Lists, Stacks, and Queues

Many significant programs use lists, stacks, or queues in some form.

- Motivation:
  - ☐ Review ADTs
  - ☐ Review familiar list, stack, and queue data types
  - ☐ Introduce analysis with them
  - ☐ Discuss efficient implementations of lists, stacks, queues
  - ☐ Review some common applications of lists, stacks, queues

Lists

- **list**: a finite, ordered sequence of data items called **elements**
- Associated definitions/concepts:
  - ☐ Each list element has a data type
  - ☐ The **empty list** contains no elements
  - ☐ The **list length** is the number of elements currently stored
  - ☐ The beginning of the list is the **head**
  - ☐ The end of the list is the **tail**
  - ☐ **Sorted lists** have elements positioned in ascending order of value
  - ☐ **Unsorted lists** have no relationship between position and element value
  - ☐ Notation: A_1, A_2, A_3, ..., A_n

    or $(A_1, A_2, A_3, \ldots, A_n)$
  - ☐ Popular operations: `print`, `makeEmpty`, `insert`, `remove`, `next`, `prev`, etc.

List Implementation Concepts

- List defined in terms of *left* and *right* partitions
  - ☐ Either or both partitions may be empty
  - ☐ Each partition is separated by a *fence*.
  - ☐ Example: <20, 23 | 12, 15>

- List ADT:

```
template <class Elem> class List {
  public:
    virtual void clear() = 0;
    virtual bool insert(const Elem&) = 0;
    virtual bool append(const Elem&) = 0;
    virtual bool remove(const Elem&) = 0;
    virtual void setStart() = 0;
    virtual void setEnd() = 0;
    virtual void prev() = 0;
    virtual void next() = 0;
    virtual int leftLength() const = 0;
    virtual int rightLength() const = 0;
    virtual bool setPos(int pos) = 0;
    virtual bool getValue(Elem&) = 0;
    virtual void print() const = 0;
};
```


List ADT Examples

- A list containing <12 | 32, 15>
  - ☐ Execute `MyList.insert(99);`
  - ☐ Result: <12 | 99, 32, 15>

- List Iteration:

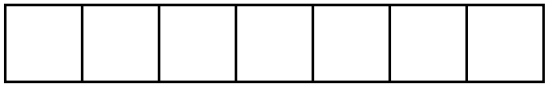
```
for (MyList.setStart(); MyList.getValue(it);
     MyList.next()) {
  (Do something with this list element.)
}
```

- List Find Function

```
bool find(List<int>& L, int K) {
  int it;
  for (L.setStart(); L.getValue(it);
       L.next())
    if (K == it) return true;
  return false;
}
```

Array-Based Lists

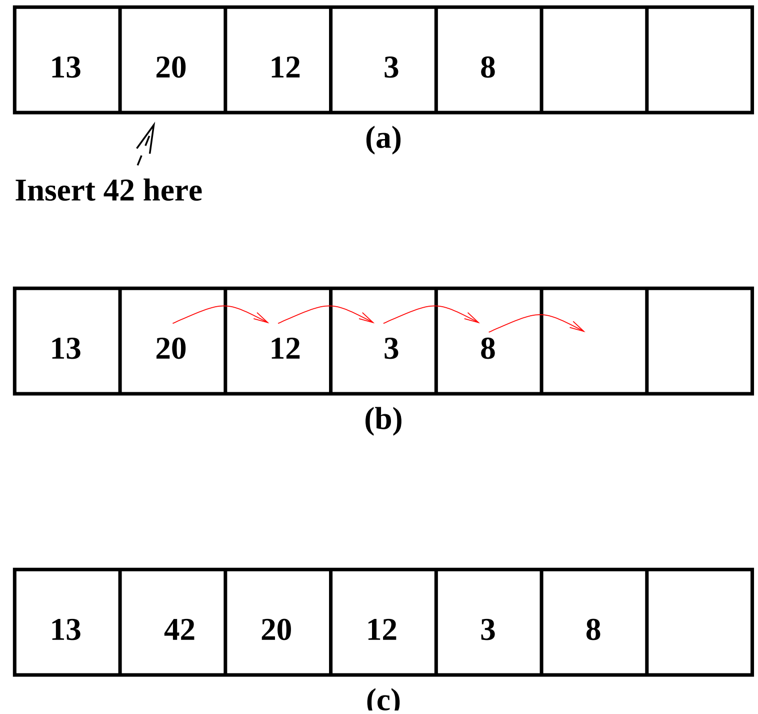
- A contiguous block of memory containing elements:



- Time estimates for:
  - ☐ `print`
  - ☐ `find`

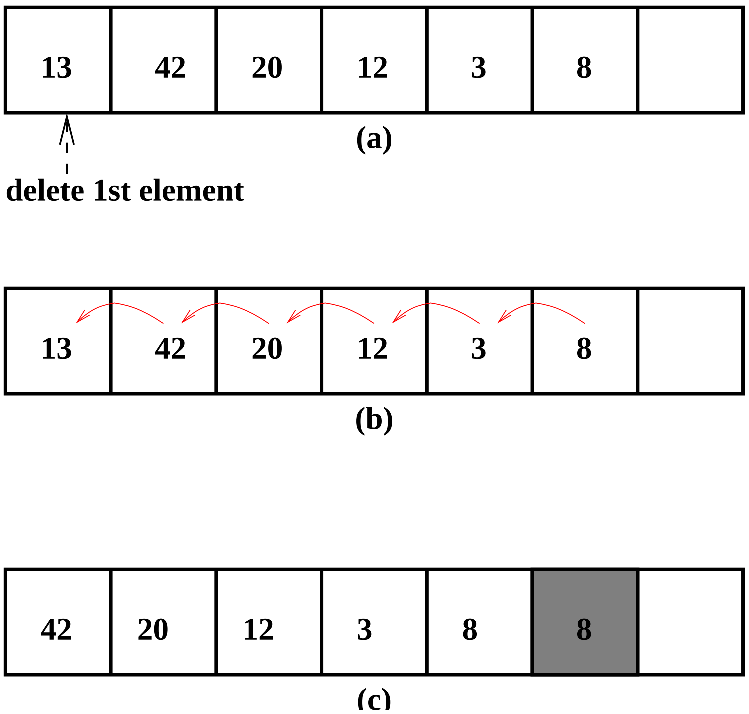
- See web site for code examples

Array-Based List Insert



- Time to `insert`:

Array-Based List Delete



- Time to `delete`:

Array-Based List Class

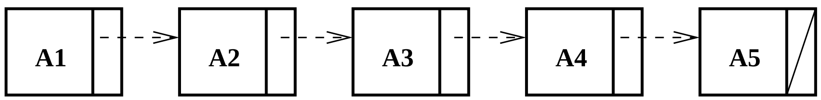
- The class header:

```
#include "list.h"
template <class Elem>
class AList : public List<Elem> {
private:
  int maxSize;      // Maximum size of list
  int listSize;     // Actual number of elements in list
  int fence;        // Position of fence
  Elem* listArray; // Array holding list elements
public:
  AList(int size=DefaultListSize);
  ~AList();
  void clear();
  bool insert(const Elem&);
  bool append(const Elem&);
  bool remove(Elem&);
  void setStart();
  void setEnd();
  void prev();
  void next();
  int leftLength() const;
  int rightLength() const;
  bool setPos(int pos);
  bool getValue(Elem& it) const;
  void print() const;
};
```

- (See web site for remaining code.)

Linked Lists

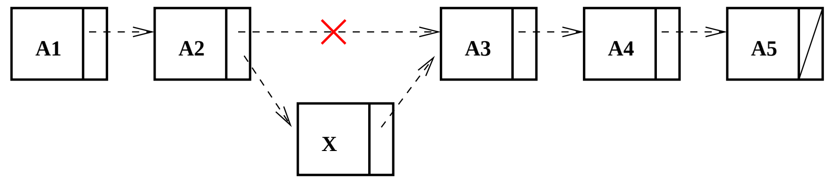
- A series of memory blocks containing *nodes*:



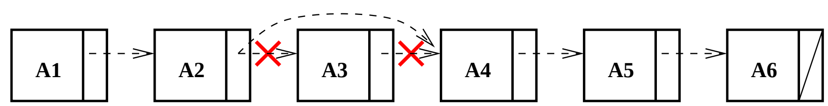
- Nodes contain:
  - ☐ element (the data)
  - ☐ **next** link to another node containing the successor element
- Time estimates for:
  - ☐ `print`
  - ☐ `find`

linked List Insert/Delete

- Inserting X between A_2 and A_3:



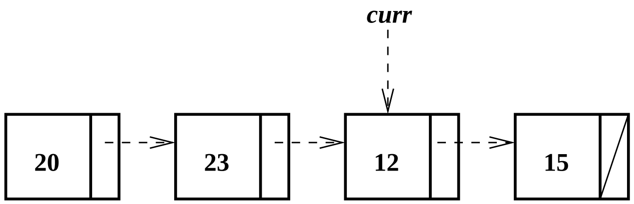
- Time to `insert`:
- Deleting A_3:



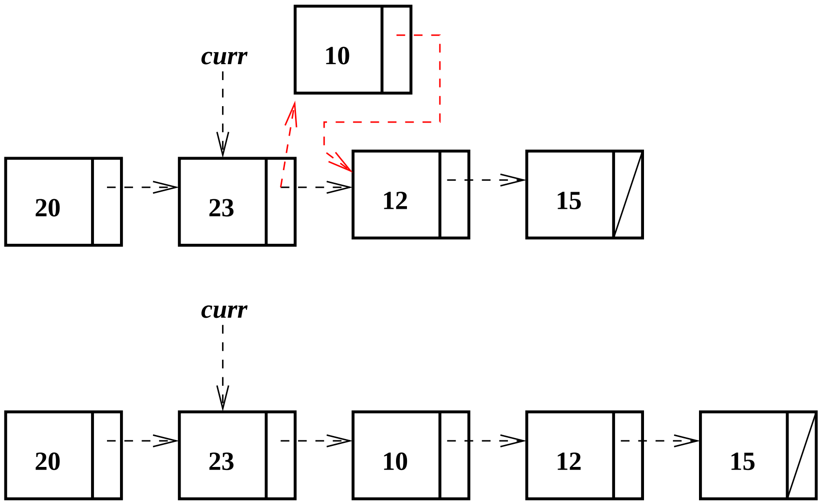
- Time to `delete`:

Linked List Positioning

- How do we insert 10 before the 12?
  - ☐ Naive approach:

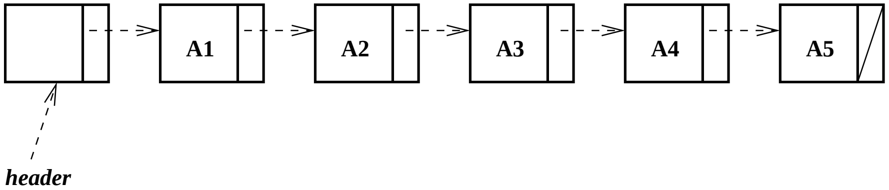


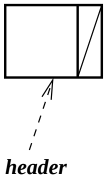
  - ☐ Better approach:



Use of a Header Node

- Several problems not yet solved:
  - ☐ There is no obvious way to insert at the head of the list
  - ☐ Removing from the front is a special case
  - ☐ Deletion requires finding the node before the one to be deleted
- Simple change solves all three: use a dummy header node

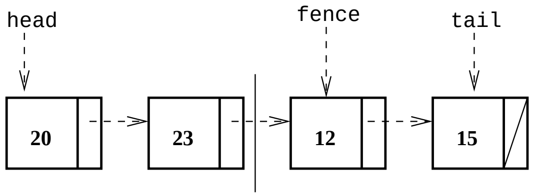


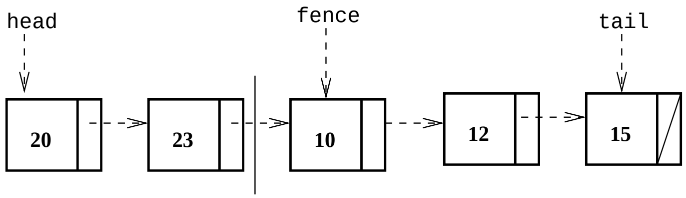


Use of Fence in Linked List

Shaffer uses the "fence" instead of a "curr" pointer.

