CS162 Week 9

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Overview

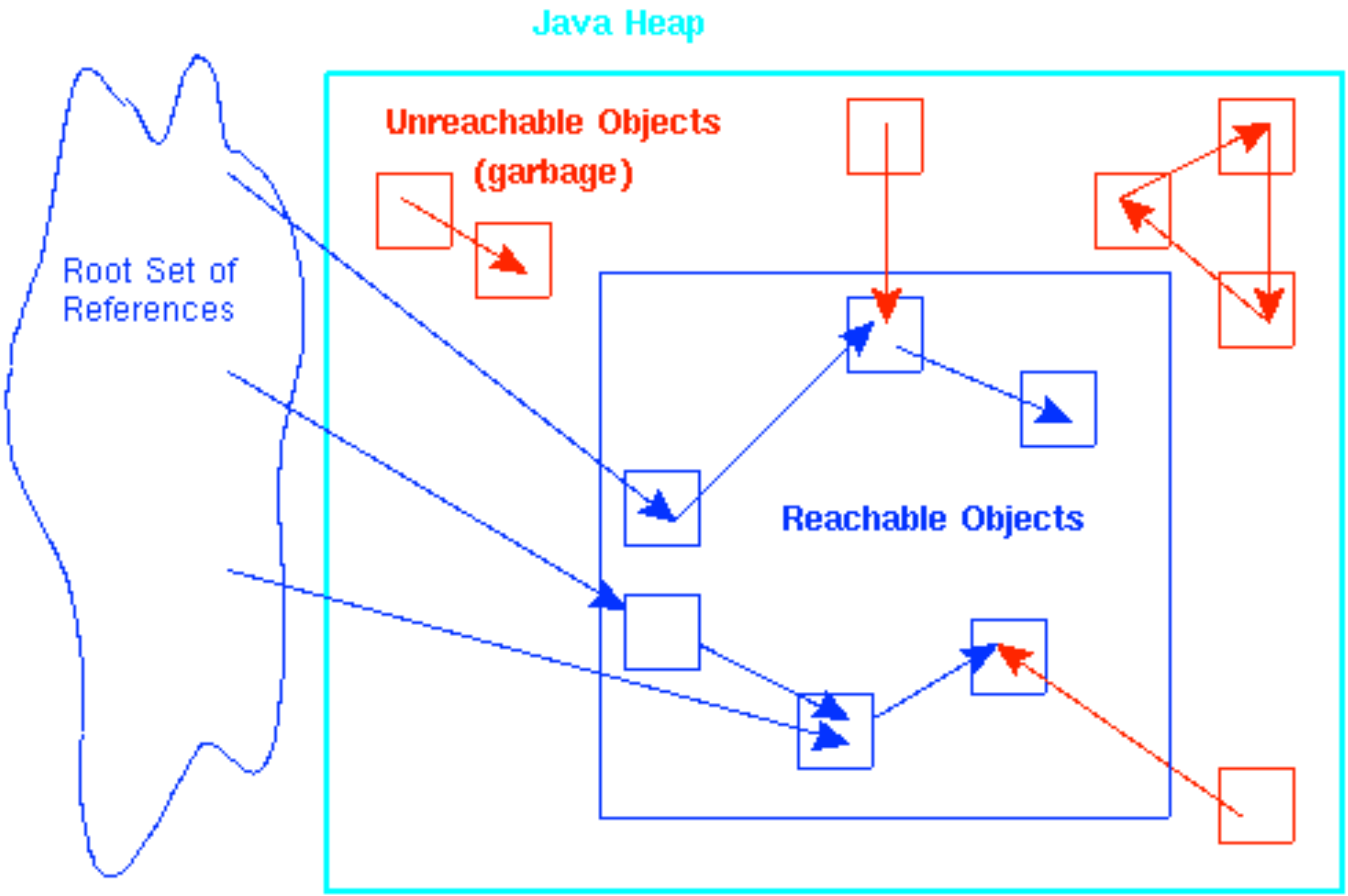
- What needs to be done
- Quirks with GC on miniJS
- Implementing GC on miniJS

