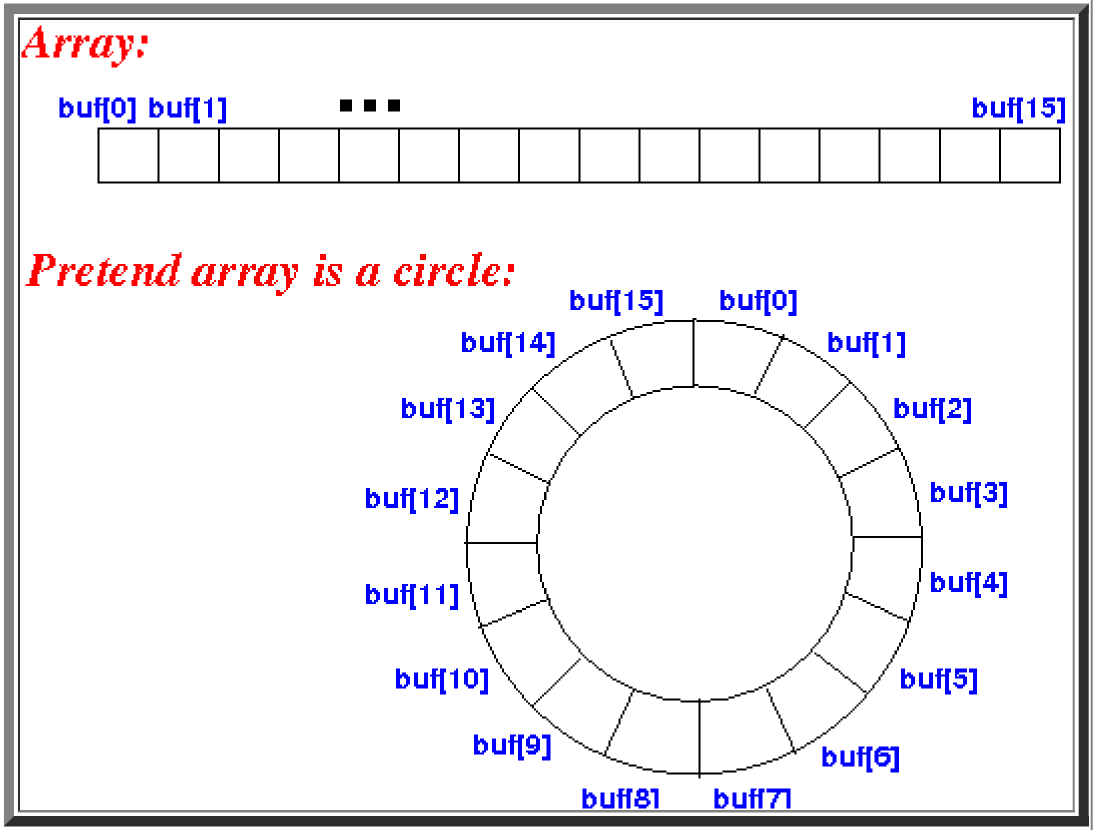
Implementing a Queue using a *circular* array

- **The *circular* array (a.k.a. circular buffer)**
  - **Circular array:**
    - ***Circular* array** = a **data structure** that used a ***array*** as if it were ***connected* end-to-end**

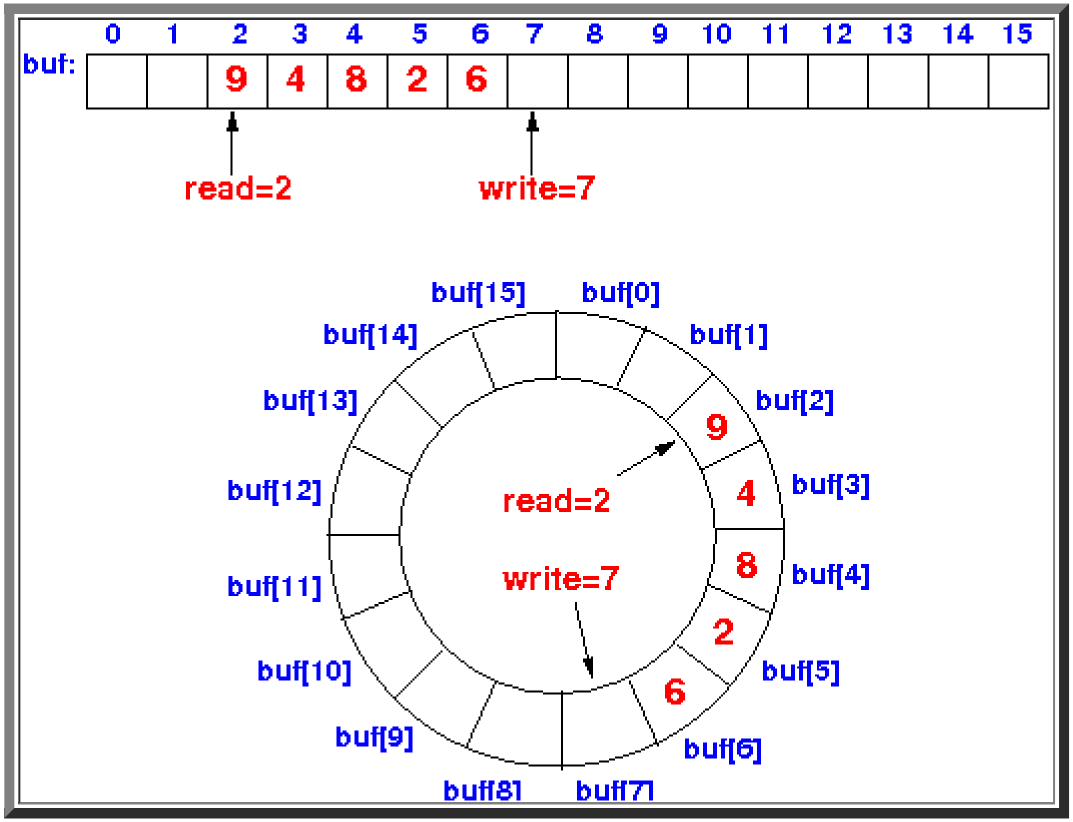
      Schematically:

    - This **data structure** is **also** known as:
      - **Circular buffer**

- **Cyclic buffer**
- **Ring buffer**

- **Read and write pointers of a circular array**
  - A **circular buffer** has **2 "pointers"** (or **indices**):



  - **Read pointer:** (or **read position**)

    - **Read pointer** = the **index** of the **circular array** used by a ***read* operation**

      Example:

- In the **above figure**, a ***read* operation** will return the **value 9** in `buf[2]`

  (because the ***read* pointer** `read` **= 2**)

- **Read pointer:** (or **write position**)

  - **Write pointer** = the **index** of the **circular array** used by a ***write* operation**

    Example:

    - In the **above figure**, a ***write* operation** will update the **array element** `buf[7]`

      (because the ***write* pointer** `write` **= 7**)

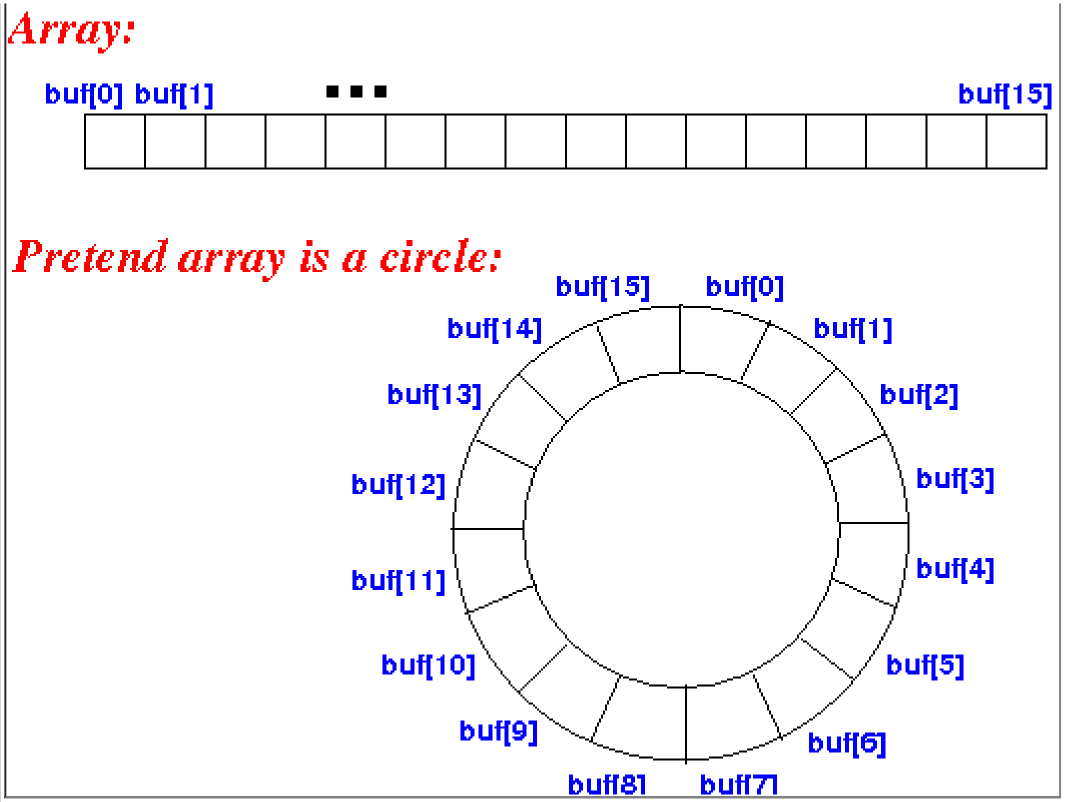
- **Advancing the read and write pointers in a circular array**

  - **Fact:**

    - The **read** and **write** operations will **advance** their **corresponding pointers**

      (Because you don't want the **read** and **write** operations to read/write the ***same* array element** over and over again....)