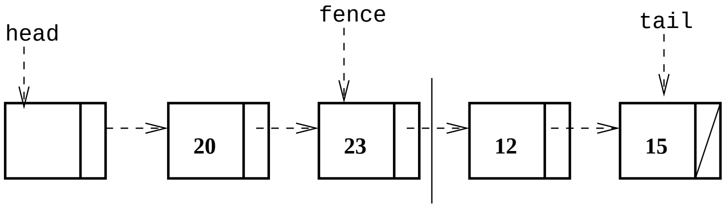
- Again, how do we insert 10 before the 12?
- Naive approach:

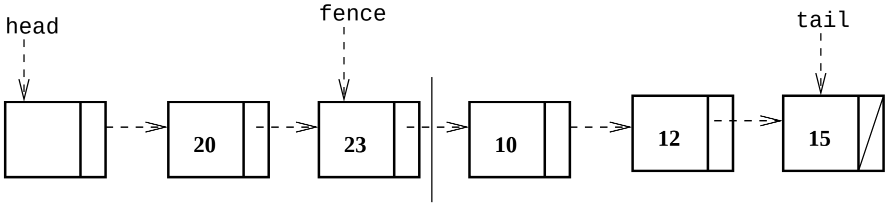




Use of Fence in Linked List

- Better approach:





Linked List Implementation

- One view: implement three separate classes:
  - ☐ `ListNode`, to implement the nodes themselves
  - ☐ `ListItr`, to implement the concept of position
  - ☐ `List`, to implement the list
- Shaffer uses two classes: `Link` nodes and the list itself
  - ☐ The link class stores the data and pointer to next node
  - ☐ The list class stores list functions and pointers to Link nodes.

Link Class

Uses dynamic allocation of new list elements.

- Class header:

```
template <class Elem> class Link {
public:
  Elem element;      // Value for this node

  Link *next;        // Pointer to next node in list

  Link(const Elem& elemval, Link* nextval =NULL)
    { element = elemval;  next = nextval; }

  Link(Link* nextval =NULL) { next = nextval; }
};
```

Linked List Class

- Linked list header file:

```
template <class Elem> class LList: public List<Elem> {
private:
  Link<Elem>* head;   // Pointer to list header
  Link<Elem>* tail;   // Pointer to last Elem in list
  Link<Elem>* fence;  // Last element on left side
  int leftcnt;        // Size of left partition
  int rightcnt;       // Size of right partition
  void init();        // Initialization routine
  void removeall();   // Return link nodes to free store
public:
  LList(int size=DefaultListSize);
  ~LList();
  void clear();       // Remove and reset the list
  bool insert(const Elem&);
  bool append(const Elem&);
  bool remove(Elem&);
  void setStart();    // Move the fence to the far left
  void setEnd();      // Move the fence to the far right
  void prev();        // Move the fence one left
  void next();        // Move the fence one right
  int leftLength() const;
  int rightLength() const;
  bool setPos(int pos);
  bool getValue(Elem& it) const;
  void print() const;
};
```


Insert and Append

- Insert at front of right partition:

```
template <class Elem>
bool LList<Elem>::insert(const Elem& item) {
  fence->next = new Link<Elem>(item, fence->next);
  if (tail == fence) tail = fence->next;  // New tail
  rightcnt++;
  return true;
}
```

- Append Elem to the end of the list:

```
template <class Elem>
bool LList<Elem>::append(const Elem& item) {
  tail = tail->next = new Link<Elem>(item, NULL);
  rightcnt++;
  return true;
}
```

Remove

- Remove and return the first element (Elem) in the right partition

```
template <class Elem> bool LList<Elem>::remove(Elem& it) {
  if (fence->next == NULL) return false; // Empty right
  it = fence->next->element;       // Remember value
  Link<Elem>* ltemp = fence->next; // Remember link node
  fence->next = ltemp->next;       // Remove from list
  if (tail == ltemp) tail = fence; // Reset tail
  delete ltemp;                    // Reclaim space
  rightcnt--;
  return true;
}
```


Positioning

- Next and Prev:

```
// Move fence one step right; no change if at tail.
template <class Elem> void LList<Elem>::next() {
  if (fence != tail) {
    fence = fence->next;
    rightcnt--; leftcnt++;
  }
}

// Move fence one step left; no change if left is empty
template <class Elem> void LList<Elem>::prev() {
  Link<Elem>* temp = head;
  if (fence == head) return; // No previous Elem
  while (temp->next!=fence) temp=temp->next;
  fence = temp;
  leftcnt--; rightcnt++;
}
```

- SetPos:

```
// Set the size of left partition to pos
template <class Elem>
bool LList<Elem>::setPos(int pos) {
  if ((pos < 0) || (pos > rightcnt+leftcnt))
    return false;
  rightcnt = rightcnt + leftcnt - pos; // Set counts
  leftcnt = pos;
  fence = head;
  for (int i=0; i<pos; i++)
    fence = fence->next;
  return true;
}
```

