Designing a Safe Doubly Linked List with C++-like Iterators in Rust

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- My favourite languages are Rust, Ruby, F# and C++ (in order).
- If I had to describe myself with a single expression, that would be "Jack of all trades, master of none".

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- Why linked lists? My PhD revolves around heuristic algorithms. I need the asymptotic behaviour of doubly linked lists.
- But again, why Rust? Before changing PhD subject, I wanted to create a better C++. Someone noticed that my language looked a lot like Rust pre-1.0.0...The rest is history :)

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- Never stop redesigning the wheel. Programming in itself is *not* a solved problem.
- Mutable doubly linked lists are *not* a solved problem. A datatype that *cannot* expose a safe interface is *not* a solution to *any* problem.
- Linked lists in Rust are a complete PITA. I urge you to read a book called “Learning Rust With Entirely Too Many Linked Lists” [3] at some point. Standing on the shoulders of giants and such :)

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- `std::list<T>`

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3. What you are thinking right now is not an exception :)

Exception: Formal Proofs

```
let rec maxlist (lst: 'a list) =
    match lst with
    | [x] -> x
    | (x :: xs) -> max x (maxlist xs)
```

vs

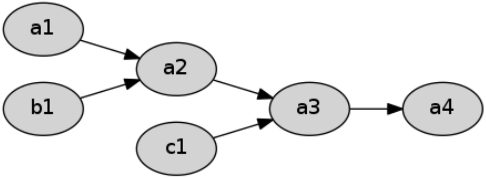
```
let maxarr (arr: 'a []) =
    let mutable ret = arr.[0]
    let mutable i = 1 (* 1 or 0? What is easier to prove? *)
    let l = Array.length arr

    while i < l do (* Does this even terminate? *)
        ret <- max ret arr.[i]
        i <- i + 1
        (* What is the invariant here? *)

    ret
```

Exception: Persistent Datatypes

You might need to generate many lists with a common suffix, and you want to abstract this away from you.



This makes sense only for *immutable* singly linked lists.

So, let's be honest. Singly linked lists are *useless* as general purpose datatypes and have no place in a language in which they need more than one line to be defined (i.e., a non-functional language).

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When are doubly linked lists needed?

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- You've seen the talk from Bjarne Stroustup [1], right?

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Defined in header <queue>

```
template<
    class T,
    class Container = std::deque<T>
> class queue;
```

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Also, a fun fact is that Rust standard library defines deque using an underlying vector.

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- The same as above, but you already have an iterator there. If you don't care about the order of elements, swap with the last element and then `pop_back`.
- The same as above, but you actually care about order. Well, congrats! You actually *need* to use a doubly linked list!

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- The same as above, but you actually care about order. Well, congrats! You actually *need* to use a doubly linked list!
- There are other somewhat valid cases. The Rust standard library states frequent splitting / merging as another reason to use linked lists. Another somewhat valid case is iterator invalidation rules.

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2. Always benchmark the datatypes you choose.
3. Doubly linked lists are niche datatypes and it is questionable whether they should be in a standard library.

What is Ownership?

When C++ passes something by value, it performs a deep copy.

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```cpp
struct Foo { int field; /* + other fields */ };

void print(vector<Foo> vec)
{
    for (Foo elem : vec) // will copy each element
        cout << elem.field << endl;
}

int main()
{
    vector<Foo> x;
    // push several values to x;
    vector<Foo> y = x; // will copy whole vector
    print(y); // will copy whole vector to local variable
    return 0;
}
```

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Of course, that depends on the correct implementation of the rule of three/five/zero.

When Rust passes something by value, it moves it. Or, on Rust terms, it passes the ownership. On the low level, it performs a shallow copy. On the high level, it invalidates the old object (with some exceptions to primitive types). So, this fails to compile:

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```rust
fn print_vec_5(myvec: Vec<i32>)
{
    println!("{}", myvec[5]);
}

fn main()
{
    let myvec = vec![0,1,2,3,4,5,6];
    print_vec_5(myvec);
    println!("{}", myvec[5]);
}
```

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```
fn ret_vec_5_plus_1(mut myvec: Vec<i32>) -> Vec<i32>
{
    myvec[5] += 1;
    myvec
}

fn main()
{
    let myvec = vec![0,1,2,3,4,5,6];
    let myvec2 = ret_vec_5_plus_1(myvec.clone());
    println!("{:?}", myvec);
    println!("{:?}", myvec2);
}
```

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- A local variable
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Finally, ownership is not Rust specific. It also exists in C++.

void QWidget::addAction(QAction **action*)

Appends the action *action* to this widget's list of actions.

All QWidgets have a list of QActions, however they can be represented graphically in many different ways. The default use of the QAction list (as returned by actions()) is to create a context QMenu.

A QWidget should only have one of each action and adding an action it already has will not cause the same action to be in the widget twice.

The ownership of *action* is not transferred to this QWidget.

See also removeAction(), insertAction(), actions(), and QMenu.

QWidget *QWidget::createWindowContainer(QWindow *window, QWidget *parent = nullptr, Qt::WindowFlags flags = ...) `[static]`

Creates a QWidget that makes it possible to embed *window* into a QWidget-based application.

The window container is created as a child of *parent* and with window flags *flags*.

Once the window has been embedded into the container, the container will control the window's geometry and visibility. Explicit calls to QWindow::setGeometry(), QWindow::show() or QWindow::hide() on an embedded window is not recommended.

The container takes over ownership of *window*. The window can be removed from the window container with a call to QWindow::setParent().

What is borrow checking?

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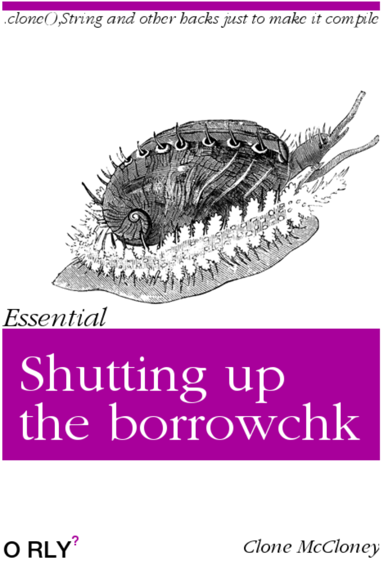
This does not compile:

```rust
fn main()
{
    let mut myvec = vec![0,1,2,3,4,5,6];
    let r = &myvec[4];

    myvec.push(42);

    println!("{}", *r);
}
```


.clone(),String and other hacks just to make it compile
Essential
Shutting up the borrowchk
O RLY?
Clone McCloney

What to remember: Borrow checker ensures that each object can only be mutated by a single variable.

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Splits the list into two at the given index. Returns everything after the given index, including the index.

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Oh come on! Give me a break! O(n) splitting‽ Adding only in the ends‽ At least it provided a valid reason to use two interrobangs!

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* Sane (noun): Without using `Rc<RefCell<_>>` or `Arc<Mutex<_>>`

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```
fn reset  (&mut self)
fn next   (&mut self) -> Option<&mut T>
fn prev   (&mut self) -> Option<&mut T>
fn insert (&mut self, elem: T)
fn remove (&mut self) -> Option<T>
fn split  (&mut self) -> LinkedList<T>
fn splice (&mut self, other: &mut LinkedList<T>)
```

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Notice that this function borrows self (i.e. our list) as mut, and gives the `Cursor` the lifetime of the mutable reference. This means that, as long as the `Cursor` lives, it holds a mutable (i.e. exclusive) borrow on the LinkedList.

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So, we cannot call this function on the same LinkedList a second time without first dropping the cursor. Therefore, we cannot do the first pass - keep best position - insert there magic stuff, because this requires keeping two cursors, the current and the best position.

Can we do better?

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"Simplicity does not precede complexity, but follows it"
Alan Perlis

First of all, let's tackle the linked list datatype. We obviously *cannot* have a full-fledged C++ linked list. We cannot have stray elements throughout the memory and expect to be able to validate on runtime if a pointer pointing to one of those elements is a valid pointer, or points to free memory.

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So, after researching code found on the internet [2], let's use a Vec for the storage. Later, we will discuss the drawbacks.

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- On deletion from the middle, do not shift the elements. Instead, add the deleted index on a second “free memory” vector.
- On insert, if the free memory has an element then insert there, else insert on the end.

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Remember, lists instead of vectors are *optimizations*, therefore a non-generalized custom implementation is warranted.

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So, the verdict is, do not hold file handles or MutexGuards on a list. Hold indices to a vector if you must.

Actually, in my opinion, lists make sense as *short lived* data structures that live while an algorithm runs, and should dissolve as soon as it finishes.

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- Random access iterators are Bidirectional iterators that can also be added, subtracted, checked for ordering and indexed.

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```
pub trait ImmutableIndex<Idx>
{
    fn begin(&self) -> Idx;
    fn end(&self) -> Idx;
    fn valid(&self, &Idx) -> bool;
}

pub trait ForwardIndex<Idx>: ImmutableIndex<Idx>
{
    fn increment(&self, &mut Idx);
}
```

```rust
pub trait BackwardIndex<Idx>: ImmutableIndex<Idx>
{
    fn decrement(&self, &mut Idx);
}

pub trait BidirectionalIndex<Idx>:
    ForwardIndex<Idx> + BackwardIndex<Idx> {}

impl<Idx, T> BidirectionalIndex<Idx> for T
    where T: ForwardIndex<Idx> + BackwardIndex<Idx> {}
```

```rust
impl<T> ImmutableIndex<usize> for Vec<T>
{
    fn begin(&self) -> usize { 0 }
    fn end(&self) -> usize { self.len() - 1 }
    fn valid(&self, i: &usize) -> bool { *i < self.len() }
}

impl<T> ForwardIndex<usize> for Vec<T>
{
    fn increment(&self, i: &mut usize) { *i += 1; }
}

impl<T> BackwardIndex<usize> for Vec<T>
{
    fn decrement(&self, i: &mut usize) { *i = i.wrapping_sub(1); }
}
```

With these definitions, we can write generic code over collections:

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```
fn find_first_index_eq_to_0<Col, Idx>(col: &Col) -> Idx
    where Col: ForwardIndex<Idx> + Index<Idx, Output=i32>,
          Idx: Clone
{
    let mut curr = collection.begin();

    while collection.valid(&curr)
    {
        if collection[curr.clone()] == 0 {
            return curr;
        }
        collection.increment(&mut curr);
    }

    panic!("Did not find zero element!");
}
```

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Of course, the previous cannot be implemented for already defined containers. The orphan rule [5] is why we can't have nice things. The only way to overcome this is to have these Index Traits in the standard library.

Questions?

Bjarne stroustrup: Why you should avoid linked lists.
`https://www.youtube.com/watch?v=YQs6IC-vgmo`.

ixlist.
`https://bluss.github.io/ixlist/target/doc/ixlist/struct.List.html`.

Learning rust with entirely too many linked lists.
`https://cglab.ca/~abeinges/blah/too-many-lists/book/`.

linked-list on crates.io.
`https://crates.io/crates/linked-list`.

Rust book on traits (orphan rule).
`https://doc.rust-lang.org/book/ch10-02-traits.html`.