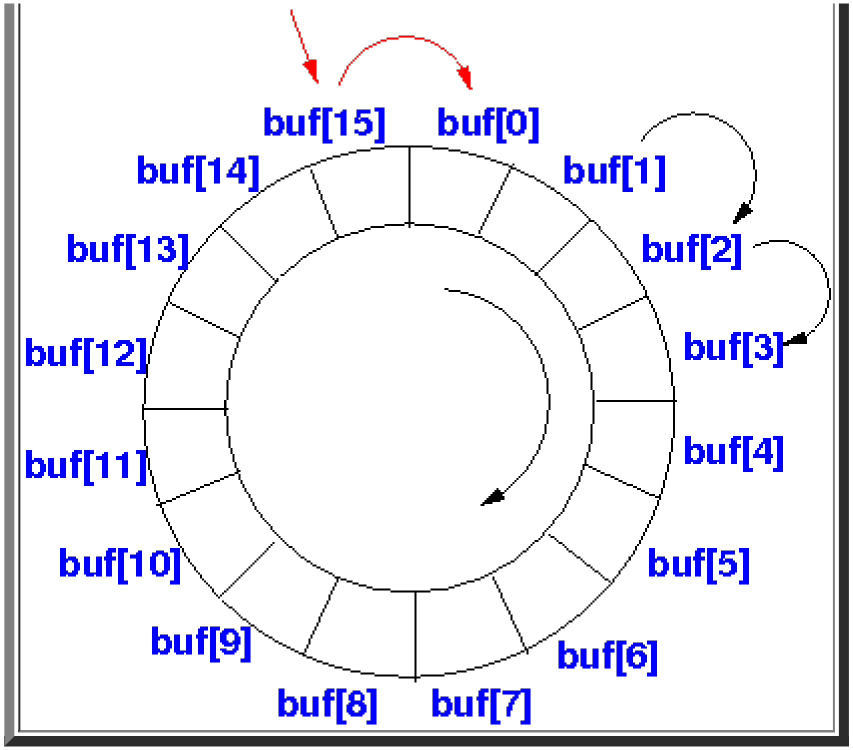
  - The **read/write pointers** in the following **circular array**:



will **advance** in the **following manner**:

- 0, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, **0**, 1, 2, 3, ... and so on...

because the **indices** will ***wrap* around**:



- It is **very easy** to increase an **index** in a **wrap around manner**:

```
index = (index + 1) % N

    where N = the number of indices
```

Example:

```
read = (read + 1) % 4   // will increase read as:
                        //   0, 1, 2, 3, 0, 1, 2, 3, 0, 1, 2, ...
```

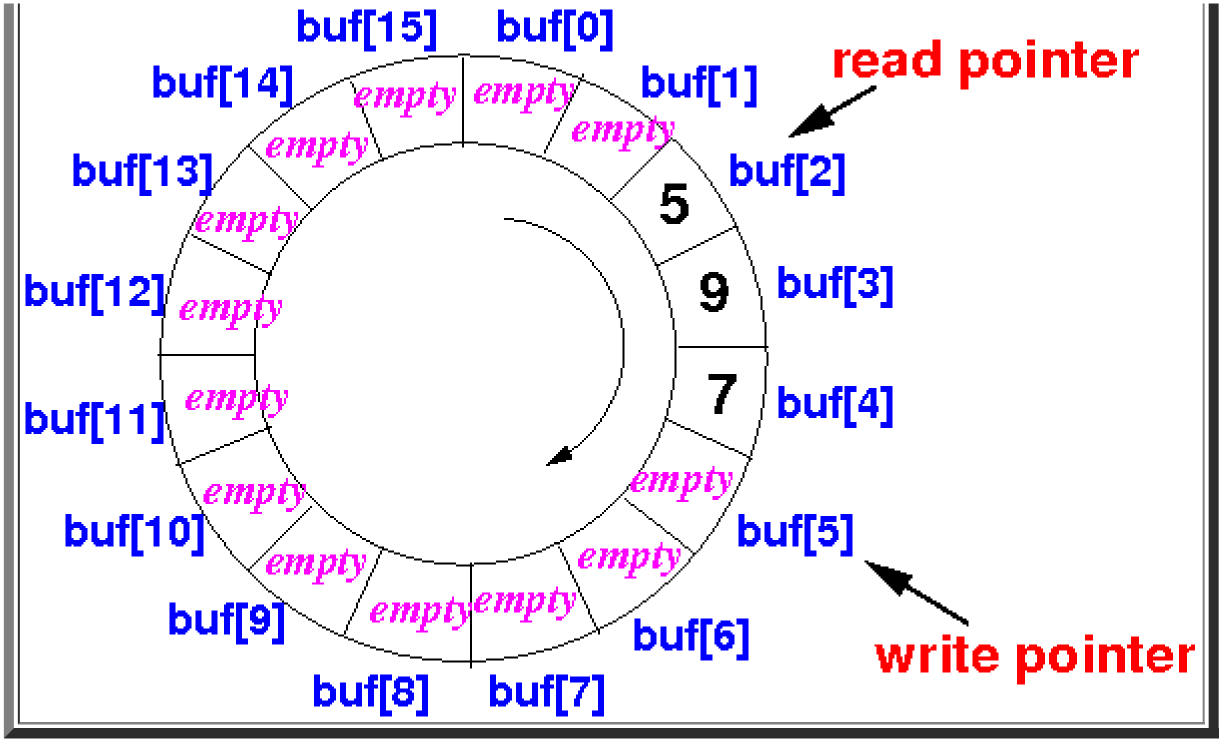
- **Read and write operations on a circular array**
  - The ***read* operation** on a **circular array** is as follows:

```
DataType read()
{
   DataType r;   // Variable used to save the return value

   r = buf[read];                    // Save return value
   read = (read+1)%(buf.length);   // Advance the read pointer

   return r;
}
```

