Using a List Container

```
(define lc (make-list-container))

(for ([i (in-lines)])
  (add-to-front! lc i))

(print-list (get-list lc))
```

A List Container

```
(define-struct container (ls)
  #:mutable)

(define (make-list-container)
  (make-container empty))

(define (add-to-front! lc i)
  (set-container-ls!
   lc
   (cons i (container-ls lc))))

(define (get-list lc)
  (container-ls lc))
```

List Container

Before:

```
(define LC₁ (make-container (list 1)))
(add-to-front! LC₁ 0)
```

After:

```
(define LC₁ (make-container (list 0 1)))
```

Using a List Container

```
int main() {
  list_container lc;
  char buffer[256];

  lc = make_list_container();

  for (; fgets(buffer, 256, stdin); ) {
    add_to_front(lc, atoi(buffer));
  }

  print_list(get_list(lc));

  return 0;
}
```

Copy

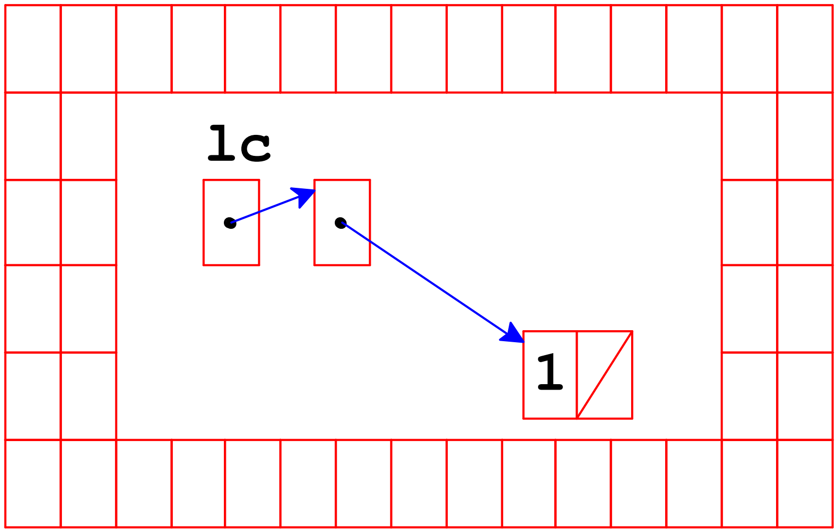
A List Container

```
struct container {
  list ls;
};
typedef struct container * list_container;

list_container make_list_container() {
  list_container lc;
  lc = (list_container)malloc(sizeof(struct container));
  lc->ls = NULL;
  return lc;
}

void add_to_front(list_container lc, int i) {
  lc->ls = cons(i, lc->ls);
}

list get_list(list_container lc) {
  return lc->ls;
}
```

Copy

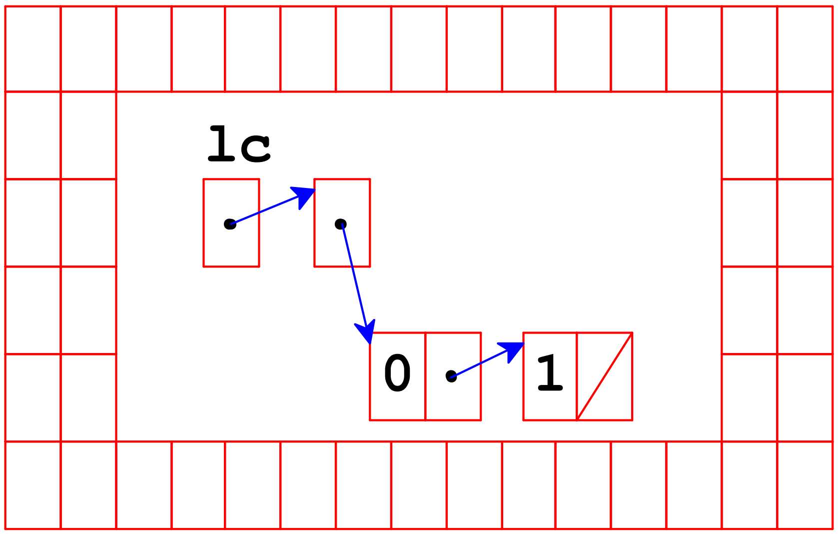
List Container

Before:




```
add_to_front(lc, 0);
```

After:



Mini Lab

Start with **`lc.c`**

Write tests for **`make_container()`**, **`add_to_front()`**, and **`get_list()`**

Adding to the End of a List

```
(define (add-to-back! lc i)
  (set-container-ls!
   lc
   (snoc i (container-ls lc))))

(define (snoc i ls)
  (cond
    [(empty? ls) (list i)]
    [else (cons (first ls)
                (snoc i (rest ls)))]))
```

Adding to the End of a List

`snoc` is painful to implement with a limited stack, so add to the end by finding and mutating the last **`int_cons`**:

```
void add_to_back(list_container lc, int i) {
  if (lc->ls == NULL)
    lc->ls = cons(i, NULL);
  else {
    list ls;
    for (ls = lc->ls; ls->rest != NULL; ls = ls->rest) {
    }
    ls->rest = cons(i, NULL);
  }
}
```

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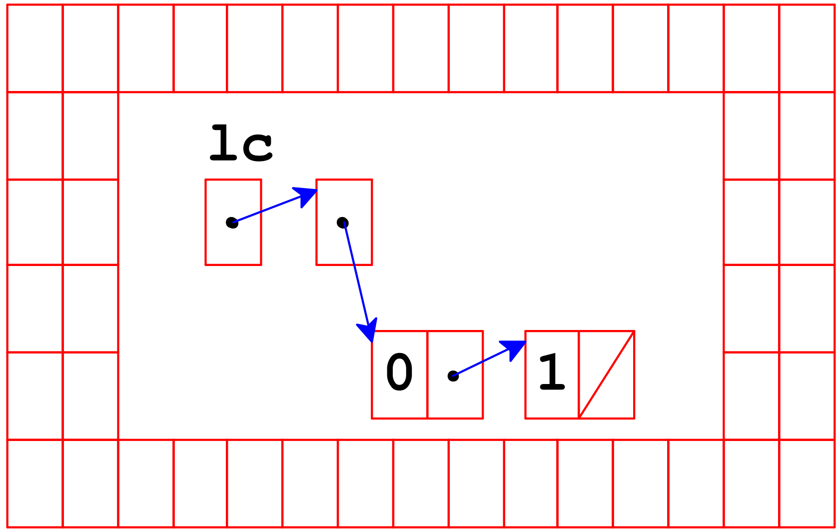
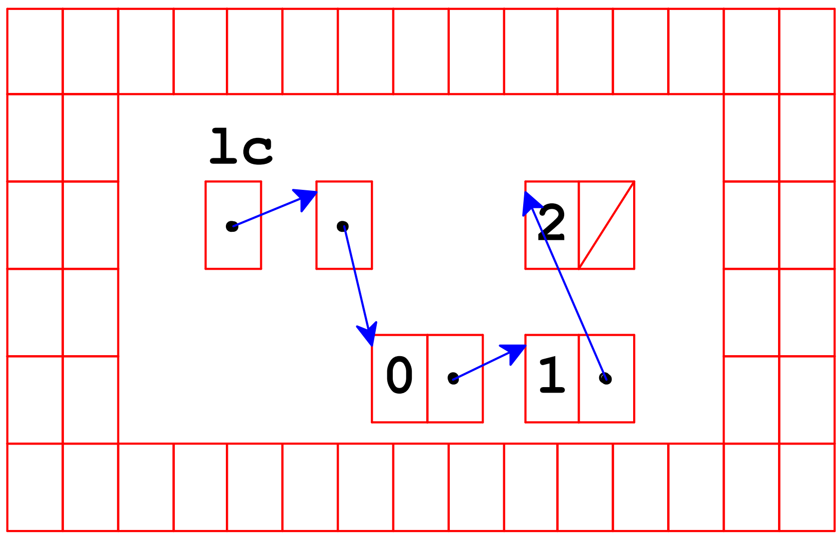
Adding to the End of a List

Before:



add_to_back(lc, 2);

After:



Mini Lab

Recreate

```
void add_to_back(list_container lc, int i)
```

without consulting the previous slide

Test it

Linked List Performance

on 25000 numbers

Racket:

- Add to front: 25 ms
- Add to back: 7360 ms

C:

- Add to front: 6 ms
- Add to back: 709 ms

Linked List Performance

on 50000 numbers

Racket:

- Add to front: 38 ms
- Add to back: 36540 ms

C:

- Add to front: 13 ms
- Add to back: 2854 ms

List Performance: Why

Adding to the front:

- Allocate one cons cell: O(1)
- *n* items: O(*n*)

Adding to the back:

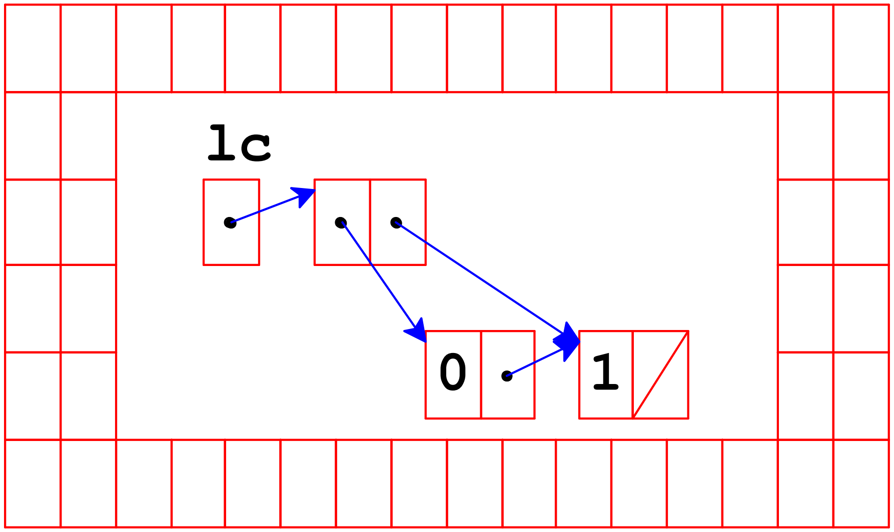
- Traverse existing *n* cons cells: O(*n*)
- *n* items: O(n^2)

Adding to the Front And Back

```
struct container {
  list hd;
  list tl;
};
```

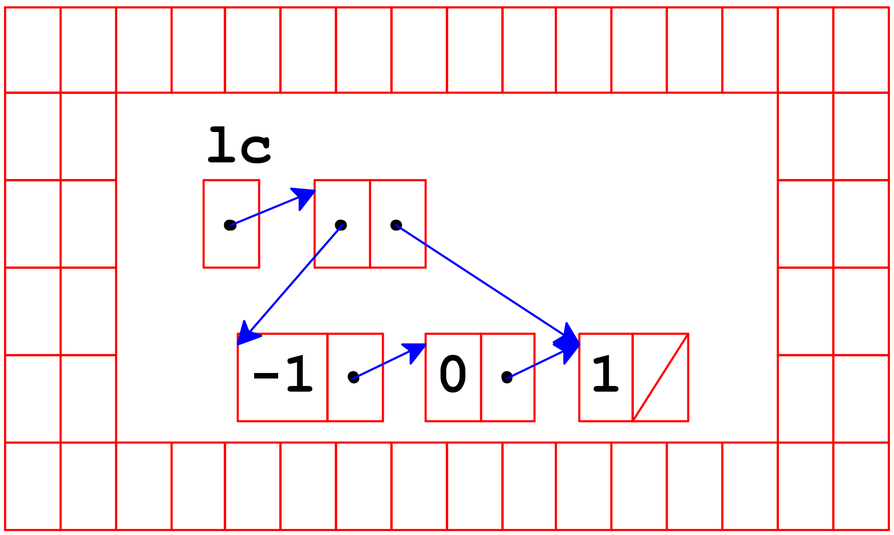
Adding to the Front And Back

Before:



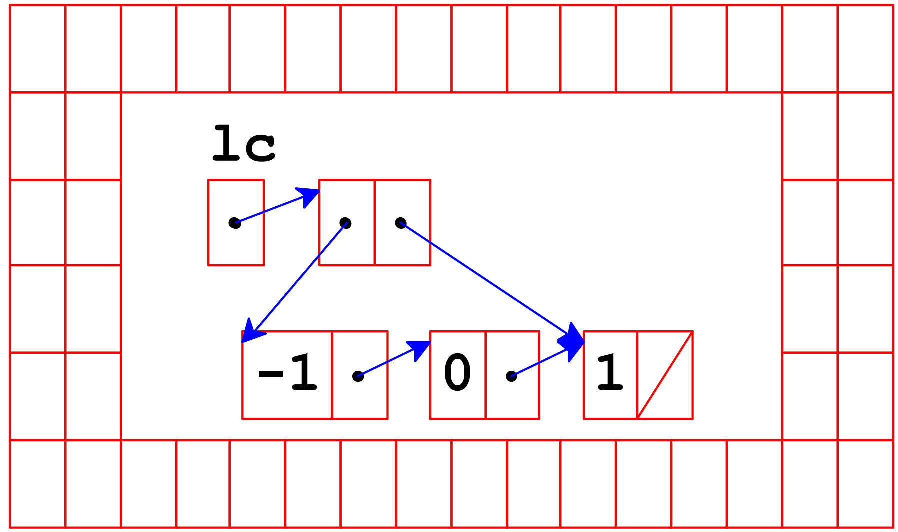
`add_to_front(lc, -1);`

After:



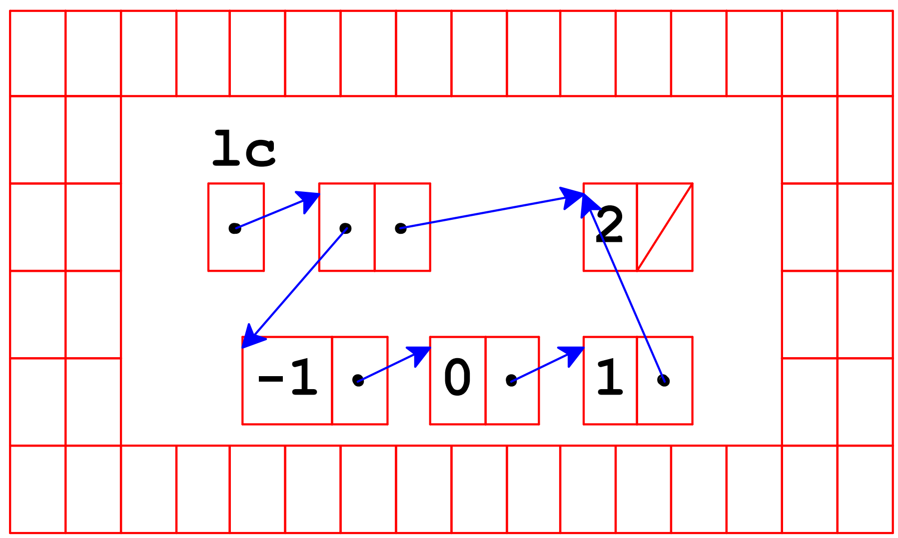
Adding to the Front And Back

Before:



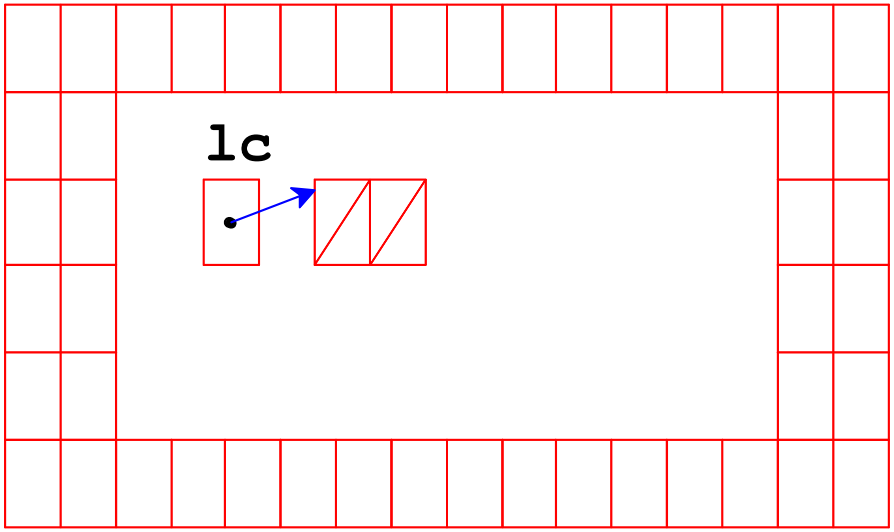
`add_to_back(lc, 2);`

After:



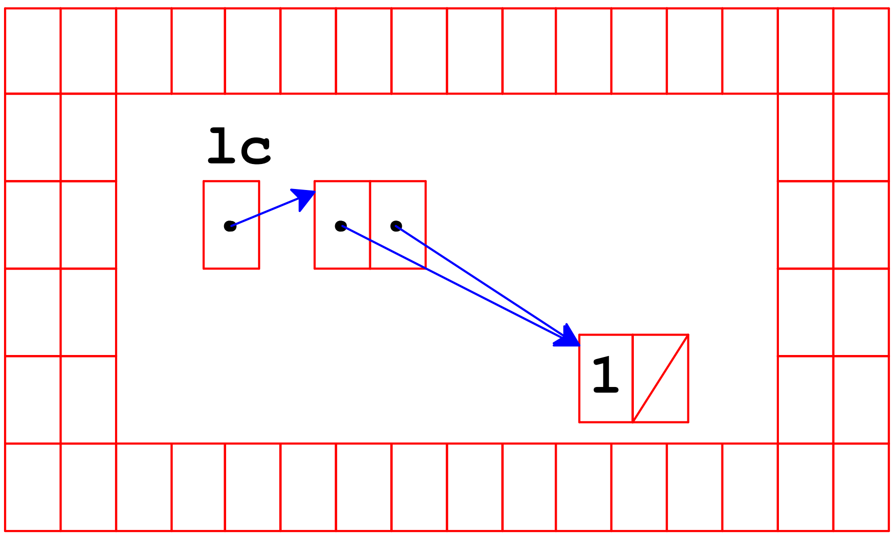
Adding to the Front And Back

Before:



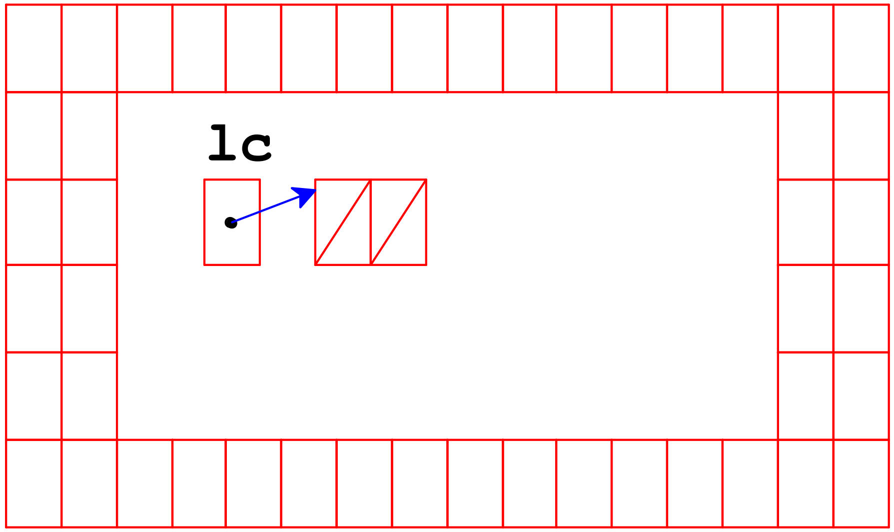

```
add_to_back(lc, 1);
```

After:



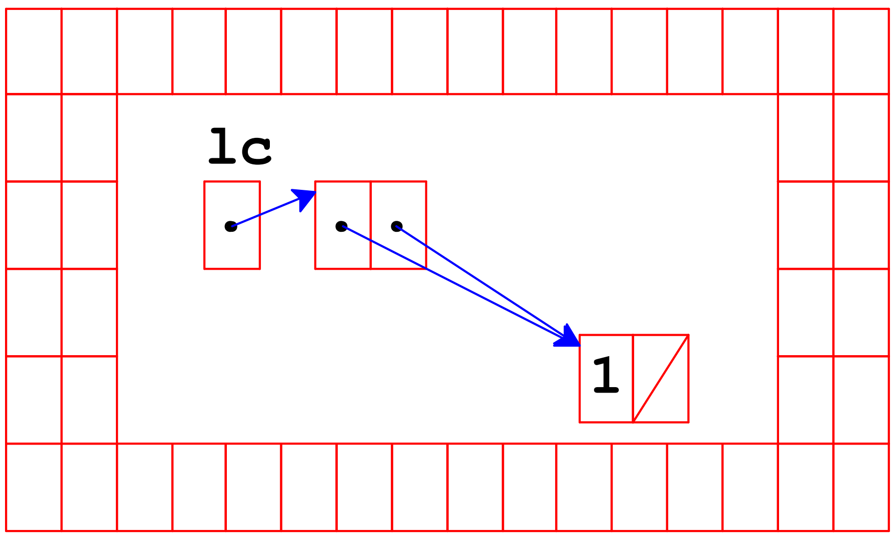
Adding to the Front And Back

Before:



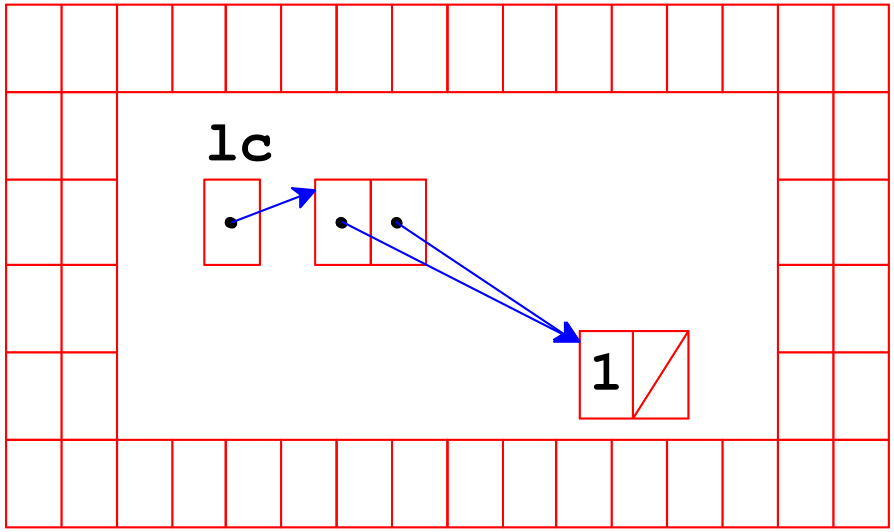

```
add_to_front(lc, 1);
```

After:



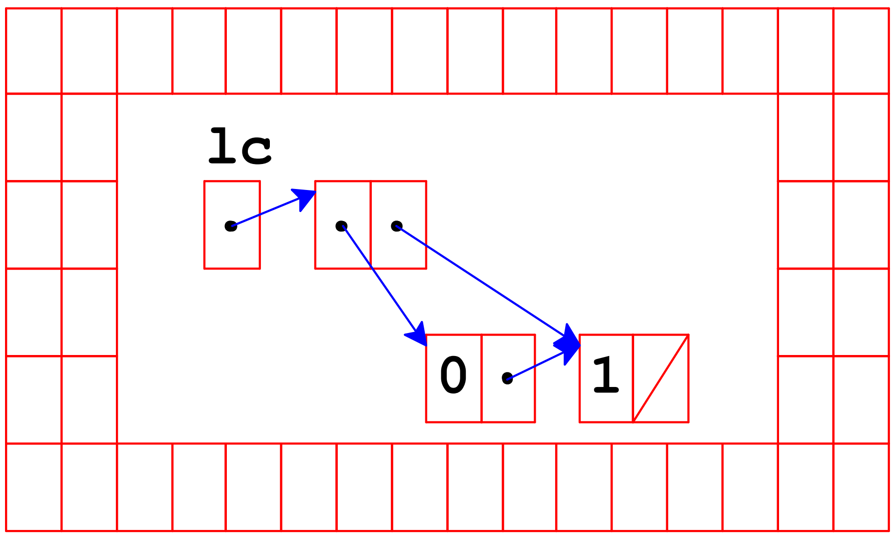
Adding to the Front And Back

Before:



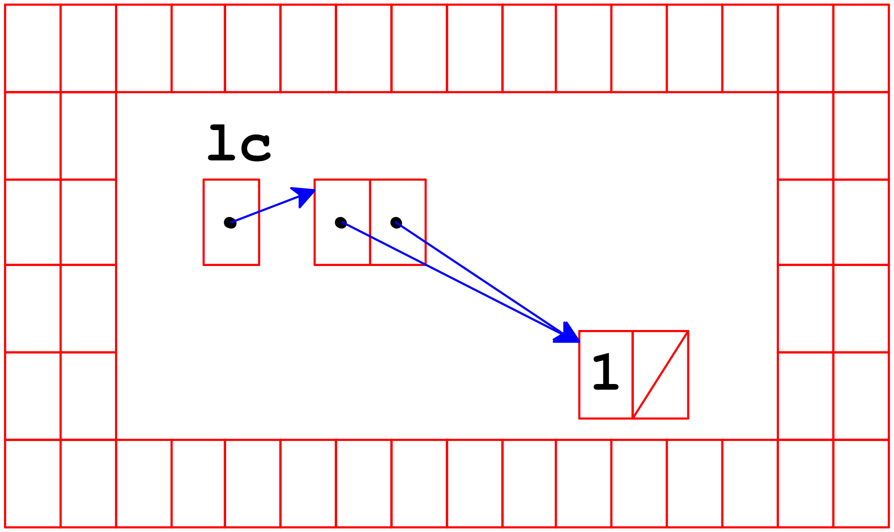
`add_to_front(lc, 0);`

After:



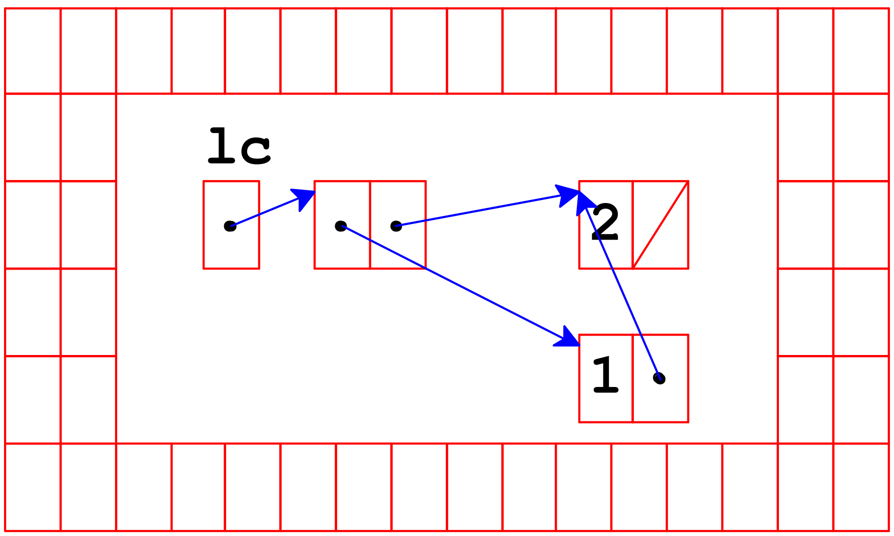
Adding to the Front And Back

Before:



`add_to_back(lc, 2);`

After:



The New List Container

```
list_container make_list_container() {
  list_container lc;

  lc = (list_container)malloc(sizeof(struct container));
  lc->hd = NULL;
  lc->tl = NULL;

  return lc;
}
```

Adding to the New List Container

```
void add_to_front(list_container lc, int i) {
  lc->hd = cons(i, lc->hd);
  if (lc->tl == NULL)
    lc->tl = lc->hd;
}

void add_to_back(list_container lc, int i) {
  if (lc->tl == NULL) {
    lc->hd = cons(i, NULL);
    lc->tl = lc->hd;
  } else {
    lc->tl->rest = cons(i, NULL);
    lc->tl = lc->tl->rest;
  }
}
```

Mutable Cons in Racket

```
(require racket/mpair)

(define ml (mlist 1 2 3))

(mcar ml) ; = 1
(mcdr ml) ; = (mlist 2 3)

(set-mcar! ml 0)
(mcar ml) ; = 0
ml ; = (mlist 0 2 3)

(set-mcdr! ml (mlist 5))
ml ; = (mlist 1 5)
```

New List Container

```
(define-struct container (hd tl) #:mutable)

(define (make-list-container) (make-container empty #f))

(define (add-to-front! lc i)
  (let ([p (mcons i (container-hd lc))]
        [tl (container-tl lc)])
    (unless tl
      (set-container-tl! lc p))
    (set-container-hd! lc p)))

(define (add-to-back! lc i)
  (let ([p (mcons i empty)]
        [tl (container-tl lc)])
    (if tl
        (set-mcdr! tl p)
        (set-container-hd! lc p))
    (set-container-tl! lc p)))

(define (get-list lc)
  (mlist->list (container-hd lc)))
```

New Linked List Performance

on 25000 numbers

Racket:

- Add to front: 13 ms
- Add to back: 13 ms

C:

- Add to front: 6 ms
- Add to back: 6 ms

Removing from a Container

Which cotainer variant supports a fast *remove* operation?