Comparison of List Implementations

- Array-based lists:
  - ☐ Insert and delete are $\Theta(n)$
  - ☐ Array must be pre-allocated
  - ☐ No overhead if the array is full
  - ☐ Inefficient use of storage if list is almost empty
- Linked lists:
  - ☐ Insertion and deletion are $\Theta(1)$, but finding previous and direct access are $\Theta(n)$
  - ☐ Space grows with number of elements
  - ☐ Every element requires overhead
- Space break-even point:

$$DE = n(P + E)$$

$$\text{or } n = \frac{DE}{P + E}$$

E is space for data value, **P** is space for pointer, and **D** is number of elements in the array

Memory Reclamation

- Removeall:

```
template <class Elem>
void LList<Elem>::removeall() {
  while(head != NULL) {
    fence = head;
    head = head->next;
    delete fence;
  }
}
```

- Removeall Makes the destructor very simple:

```
template <class Object>
LList<Elem>::~LList( )
{
    removeall( );
}
```

Freelists

- Some languages do not support dynamic memory allocation, and C++ can simulate it
- Desirable features:
  - ☐ Data are stored in a collection of nodes, each of which also contains a link to the next node
  - ☐ A new node can be obtained from system memory by a call to `new`
- Motivations for simulation in **any** C++ program:
  - ☐ Calls to the system's `new` and `delete` can be expensive (slow)
  - ☐ You can improve performance by up to 30% by replacing `new` and `delete`.
- Methodology:
  - ☐ Create a large array of "Link nodes"
  - ☐ Initially, for all i, set A[i].next to point at A[i+1]
  - ☐ Use a header node to point at A[0]
  - ☐ Remove and return (`new` and `delete`) from/to the array
- Method is also known as *cursor implementation*

Free List Link Class

- Major difference is static freelist variable plus overloaded operators.

```
template <class Elem> class Link {
private:
  static Link<Elem>* freelist; // Head of the freelist
public:
  Elem element;             // Value for this node
  Link* next;               // Point to next node in list

  Link(const Elem& elemval, Link* nextval =NULL)
    { element = elemval;  next = nextval; }

  Link(Link* nextval =NULL) { next = nextval; }

  void* operator new(size_t);  // Overloaded new operator
  void operator delete(void*); // Overloaded delete opera
};

template <class Elem>
Link<Elem>* Link<Elem>::freelist = NULL;
```

Overloaded Operators

- New and Delete:

```
template <class Elem>
void* Link<Elem>::operator new(size_t) {
  if (freelist == NULL)
    return ::new Link;          // Create space
  Link<Elem>* temp = freelist; // Can take  from freelist
  freelist = freelist->next;
  return temp;                 // Return the link
}

template <class Elem>
void Link<Elem>::operator delete(void* ptr) {
  ((Link<Elem>*)ptr)->next = freelist; // Put on freelist
  freelist = (Link<Elem>*)ptr;
}
```


Doubly Linked lists

- Simplifies insertion/deletion by adding an extra pointer.
- Doubly-linked link class header:

```
template <class Elem> class Link {
public:
  Elem element;       // Value for this node
  Link *next;         // Pointer to next node in list
  Link *prev;         // Pointer to previous node

  Link(const Elem& e, Link* prevp =NULL,
       Link* nextp =NULL) {
    element = e;
    prev = prevp;
    next = nextp;
  }

  Link(Link* prevp =NULL, Link* nextp =NULL)
    { prev = prevp;  next = nextp; }
};
```

Insert and Remove

- Doubly Linked Insert:

```
template <class Elem>
bool LList<Elem>::insert(const Elem& item) {
  fence->next = new Link<Elem>(item, fence, fence->next);
  if (fence->next->next != NULL) // If not at end
    fence->next->next->prev = fence->next;
  if (tail == fence)              // Appending new Elem
    tail = fence->next;           //   so set tail
  rightcnt++;                     // Added to right
  return true;
}
```

- Doubly Linked Remove:

```
template <class Elem> bool LList<Elem>::remove(Elem& it) {
  if (fence->next == NULL) return false; // Empty right
  it = fence->next->element;       // Remember value
  Link<Elem>* ltemp = fence->next; // Remember link node
  if (ltemp->next != NULL) ltemp->next->prev = fence;
  else tail = fence;               // Reset tail
  fence->next = ltemp->next;       // Remove from list
  delete ltemp;                    // Reclaim space
  rightcnt--;                      // Removed from right
  return true;
}
```


Comparator Class

How can comparison be generalized?