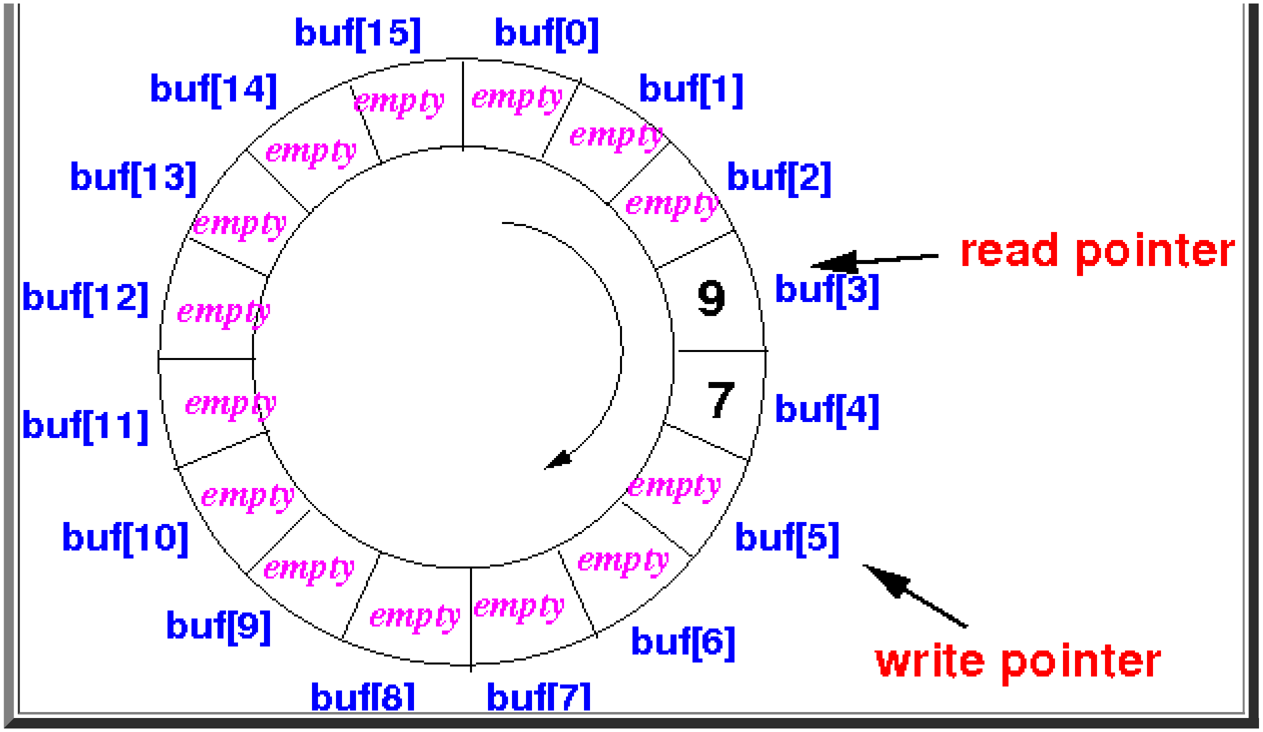
- The ***write* operation** on a **circular array** is as follows:

```
void write(DataType x)
{
   buf[write] = x;                   // Store x in buf at write pointer
   write = (write+1)%(buf.length); // Advance the write pointer
}
```

