List - Array List and Singly Linked List

Data Structures and Algorithms

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Overview

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Linear list concepts

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Linear list concepts

Definition

A linear list is a finite, ordered sequence of data items known as elements. "Ordered" in this definition means that each element has a position in the list.

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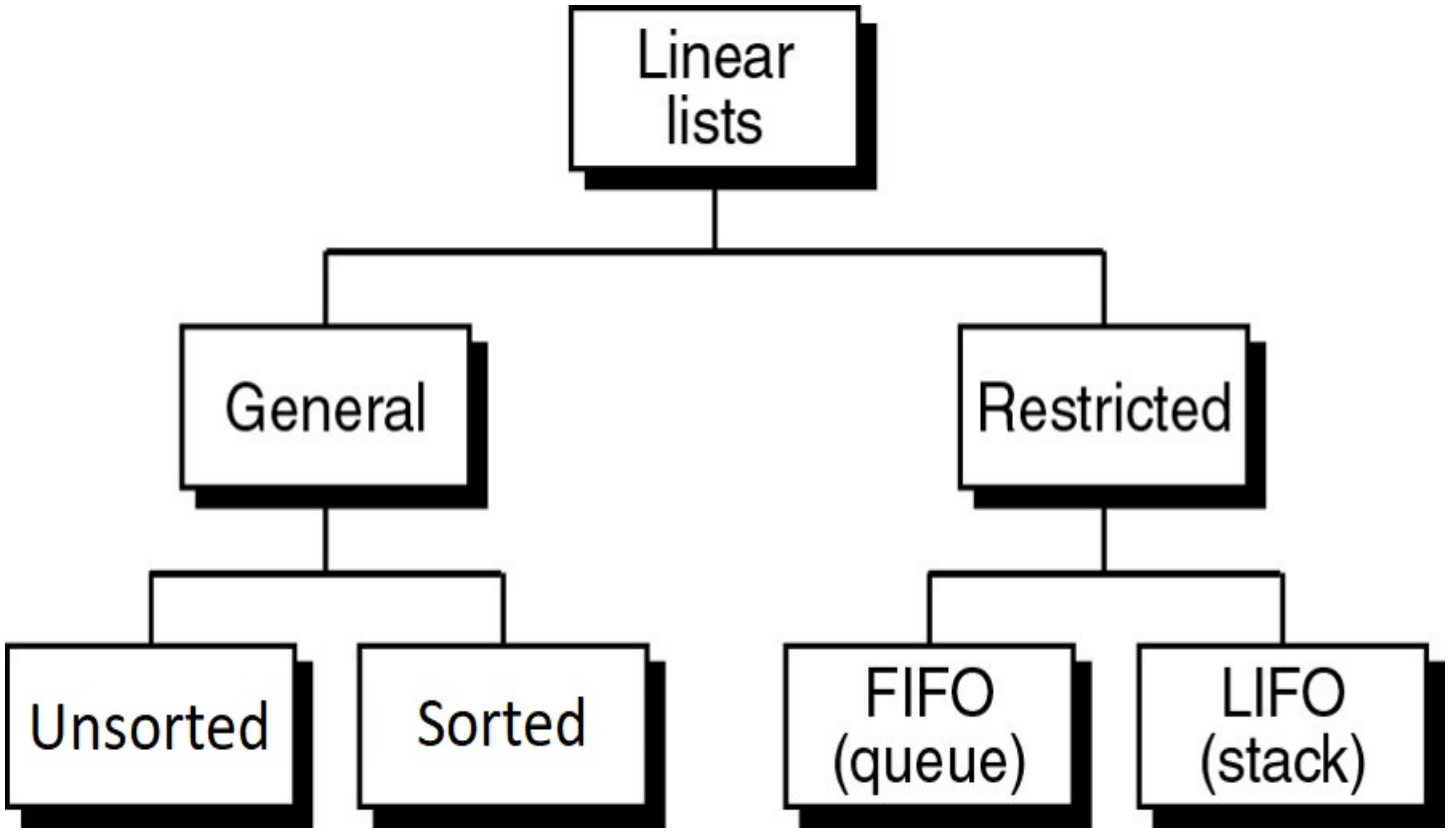
Linear list concepts



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Linear list concepts

General list:

- No restrictions on which operation can be used on the list.
- No restrictions on where data can be inserted/deleted.
- Unsorted list: data are not arranged in particular order.
- Sorted list: data are arranged according to a key.

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Linear list concepts

Restricted list:

- Only some operations can be used on the list.
- Data can be inserted/deleted only at the ends of the list.
- Queue: FIFO (First-In-First-Out).
- Stack: LIFO (Last-In-First-Out).

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List ADT

Definition

A list of elements of type T is a finite, ordered sequence of elements of T.

Basic concepts:

- A list is empty when it contains no elements.
- The number of elements currently stored is called the length (size) of the list.
- The beginning of the list is called the head, the end of the list is called the tail.

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List ADT

Basic operations:

- Construct a list, leaving it empty.
- Insert an element.
- Remove an element.
- Search an element.
- Retrieve an element.
- Traverse the list, performing a given operation on each element.

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List ADT

Extended operations:

- Determine whether the list is empty or not.
- Determine whether the list is full or not.
- Find the size of the list.
- Clear the list to make it empty.
- Replace an element with another element.
- Merge two ordered list.
- Append an unordered list to another.

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List ADT: Implementation in C++

```
template <class T>
class IList
{
public:
    virtual void add(T e) = 0;
    virtual void add(int index, T e) = 0;
    virtual T removeAt(int index) = 0;
    virtual bool removeItem(T item) = 0;
    virtual bool empty() = 0;
    virtual int size() = 0;
    virtual void clear() = 0;
    virtual T get(int index) = 0;
    virtual void set(int index, T e) = 0;
    virtual int indexOf(T item) = 0;
    virtual bool contains(T item) = 0;
    virtual string toString() = 0;
};
```


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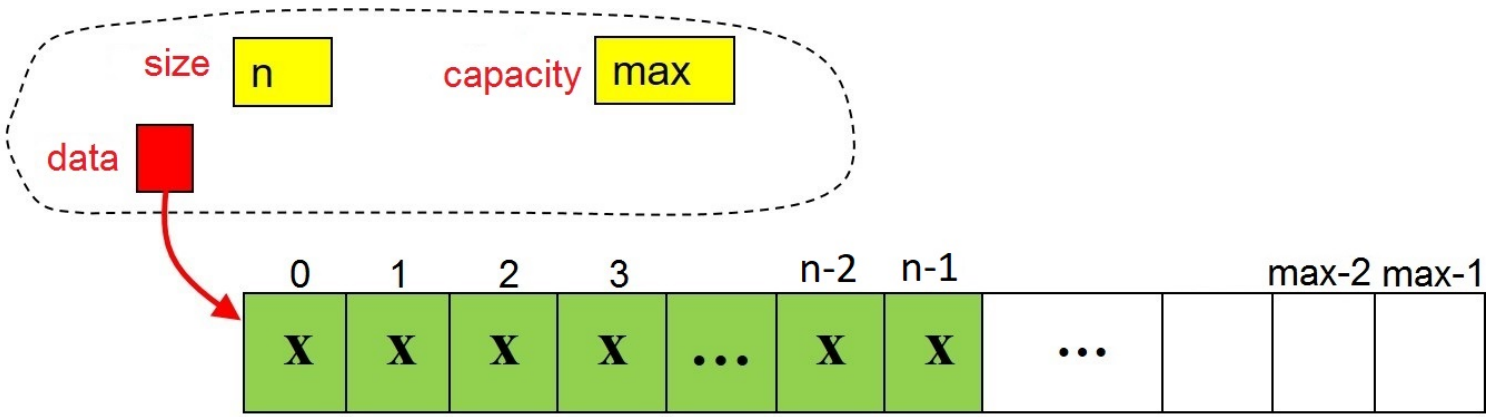
Array implementation

Dynamically Allocated Array




```
List // Contiguous Implementation of List
  // number of used elements (mandatory)
  count <integer>

  // (Dynamically Allocated Array)
  data <Array List of <DataType> >

  capacity <integer>
End List
```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Array List: Implementation in C++ with Integer

```
class IntArrayList : public IList<int> {
protected:
    int *data;
    int capacity;
    int count;
public:
    IntArrayList();
    virtual ~IntArrayList();
    virtual void add(int element);
    virtual void add(int index, int element);
    virtual int removeAt(int index);
    virtual bool removeItem(int item);
    virtual bool empty();
    virtual int size();
    virtual void clear();
    virtual int get(int index);
    virtual void set(int index, int element);
    virtual int indexOf(int item);
    virtual bool contains(int item);
    virtual string toString();
    virtual void dump();
};
```


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Array List: Implementation in C++ with Integer

```
class IntArrayList : public IList<int>
{
// ...

private:
    void checkIndex(int index);
    void ensureCapacity(int capacity);
};
```


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Array List: Implementation in C++ with Integer

```
IntArrayList::IntArrayList()
{
    this->capacity = 10;
    this->data = new int[this->capacity];
    this->count = 0;
}

IntArrayList::~IntArrayList()
{
    delete[] this->data;
}
```


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Array List: Implementation in C++ with Integer

```
void IntArrayList::add(int element)
{
    this->ensureCapacity(this->count + 1);

    this->data[this->count] = element;
    this->count++;
}

void IntArrayList::add(int index, int element)
{
    this->checkIndex(index);
    this->ensureCapacity(this->count + 1);

    int moveCount = this->count - index;
    if (moveCount > 0)
        memmove(this->data + index + 1,
                this->data + index,
                moveCount * sizeof(int));

    this->data[index] = element;
    this->count++;
}
```


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Array List: Implementation in C++ with Integer

```
int IntArrayList::removeAt(int index) {
    this->checkIndex(index);
    int elementToRemove = this->data[index];

    int moveCount = this->count - index - 1;
    if (moveCount > 0)
        memmove(this->data + index,
                this->data + index + 1,
                sizeof(int) * moveCount);

    this->count--;
    return elementToRemove;
}

bool IntArrayList::removeItem(int element) {
    for (int index = 0; index < this->count; index++) {
        if (this->data[index] == element) {
            this->removeAt(index);
            return true;
        }
    }
    return false;
}
```


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Array List: Implementation in C++ with Integer

```
bool IntArrayList::empty()
{
    return this->count == 0;
}

int IntArrayList::size()
{
    return this->count;
}

void IntArrayList::clear()
{
    delete[] this->data;

    this->capacity = 10;
    this->data = new int[this->capacity];
    this->count = 0;
}
```


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Array List: Implementation in C++ with Integer

```
int IntArrayList::get(int index) {
    this->checkIndex(index);

    return this->data[index];
}

void IntArrayList::set(int index, int element) {
    this->checkIndex(index);

    this->data[index] = element;
}

int IntArrayList::indexOf(int element) {
    for (int index = 0; index < this->count; index++) {
        if (this->data[index] == element) {
            return index;
        }
    }

    return -1;
}

bool IntArrayList::contains(int element) {
    return this->indexOf(element) != -1;
}
```


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Array List: Implementation in C++ with Integer

```
string IntArrayList::toString() {
    stringstream ss;
    ss << "[";
    for (int index = 0; index < count - 1; index++) {
        ss << data[index] << ", ";
    }
    if (count > 0) ss << data[count - 1] << "]";
    else ss << "]";

    return ss.str();
}

void IntArrayList::dump() {
    string line(50, '=');
    cout << line << endl;
    cout << "Integer list's information:" << endl;
    cout << "- Capacity: " << this->capacity << endl;
    cout << "- Size: " << this->count << endl;
    cout << "- Data: " << this->toString() << endl;
    cout << line << endl;
}
```


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Array List: Implementation in C++ with Integer

```
void IntArrayList::checkIndex(int index) {
    if (index < 0 || index >= this->count)
        throw std::out_of_range(
                    "Index is out of range");
}

void IntArrayList::ensureCapacity(int capacity) {
    if (capacity > this->capacity) {
        int newCapacity = this->capacity * 3 / 2;
        int *newData = new int[newCapacity];
        memmove(newData, this->data,
                         this->count * sizeof(int));
        this->capacity = newCapacity;
        delete[] this->data;

        this->data = newData;
    }
}
```


Contiguous Implementation of List

In processing a contiguous list with n elements:

- Insert and Remove operate in time approximately proportional to n (require physical shifting).
- Clear, Empty, Full, Size, Replace, and Retrieve in constant time.

