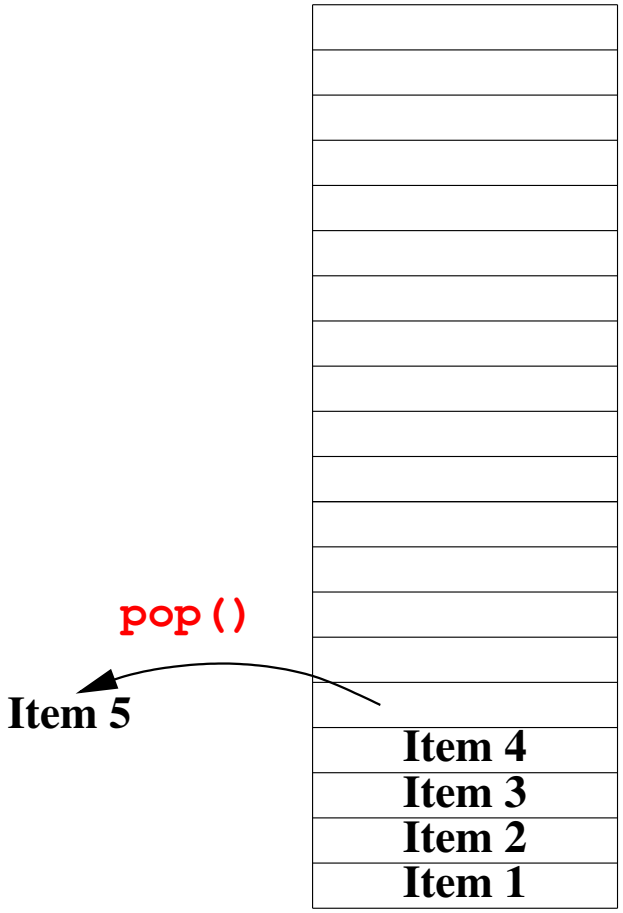

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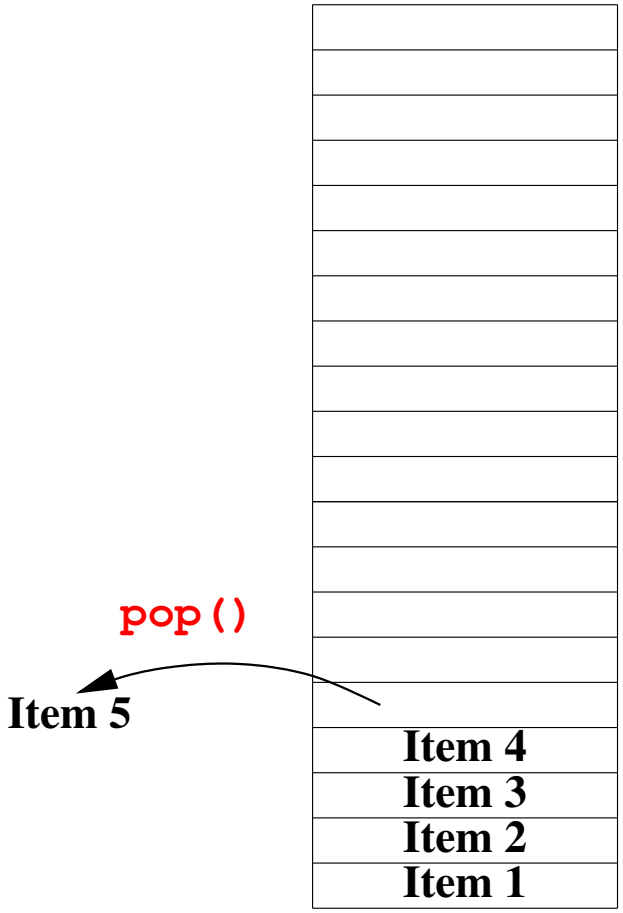
- Last In First Out (LIFO) memory
- Standard operations
  - `push(item)`
  - `T peek()`
  - `T pop()`
  - `boolean isEmpty()`
- Implemented using an array or a linked list
  - **Complexity of above operations using the array implementation?**



Why Use a Stack?

- Gives you a very simple interface
- Reduces the access to memory – no longer random access !
  - ⋆ Seems counter intuitive to reduce what you can do . . .
  - ⋆ . . . but prevents another programmer from using memory in a way that will break existing code
- Sufficient for large number of algorithms

Uses of Stacks

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

Evaluating Arithmetic Expressions

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

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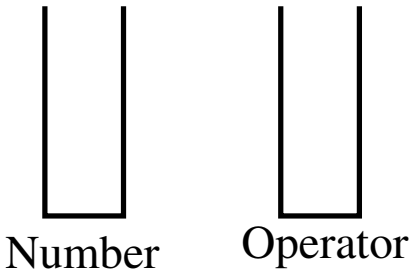

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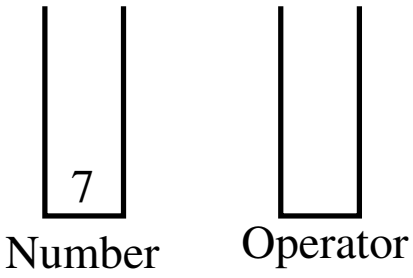

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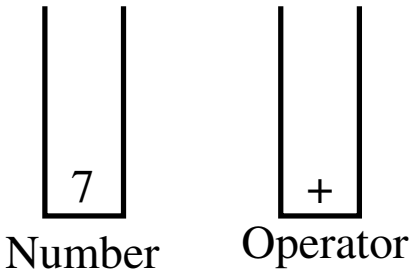

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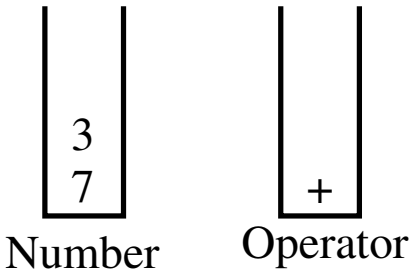

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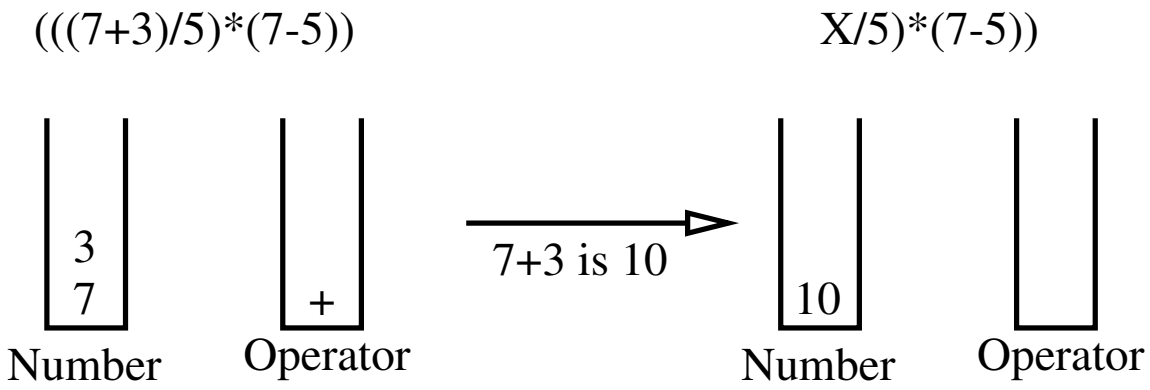

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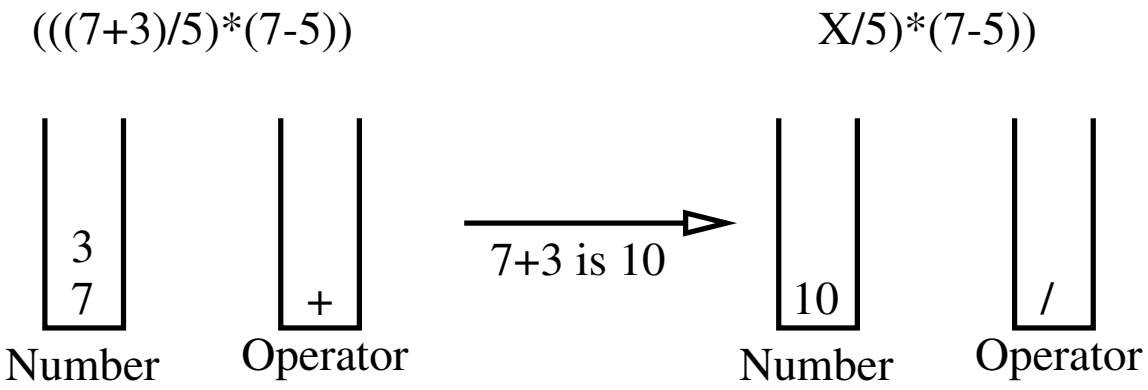

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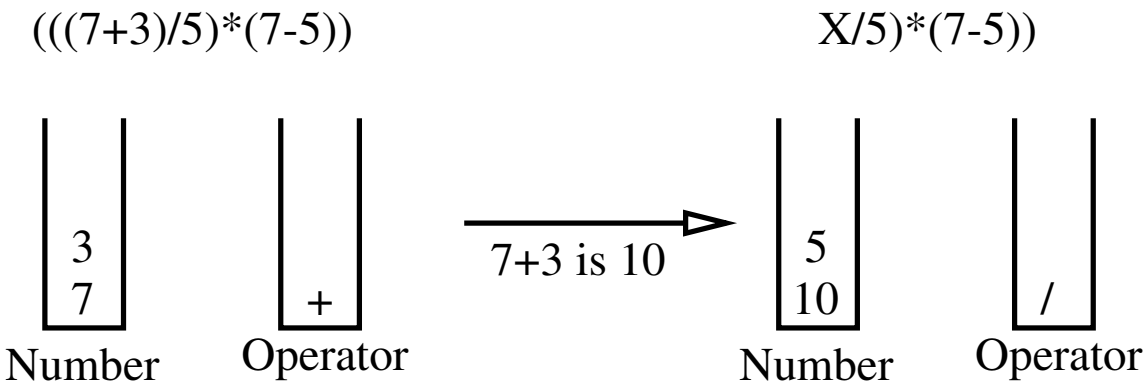

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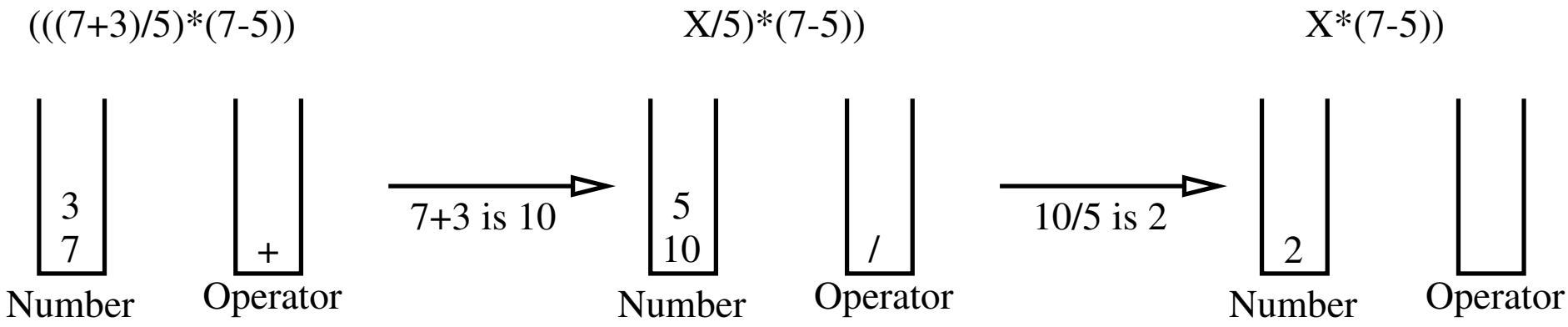

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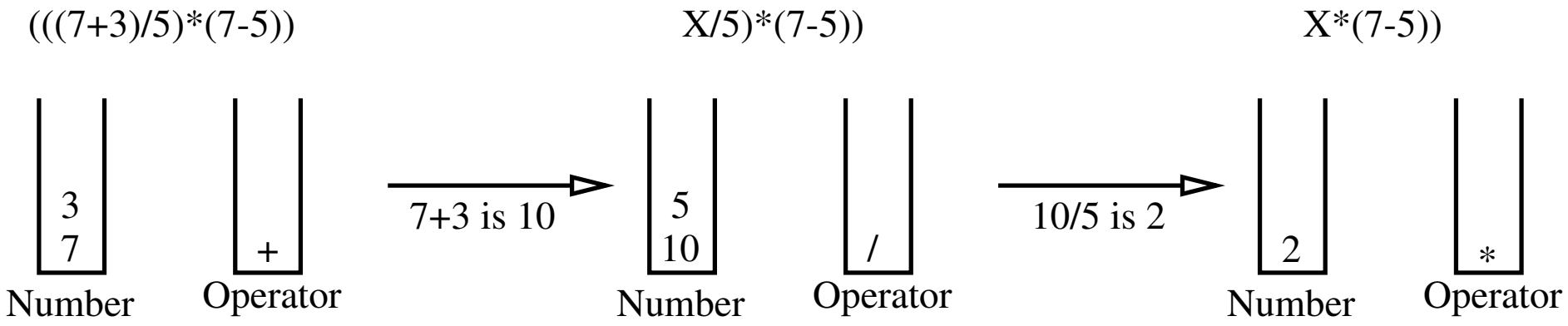

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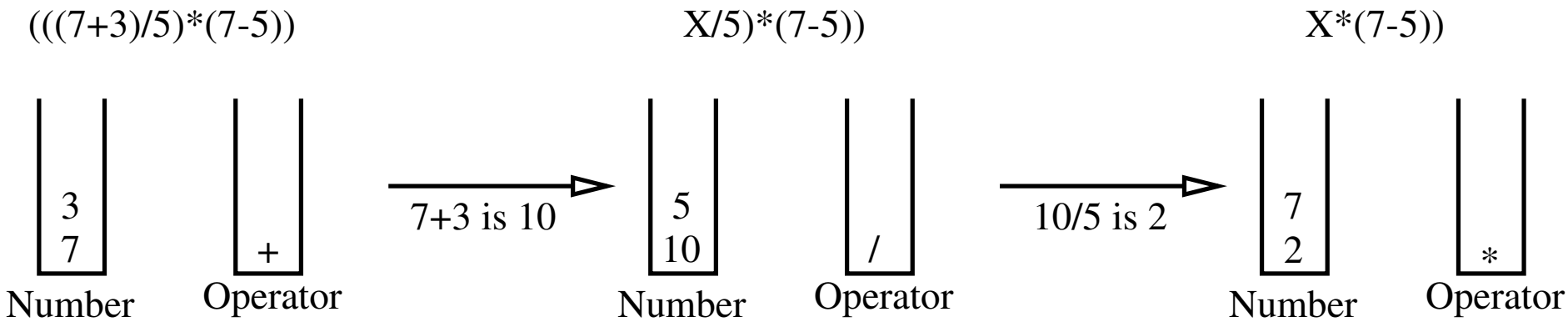