The Plan

- Implement three garbage collectors: semispace, mark/sweep, and generational
- Semispace + mark/sweep: 90% of score
- Semispace + mark/sweep + generational: **130%** of score

GC Reachability

- Reachability means we can access the object



Liveness

- If we can reach an object from the **root set**, then the object is live
- If we cannot reach it, then it is dead
- Reclaim only dead objects

Question

- The typical root set consists of the values of variables on the stack
- What is the root set for miniJS?

```
var a, obj in
  obj := {foo: “bar”};
  obj.bar := obj.foo;
  a := 12;
  obj := {b: a, o: obj}
```

Issue #1: Variables on the Stack

- miniJS does not have a usual stack
- Variable values tracked by recursive calls to eval with `InScope` objects

```
case Let( xs, t ) ⇒
{
  val bindings = xs map ( _.x → ( σ += UndefV() ) )
  inScope( ρ ++ bindings ) eval t
}
```

Solving Issue #1

- Introduce a global mutable stack that acts as the environment
- Variable to address bindings are pushed onto it in the same was as seen with a usual runtime stack

Original

```
case Let( xs, t ) ⇒
{
  val bindings = xs map ( _.x → ( σ += UndefV() ) )
  inScope( ρ ++ bindings ) eval t
}
```

New

```
case Let( xs, t ) ⇒
{
  val addrs = addBindings(xs.map(_.x → UndefV()))
  val retval = eval(t)
  ρ.popTimes(addrs.size)
  retval
}

def addBindings(bindings: Seq[(String, Storable)]): Seq[Address] =
  bindings.map(pair ⇒ {
    val ref = (σ += pair._2)
    ρ.push(pair._1 → ref)
    ref
  })
```

Issue #2: Intermediate Values

- What's problematic with this for GC?

```
case Update( e1, e2, e3 ) ⇒
{
  val adr = eval( e1 )
  val fld = eval( e2 )
  val rhs = eval( e3 )

  (adr, fld) match {
    case (adr:Address, fld:StrV) ⇒
    {
      σ(adr) = toObj( σ(adr) ) :+ (fld → rhs)
      UndefV()
    }
    case _ ⇒ throw undefined
  }
}
```

Issue #2: Intermediate Values

- We can operate on store-allocated values without having a binding in the environment

```
({foo: "bar"}).baz := {"temp": 1}
```

Solving Issue #2

- Put all temporary variables into the root set

```
case Update( e1, e2, e3 ) ⇒
{
  val adr = eval( e1 )
  RootSet.pushExtra(adr)
  val fld = eval( e2 )
  RootSet.pushExtra(fld)
  val rhs = eval( e3 )
  RootSet.pushExtra(rhs)

  (adr, fld) match {
    case (adr:Address, fld:StrV) ⇒
      {
        σ(adr) = toObj( σ(adr) ) :+ (fld → rhs)
        RootSet.popExtraTimes(3)
        UndefV()
      }
    case _ ⇒ throw undefined
  }
}
```

Getting the Root Set

- Calling `RootSet()` will get the global root set
- This root set is a set of `Storable`, not `Address` as in the usual definition

Representing the Heap

```
class Heap(size: Int) extends HeapInterface {
  protected val heap = new Array[Any](size)
}

// blocksAllocated includes the metadata
case class AllocatedMetadata(blocksAllocated: Int, typ: StorableType)

// blocksAvailable includes the metadata
case class FreeMetadata(blocksAvailable: Int, next: Int)
```

- `HeapInterface` provides functions for reading / writing objects
- See the `StubCollector` for detailed information on usage

Heap With `StubCollector`

- After allocating the number 1:

Allocated Metadata Size: 2 Type: NumV	NumV(1)			

Heap With `StubCollector`

- After allocating the number 1 and a closure:

Allocated Metadata Size: 2 Type: NumV	NumV(1)	Allocated Metadata Size: 4 Type: CloV	<<Variable Names>>	<<Closure Term>>