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Singly linked list

Linked List

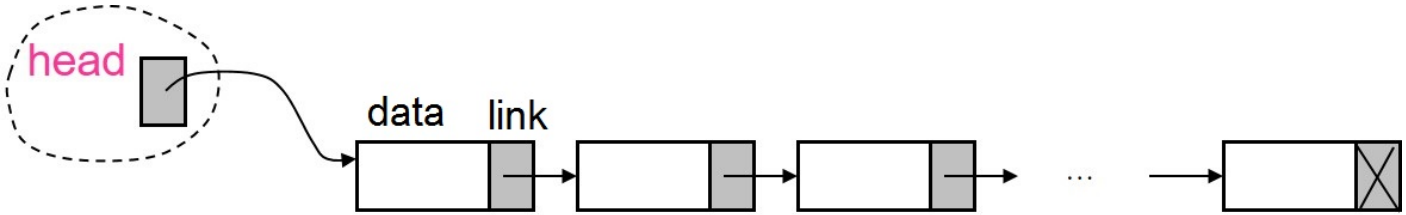

Figure: Singly Linked List

```
list // Linked Implementation of List
  head <pointer>
  tail <pointer>  // (optional)
  count <integer> // number of elements (optional)
end list
```


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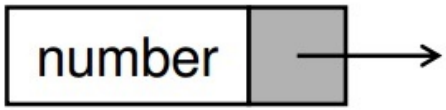
Nodes

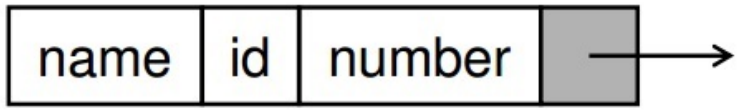
The elements in a linked list are called nodes.
A node in a linked list is a structure that has at least two fields:

- the data,
- the address of the next node.

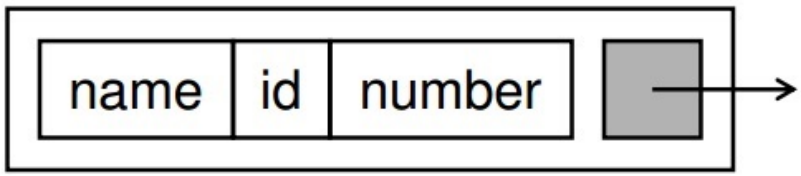
A node with one data field



A node with three data fields



A node with one structured data field



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Nodes

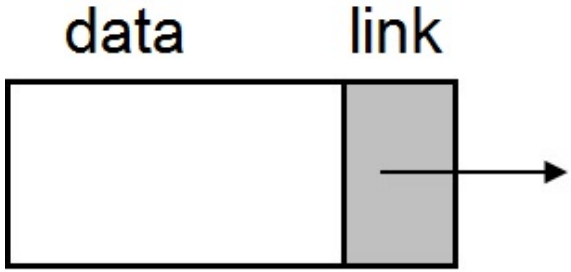

Figure: Linked list node structure

```
node
   data <dataType>
   link <pointer>
end node
```

```
// General dataType:
dataType
   key <keyType>
   field1 <...>
   field2 <...>
   ...
   fieldn <...>
end dataType
```


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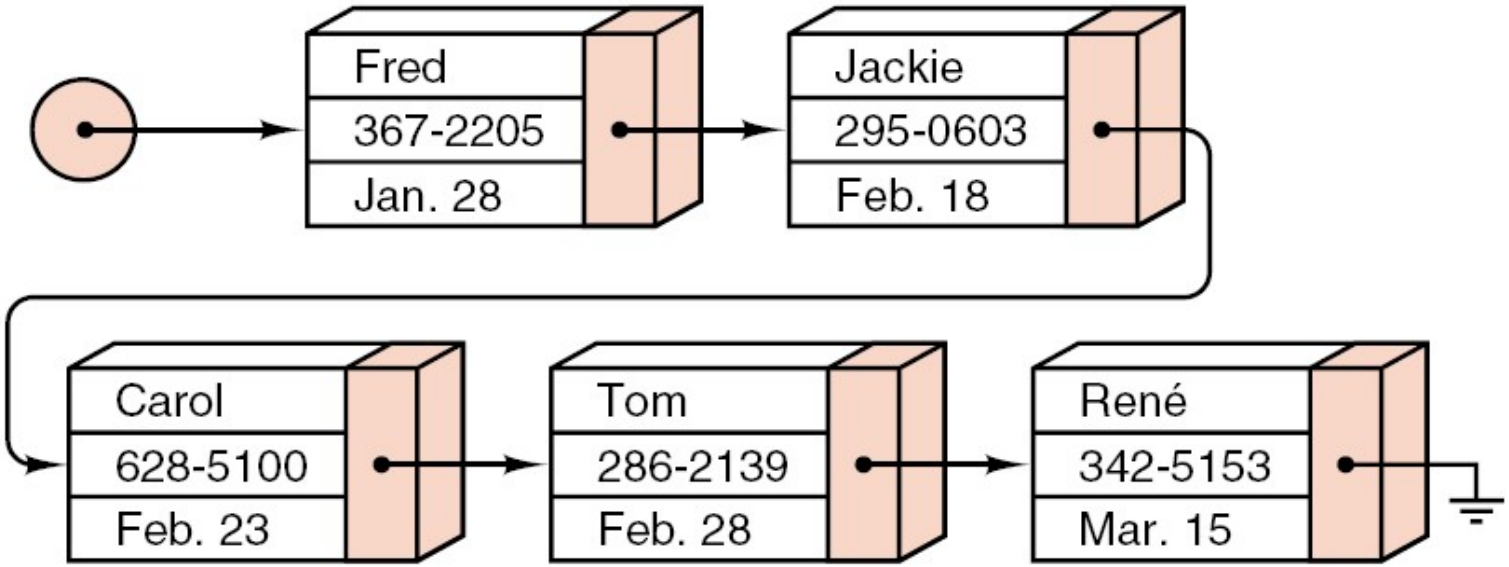
Example



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Example

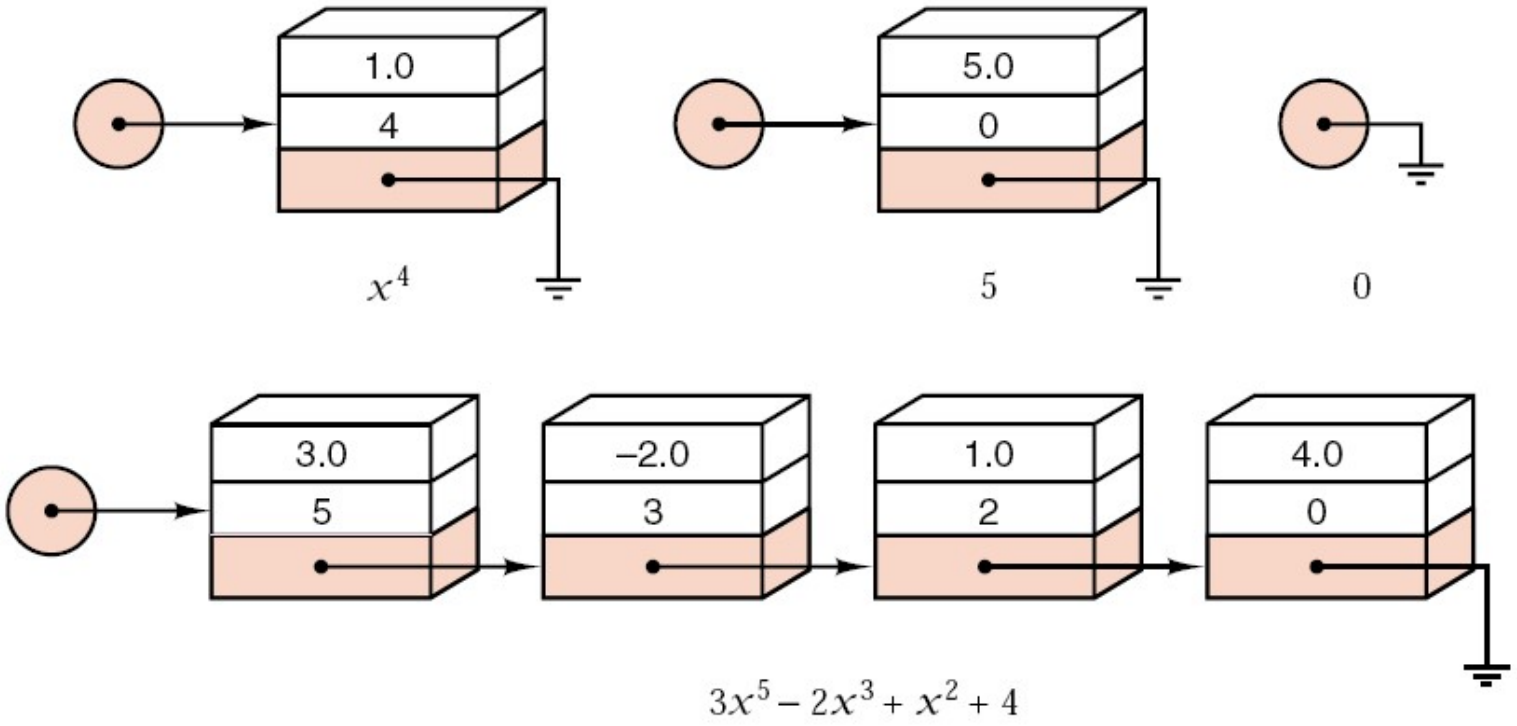

Figure: List representing polynomial

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Implementation in C++

Example

```
node
  data <dataType>
  next <pointer>
end node
```

```
struct Node {
    int data;
    Node *next;
};
```


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Implementation in C++ with `struct`

Example

```
struct Node {
    int data;
    Node *next;
};
```

```
struct Node {
    float data;
    Node *next;
};
```

```
template <class T>
struct Node {
    T data;
    Node<T> *next;
};
```


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Node implementation in C++ with nested class

```
class IntSLinkedList : public IList<int> {
public:
    class Node; // Forward declaration

protected:
    Node* head;
    Node* tail;
    int count;

public:
    IntSLinkedList() :
        head(NULL), tail(NULL), count(0) {};

public:
    class Node {
    protected:
        int data;
        Node* next;

    public:
        Node() : next(NULL) {};
        Node(int data) :
            data(data), next(NULL) {};
    };
};
```


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Linked list operations

- Create an empty linked list
- Insert an item into a linked list
- Remove an item from a linked list
- Traverse a linked list
- Destroy a linked list
- ...

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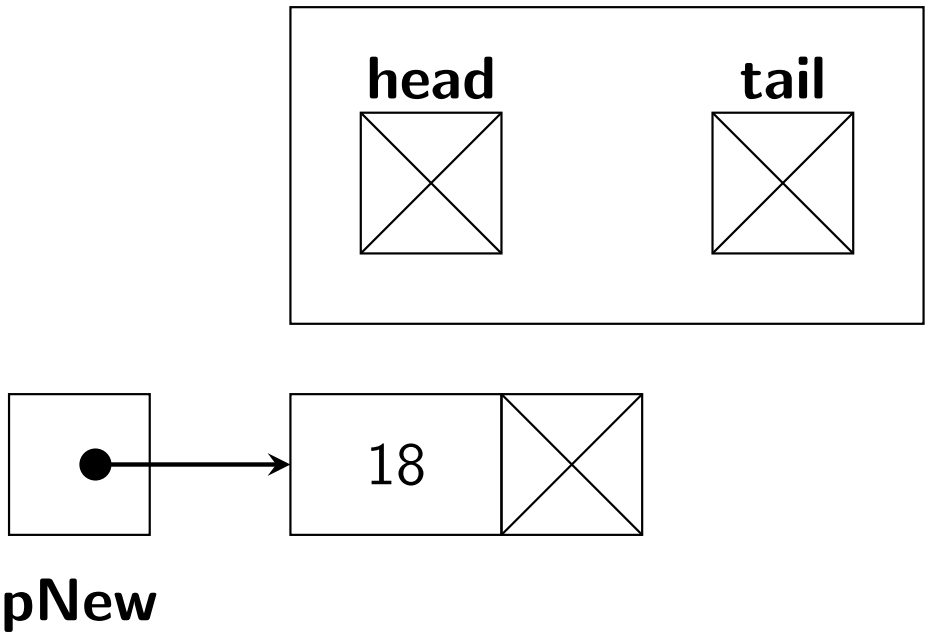
Insertion: Prepend to an empty list



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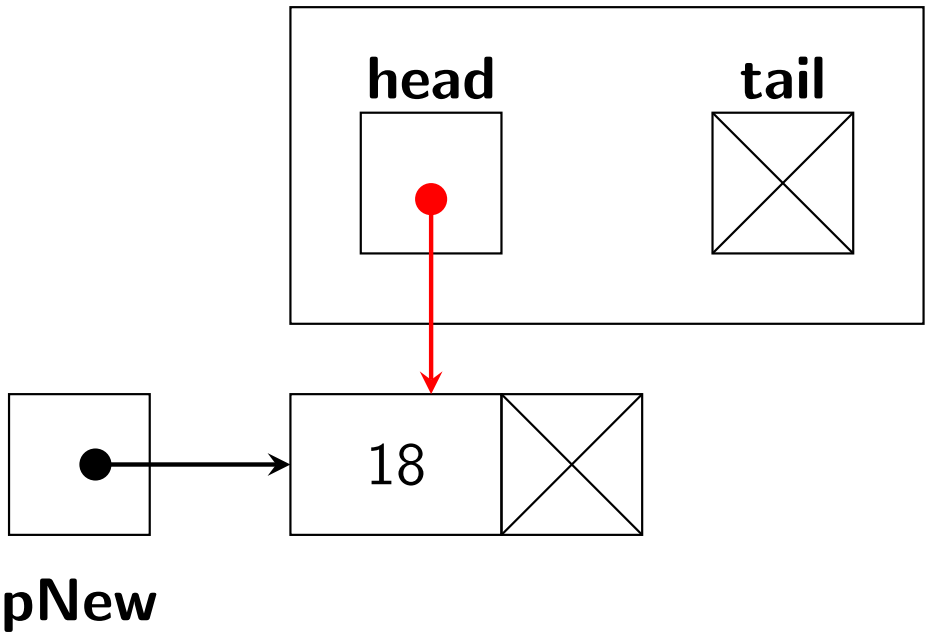
Insertion: Prepend to an empty list