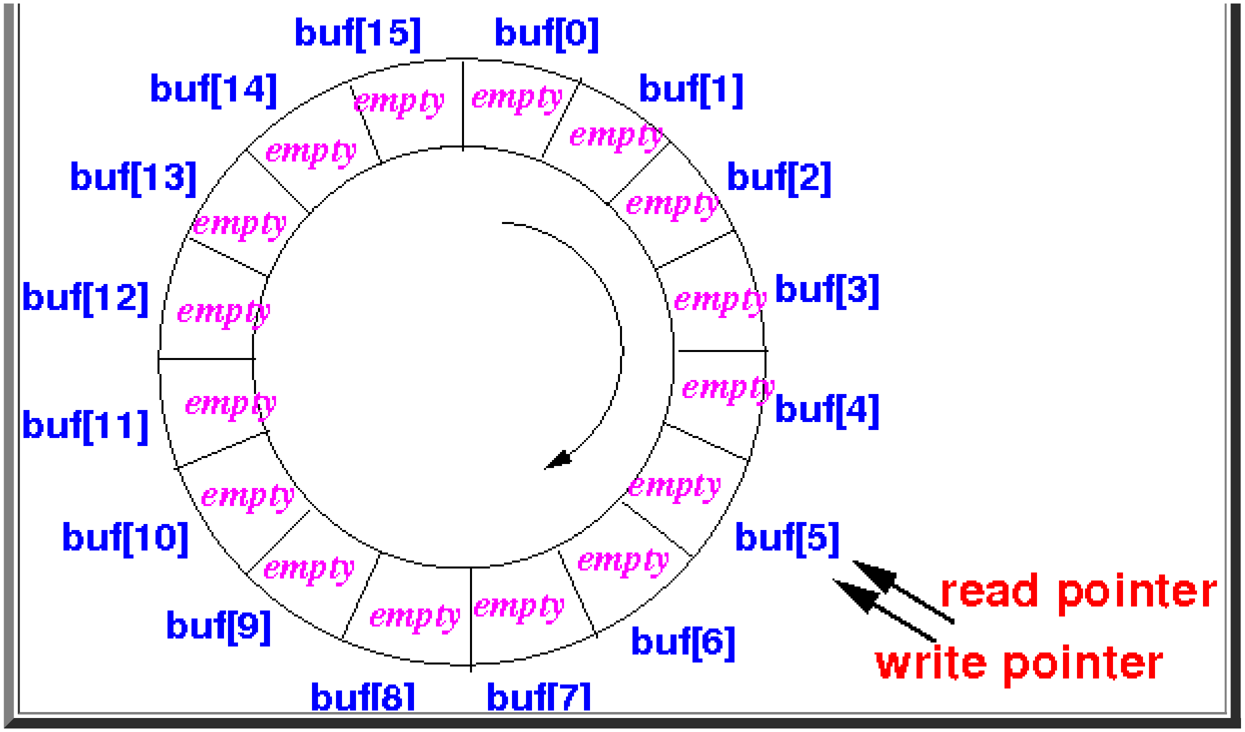
- **Representing an *empty* circular buffer**
  - To **discover *how to* represent** an ***empty* circular buffer**:
    - Let's find out **how** the **information *changes*** when we **read** data from a **circular buffer** first....
  - The **following diagram** depicts a **circular buffer (array)** with **3 data items**:



* After **reading** ***one*** **data item**, the **circular buffer (array)** will contain **2 data items**:



- After **reading** ***two*** **more data item**, the **circular buffer (array)** will become ***empty***:

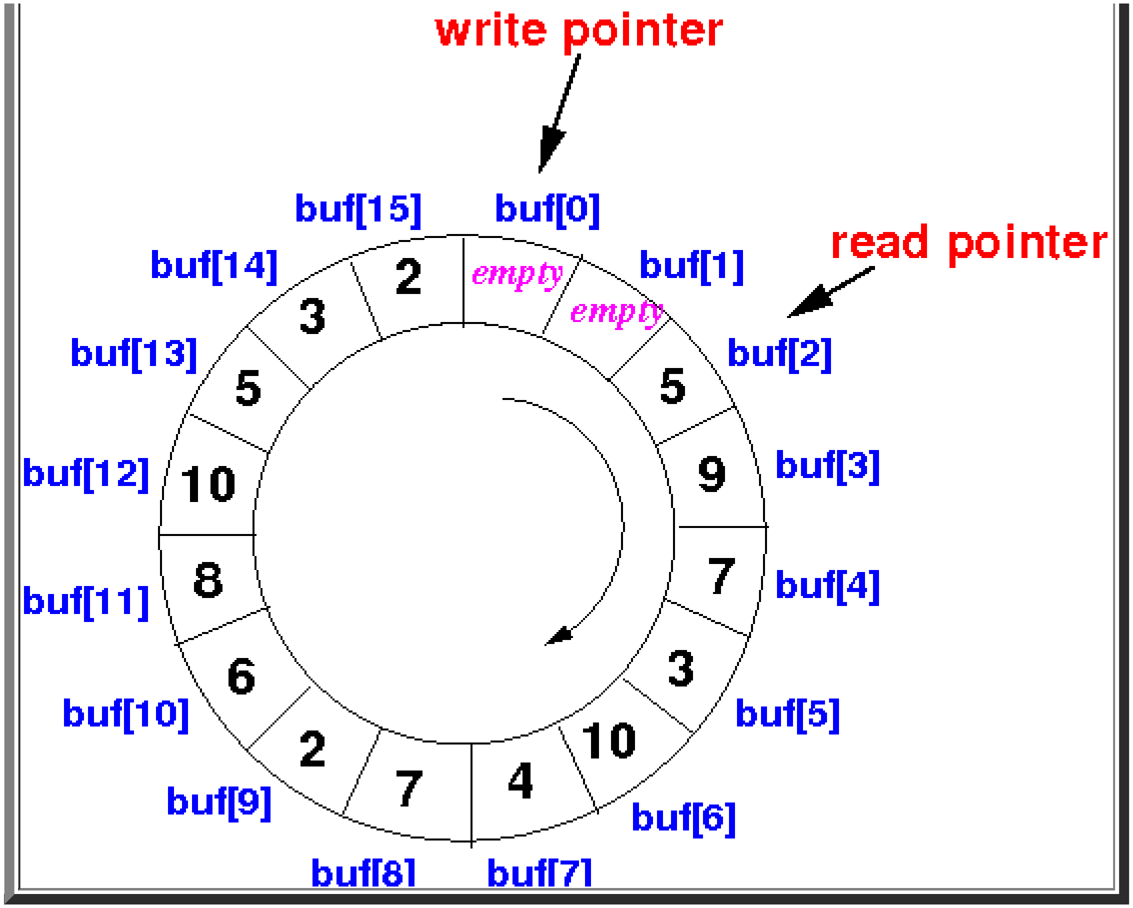


Therefore, a **circular array (buffer)** is ***empty*** if:

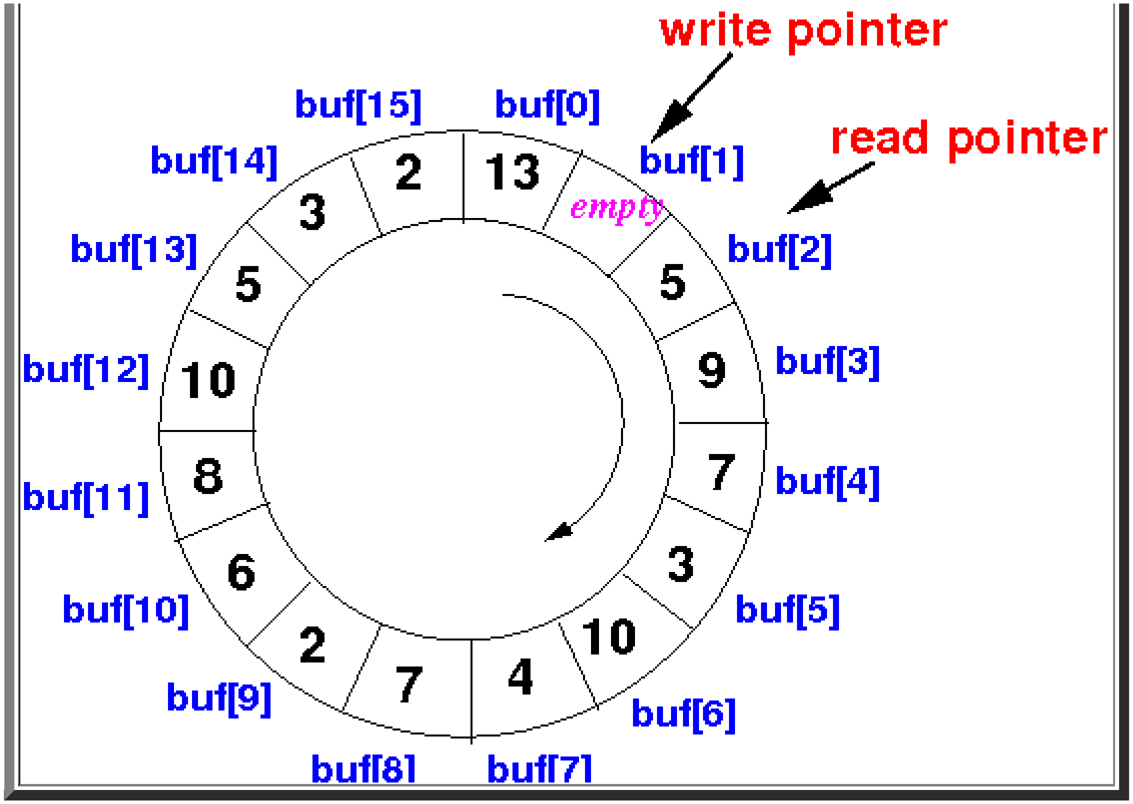
```
read pointer == write pointer
```

- **Representing an *full* circular buffer**
  - To **discover** ***how to*** **represent** an ***empty*** **circular buffer**:
    - Let's find out **how** the **information** ***changes*** when we **write** data into a **circular buffer** first....