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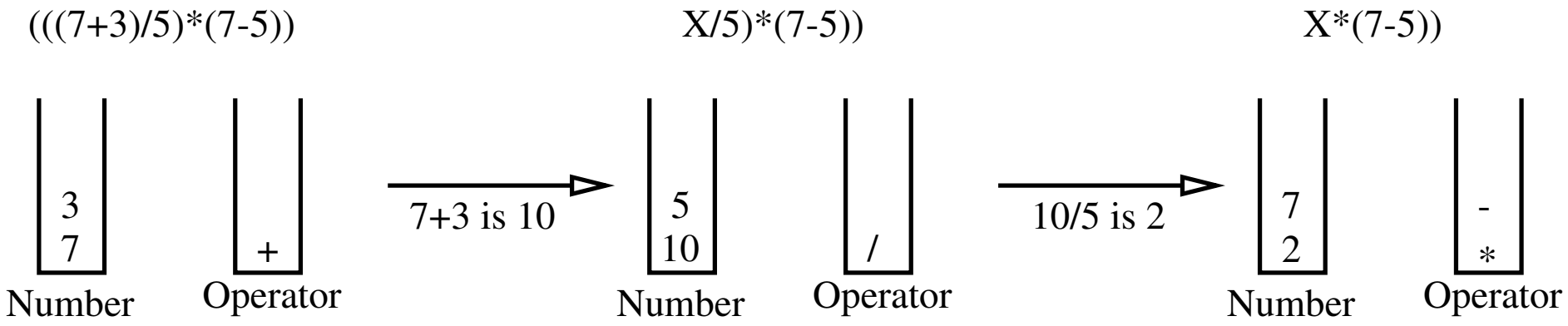

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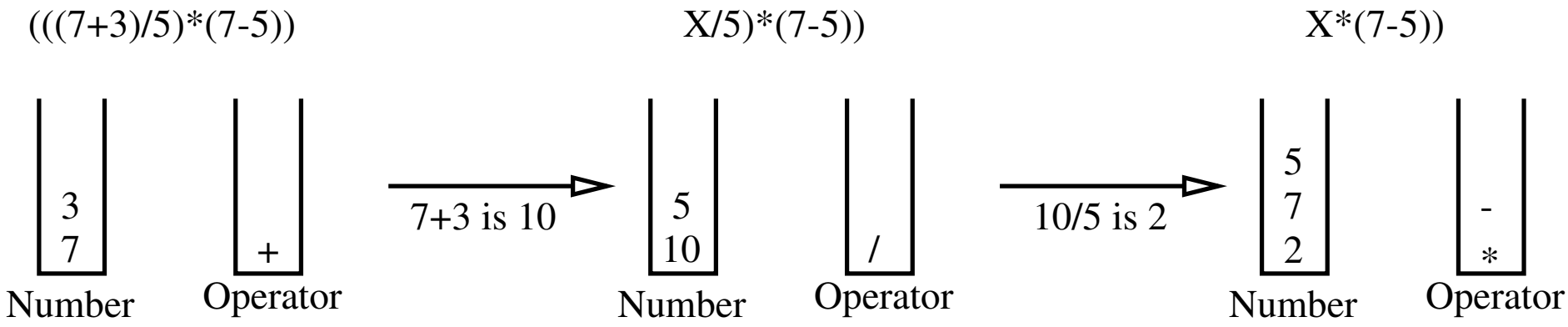

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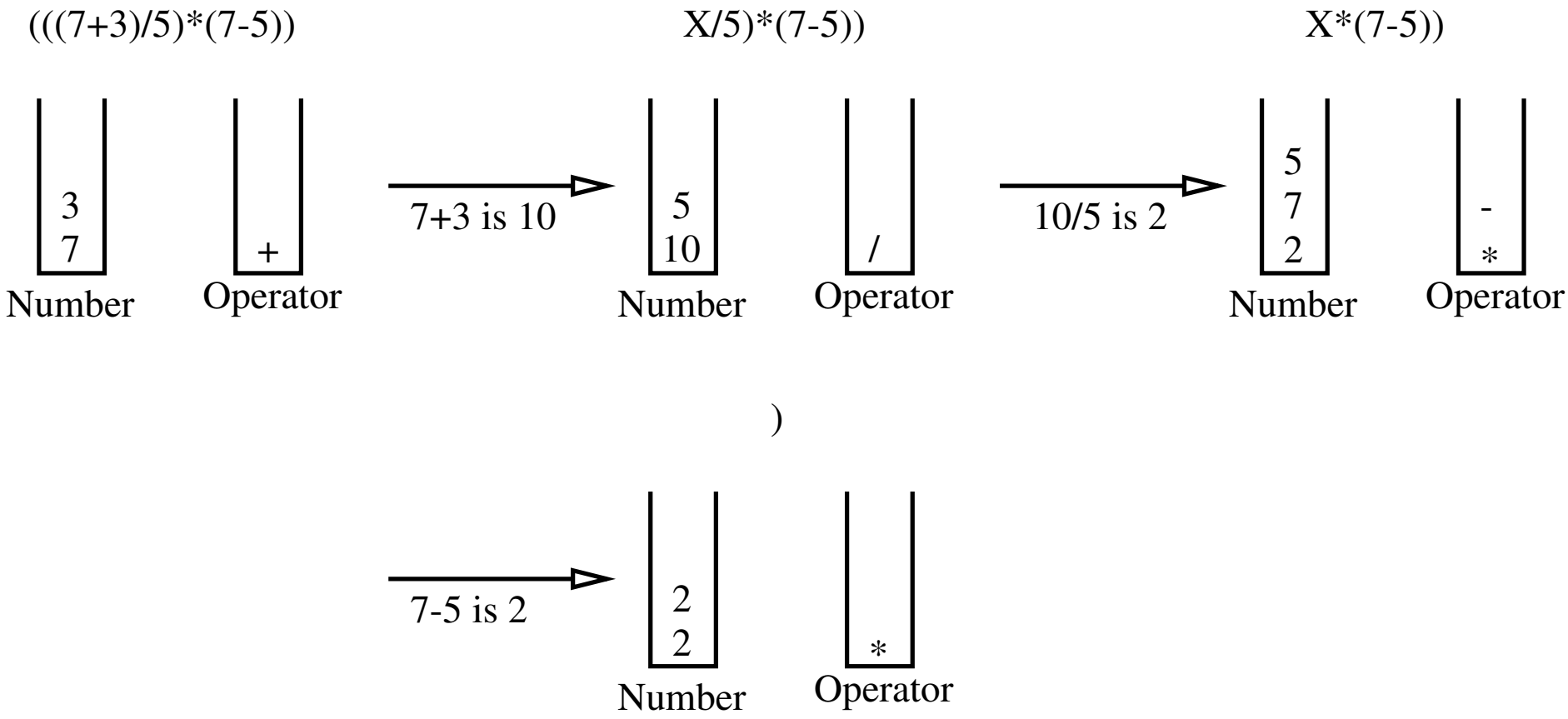

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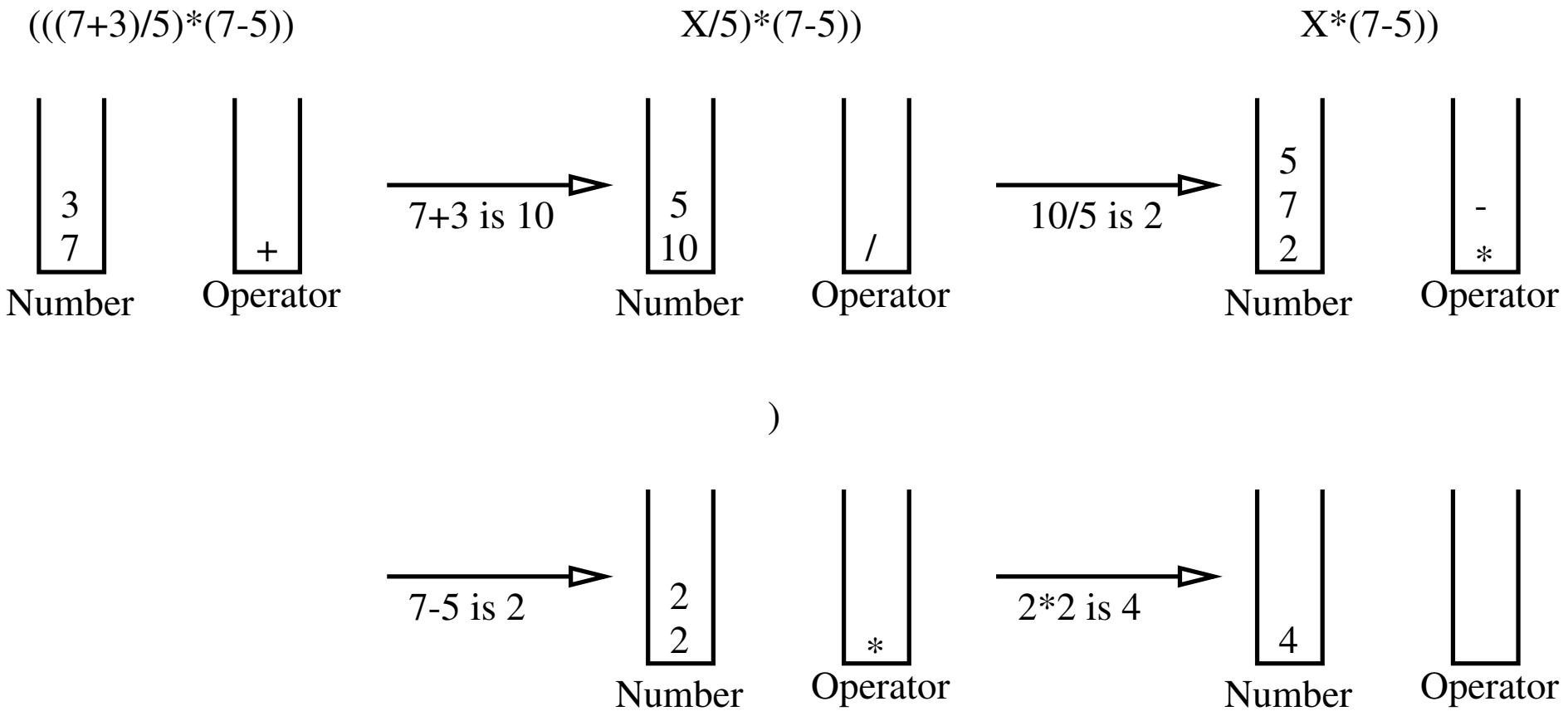

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- It extends the `Vector` class
- **Yes, it's a mess !**
- Why `search`?
- A `stack` isn't a type of `vector` – it could be implemented by a `Vector` but it should not extend `Vector` !

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Queues

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

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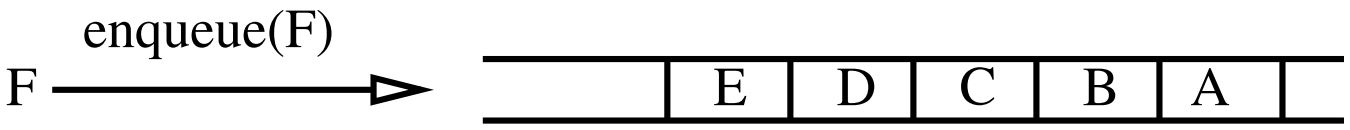
- First-in-first-out (FIFO) memory model
- `enqueue(elem)`



Queues

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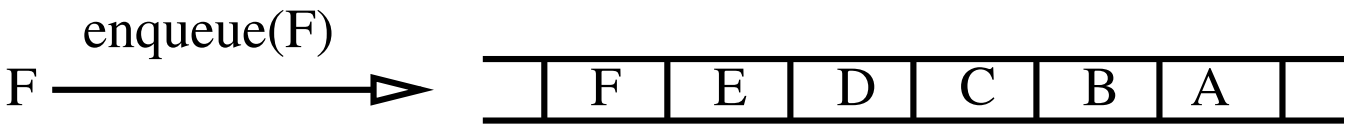

Queues

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- `peek()`

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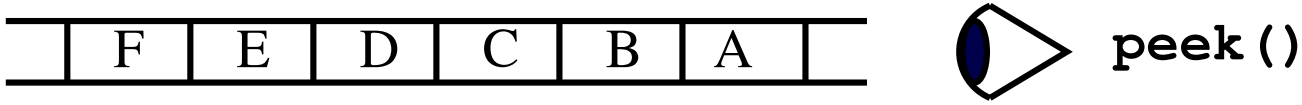

Queues

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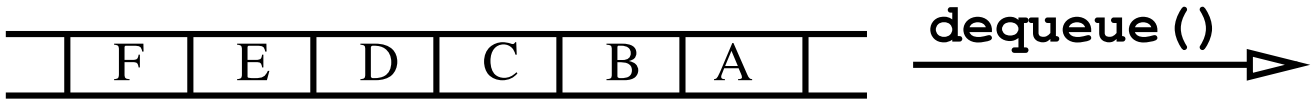

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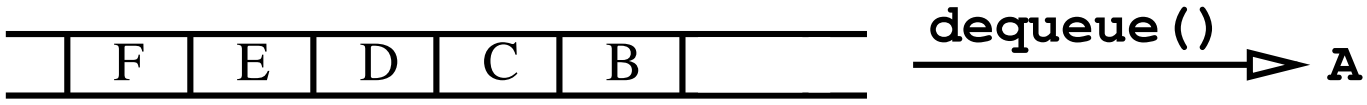


