TECHNISCHE UNIVERSITÄT MÜNCHEN
FAKULTÄT FÜR INFORMATIK

Garbage Collection & Reference Counting

Memory management in Rust

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Summer Term 2017

Overview

Methods of Memory Management

1. Shortcomings of Manual Memory Management
2. Garbage Collection
3. Rust’s approach

Memory Management in Rust

1. Stack Allocation
2. Heap Allocation
3. Reference Counting in Rust
4. The ’unsafe’ keyword

Problems - Memory Leaks

```c
int main(void) {
    while(1) {

        // Allocate some amount of memory on the heap.
        char *c;
        if(!(c = malloc(20 * sizeof(char)))) {
            perror("Could not allocate memory on heap.");
            return 1;
        }

        // Do something with allocated memory.

        // Memory is never freed, and can never be reclaimed
        // by the system.
    }
    return 0;
}
```

Problems - Double Free

```c
int main(void) {
    // Allocate some memory just like before.
    char *c = malloc(10);

    do_something(c);

    // Do something again, but the memory was already freed!
    do_something(c);
}

void do_something(char *c) {
    // Do something with the memory here.

    // Then free the memory.
    free(c);
}
```

Problems - Use after Free

```c
int main(void) {
    // Allocate memory, what a surprise.
    char *c = malloc(10);

    // Do something and then free the memory.
    free(c);

    // The memory now doesn't belong to us anymore, so this
    // will result in a segmentation fault.
    *c++;
}
```

Garbage Collection

Garbage Collection is a form of automatic memory management. It attempts to reclaim memory used by objects that are no longer in use.

Example - Mark & Sweep

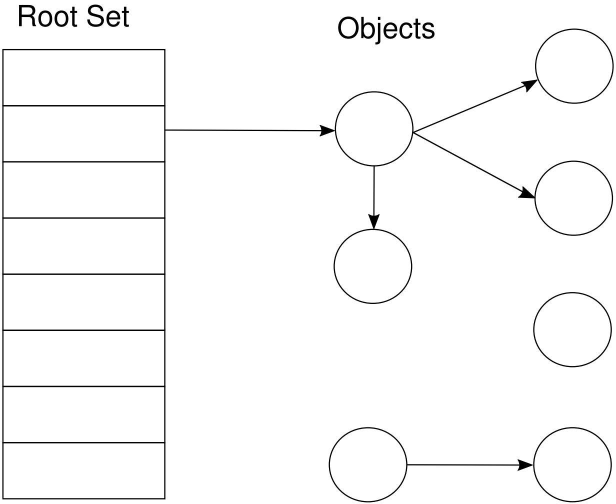


Figure: A graph-represenation of alive objects.

Example - Mark & Sweep

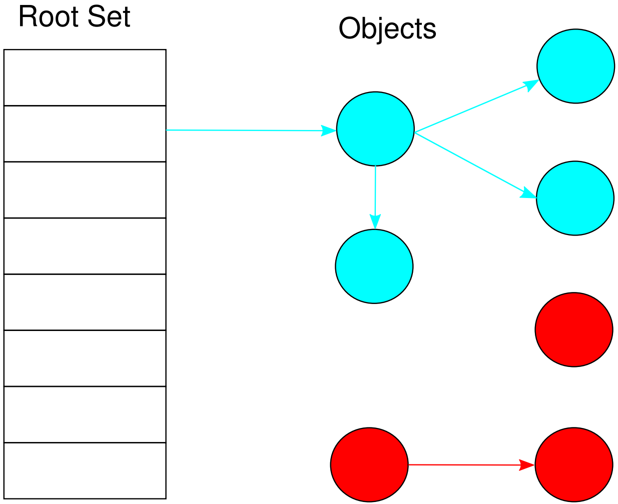


Figure: The 'Mark' stage of the algorithm.

Example - Mark & Sweep

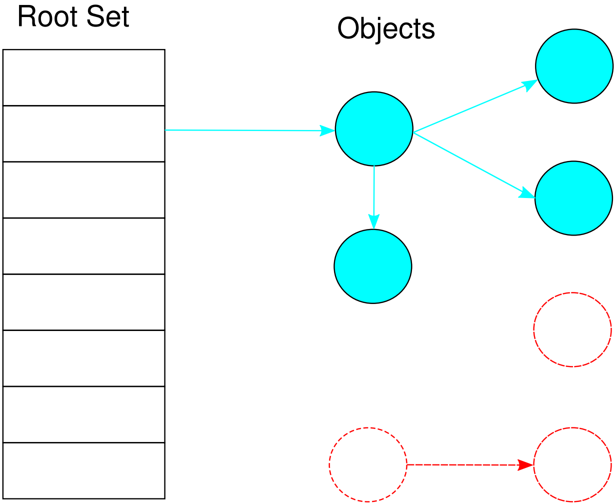


Figure: The 'Sweep' stage of the algorithm.