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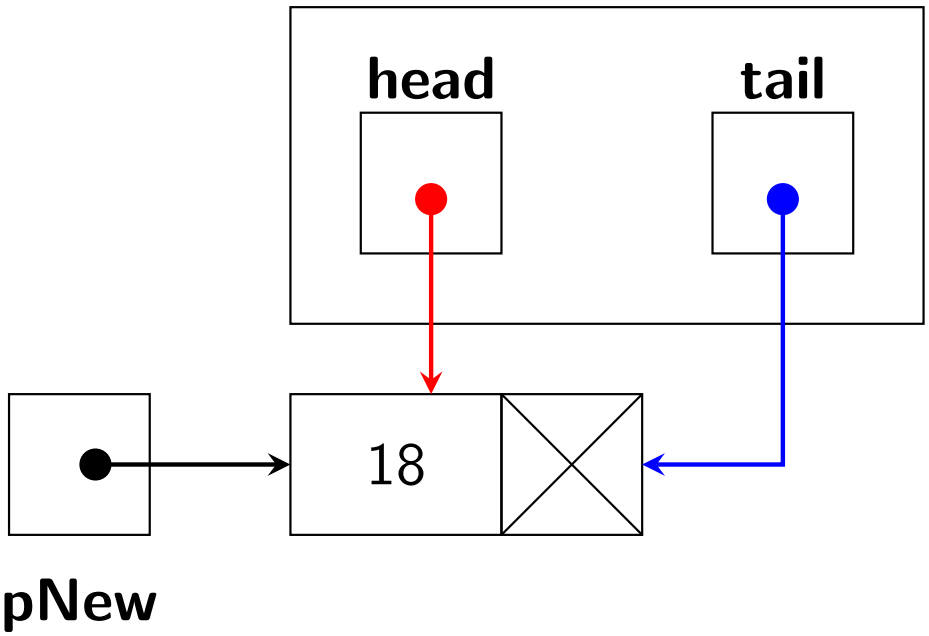
Insertion: Prepend to an empty list



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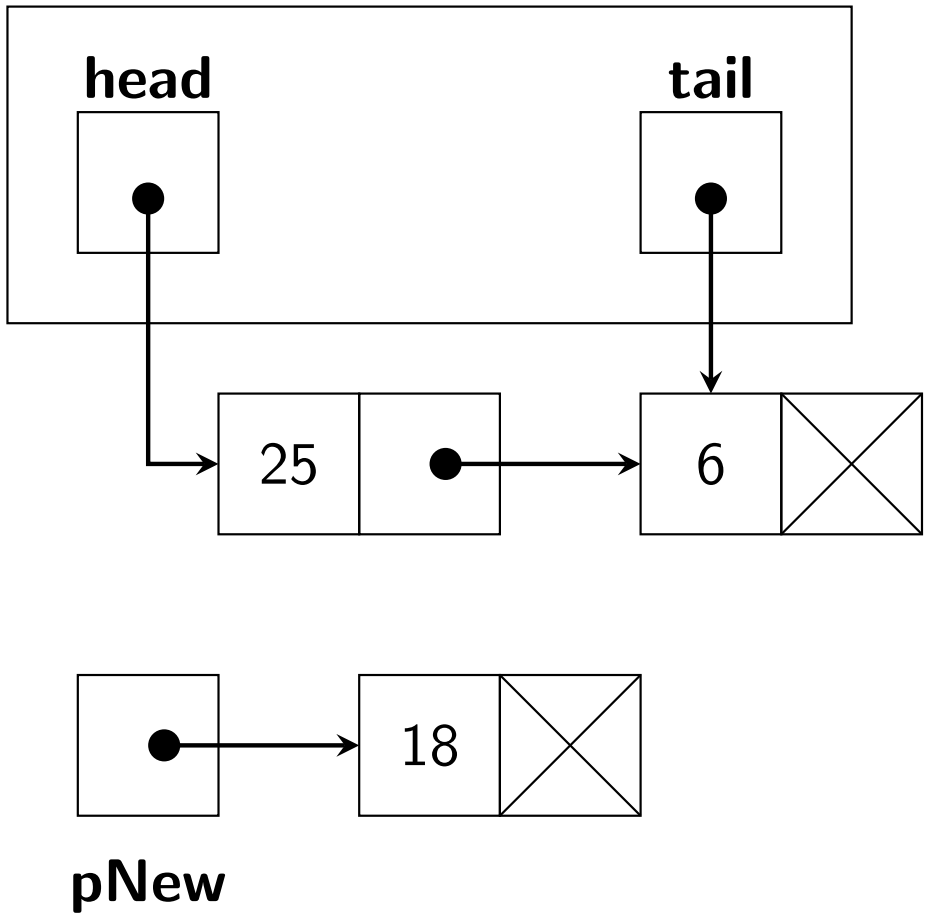
Insertion: Prepend to a non-empty list



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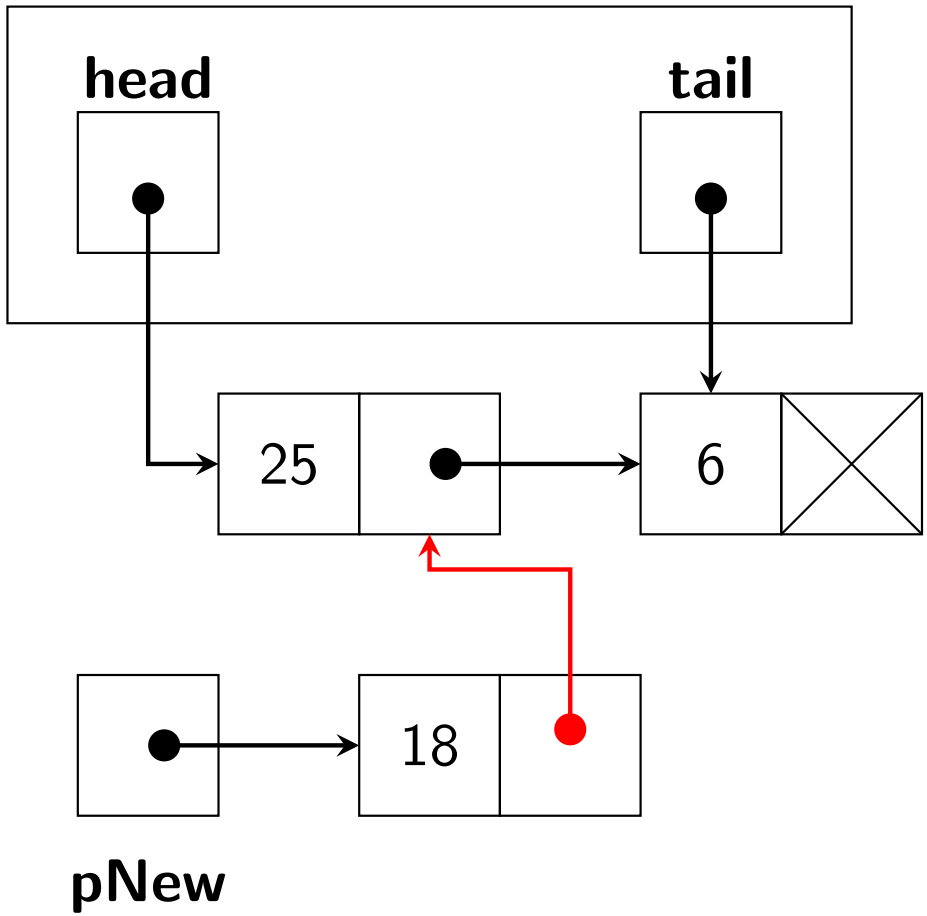
Insertion: Prepend to a non-empty list



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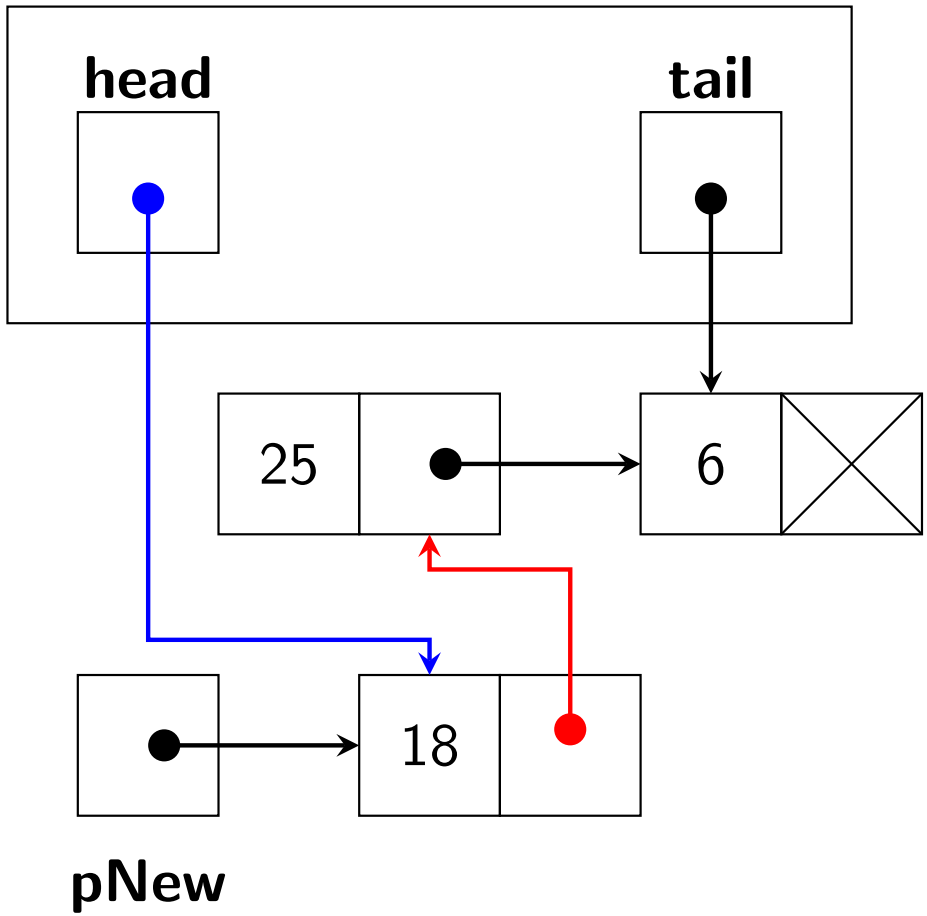
Insertion: Prepend to a non-empty list



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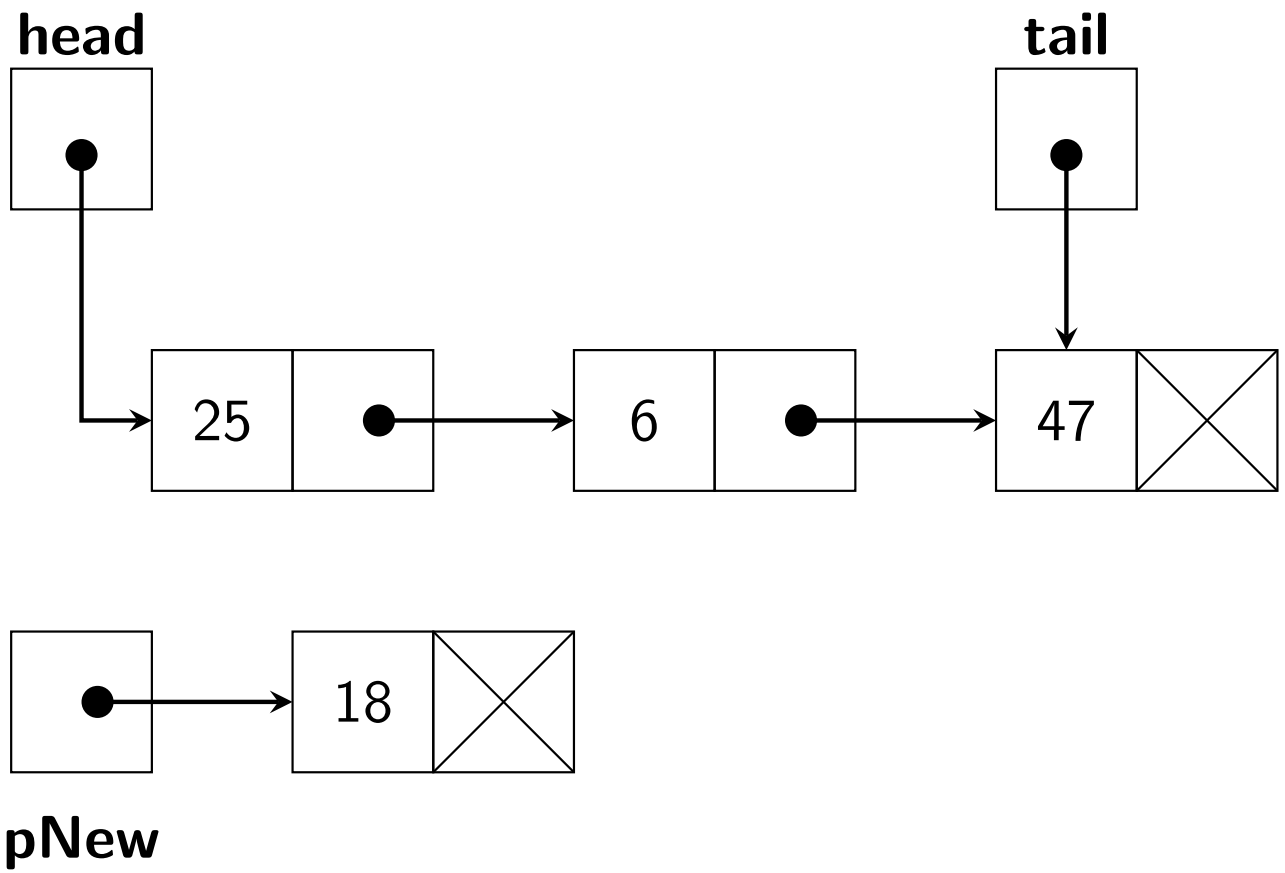
Insertion: At the index i

Insert **18** at index **2**.