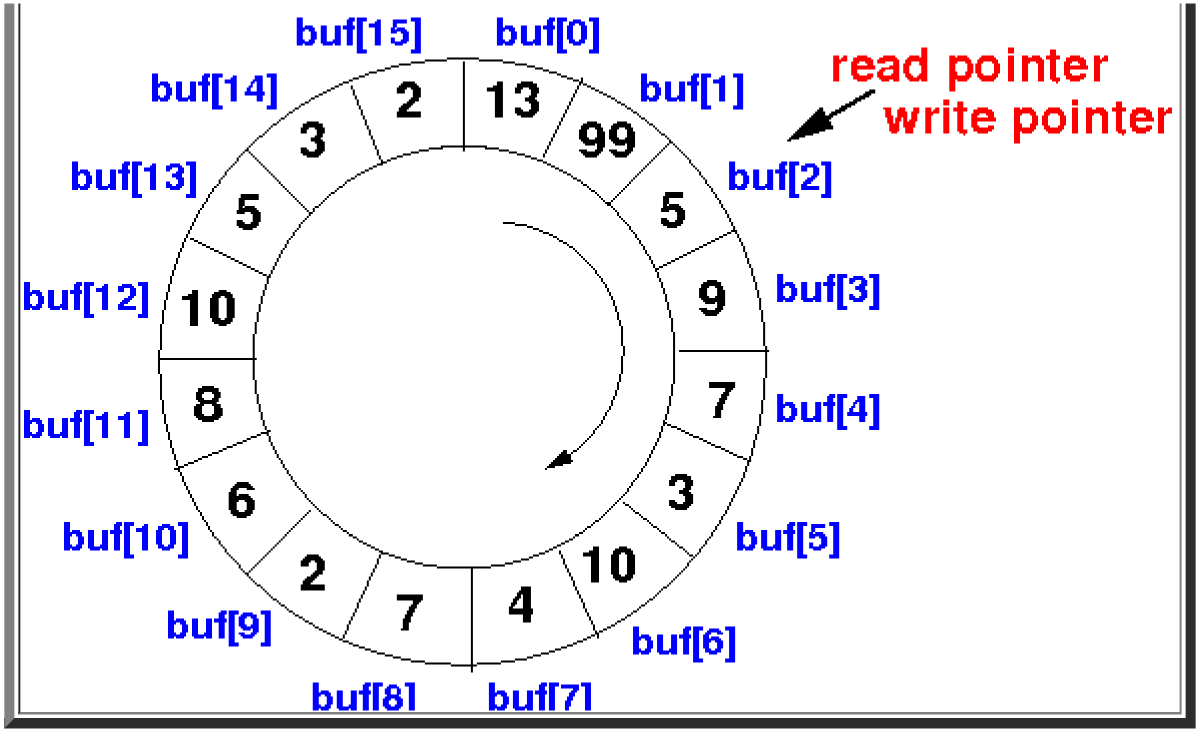
  - The **following diagram** depicts a **circular buffer (array)** with **2 empty slots**:



- After **writing** ***one*** **data item**, the **circular buffer (array)** will contain **1 empty slot**:



- After **writing** ***another*** **data item**, the **circular buffer (array)** will become ***full***:



Therefore, a **circular array (buffer)** is ***full*** if:

```
read pointer == write pointer
```

- **Trouble**:

  - The **condition** `read pointer == write pointer` can **indicate**:
    - an ***empty* buffer**, **or**
    - a ***full* buffer**