Queues

- First-in-first-out (FIFO) memory model
- `enqueue(elem)`
- `peek()`
- `dequeue()`
- `isEmpty()`

Uses of Queues

- In operating systems
  - ⋆ print queues
  - ⋆ job queues
- Communication/Message passing

Implementation of Queues

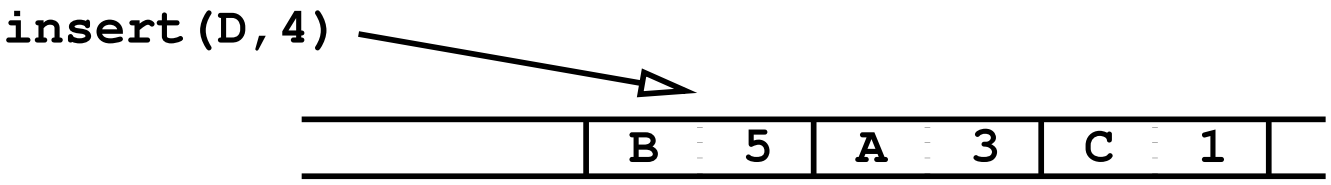
- Either using arrays or using linked lists
- Java has a `Queue<T>` interface with all the wrong names
  - ⋆ `add(elem)` or `offer(elem)` instead on enqueue
  - ⋆ `remove()` or `poll()` instead of dequeue
  - ⋆ `element()` and `peek()` to peek
- Java 6 adds
  - ⋆ Double ended queues, `Deque` (allow add/remove at both ends)
  - ⋆ `BlockingQueue` and `BlockingDeque` that supports concurrency

Priority Queues

- Queue with priorities

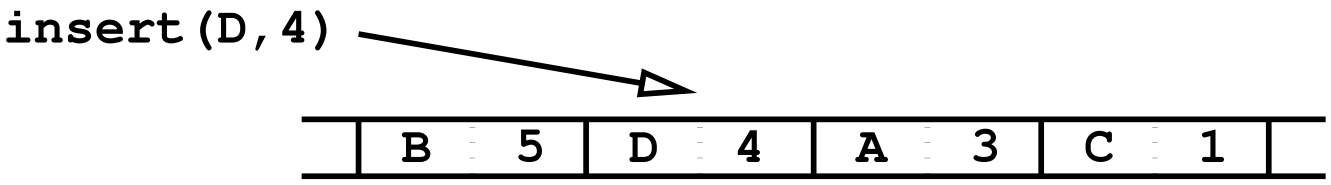
Priority Queues

- Queue with priorities
- `insert(elem,priority)`



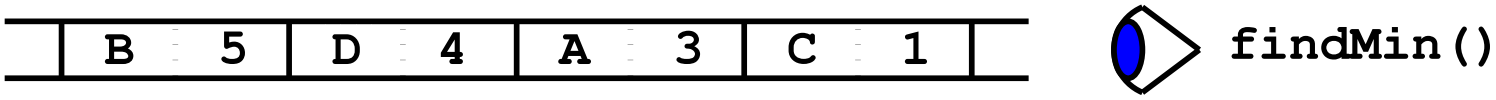
Priority Queues

- Queue with priorities
- `insert(elem,priority)`



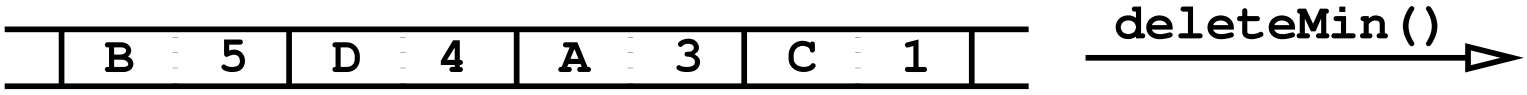
Priority Queues

- Queue with priorities
- `insert(elem,priority)`
- `findMin()`



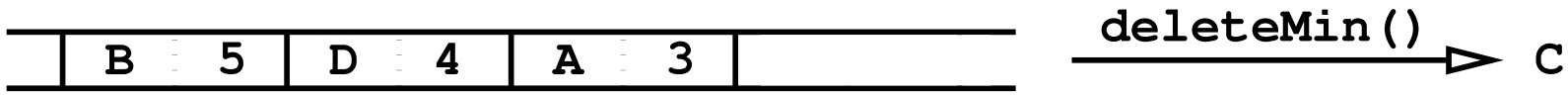
Priority Queues

- Queue with priorities
- `insert(elem,priority)`
- `findMin()`
- `deleteMin()`



Priority Queues

- Queue with priorities
- `insert(elem,priority)`
- `findMin()`
- `deleteMin()`



Uses of Priority Queues

- Queues with priorities (e.g. which threads should run)
- Often used in "greedy algorithms"
  - ⋆ Prim's minimum spanning tree algorithm

Implementation of Priority Queues

- Could be implemented using a linked list or a binary tree
- Most efficient implementation uses a **heap** (binary tree implemented using an array)

Outline

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

IN
CONGRESS,
JULY 4, 1776.
A
DECLARATION
BY THE
REPRESENTATIVES
OF THE
UNITED STATES OF AMERICA,
In GENERAL CONGRESS assembled.

WHEN in the course of human events, it becomes necessary for one people to dissolve the political bands which have connected them with another, and to assume among the powers of the earth, the separate and equal station to which the laws of nature and of nature's God entitle them, a decent respect to the opinions of mankind requires that they should declare the causes which impel them to the separation.

We hold these truths to be self-evident, that all men are created equal, that they are endowed by their Creator with certain unalienable rights, that among these are life, liberty, and the pursuit of happiness. That to secure these rights, governments are instituted among men, deriving their just powers from the consent of the governed, that whenever any form of government becomes destructive of these ends, it is the right of the people to alter or to abolish it, and to institute new government, laying its foundation on such principles, and organizing its powers in such form, as to them shall seem most likely to effect their safety and happiness. Prudence, indeed, will dictate that governments long established should not be changed for light and transient causes; and accordingly all experience hath shewn, that mankind are more disposed to suffer, while evils are sufferable, than to right themselves by abolishing the forms to which they are accustomed. But when a long train of abuses and usurpations, pursuing invariably the same object, evinces a design to reduce them under absolute despotism, it is their right, it is their duty, to throw off such government, and to provide new guards for their future security. Such has been the patient sufferance of these Colonies; and such is now the necessity which constrains them to alter their former systems of government. The history of the present King of Great-Britain is a history of repeated injuries and usurpations, all having in direct object the establishment of an absolute tyranny over these states. To prove this, let facts be submitted to a candid world.

He has refused his assent to laws, the most wholesome and necessary for the public good.

He has forbidden his Governors to pass laws of immediate and pressing importance, unless suspended in their operation till his assent should be obtained; and when so suspended, he has utterly neglected to attend them.

He has refused to pass other laws for the accommodation of large districts of people, unless those people would relinquish the right of representation in the legislature, a right inestimable to them, and formidable to tyrants only.

He has called together legislative bodies at places unusual, uncomfortable, and distant from the depository of their public records, for the sole purpose of fatiguing them into compliance with his measures.

He has dissolved representative houses repeatedly, for opposing with manly firmness his invasions on the rights of the people.

He has refused for a long time, after such dissolutions, to cause others to be elected; whereby the legislative powers, incapable of annihilation, have returned to the people at large for their exercise; the state remaining in the mean time exposed to all the dangers of invasion from without, and convulsions within.

He has endeavored to prevent the population of these states; for that purpose obstructing the laws for naturalization of foreigners; refusing to pass others to encourage their migrations hither, and raising the conditions of new appropriations of lands.

He has obstructed the administration of justice, by refusing his assent to laws for establishing judiciary powers.

He has made judges dependent on his will alone, for the tenure of their offices, and the amount and payment of their salaries.

He has erected a multitude of new offices, and sent hither swarms of officers to harass our people, and eat out their substance.

He has kept among us, in times of peace, standing armies, without the consent of our Legislatures.

He has affected to render the military independent of and superior to the civil power.

He has combined with others to subject us to a jurisdiction foreign to our constitution and unacknowledged by our laws; giving his assent to their acts of pretended legislation:

For quartering large bodies of armed troops among us:

For protecting them, by a mock trial, from punishment for any murders which they should commit on the inhabitants of these states:

For cutting off our trade with all parts of the world:

For imposing taxes on us without our consent:

For depriving us, in many cases, of the benefits of trial by jury:

For transporting us beyond seas to be tried for pretended offenses:

For abolishing the free system of English laws in a neighboring province, establishing therein an arbitrary government, and enlarging its boundaries, so as to render it at once an example and fit instrument for introducing the same absolute rule into these Colonies:

For taking away our Charters, abolishing our most valuable laws, and altering fundamentally the forms of our governments:

For suspending our own Legislatures, and declaring themselves invested with power to legislate for us in all cases whatsoever.

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He has plundered our seas, ravaged our coasts, burnt our towns, and destroyed the lives of our people.

He is at this time transporting large armies of foreign mercenaries to compleat the works of death, desolation and tyranny, already begun with circumstances of cruelty and perfidy scarcely paralleled in the most barbarous ages, and totally unworthy the head of a civilized nation.

He has constrained our fellow citizens taken captive on the high seas to bear arms against their country, to become the executioners of their friends and brethren, or to fall themselves by their hands.

He has excited domestic insurrections amongst us, and has endeavored to bring on the inhabitants of our frontiers, the merciless Indian Savages, whose known rule of warfare, is an undistinguished destruction of all ages, sexes, and conditions.

In every stage of these oppressions we have petitioned for redress, in the most humble terms: Our repeated petitions have been answered only by repeated injury. A Prince, whose character is thus marked by every act which may define a Tyrant, is unfit to be the Ruler of a free People.

Nor have we been wanting in attentions to our British brethren. We have warned them from time to time of attempts by their legislature to extend an unwarrantable jurisdiction over us. We have reminded them of the circumstances of our emigration and settlement here. We have appealed to their native justice and magnanimity, and we have conjured them by the ties of our common kindred to disavow these usurpations, which would inevitably interrupt our connections and correspondence. They too have been deaf to the voice of justice and of consanguinity. We must, therefore, acquiesce in the necessity which denounces our separation, and hold them, as we hold the rest of mankind, enemies in war; in peace, friends.

We, therefore, the Representatives of the UNITED STATES OF AMERICA, in GENERAL CONGRESS assembled, appealing to the Supreme Judge of the world for the rectitude of our intentions, do in the name and by the authority of the good People of these Colonies, solemnly publish and declare, That these United Colonies are, and of right ought to be, FREE AND INDEPENDENT STATES; that they are absolved from all allegiance to the British Crown, and that all political connection between them and the State of Great-Britain, is, and ought to be totally dissolved; and that as FREE AND INDEPENDENT STATES, they have full power to levy war, conclude peace, contract alliances, establish commerce, and to do all other acts and things which INDEPENDENT STATES may of right do. And for the Support of this Declaration, with a firm reliance on the protection of Divine Providence, we mutually pledge to each other our lives, our fortunes, and our sacred honor.

Signed by ORDER *and in behalf of the* CONGRESS,
JOHN HANCOCK, PRESIDENT.
ATTEST,
CHARLES THOMPSON, Secretary.

Lists

- A **list** is a collection where the order of elements is important
- Repetitions are allowed
- You can `add` (at a specified position), `remove` (from a specified position), `set` (at a specified position) and, `get` elements
- Java has a `List<T>` interface
- Java provides specific implementations as `ArrayList<T>` and `LinkedList<T>`

Sets

- Models mathematical sets
  - ⋆ no ordering or repetitions
- operations: `add`, `remove`, `contains`, `size`, `isEmpty`
- Java has a `Set<T>` interface
- Two common implementations of sets are
  - ⋆ `HashSet`s using hash tables (fast access)
  - ⋆ `TreeSet`s using binary trees
- Which is most efficient depends on the application

Maps

- A map provides a content addressable memory for pairs $key{:}data$
- It provides fast access to the data through the key
  - ⋆ no duplicate keys!
- Implemented using trees or hash tables
- Multimaps allow each key to be associated with multiple values

Program to Interfaces not Implementations

- Use data structures through their interfaces (ADT)

```
Set<String> myset = new HashSet<String>();
List<Integer> mylist = new ArrayList<Integer>();%
```

- Much better than

```
HashSet<String> myset = new HashSet<String>();
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```

  which is implementation dependent and can make modification and maintenance hard

- Learn to program to interfaces not implementations

- Declare your intentions not your actions

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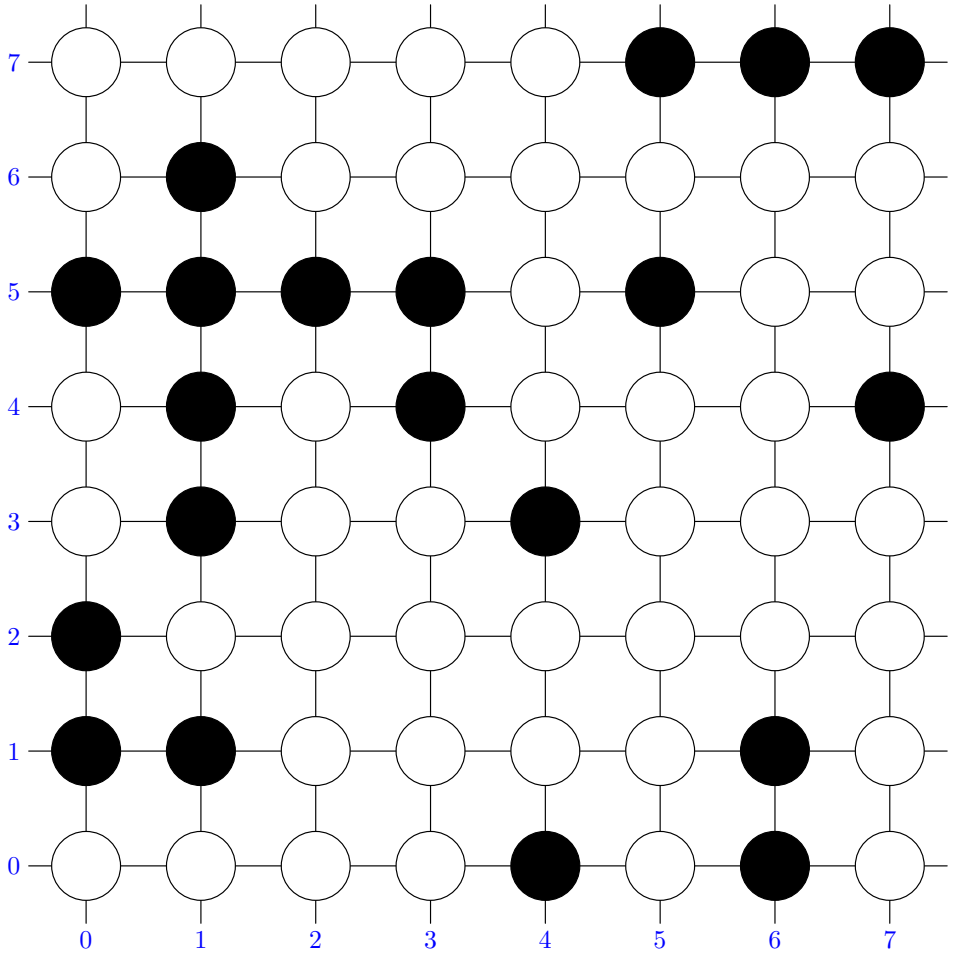
Clustering



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

Assume a `Graph` interface with methods `getNeighbours(Node n)`, `isOccupied(Node n)`.

Clustering Algorithm