- Use ==, <=, >= with no modification.
  - Problems?
- Overload ==, <=, >=, etc.
  - Problems?
- Define a function with a standard name
  - Problems:
    - Implied obligation
    - Breaks down if multiple key fields or indices are used for the same object
- Pass in a function
  - Requires an explicit obligation
  - Can pass in as a function parameter in the template parameter
  - Shaffer uses his Dictionary ADT to illustrate this

The Stack ADT

Also known as a **LIFO** (Last-In, First-Out) list

- A stack is a list with access restrictions:
  - ☐ insertion and deletions may only be performed at one end of the list, the *top*
  - ☐ Implementation may determine which physical end of the list is actually used
- Notation
  - ☐ Insert: **push**
  - ☐ Delete: **pop**
  - ☐ Only accessible element: **top**
- Stack Class Header

```
template <class Elem> class Stack {
  public:
    virtual void clear() = 0;
    virtual bool push(const Elem&) = 0;
    virtual bool pop(Elem&) = 0;
    virtual bool topValue(Elem&) const = 0;
    virtual int length() const = 0;
};
```


Array-Based Stack

- Some implementation details:

```
private:
  int size;
  int top;
  Elem *listArray;
```

- Issues:
  - ☐ Which end of the array is the top?
  - ☐ Where does top point to?
  - ☐ What is the cost of operations?

Linked List Stack

- Some implementation details:

```
private:
  Link<Elem>* top;
  int size;
```

- Issues:
  - ☐ What is the cost of operations?
  - ☐ How do space requirements compare to that of the array-based implementation?

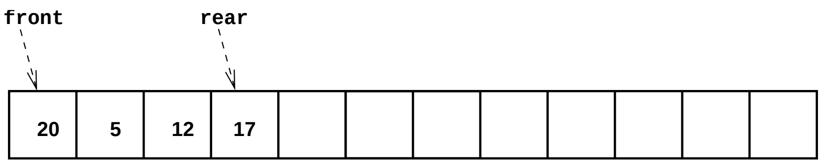
The Queue ADT

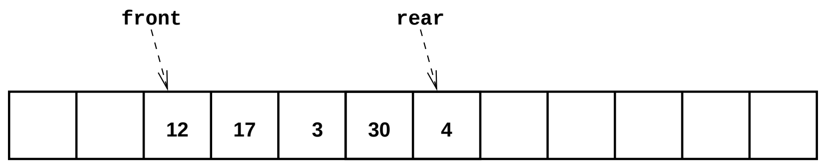
Also known as a **FIFO** (First-In, First-Out) list

- A queue is also a list with access restrictions:
  - ☐ insertion and deletions are performed at opposite ends of the list.
- Notation
  - ☐ Insert: **enqueue**
  - ☐ Delete: **dequeue**
  - ☐ First element: **front**
  - ☐ First element: **rear**
- Array-based queue implementation issues:
  - ☐ What to do with “drift” of front and rear indices?
  - ☐ When array is “circular”, how to distinguish full and empty?
- Applications:
  - ☐ Operating Systems
  - ☐ Real-life lines
  - ☐ Computer networking
  - ☐ Computer simulation

Array-Based Queue

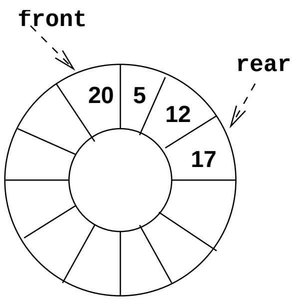
- Queue drift

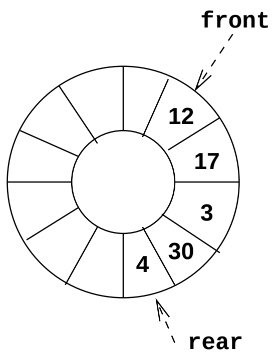




Array-Based Queue

- Circular implementation issues





- Use of mod function gives effect of circular queue
- Questions:
  - ☐ Where do front/rear pointers point?
  - ☐ How do we distinguish full from empty?
    - ∘ Leave an empty slot
    - ∘ Use external variable