Compiler Construction

Week 8: Code generation II & Extensions

Sjaak Smetsers Mart Lubbers Jordy Aaldering

2024/2025 KW3

Radboud University

Notices

Extensions Ideas

Higher order functions

Garbage collection
- Tracing Garbage Collection
- Reference Counting

Real architectures

Conclusion

Notices

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- Make sure your git repo is kept up to date

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- Oral exams: June 16^{th}, 17^{th} and 19^{th}

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Extensions Ideas

Types

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Higher order functions

Functions as arguments (later)

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Local functions

Nested functions

- Lambda lifting (later)
- Display (array of frame pointers)
- Static link (fp as argument)

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Local functions

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Proper overloading

Class dictionaries

Pattern matching & User defined types

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```
type IntList = INil | ICons Int IntList;
type List a  = Nil | Cons a (List a);
type Person  = {name :: [Char], age :: Int};
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```
print (p : Person) : Void {
  print(p.name);
  print('(');
  print(p.age);
  print(')');
}
```

Pattern matching & User defined types

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type IntList = INil | ICons Int IntList;
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```
tl (l : List a) : List a {
  case l of
    Nil = return Nil
    Cons a t = return t
}
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  print(p.name);
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}
```

```
tl (l : List a) : List a {
  case l of
    Nil = return Nil
    Cons a t = return t
}

hd (l : List a) : a {
  case l of
    Cons a t = return a
    /* what happens here? */
}
```

Memory related

Garbage collection

Free space on the heap

Memory related

Garbage collection

Free space on the heap

Smart pointers

Less general solution

Optimisations

Reorder basic blocks

Last lecture

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Register allocation

Not very interesting on SSM.

Not necessary in LLVM.

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Optimize intermediate lists

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```
countdown (x : Int) : Int {
  if (x == 0) { return 0; }
  else { return countdown (x-1); }
}
```

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```
factorial (x : Int) : Int {
  if (x == 0) { return 1; }
  else { return x * factorial (x-1);
    }
}
```

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```
factorial‘ (x : Int, acc : Int) : Int
    {
  if (x == 0) { return acc; }
  else { return factorial‘(x-1, x*acc
   ); }
}
```