```
public Set<Node> findCluster(Node startNode, Graph graph)
```

Clustering Algorithm

```
public Set<Node> findCluster(Node startNode, Graph graph) {
  Stack<Node> uncheckedNodes = new Stack<Node>();
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  uncheckedNodes.push(startNode);
  clusterNodes.add(startNode);
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  while (!uncheckedNodes.isEmpty()) {
```

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  while (!uncheckedNodes.isEmpty()) {
    Node next = uncheckedNodes.pop();
    List<Node> neighbours = graph.getNeighbours(next);
```

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  while (!uncheckedNodes.isEmpty()) {
    Node next = uncheckedNodes.pop();
    List<Node> neighbours = graph.getNeighbours(next);
    for (Node neigh: neighbours) {
      if (graph.isOccupied(neigh) && !clusterNodes.contains(neigh) ) {
        uncheckedNodes.push(neigh);
        clusterNodes.add(neigh);
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      }
    }
  }
  return clusterNodes;
}
```
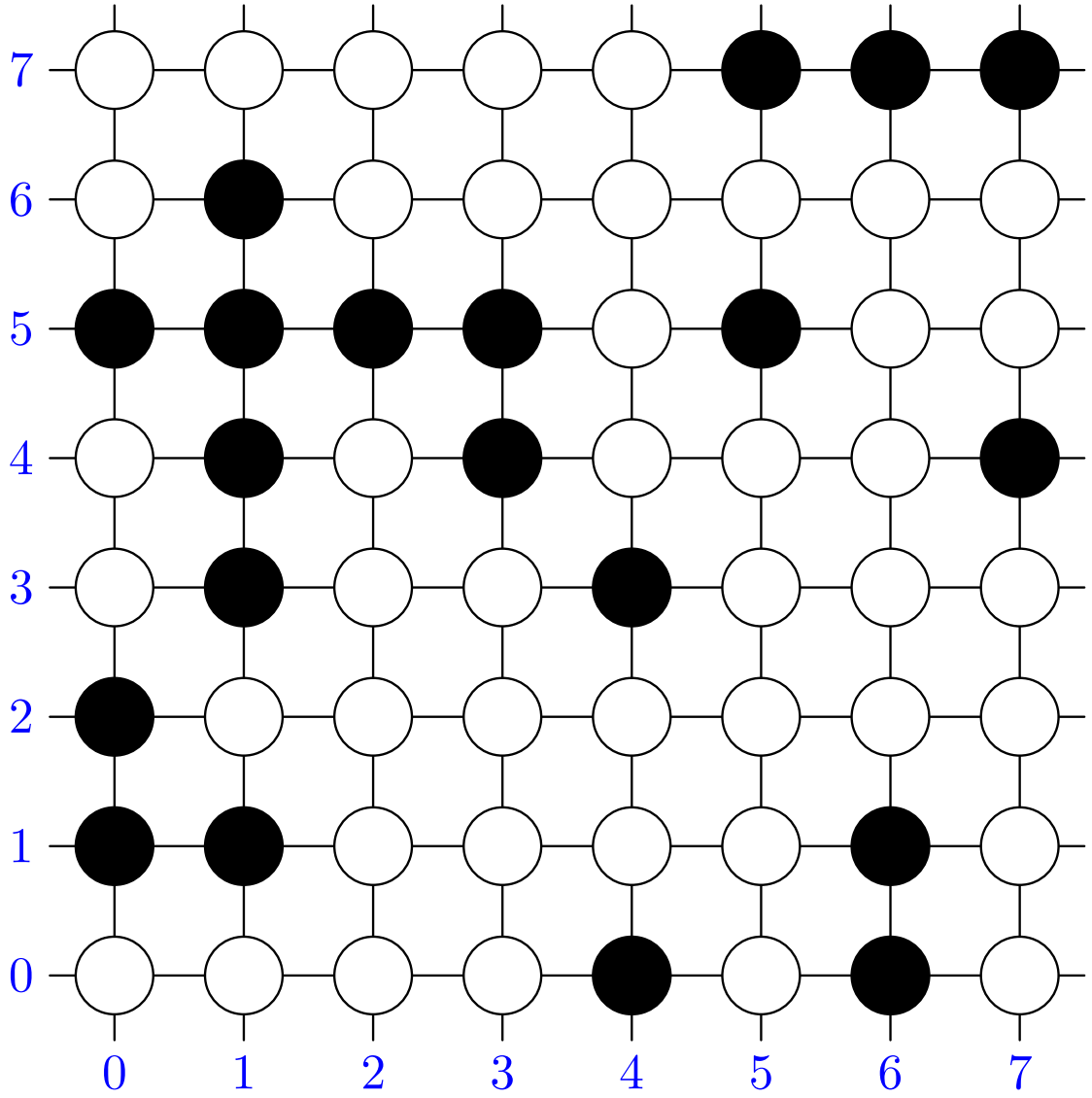
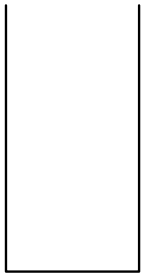

Clustering

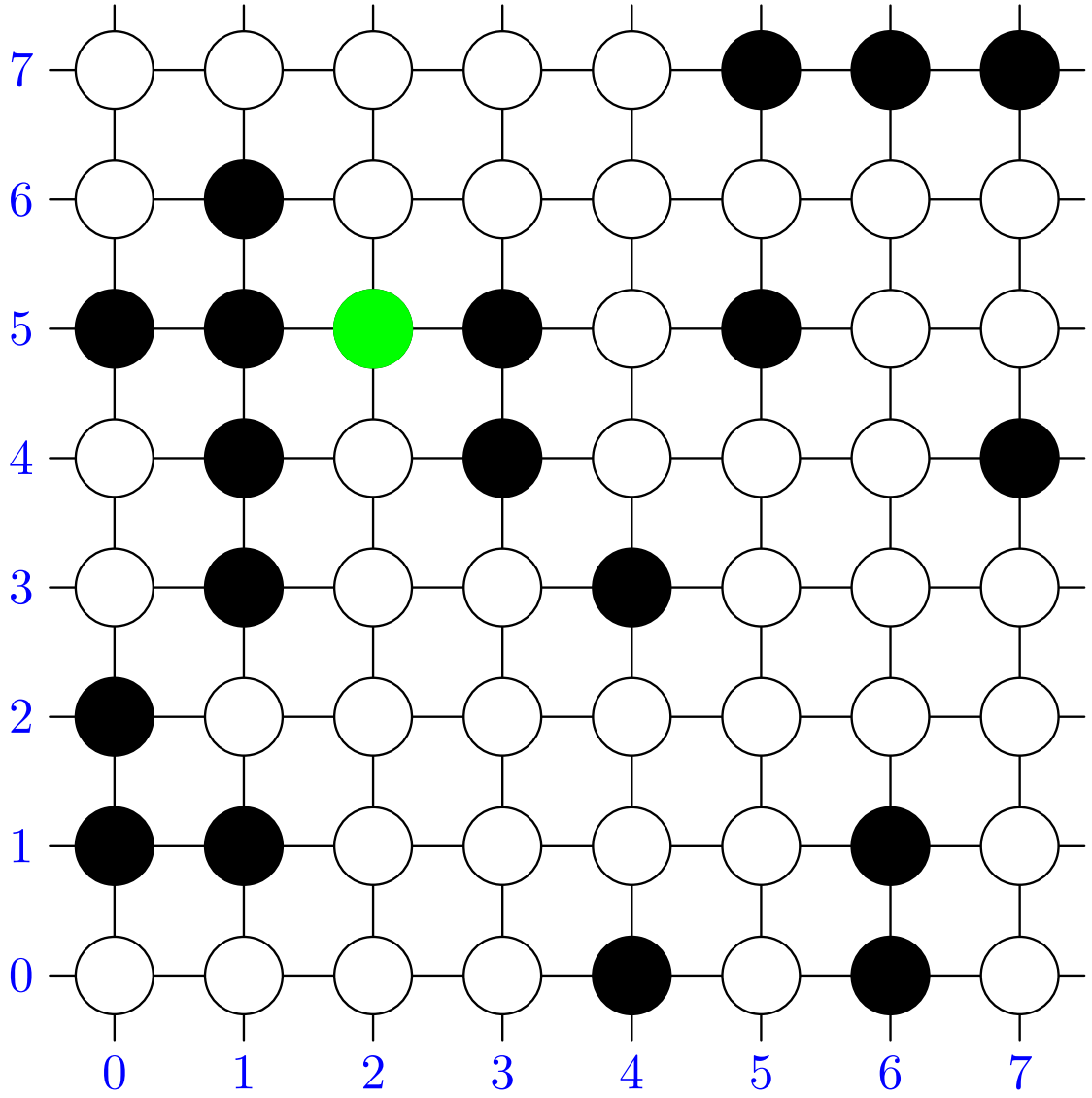


uncheckedNodes =



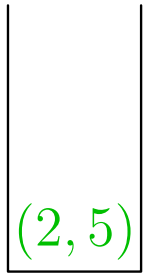
clusterNodes =
{}

Clustering



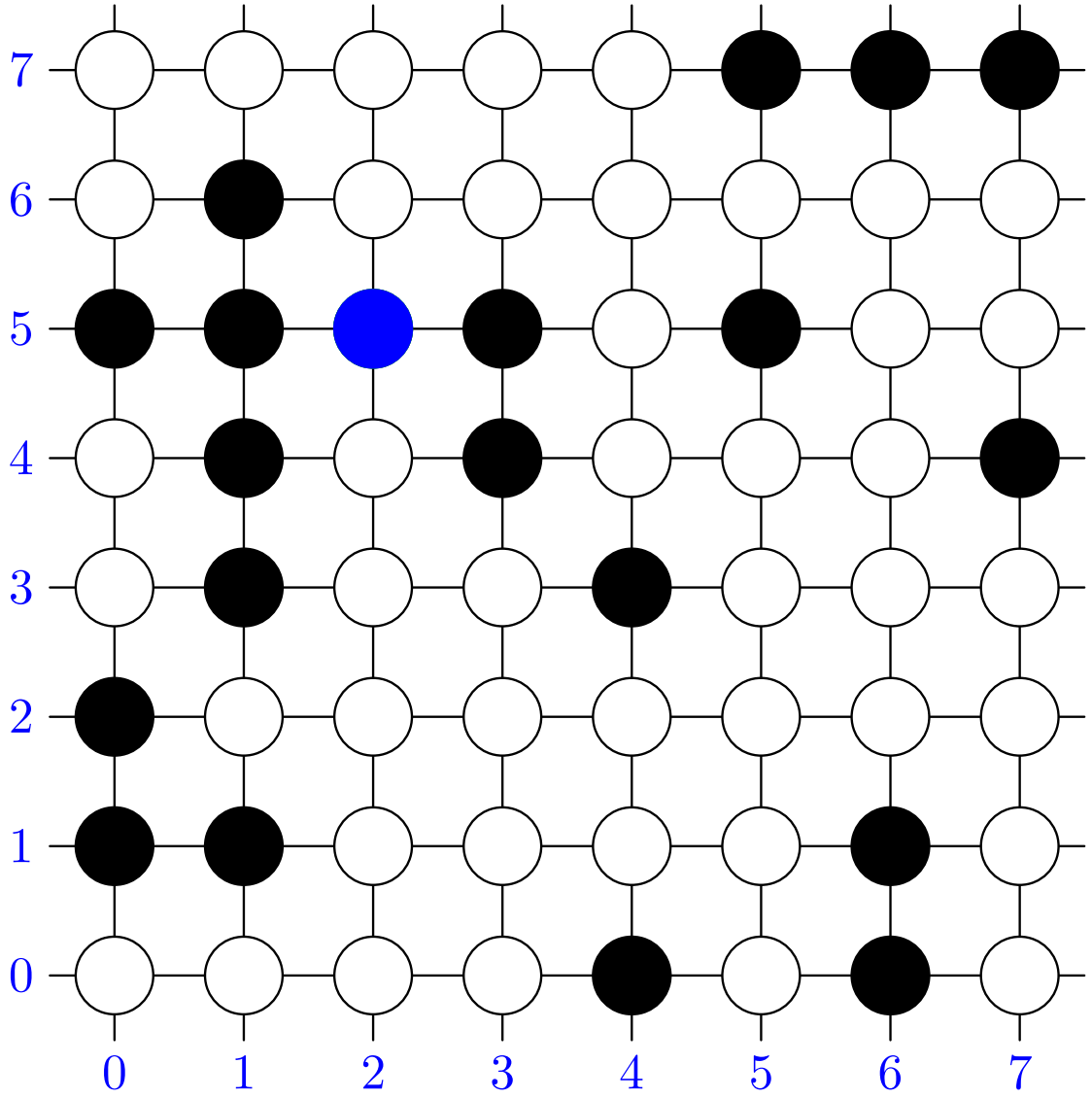
startNode = (2,5)

`uncheckedNodes` =



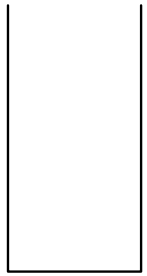
clusterNodes =
{ (2, 5) }

Clustering



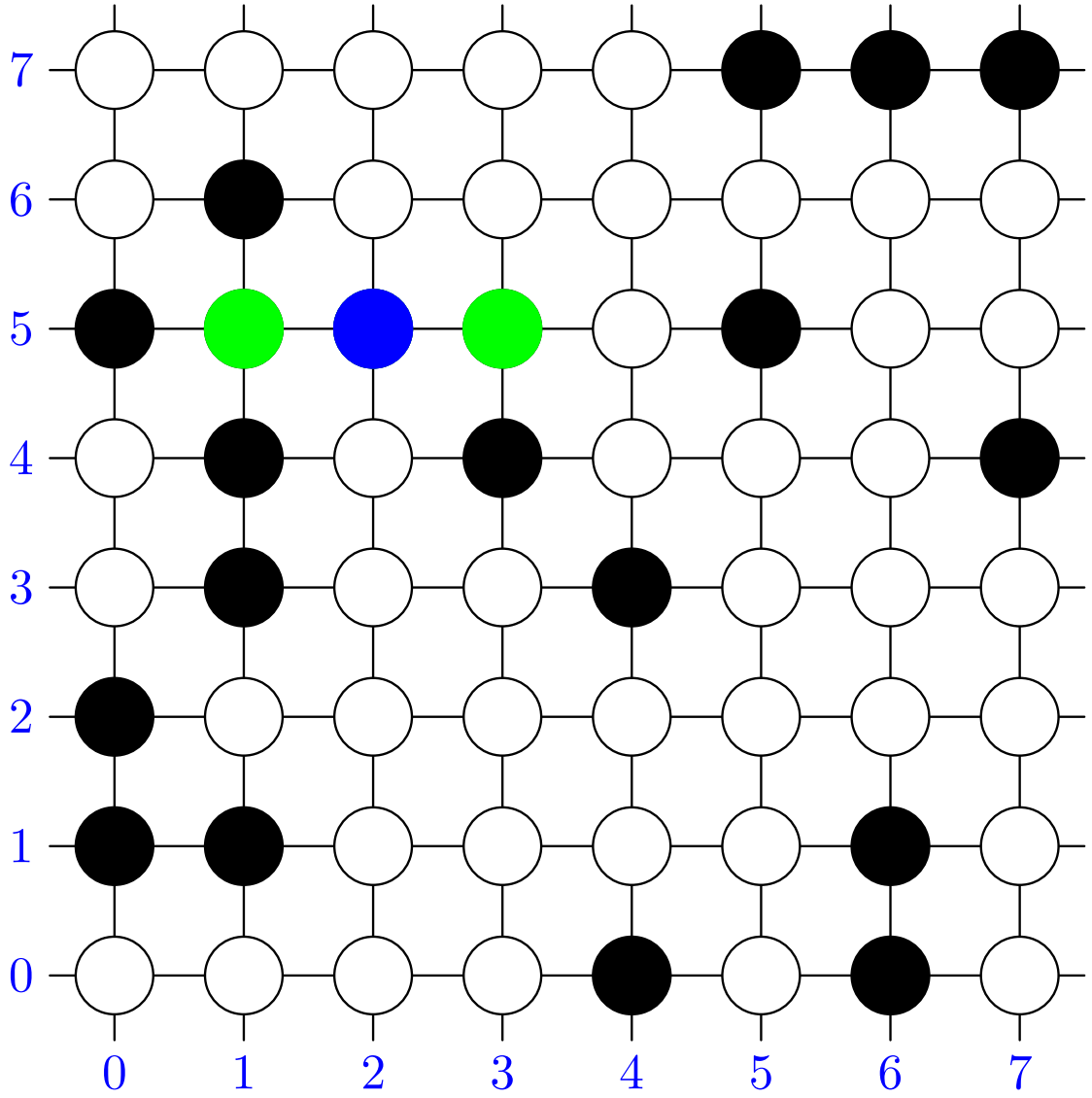
$\text{next} = (2, 5)$

`uncheckedNodes` =



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

Clustering



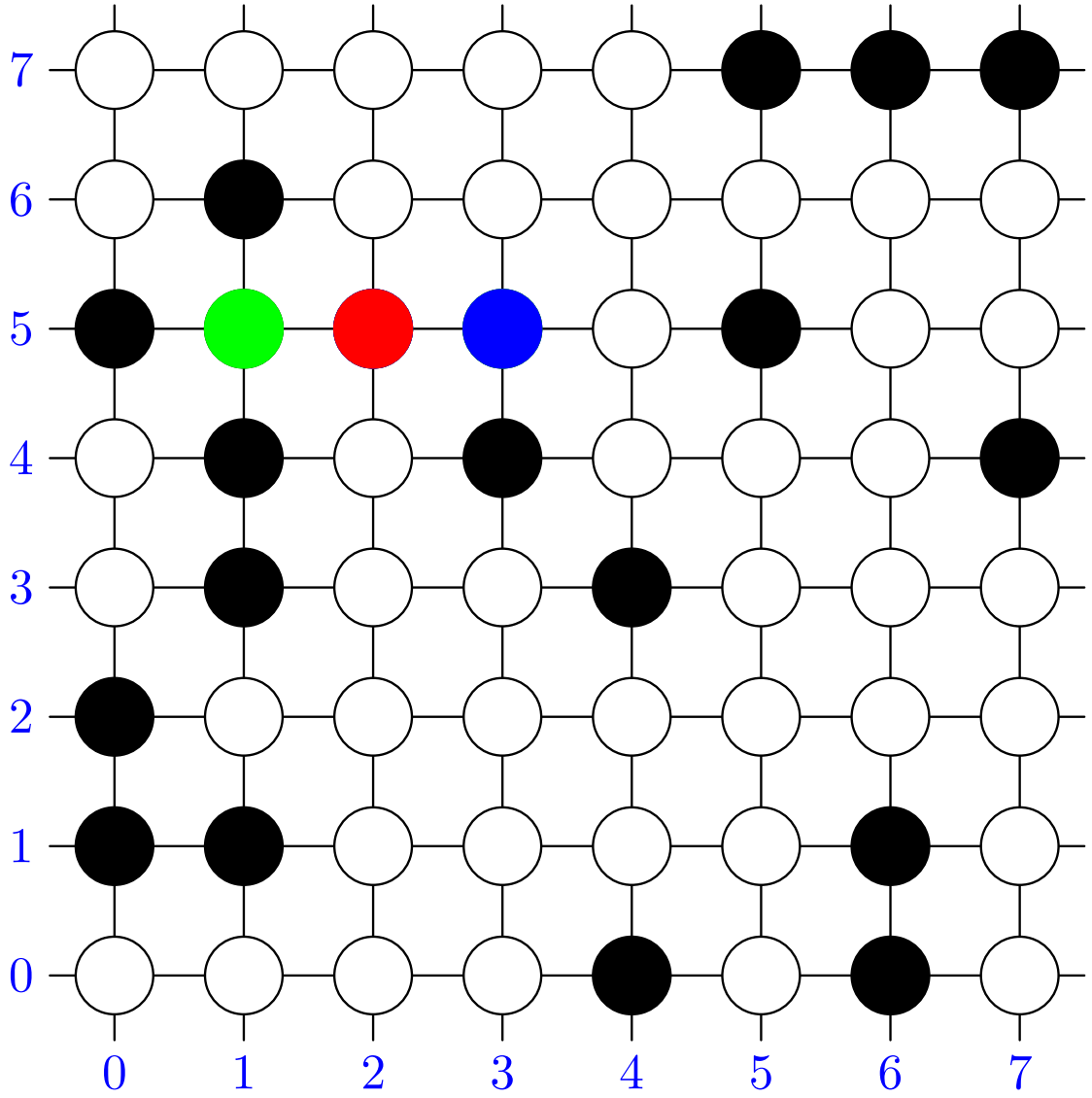
$\text{next} = (2, 5)$

`uncheckedNodes` =

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