<<Closure Environment >>				

Heap With `StubCollector`

- After allocating the number 1, a closure, and the string “foo”:

Allocated Metadata Size: 2 Type: NumV	NumV(1)	Allocated Metadata Size: 4 Type: CloV	<<Variable Names>>	<<Closure Term>>

<<Closure Environment >>	Allocated Metadata Size: 2 Type: StrV	StrV(“foo”)		

Heap With `StubCollector`

- After allocating the number 1, a closure, the string “foo”, and the boolean true:

Allocated Metadata Size: 2 Type: NumV	NumV(1)	Allocated Metadata Size: 4 Type: CloV	<<Variable Names>>	<<Closure Term>>

<<Closure Environment >>	Allocated Metadata Size: 2 Type: StrV	StrV(“foo”)	Allocated Metadata Size: 2 Type: BoolV	BoolV(true)

The Collectors

- Two key functions: `gcAlloc` and `gcRead`
- These do exactly what their names suggest

```
def gcAlloc(s: Storable): Address
def gcRead(a: Address): Storable
```

StubCollector

Mutation in miniJS

- Old semantics: update the `Storable` at a given address to be some new `Storable`
- What's wrong with this with respect to the new heap?

```
case Assign( Var(x), e ) ⇒
{
  val v = eval( e )
  σ( ρ( x ) ) = v
}
```

Mutation Issue

- Problem: different objects take up different lengths
- Since miniJS is dynamically typed, we could switch the kind of object stored
- If we want to store a new object that's bigger than what the old one took up, we generally won't have the space at the same address

Mutation Issue

```
var a, b in
  a := 1;
  b := 2;
  a := () => {output b}
```

a

Allocated Metadata Size: 2 Type: NumV	NumV(1)			

Mutation Issue

```
var a, b in
   a := 1;
   b := 2;
   a := () => {output b}
```

a		b		
Allocated Metadata Size: 2 Type: NumV	NumV(1)	Allocated Metadata Size: 2 Type: NumV	NumV(2)	

Mutation Issue

```
var a, b in
  a := 1;
  b := 2;
  a := () => {output b}
```

Closures take up 4 units, but the original address has only 2

a		b		
Allocated Metadata Size: 2 Type: NumV	NumV(1)	Allocated Metadata Size: 2 Type: NumV	NumV(2)	

Handling Mutation

- Instead of trying to reuse addresses, we allocate to a new address
- We update the old address to have the same location as the new address

```scala
def gcModify(a: Address, v: Storable) {
  // done via emulation - alloc again and update the address
  RootSet.pushExtra(v)
  val newAddr = gcAlloc(v)
  RootSet.popExtra()
  a.loc = newAddr.loc
}
```

Handling Mutation

- For this update to work, your interpreter must have the following invariant: at any point in time, there is at most one `Address` object associated with each underlying position in the heap
- If addresses are only made in `gcAlloc` for freshly allocated values, this will be guaranteed
- Without this, we can still have `Address`es that point to the old address after update

Other Assorted Notes

Tracing

- Be sure to look at `values.scala`
- Extra kinds of `Storable`s have been added
  - This miniJS has lists
  - `ObjectV`s are implemented internally with lists that extend `Storable`
- You need to be able to trace these lists

Backpointers in Generational GC

- The skeleton code handles backpointers already
- You may need to trace these backpointers entirely, in violation of typical generational GC
- Underlying issue: a reference from the tenured space to the nursery may be made long before a tenured object is updated

`trace`

- A special `trace` function is provided, which will simply print the string specified if the `-trace` flag is set
- Very useful for debugging
- If there is inadequate tracing, you will be penalized

`assert`

- For any assumptions you have, you should make sure they are true with the `assert` statement
- Many bugs will not trigger a typical error until long after they occurred, and proper usage of `assert` can help shorten this gap
  - I.e. `assert` can cause bugs to reveal themselves sooner than usual

`freelist.scala`

and `gc.scala`