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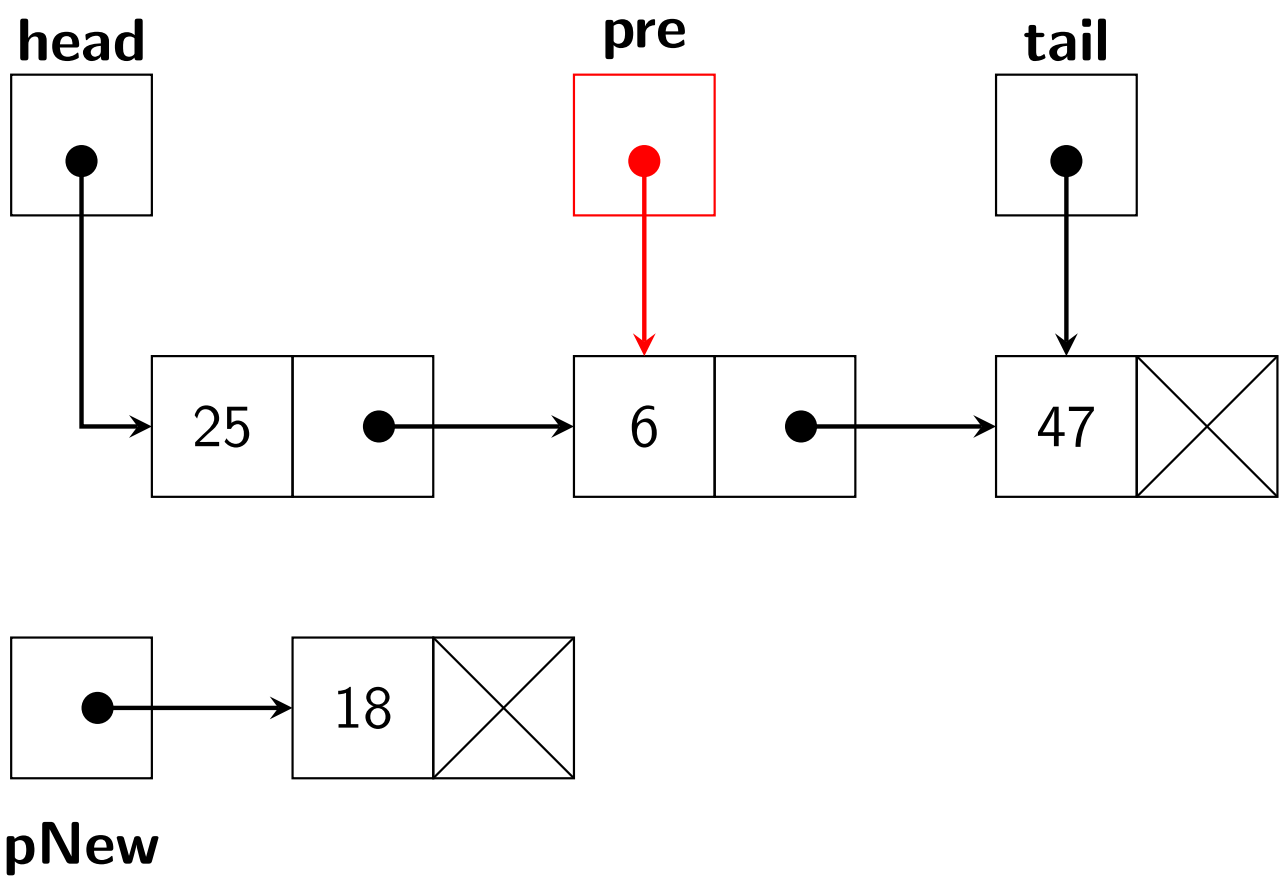
Insertion: At the index i

Insert **18** at index **2**.



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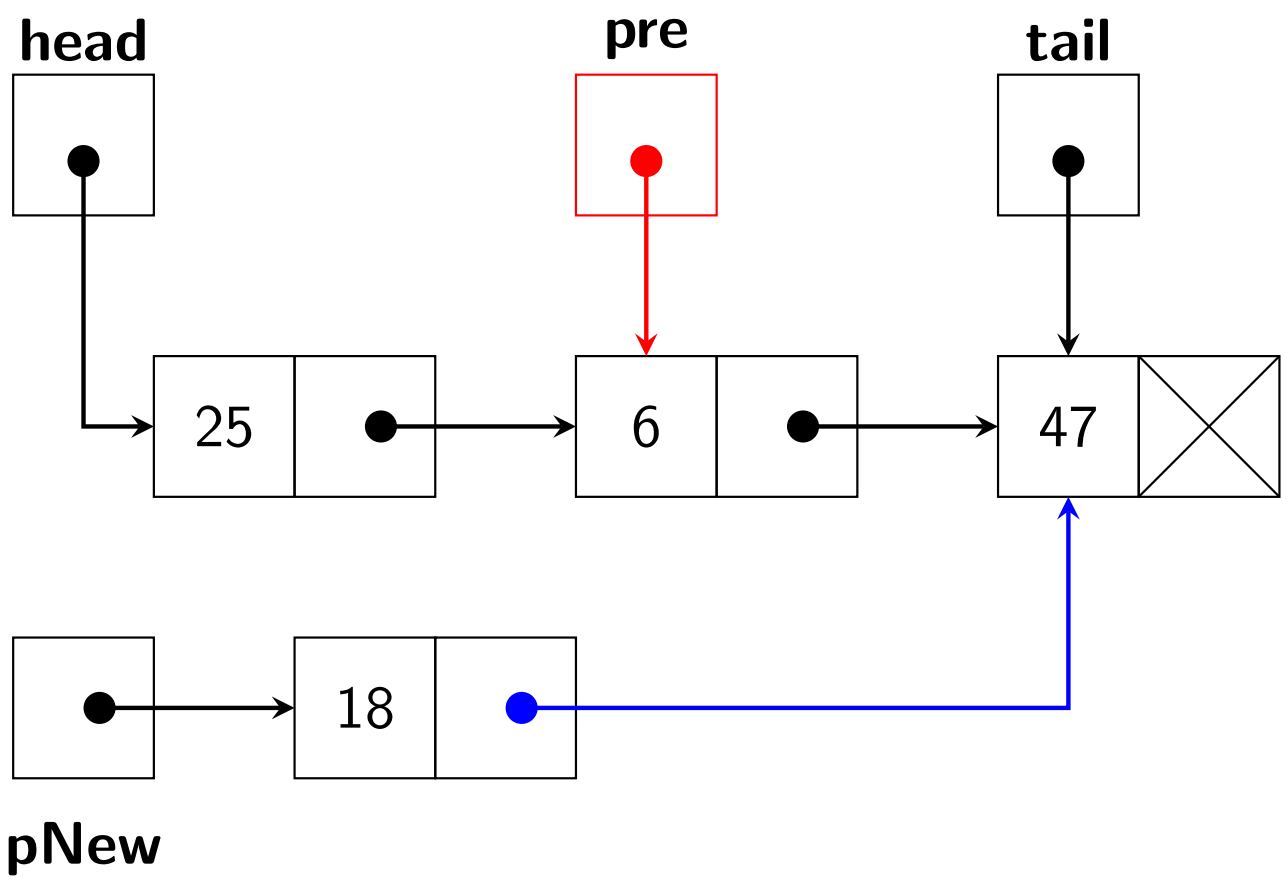
Insertion: At the index i

Insert **18** at index **2**.



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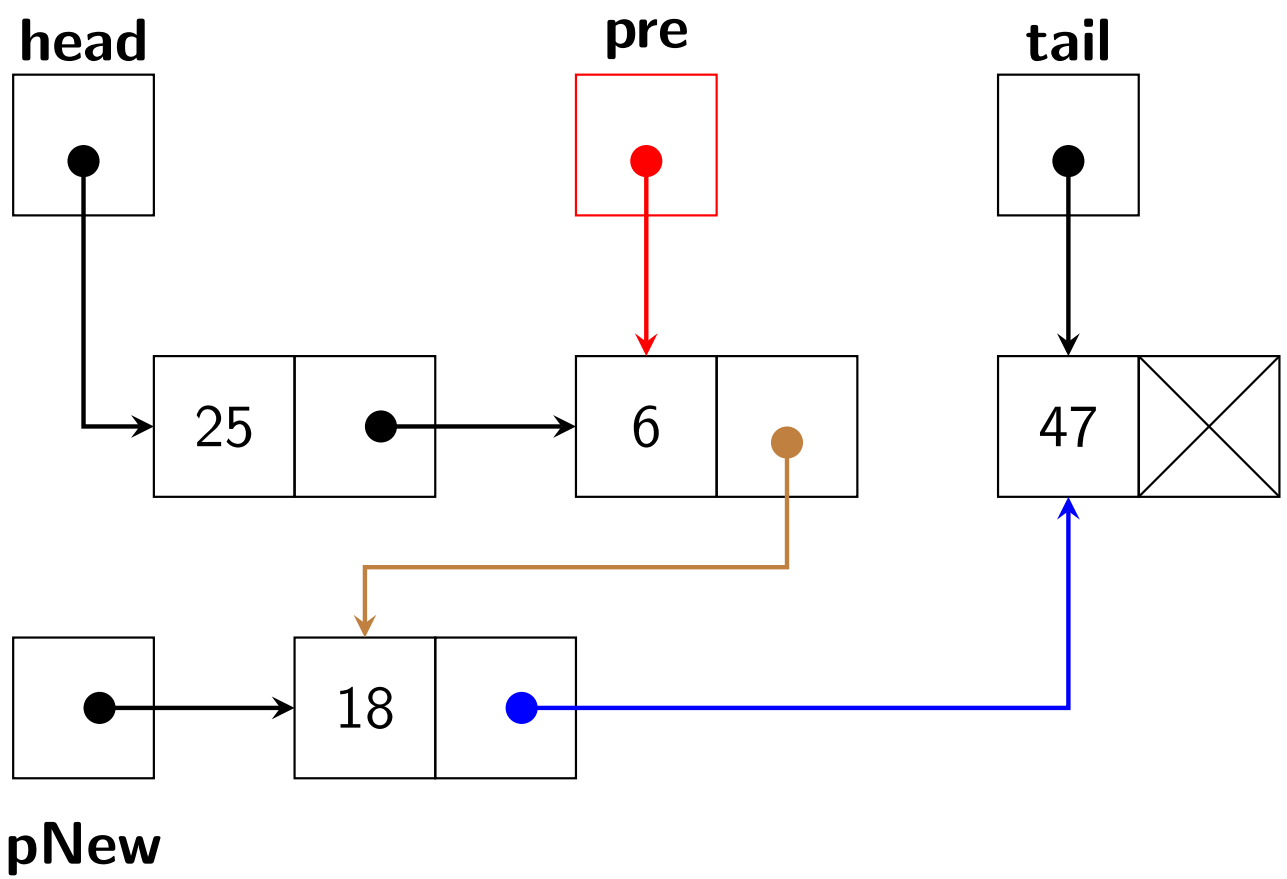
Insertion: At the index i

Insert **18** at index **2**.