Memory management in Rust

Rust employs **ownership rules** to ensure memory safety. Values are stack-allocated per default. To allocate memory on the heap one can use `Box<T>`.

Stack Allocation

After line 2:

Address	Name	Value
0	x	42

```
1 fn main() {
2     let x = 42;
3     other();
4 }
5
6 fn other() {
7     let y = 27;
8     let z = 99;
9 }
```

Stack Allocation

After line 8:

Address	Name	Value
2	z	99
1	y	27
0	x	42

```
1 fn main() {
2     let x = 42;
3     other();
4 }
5
6 fn other() {
7     let y = 27;
8     let z = 99;
9 }
```

Stack Allocation

After line 3:

Address	Name	Value
0	x	42

```
1 fn main() {
2     let x = 42;
3     other();
4 }
5
6 fn other() {
7     let y = 27;
8     let z = 99;
9 }
```

Heap Allocation

Adress	Name	Value
1	y	???
0	x	42

```rust
fn main() {
    let x = 42;
    let y = Box::new(39);
}
```

Heap Allocation

Adress	Name	Value
ffff		39
1	y	
0	x	$->$ ffff

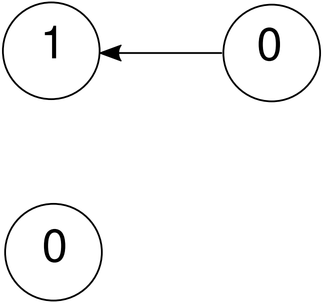
```rust
fn main() {
    let x = 42;
    let y = Box::new(39);
}
```

Comparison: Heap vs. Stack

1. Managing the Stack is trivial
2. Managing the Heap is non-trivial
3. Having stack-allocation as the default allows easier reasoning about the lifetimes of objects

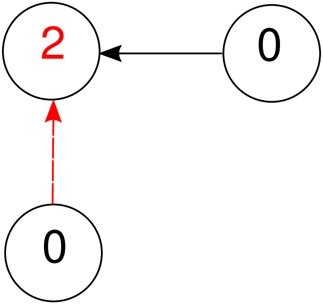
Reference Counting

References can be represented as a directed graph, where the vertices are objects and there is an edge between the nodes if one holds a reference to the other.



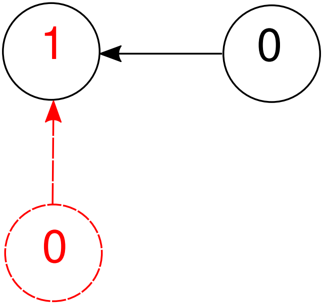
Reference Counting

Everytime a new reference to an object is created, the **reference counter** is incremented.



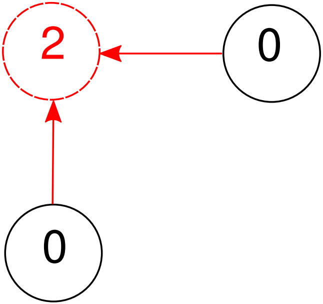
Reference Counting

When an object is freed all references it holds are freed too, and the respective reference counters are decremented.



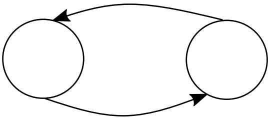
Reference Counting

Objects can only be freed, when their **reference count is 0!**
Otherwise we'll end up with dangling references.



Limitations

⚠ Reference cycles can never be reclaimed!



This can be solved by the use of a dedicated incremental garbage collector, that specifically targets reference cycles. An other approach is to simply disallow cycles in your data structure.

Reference Counting - Example

```rust
struct Owner {
    name: String,
    // Fields...
}

struct Car {
    owner: Rc<Owner>,
    // Fields...
}
```

Reference Counting - Example

```rust
fn main() {
    let owner = Rc::new(Owner{
        name: "Lars",
        // Fields...
    });

    let car = Car {
        owner: owner.clone(),
        // Fields...
    }

    let car2 = Car {
        owner: owner.clone(),
        // Fields...
    }
    // ...
}
```

Reference Counting - Example

```rust
fn main() {
    // ...

    // Drop the local variable 'owner'
    drop(owner);

    // This will still work,
    // since the owner binding survives using Rc!
    println!("{}", car.owner.name);
}
```

The ’unsafe’ keyword

The `unsafe` keyword allows:

1. Accessing or updating of a static mutable variable
2. Dereferencing of a raw pointer
3. Calling of other unsafe functions

Raw Pointers

Two types of raw pointers:

1. `*const T`
2. `*mut T`

Raw pointers have no lifetime or ownership. The only guarantee provided is they cannot be dereferenced except in code marked as `unsafe`.

Example

```rust
fn main() {
    let i: u32 = 77;

    // Creating a raw pointer in safe code is
    // perfectly acceptable.
    let x = &i as *const u32;

    // Dereferencing a raw pointer in
    // safe code is not allowed!
    let y = *x;

    // Once we marked the code as unsafe,
    // the compiler let's us do it.
    unsafe {
        let z = *x;
    }
}
```