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

Clustering



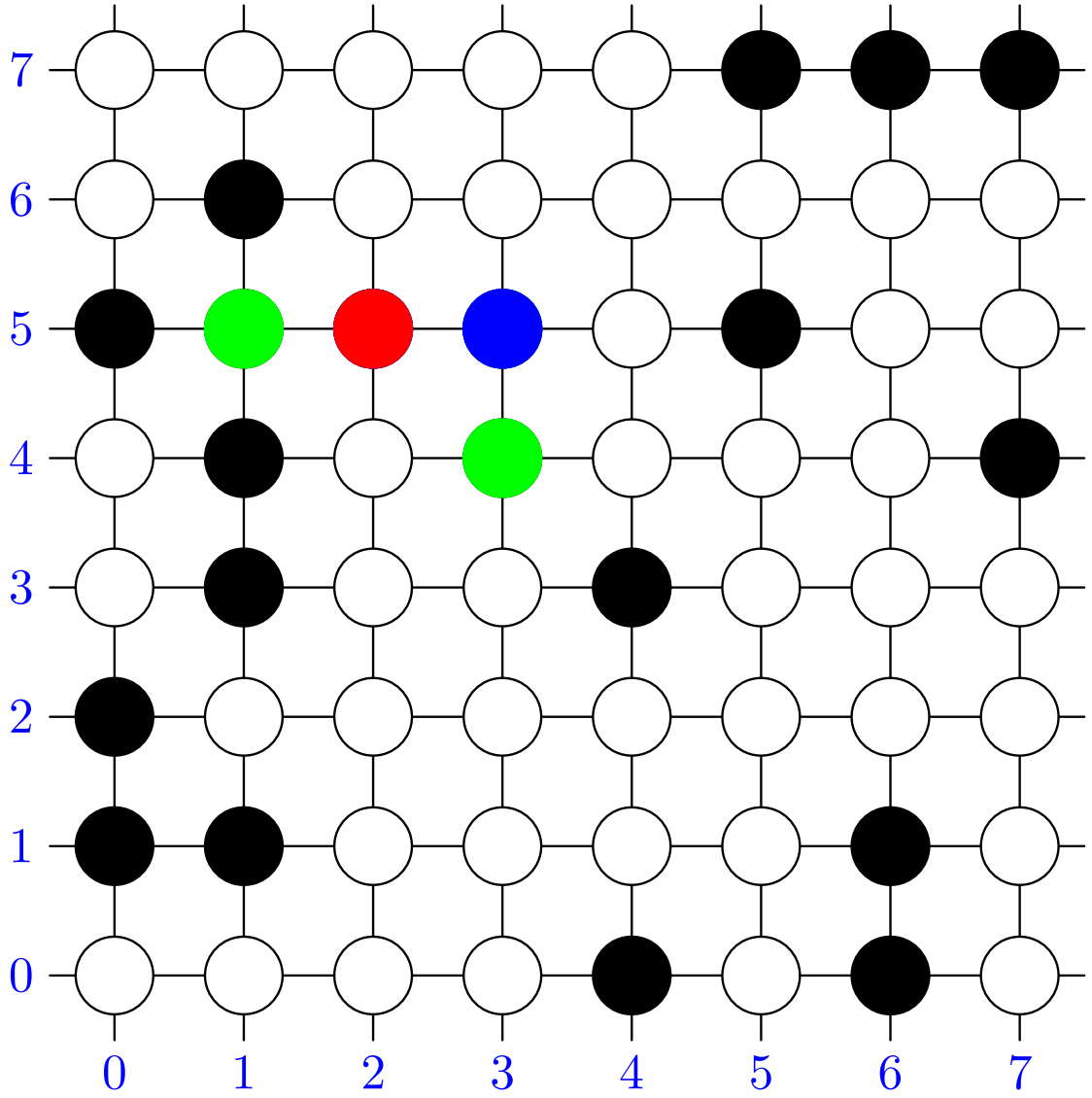
$\text{next} = (3, 5)$

`uncheckedNodes` =

$(1, 5)$

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

Clustering



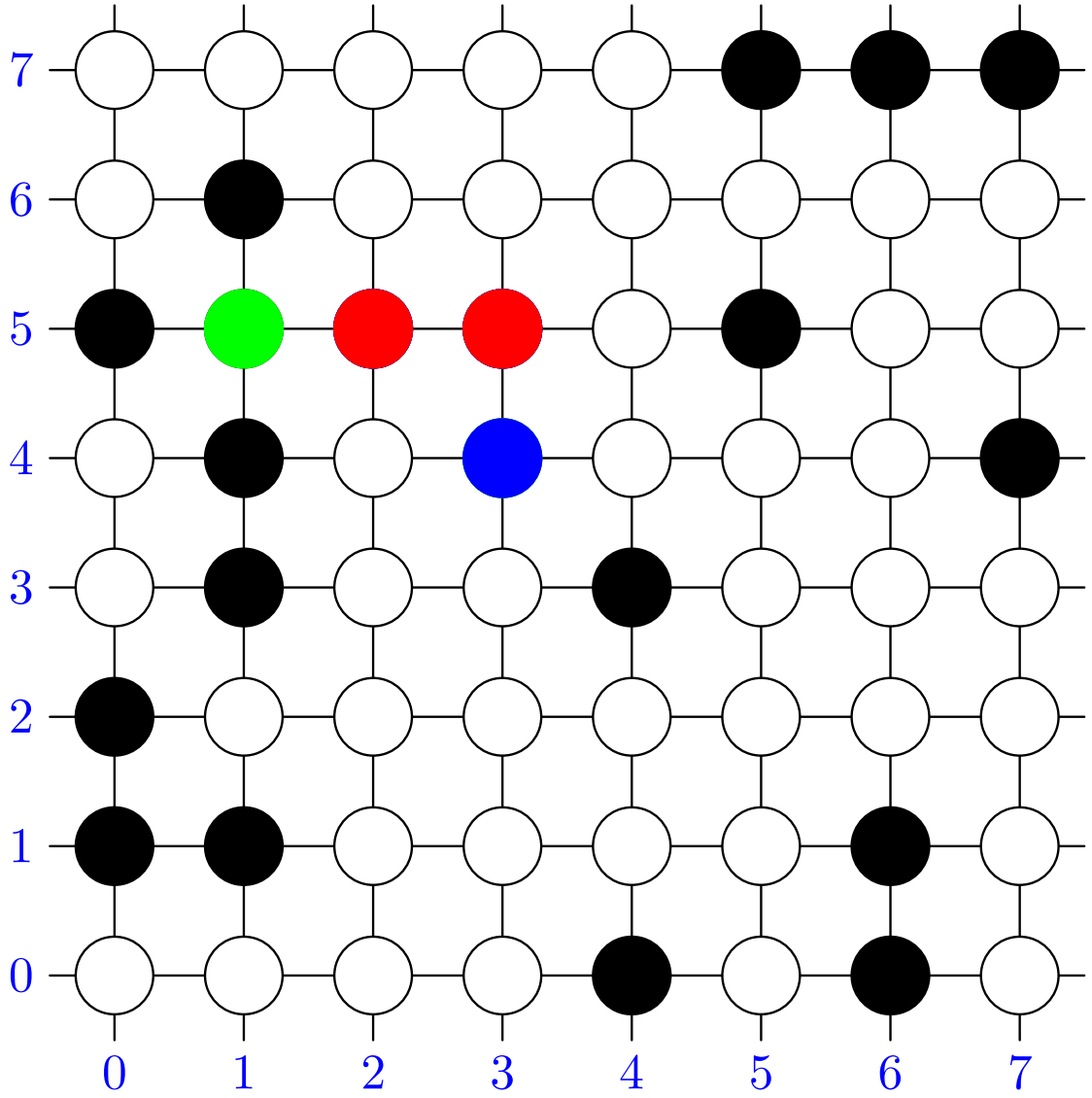
next $= (3, 5)$

`uncheckedNodes` $=$

$(3, 4)$
$(1, 5)$

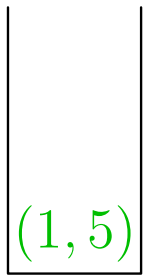
clusterNodes $=$
$\{ (2, 5), (1, 5), (3, 5),$
$(3, 4) \}$

Clustering



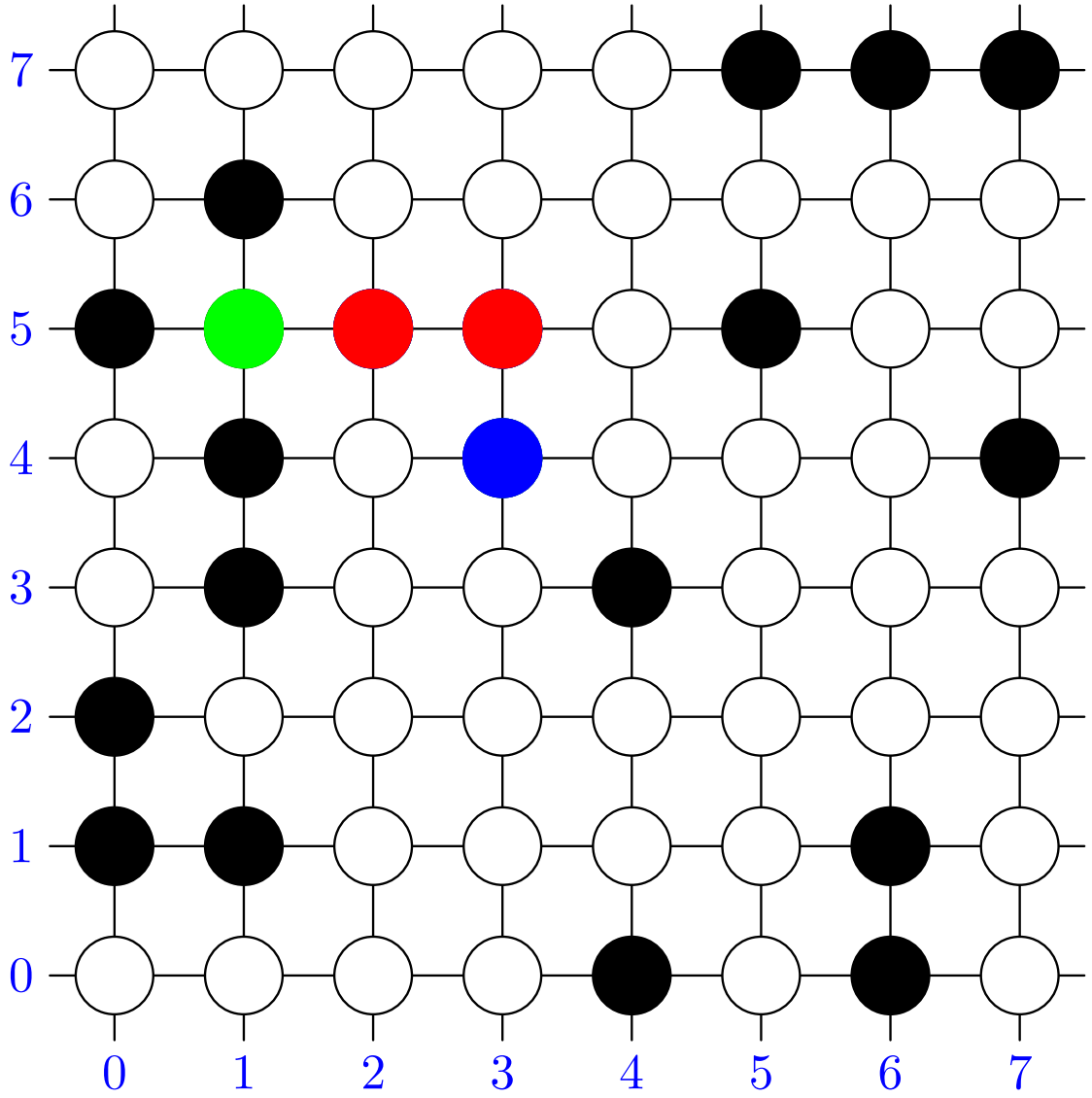
$\text{next} = (3, 4)$

`uncheckedNodes` =



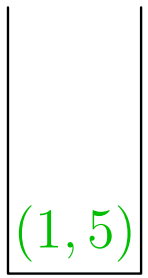
clusterNodes =
$\{ (2, 5), (1, 5), (3, 5), (3, 4) \}$

Clustering



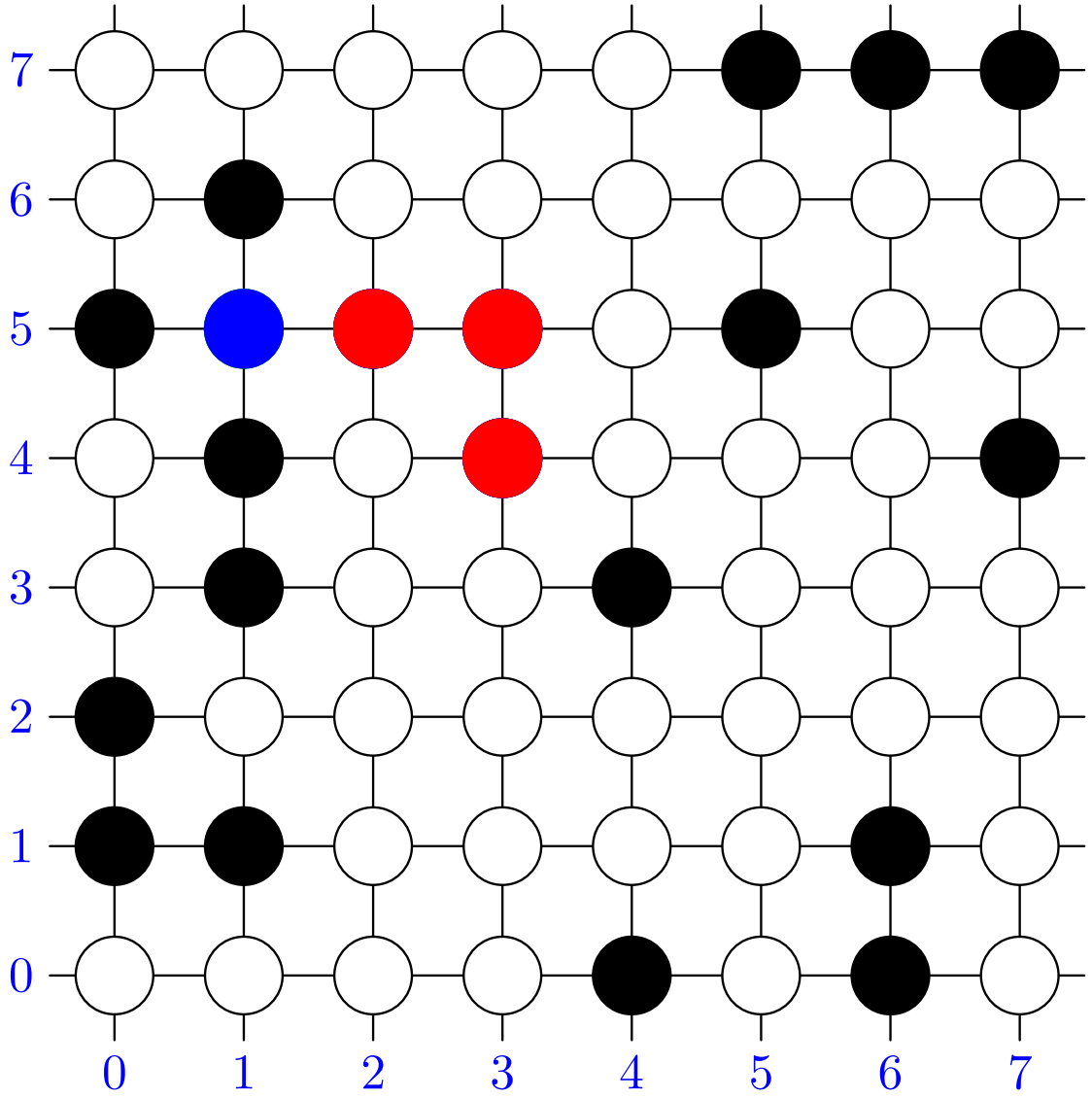
$\text{next} = (3, 4)$

`uncheckedNodes` =



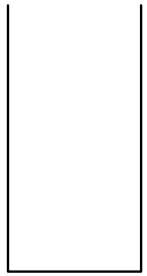
clusterNodes =
$\{ (2, 5), (1, 5), (3, 5), (3, 4) \}$

Clustering



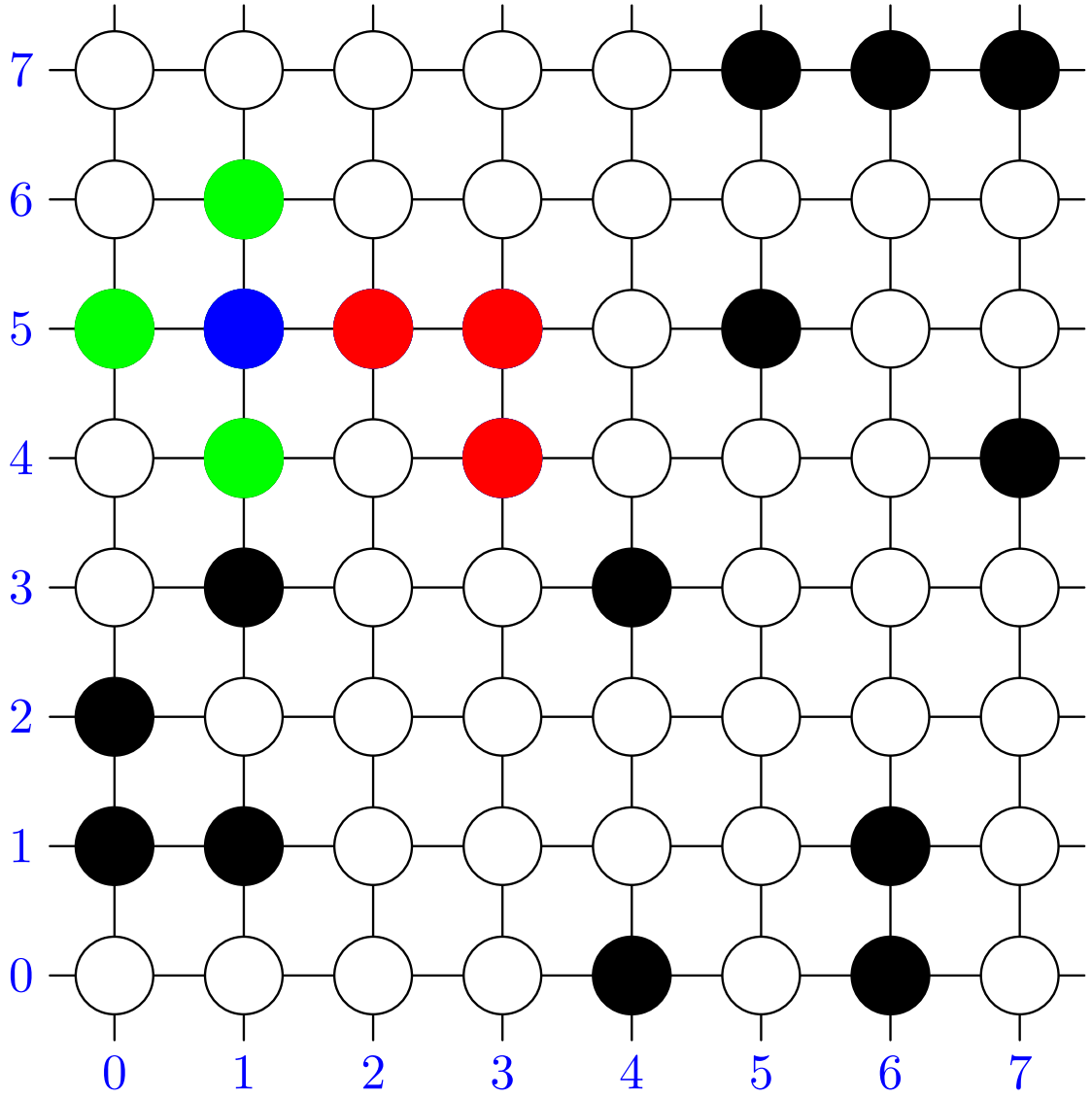
next $= (1, 5)$

`uncheckedNodes` $=$