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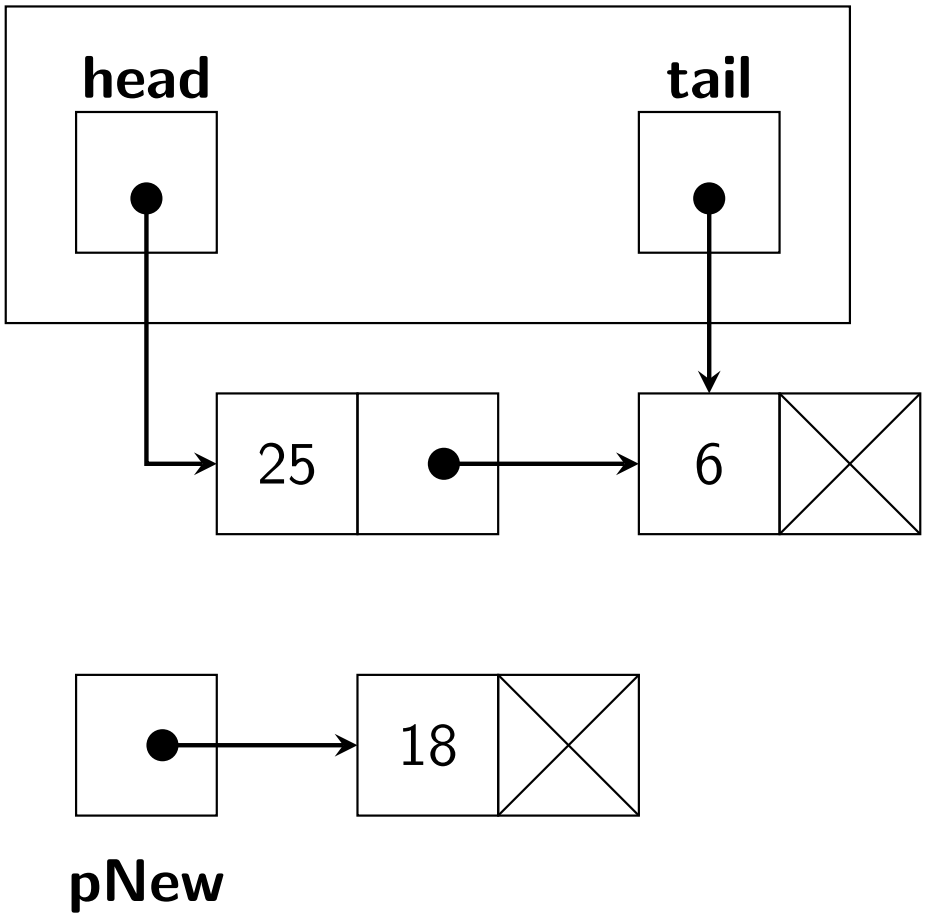
Insertion: Append to the list

Append or insert at $i = length$.



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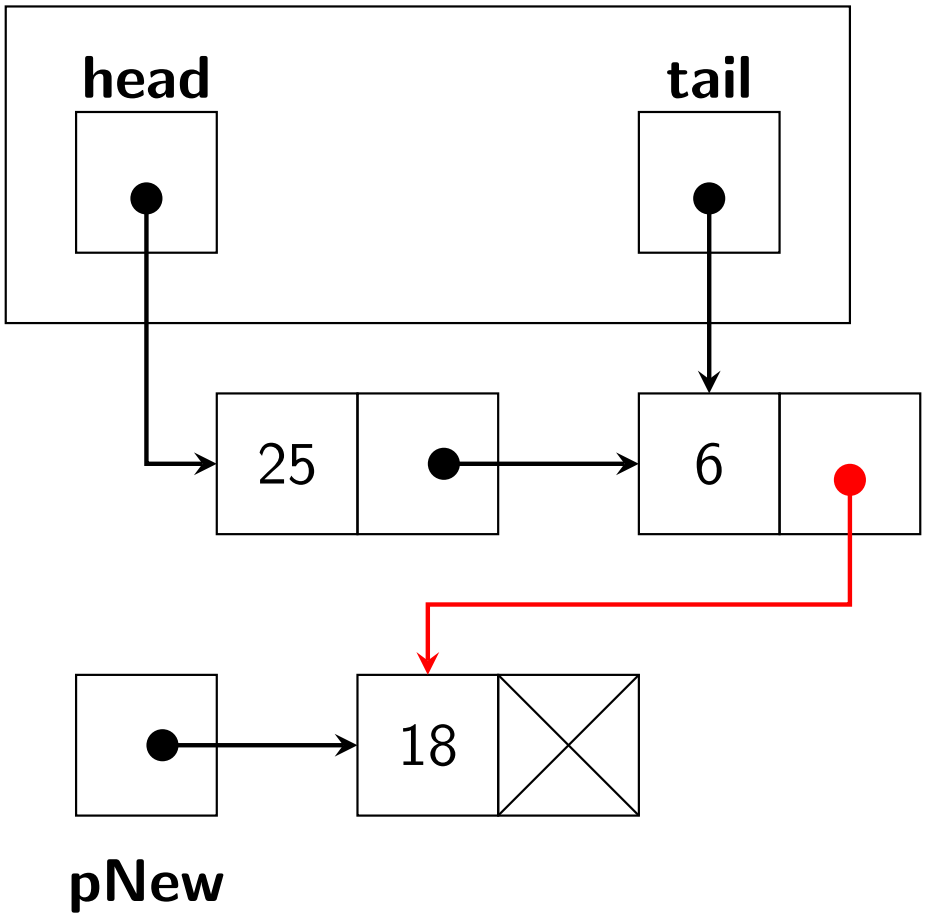
Insertion: Append to the list

Append or insert at $i = length$.



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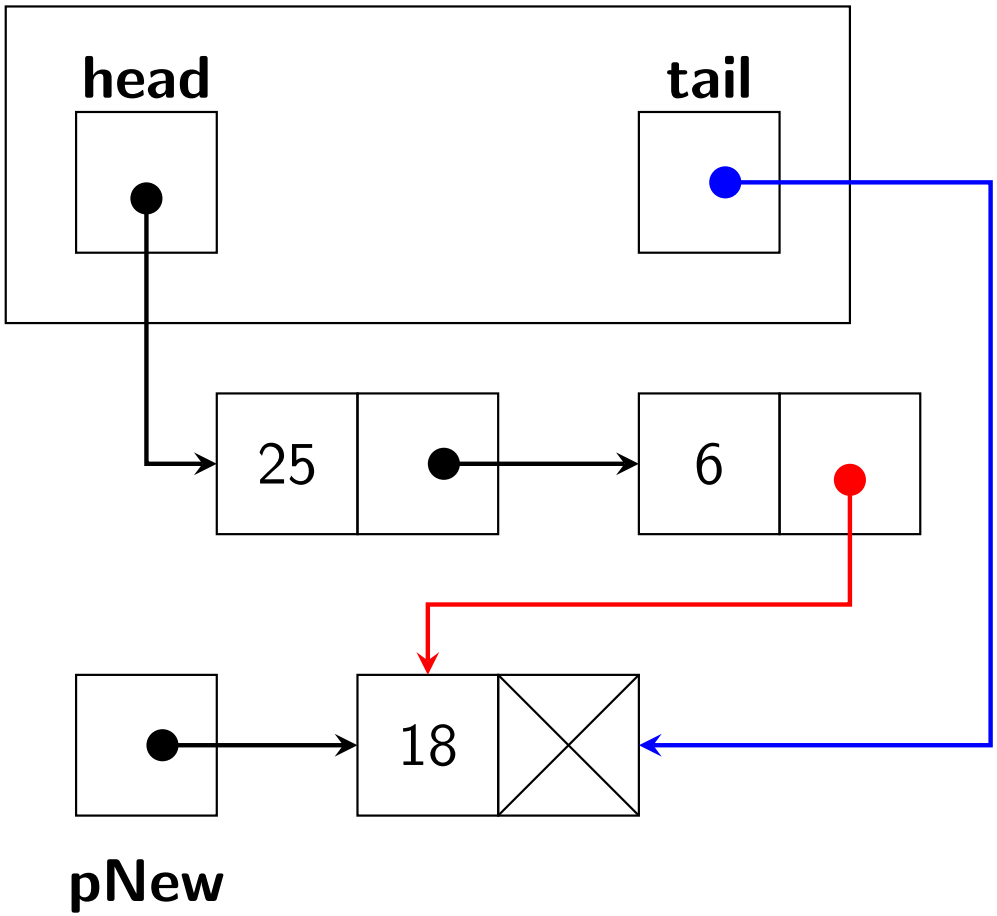
Insertion: Append to the list

Append or insert at $i = length$.



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Insertion: Implementation in C++

```
class IntSLinkedList : public IList<int> {
// Declaration of attributes, constructor, destructor.
// Declaration of nested classes.
public:
    virtual void add(int element);
    virtual void add(int index, int element);
};
```


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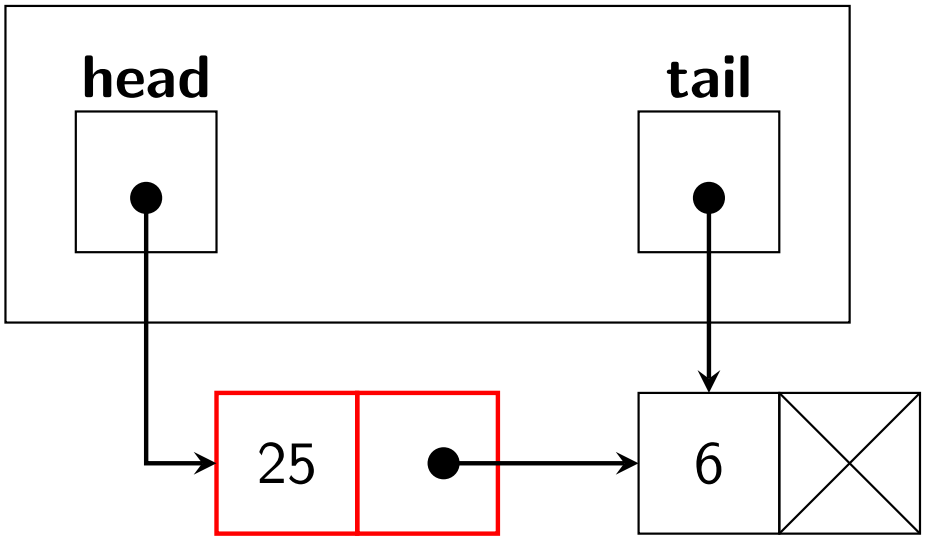
Removal: Delete the first element



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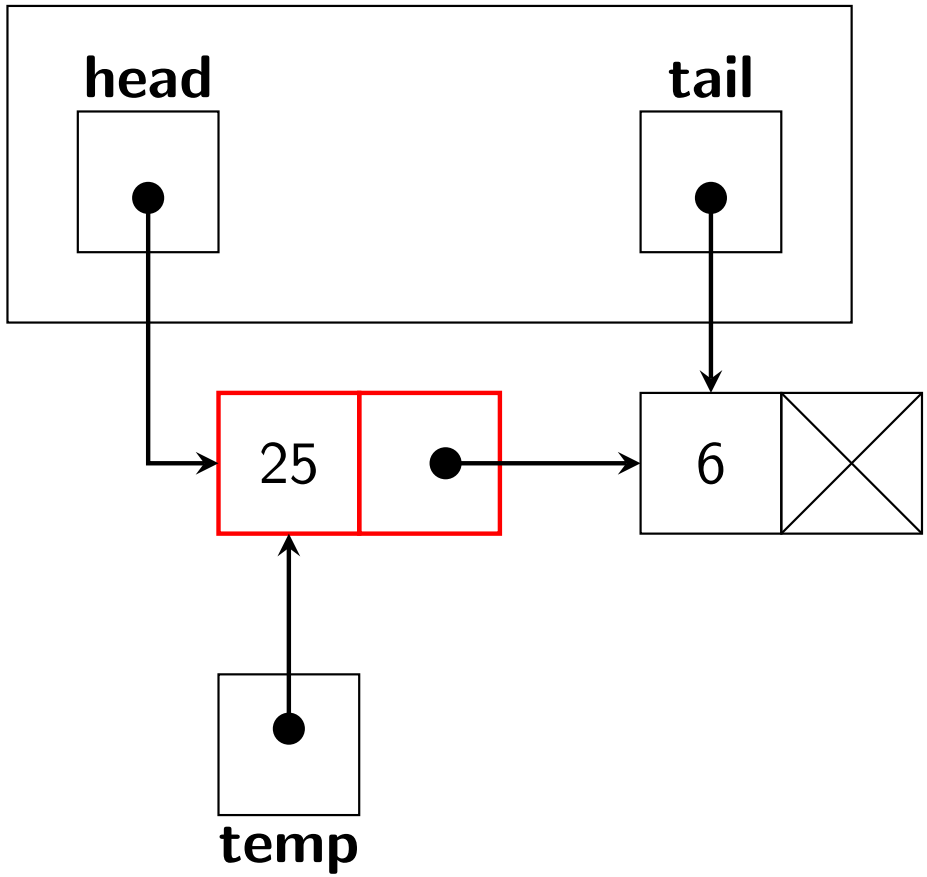
Removal: Delete the first element