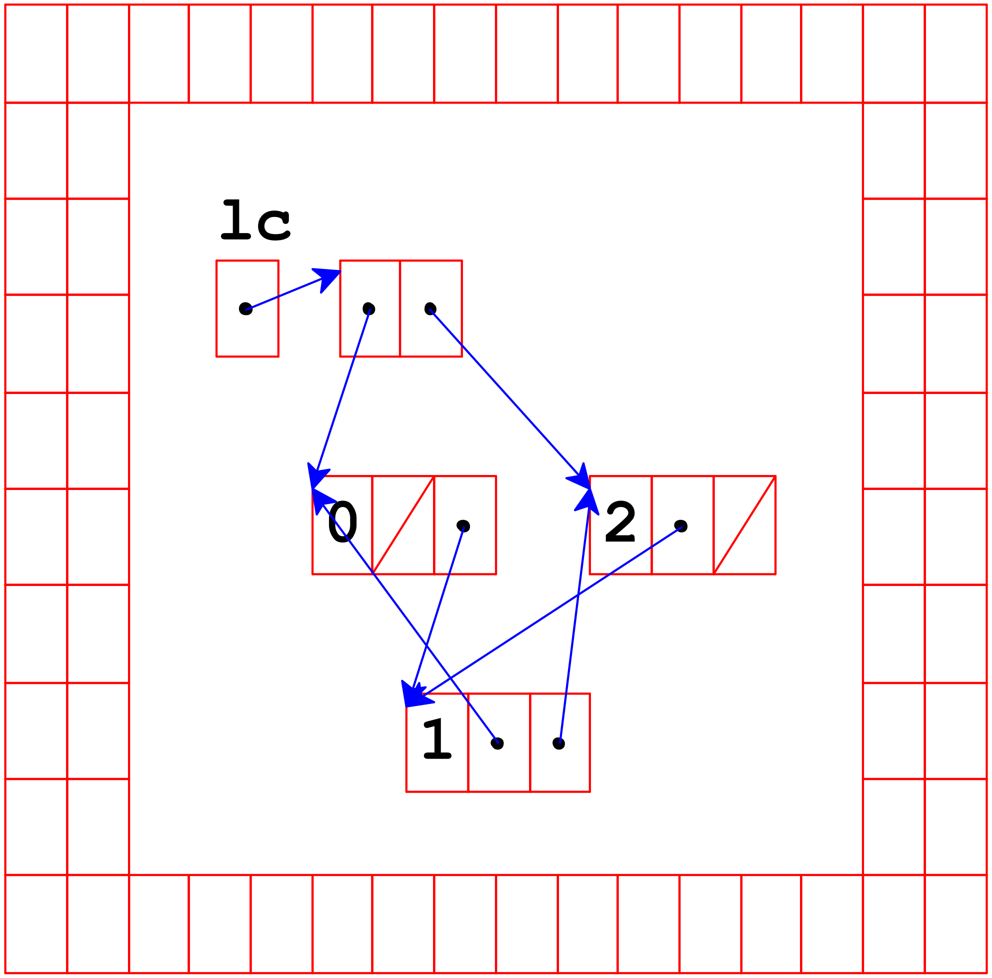
- From the **front**: **both** plain and head–tail containers
- From the **back**: **neither** plain nor head–tail containers

Doubly Linked List

```
struct int_node {
  int val;
  struct int_node * prev;
  struct int_node * next;
};

typedef struct int_node * node;
```

Doubly Linked List



Code is `doubly.c`

Changing the Middle

What about adding or removing in the middle of a list?

- If you have to find the middle: **none** of our choices so far are fast

- If you're already in the middle somehow: **doubly linked lists** can add and delete adjacent nodes quickly

Addition and deletion operations in a doubly linked list are normally expressed relative to a given node