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

Clustering



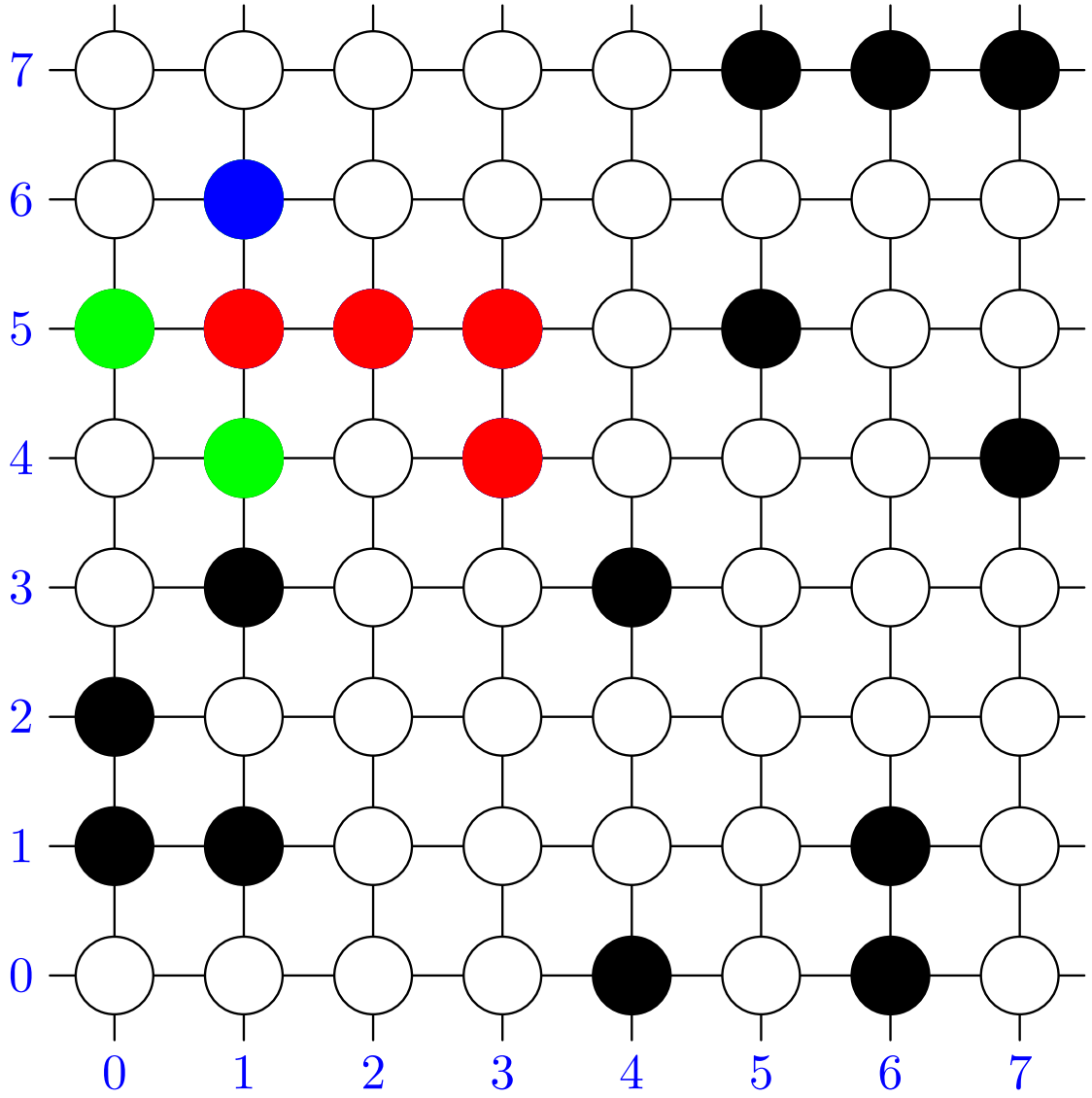
$\text{next} = (1, 5)$

`uncheckedNodes` =

$(1, 6)$
$(1, 4)$
$(0, 5)$

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

Clustering



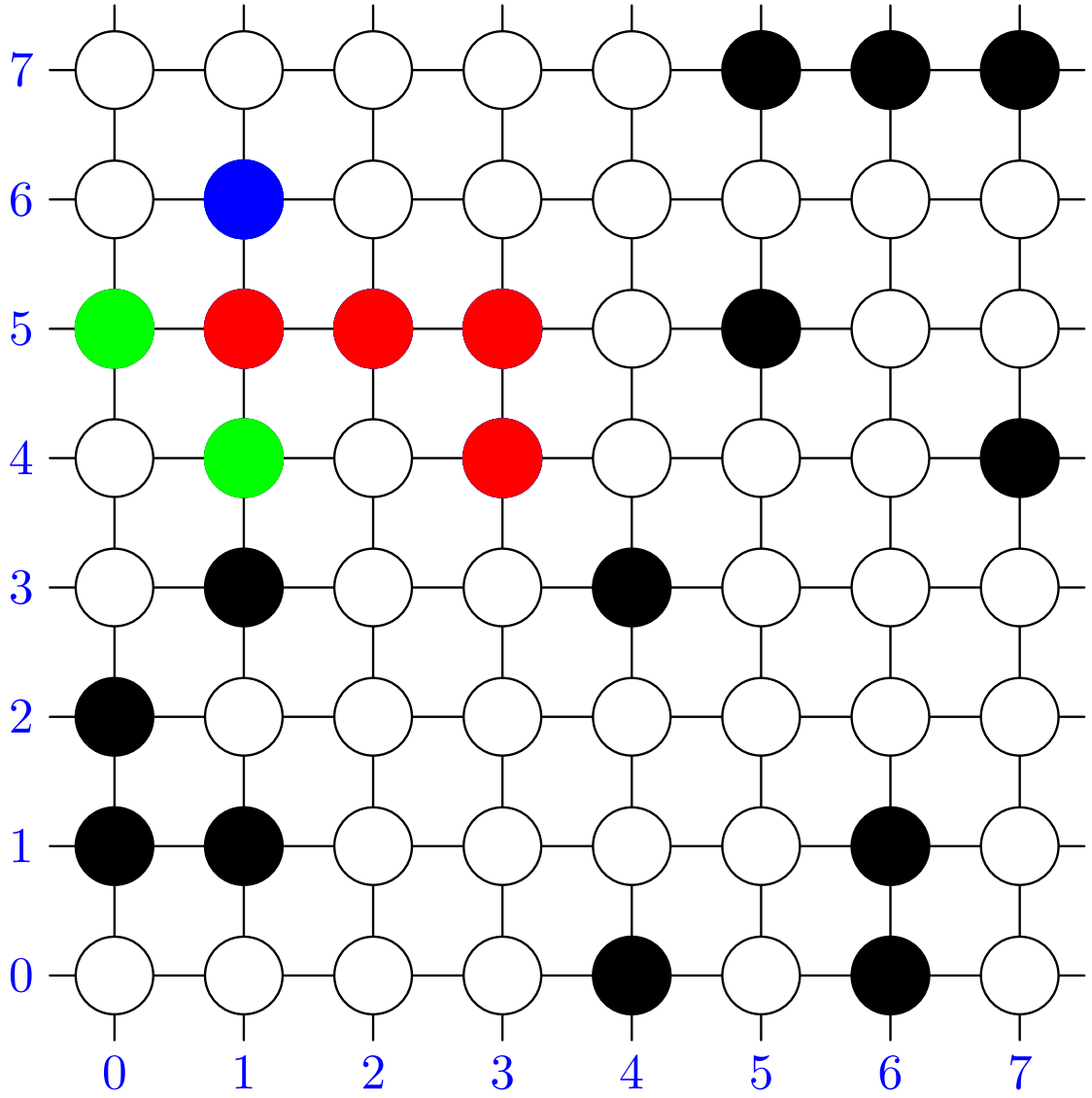
$\text{next} = (1, 6)$

`uncheckedNodes` =

$(1, 4)$
$(0, 5)$

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

Clustering



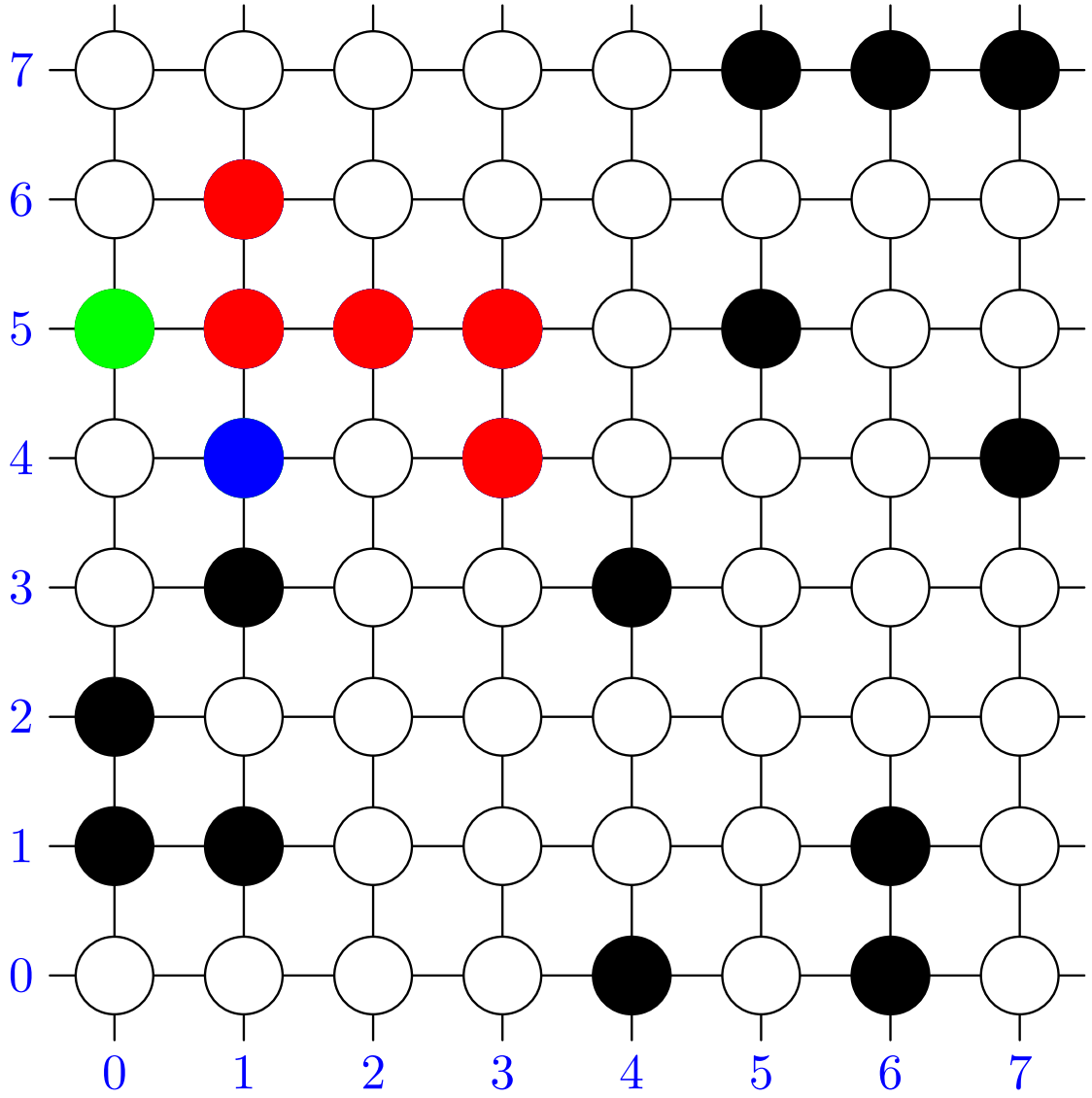
$\text{next} = (1, 6)$

`uncheckedNodes` =

$(1, 4)$
$(0, 5)$

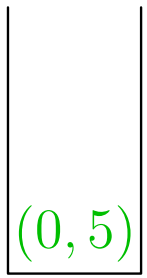
clusterNodes =
$\{ (2, 5), (1, 5), (3, 5),$
$(3, 4), (0, 5), (1, 4),$
$(1, 6) \}$

Clustering



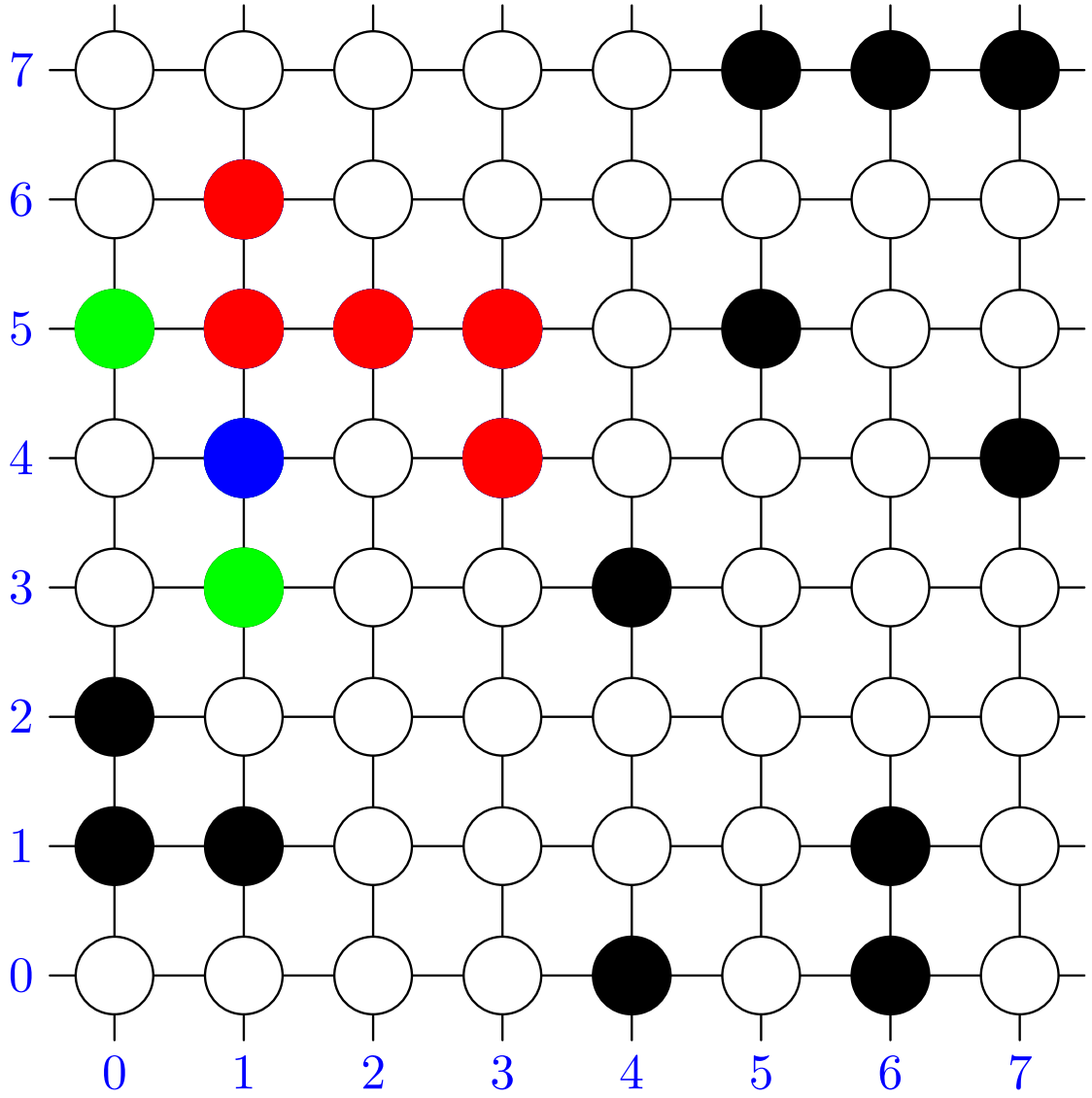
$\text{next} = (1, 4)$

`uncheckedNodes` =



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

Clustering



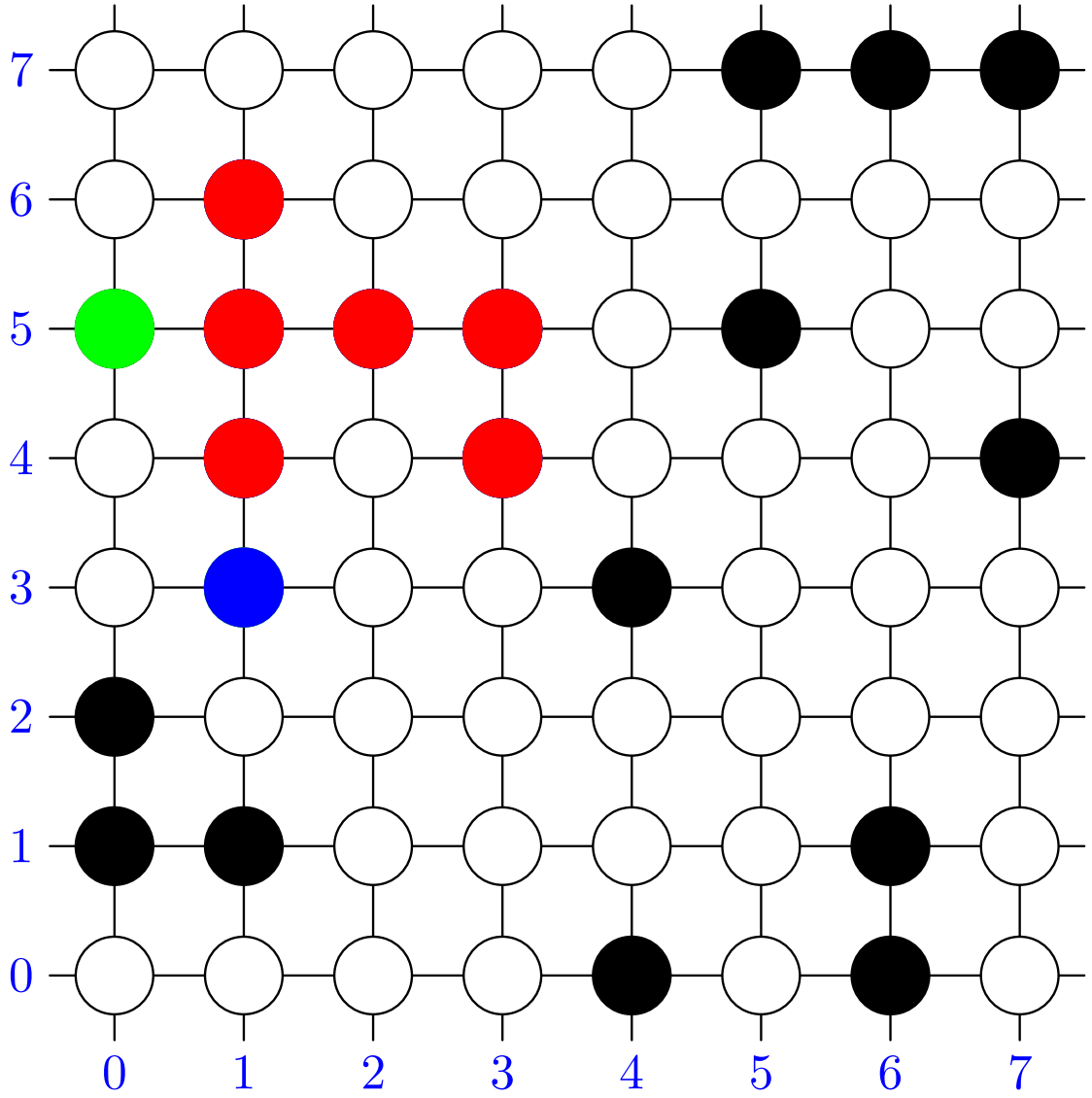
next $= (1, 4)$