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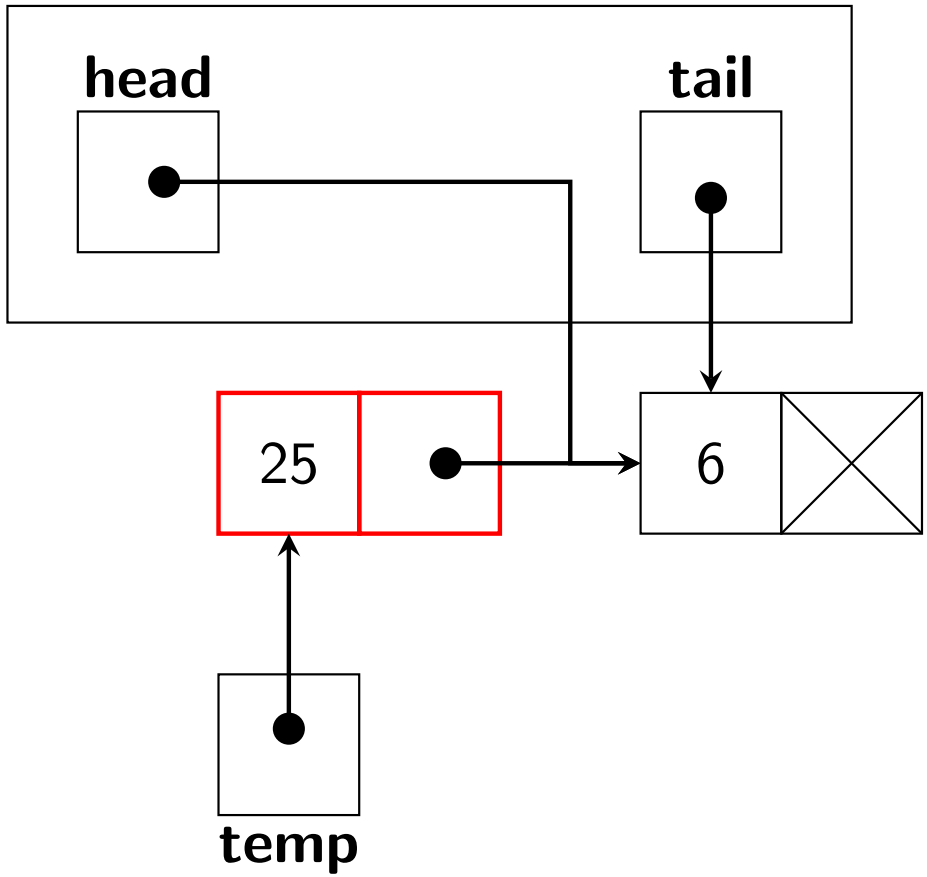
Removal: Delete the first element



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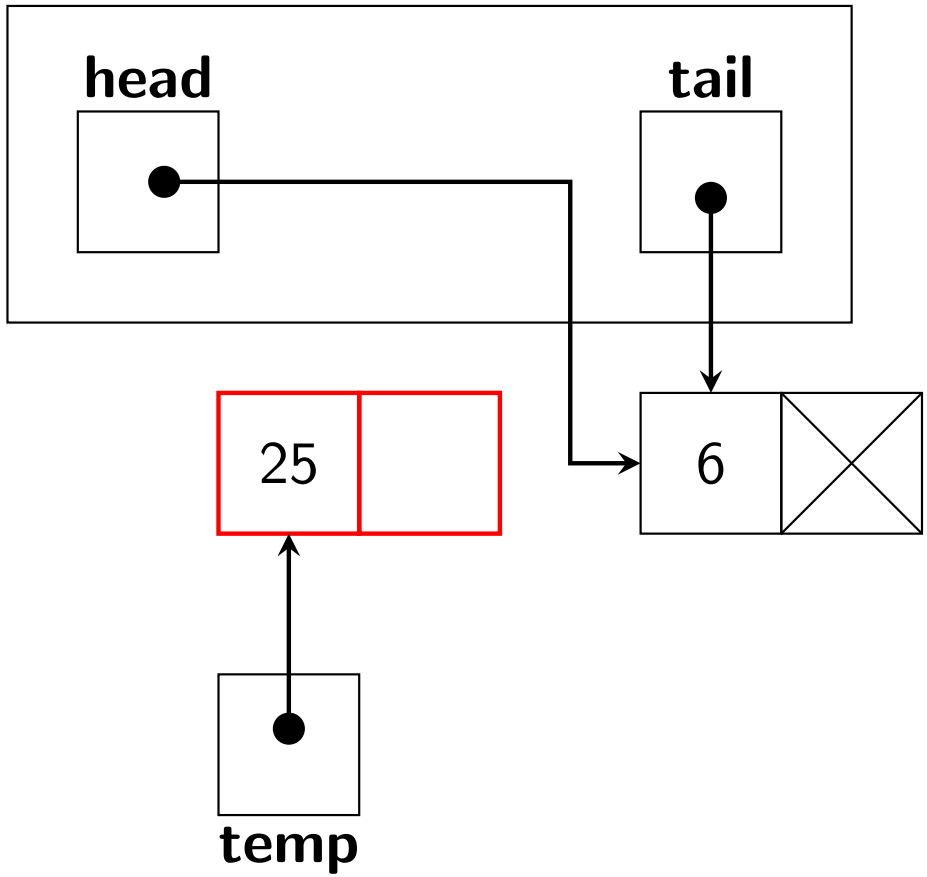
Removal: Delete the first element



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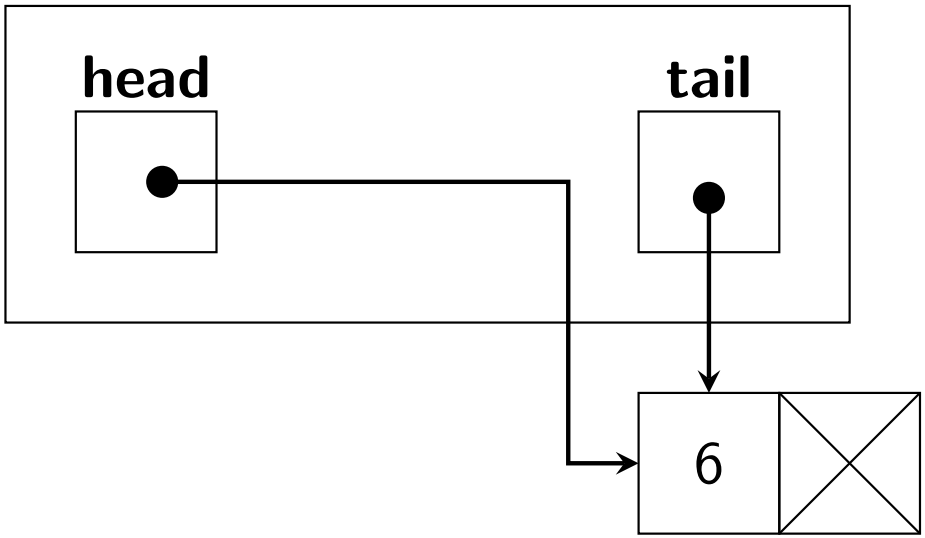
Removal: Delete the first element



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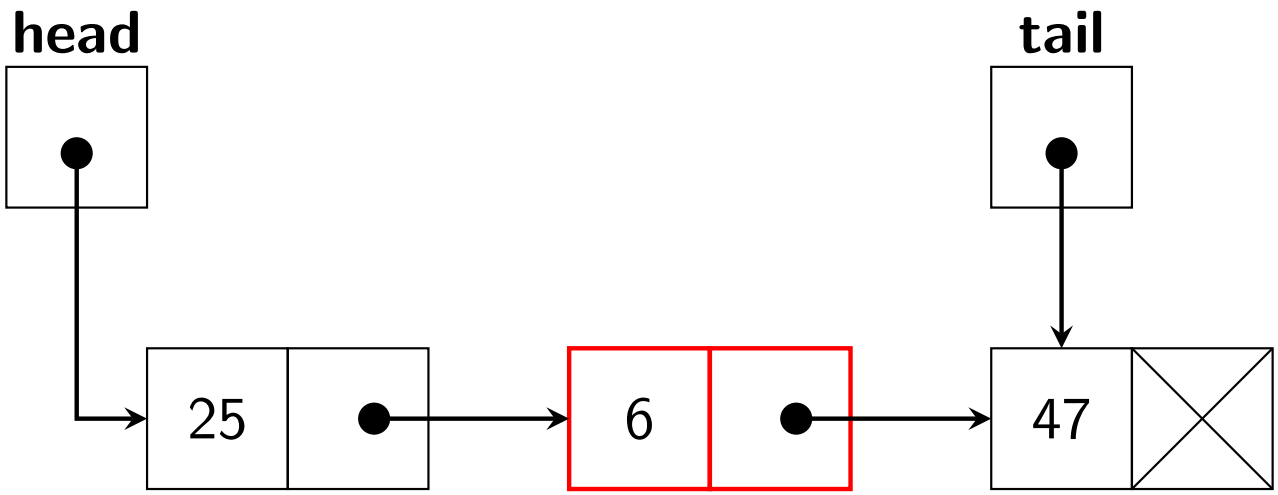
Removal: Delete at index i



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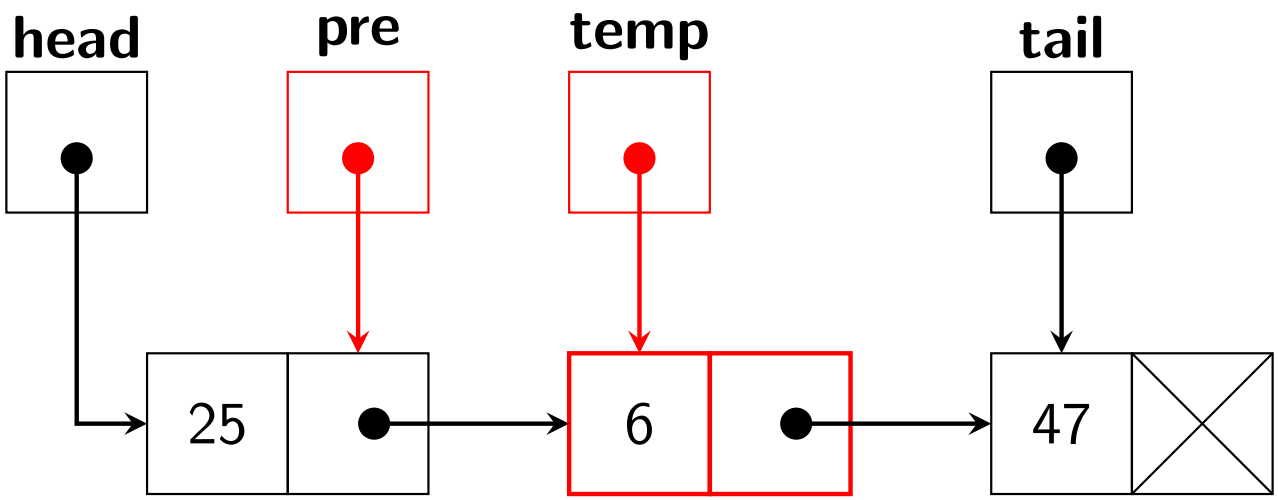
Removal: Delete at index i



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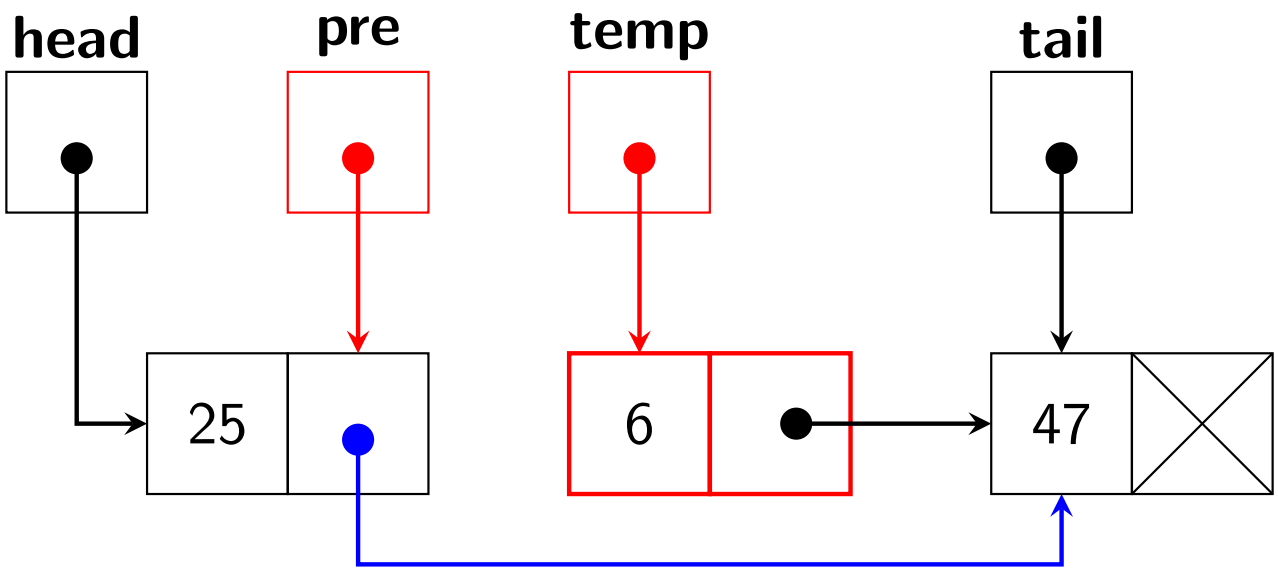
Removal: Delete at index i