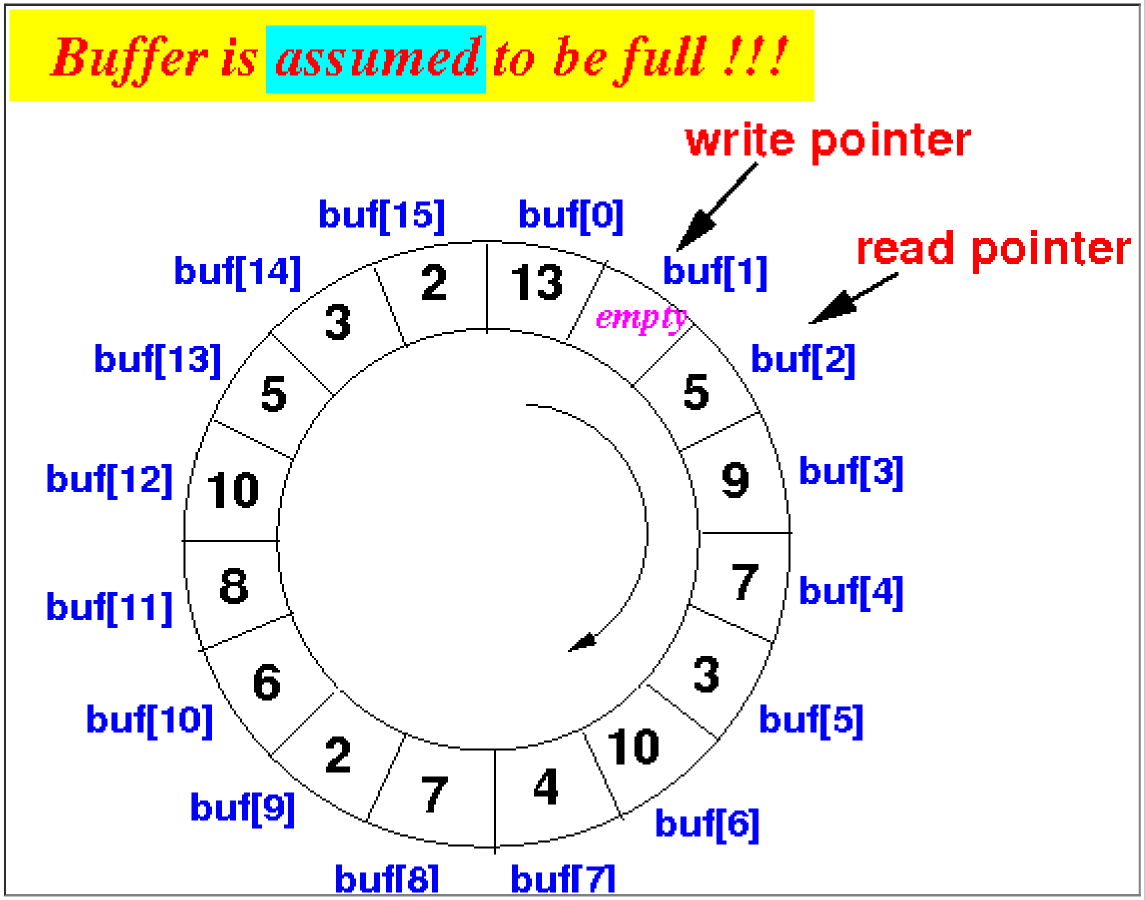
- ***Breaking* the ambiguity**

- **Traditionally**, the following ***trick*** is used to to **break** the **ambiguity**:

  - We ***assume*** that the **circular buffer** is ***full*** when:

    - There is ***one* empty slot** left in the **circular buffer**:

  Example:



In other words, we use the following **test** to check if the **circular buffer** is ***full***:

```
read pointer == ( write pointer + 1 ) % (buf.length)
```

- **Implementing a *Queue* using a circular array**
  - Just like the ***Stack***, we can **implement** a ***Queue*** using ***different* data structures**.

    You just saw the **implementation** of the **queue** using a **list**

  - The **implementation** of **operations** of a **queue** using a ***circular* array** is as follows:

```
    enqueue( x )  // This is writing in a circular buffer (See: click here)
    {
       if ( read == ( write + 1 ) % (buf.length) )
       {
           throw new Exception("Queue is full");
       }

       buf[write] = x;                  // Store x in buf at write pointer
       write = (write+1)%(buf.length); // Advance the write pointer
    }
```

```
    DataType dequeue()  // This is reading in a circular buffer (See: click here)
    {
       DataType r;   // Variable used to save the return value

       if ( read == write )
       {
           throw new Exception("Queue is empty");
       }

       r = buf[read];                  // Save return value
       read = (read+1)%(buf.length);  // Advance the read pointer

       return r;
    }
```

  - **In Java**:

```
public class  ArrayQueue  implements Queue
{
   /* ==========================================
      Node "inner class"
      ========================================== */
   public class Node
   {
      double value;
      Node   next;

      public Node( double x )
      {
         value = x;
         next  = null;
      }

      public String toString()
      {
         return "" + value;
      }
   }

   public double[] buf;          // Circular buffer
   public int      read, write;  // read and write pointers

   // Constructor
   public ArrayQueue(int size)
   {
      buf = new double[size];    // Create array for circular buffer

      read = 0;                  // Initialized read & write pointers
      write = 0;
   }

   /* ====================================================
       enqueue(x ):
      ==================================================== */
   public void enqueue( double x )   throws Exception
   {
      if ( read == ( write + 1 ) % (buf.length) )  // Full...
      {
         throw new Exception("Queue is full");
      }

      buf[write] = x;                  // Store x in buf at write pointer
      write = (write+1)%(buf.length); // Advance the write pointer
   }

   /* ====================================================
```

```
         dequeue():
       ===================================================== */
    public double dequeue( ) throws Exception
    {
       double r;   // Variable used to save the return value

       if ( read == write )
       {
          throw new Exception("Queue is empty");
       }

       r = buf[read];                     // Save return value
       read = (read+1)%(buf.length);  // Advance the read pointer

       return r;
    }
 }
```

- **Example Program:** (Demo above code)

  Example

  - The ***Queue* interface** Prog file: click here
  - The ***ArrayQueue* implementation** Prog file: click here
  - The **test** Prog file: click here

  How to run the program:

  - **Right click** on link(s) and **save** in a scratch directory
  - To compile: `javac testProg.java`
  - To run: `java testProg`

- **Empty and full conditions**

  - The following **test program** can be used to trigger a **queue *full*** error:

```
public static void main( String[] args )  throws Exception
{
   Queue  myQ = new ArrayQueue(3);
```

```
      double x;

      myQ.enqueue(1.0);
      System.out.println("enqueue(1.0): " + "myQ = " + myQ);
      myQ.enqueue(2.0);
      System.out.println("enqueue(2.0): " + "myQ = " + myQ);
      myQ.enqueue(3.0);        // <--- will cause exception
      System.out.println("enqueue(3.0): " + "myQ = " + myQ);
   }
```

- The following **test program** can be used to trigger a **queue *empty*** error:

```
   public static void main( String[] args )  throws Exception
   {
      Queue  myQ = new ArrayQueue(10);
      double x;

      x = myQ.dequeue();   // <--- will cause exception
   }
```