`uncheckedNodes` $=$

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

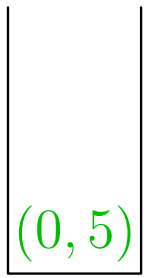
clusterNodes $=$
$\{ (2, 5), (1, 5), (3, 5),$
$(3, 4), (0, 5), (1, 4),$
$(1, 6), (1, 3) \}$

Clustering



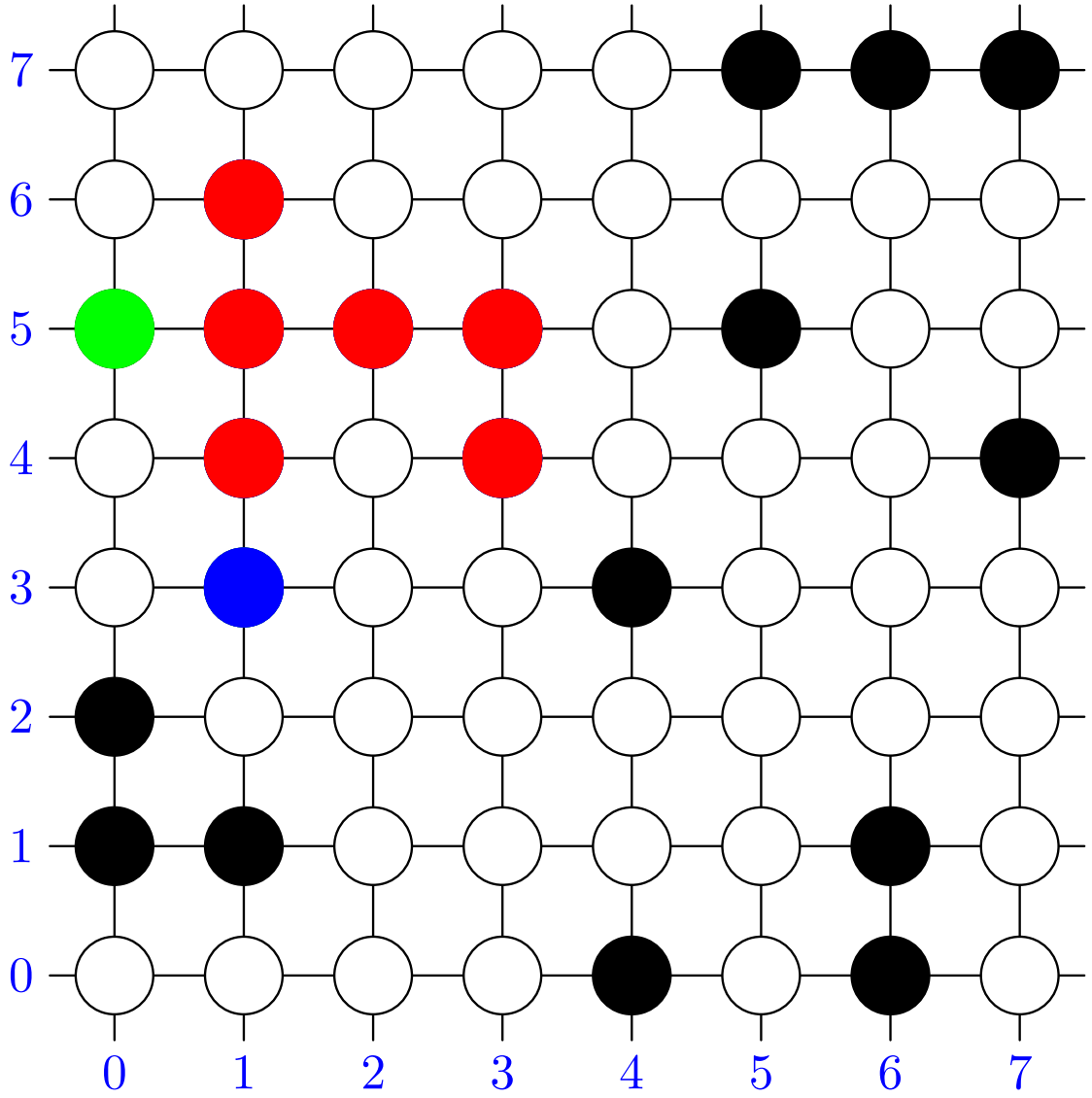
$\text{next} = (1, 3)$

`uncheckedNodes` =



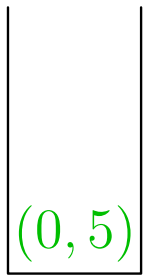
clusterNodes =
$\{ (2,5), (1,5), (3,5),$
$(3,4), (0,5), (1,4),$
$(1,6), (1,3) \}$

Clustering



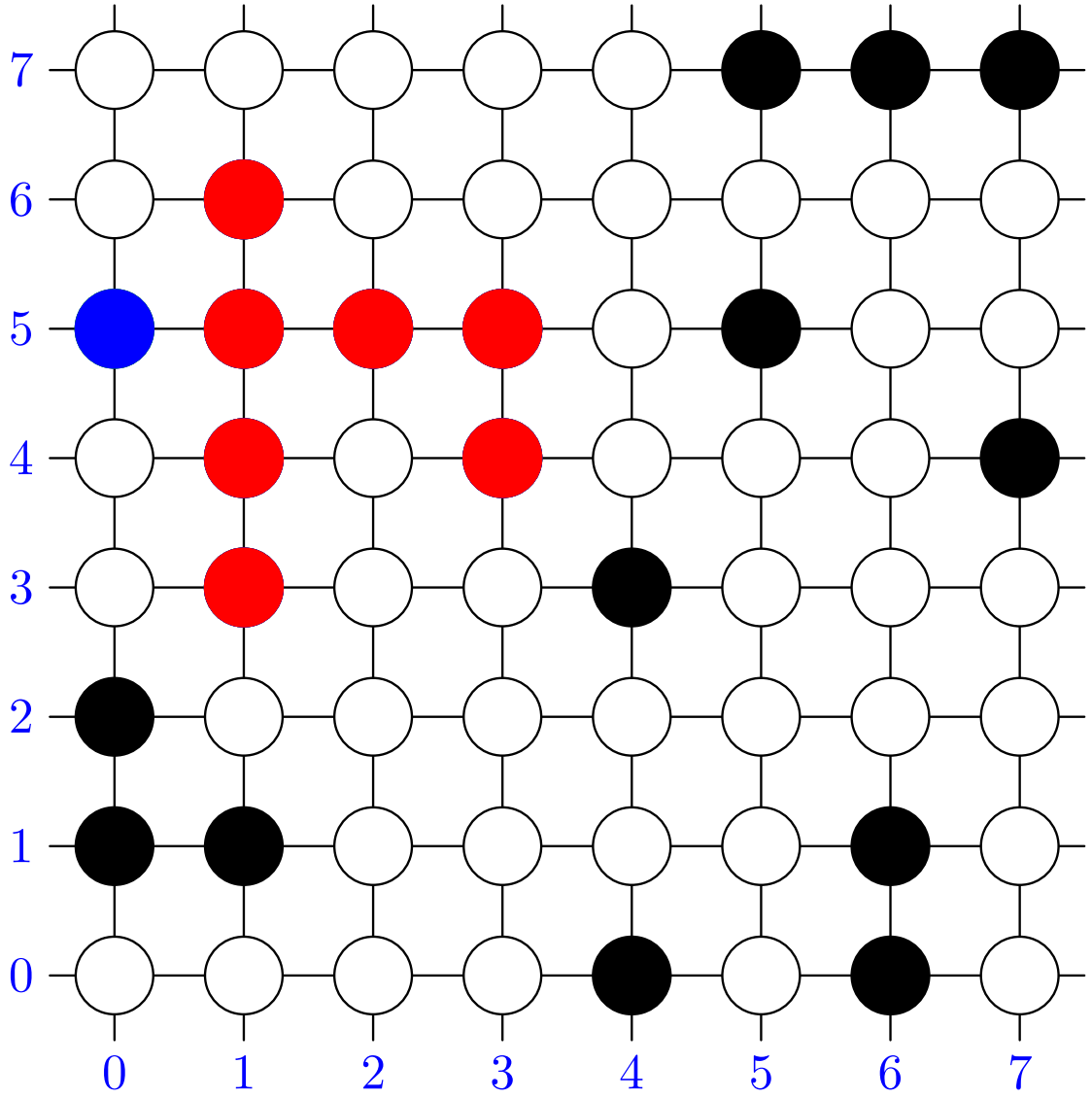
$\text{next} = (1, 3)$

`uncheckedNodes` =



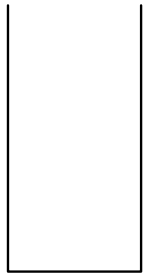
clusterNodes =
$\{ (2,5), (1,5), (3,5),$
$(3,4), (0,5), (1,4),$
$(1,6), (1,3) \}$

Clustering



next $= (0, 5)$

uncheckedNodes $=$



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

Lessons

- Abstract Data Types (ADT) are interfaces for data structures
- 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