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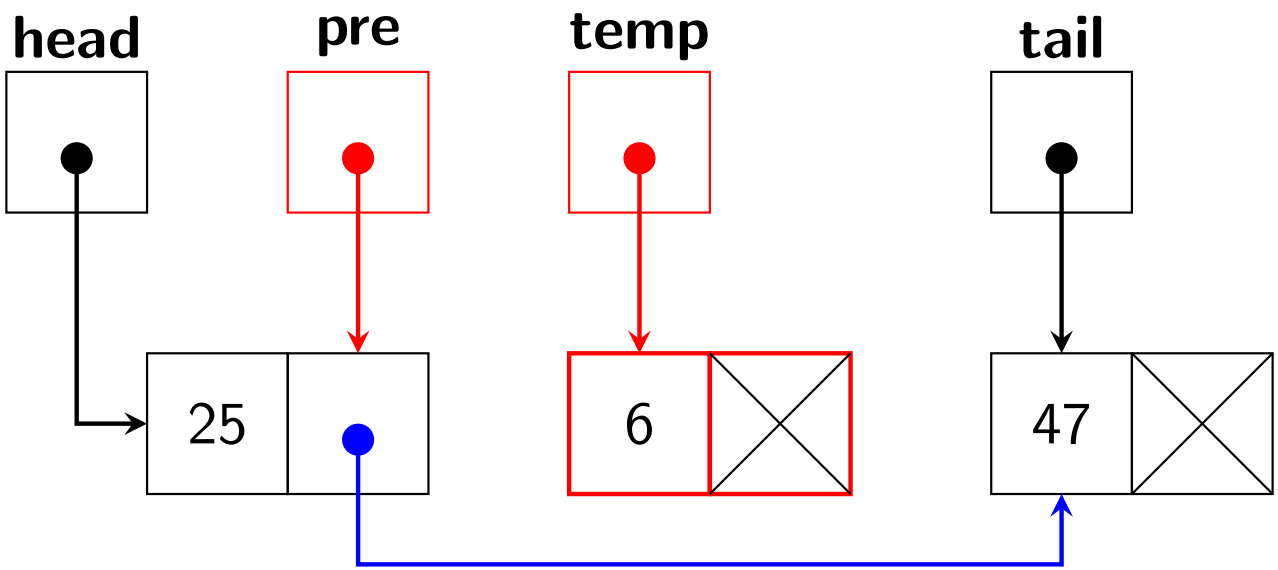
Removal: Delete at index i



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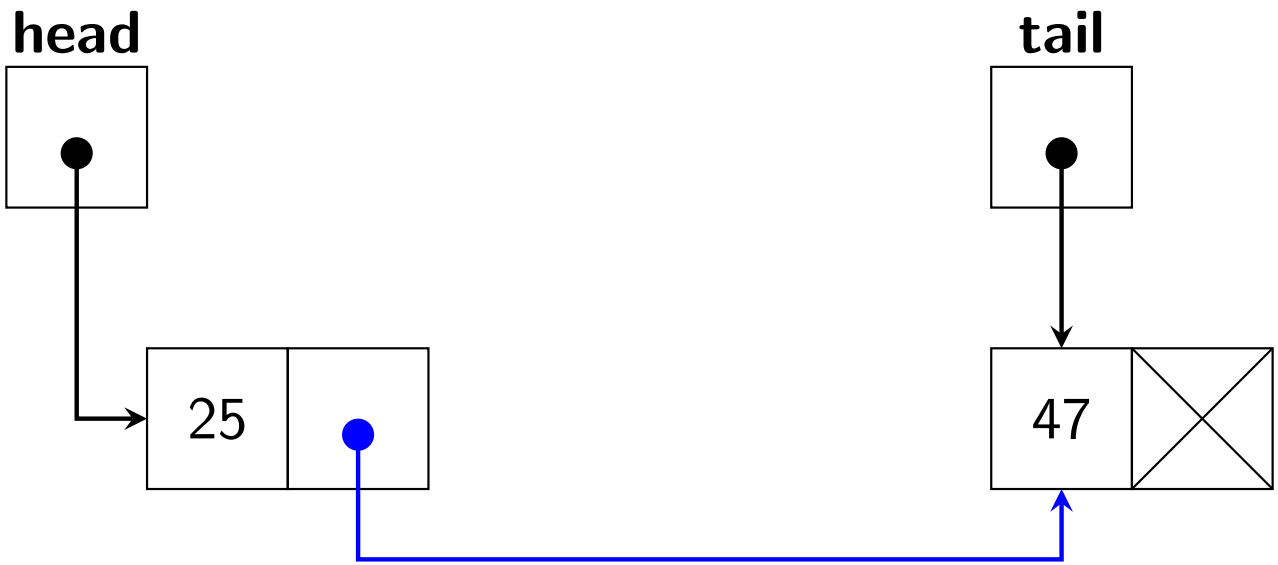
Removal: Delete at index i



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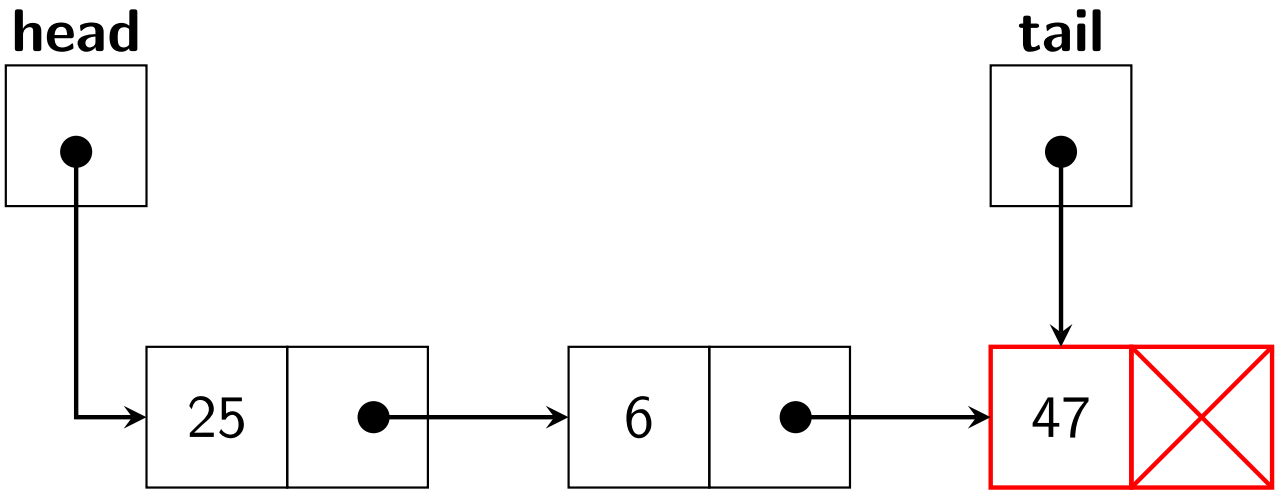
Removal: Delete the last element



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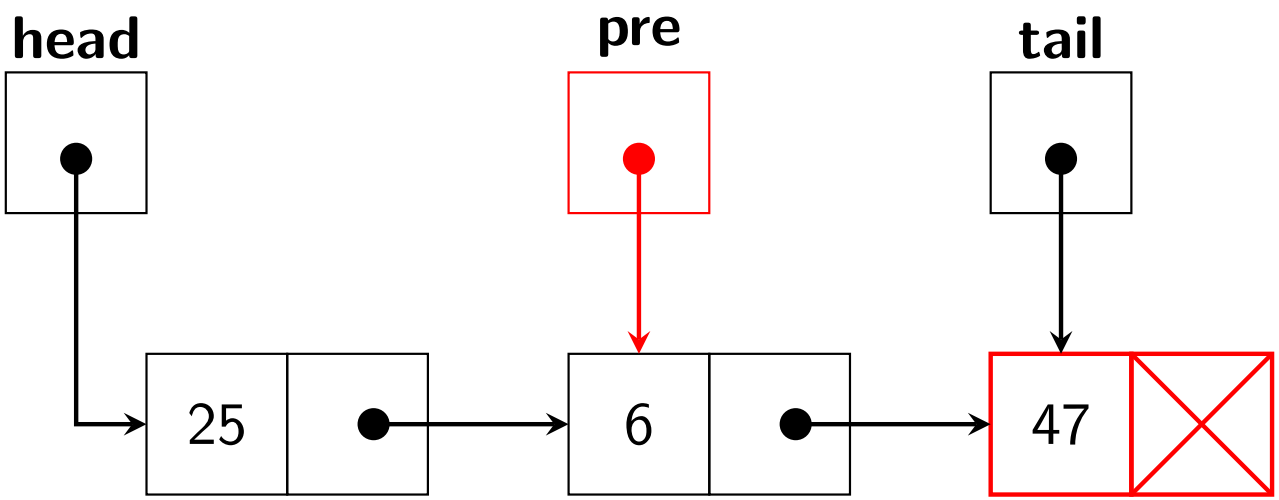
Removal: Delete the last element



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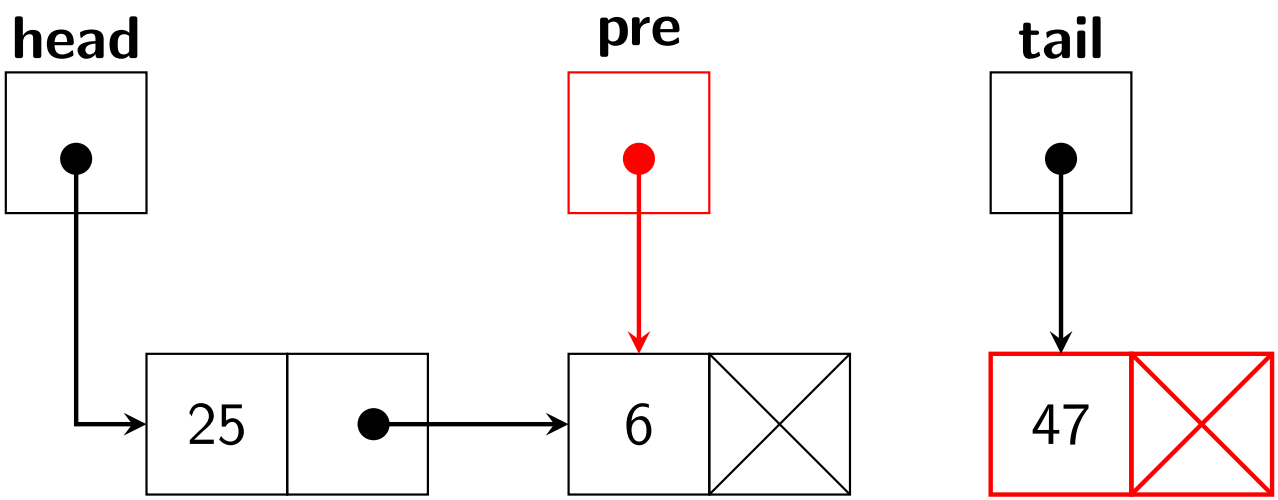
Removal: Delete the last element



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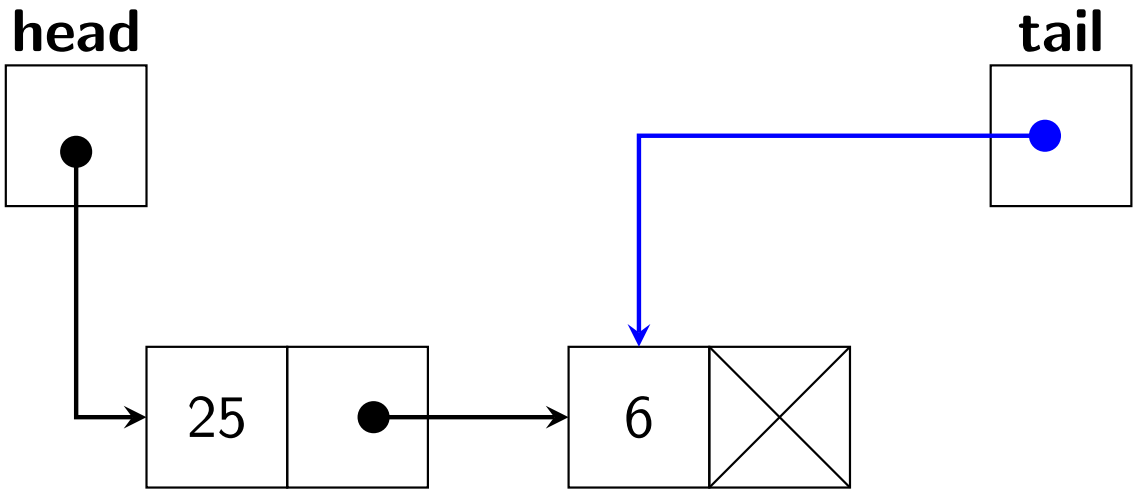
Removal: Delete the last element



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Removal: Implementation in C++

```
class IntSLinkedList : public IList<int> {
// Declaration of attributes, constructor, destructor.
// Declaration of nested classes.
public:
    virtual int removeAt(int index);
    virtual bool removeItem(int item);
};
```


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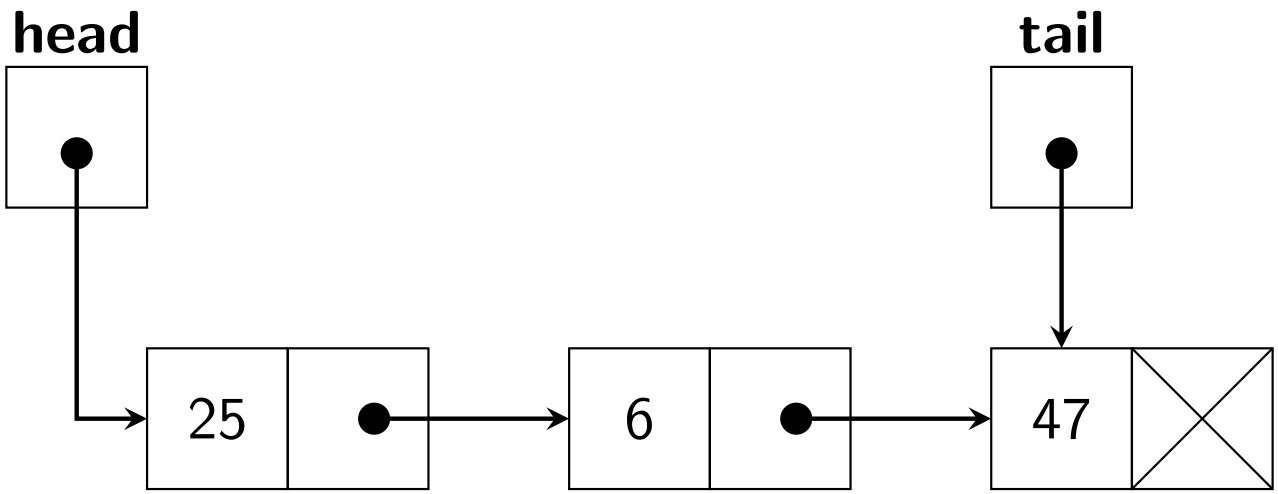
Searching

Search **element** with index **1**.



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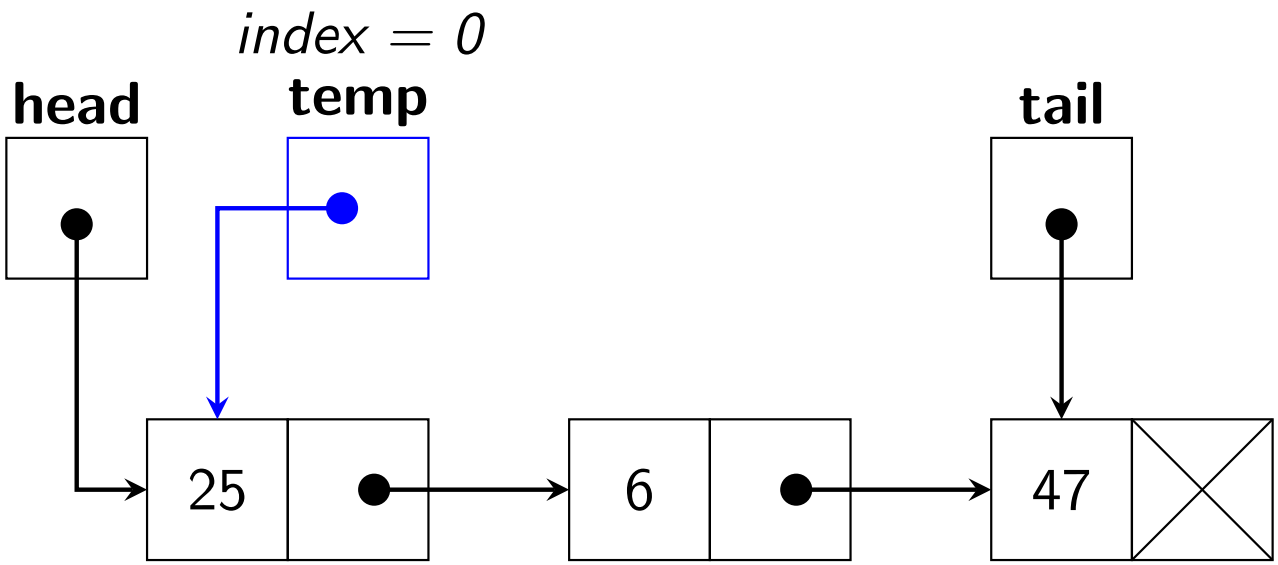
Searching

Search **element** with index **1**.



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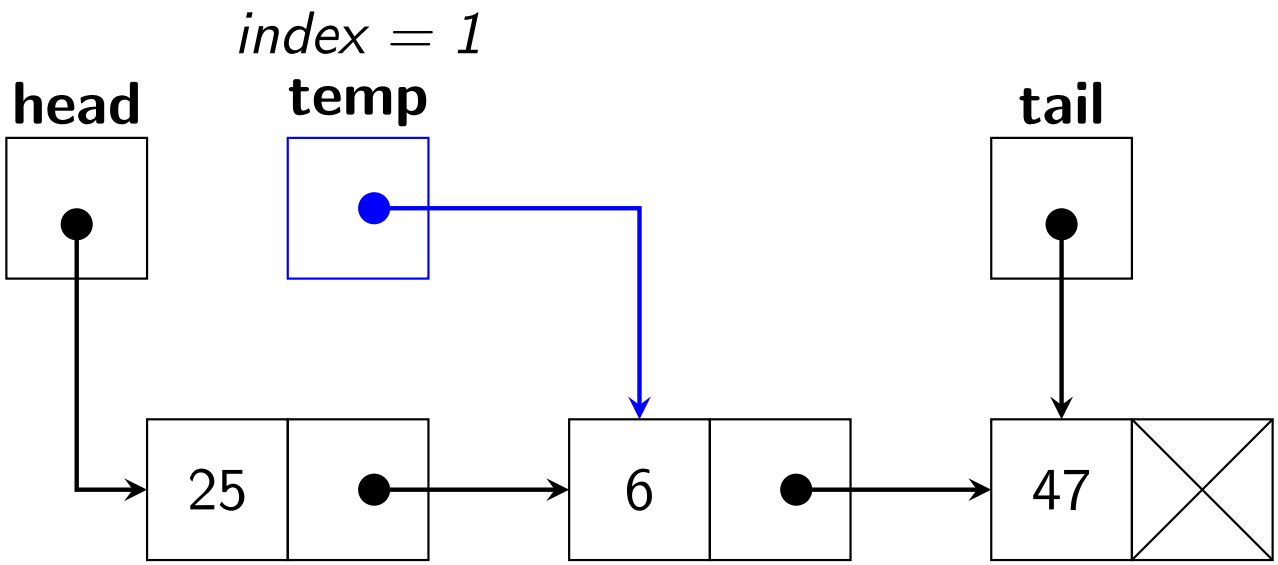
Searching

Search **element** with index **1**.



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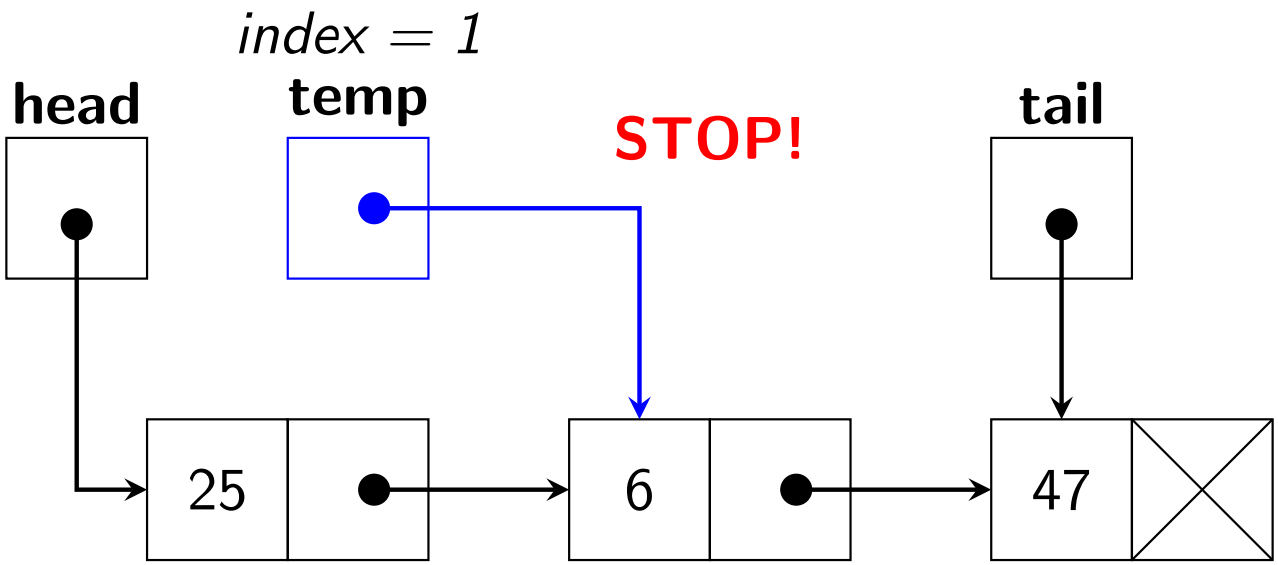
Searching

Search **element** with index **1**.



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Search and other methods: Implementation in C++

```
class IntSLinkedList : public IList<int> {
// Declaration of attributes, constructor, destructor.
// Declaration of nested classes.
public:
    virtual int get(int index);
    virtual void set(int index, int element);
    virtual int indexOf(int item);
    virtual bool contains(int item);
};
```


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Comparison of implementations of list

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Arrays: Pros and Cons

- **Pros**: Access to an array element is fast since we can compute its location quickly.
- **Cons**:
  - If we want to insert or delete an element, we have to shift subsequent elements which slows our computation down.
  - We need a large enough block of memory to hold our array.

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Linked Lists: Pros and Cons

- **Pros**: Inserting and deleting data does not require us to move/shift subsequent data elements.
- **Cons**: If we want to access a specific element, we need to traverse the list from the head of the list to find it which can take longer than an array access.

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Comparison of implementations of list

- **Contiguous storage is generally preferable when**:
  - the entries are individually very small;
  - the size of the list is known when the program is written;
  - few insertions or deletions need to be made except at the end of the list; and
  - random access is important.
- **Linked storage proves superior when**:
  - the entries are large;
  - the size of the list is not known in advance; and
  - flexibility is needed in inserting, deleting, and rearranging the entries.

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Iteration on list

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Why iteration?

Problem on iteration

Consider a problem that you have to travel all elements in list and make change some elements like increasing elements with odd data (on integer lists).

Comparision on implementations

If only use operation GET on list:

- With array implementation: $O(n)$
- With linked list: $O(n^2)$

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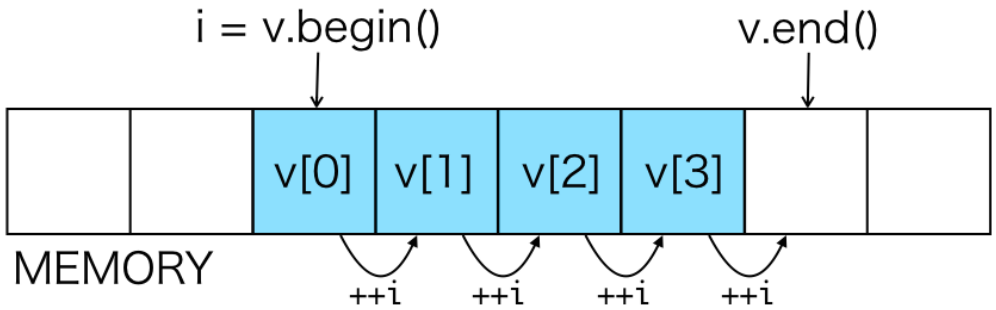
Definition

Iterator: Definition

Some operations on lists, most critically those to insert and remove from the middle of the list, require the notion of a position.

Iterators are used to point at the memory addresses of nodes in list.




```
v[k] == *(v.begin()+k)
```

Figure: Iterator and usage

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Implementation in C++

```
class IntSLinkedList : public IList<int> {
    // ...
public:
    class Iterator {
    Node *pNode;
    IntSLinkedList* pList;

    public:
        Iterator(IntSLinkedList* pList = NULL,
                                bool begin = true);
        Iterator& operator=(const Iterator&
                                        iterator);
        T& operator*();
        bool operator!=(const Iterator& iterator);
        void remove();
        void set(int element);
        Iterator& operator++();
        Iterator operator++(int);
    };
}
```


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Implementation in C++

```
class IntSLinkedList {
    //...
    public:
        Iterator begin();
        Iterator end();
};
```


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Demo using Iterator

```
int main() {
    IntSLinkedList* list = new IntSLinkedList();
    for (int i = 0; i < 10; i++)
        list->add(i);

    for (IntSLinkedList::Iterator it = list->begin();
            it != list->end(); it++)
        cout << *it << endl;
}
```


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THANK YOU.