```
factorial‘ (4, 1);
```

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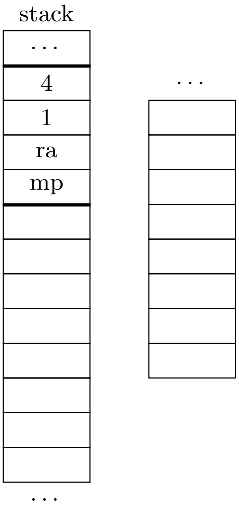

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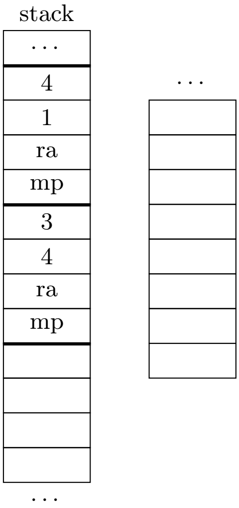

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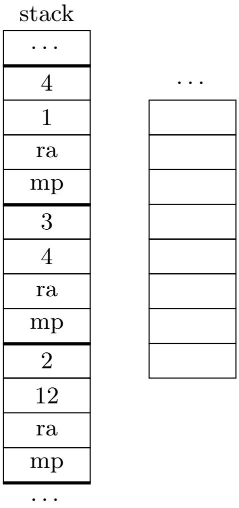

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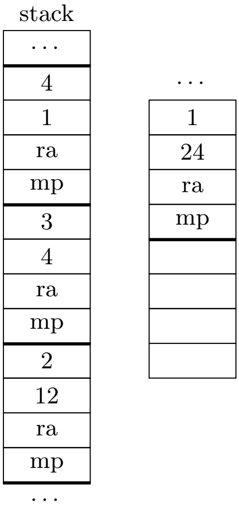

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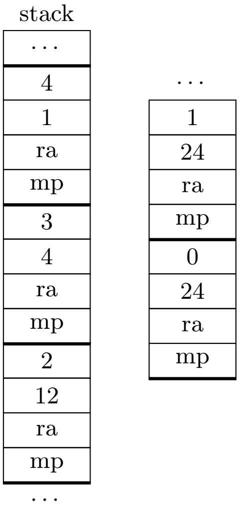

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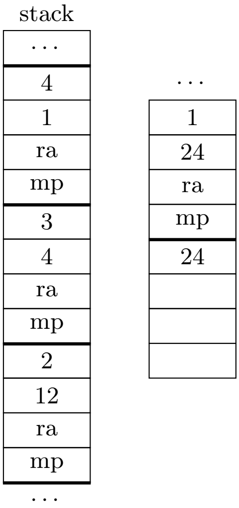

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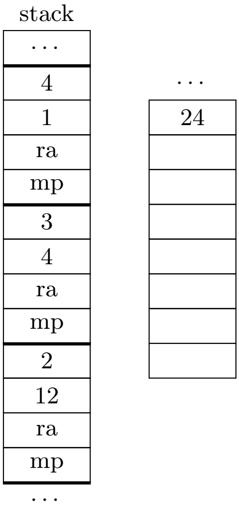

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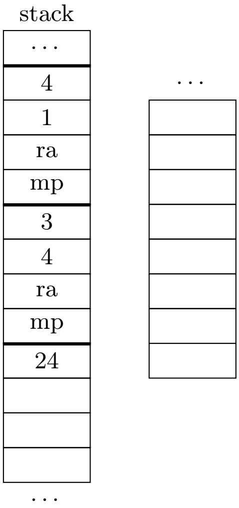

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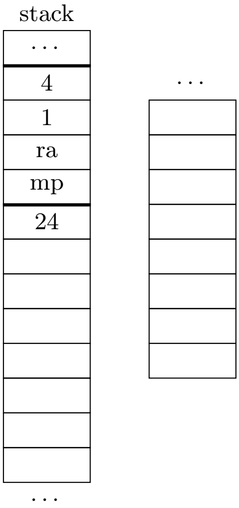

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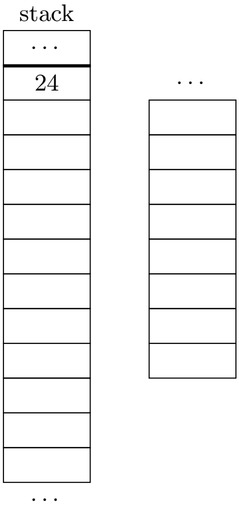

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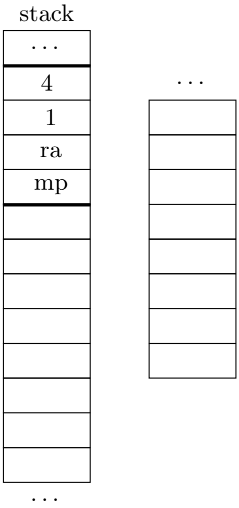

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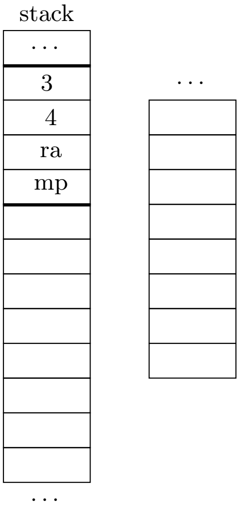

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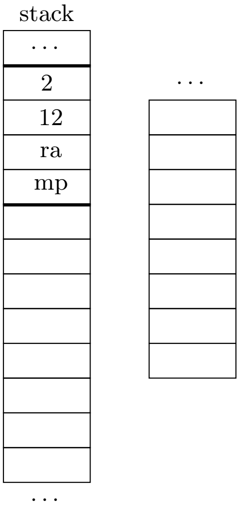

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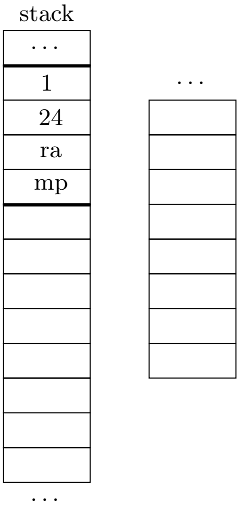

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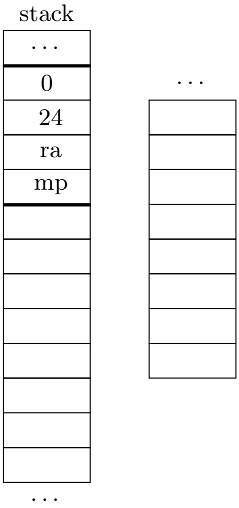

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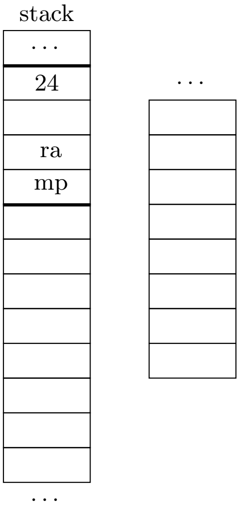

Code generator related

Separate compilation

Linker

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Linker

- Compile separate files
- Linker connects them, resolves addresses
- Header files?
- Only parse function signatures?

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Real target machine

Later

Meta extensions

Language Server Protocol

Plugin for an editor, refactor, etc.

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Language Server Protocol

Plugin for an editor, refactor, etc.

Formal semantics

Create and verify?

Higher order functions

Higher order functions

```
map (f : a -> b, l : [a]) : [b] {
  if (isEmpty(l)) {
    return [];
  } else {
    return f(l.hd) : map(f, l.tl);
  }
}

twice (f : a -> a, a : a) : a {
  return f(f(a));
}
```

Higher order functions

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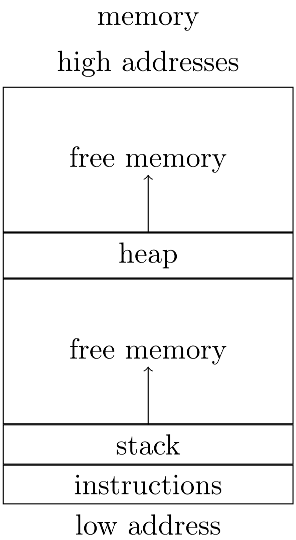

How to store this?

- Function objects
- Thunks
- Closures

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- Function objects

C

```
void qsort(void *base, size_t nmemb, size_t size,
    int (*compar)(const void *, const void *));

int cmp (const void *l, const void *r) {
  return *(int *)l < *(int *)r ? -1 : 1;
}

int arr[] = {3, 1, 4, 1, 5};
qsort (arr, sizeof(arr)/sizeof(int), sizeof(int),
     &cmp);
```

How to store this?

- Function objects

SPL

```
sort(l : [a], cmp : a -> a -> Int) : [a] { ...  }
cmp (l : Int, r : Int) :: Int Int -> Int) {
  if (l < r) { return -1;
  } else     { return 1; }
}
main () {
  print(sort(3 : 1 : 4 : 1 : 5 : [], cmp));
}
```

How to store this?

- Function objects
- Function pointer in C

SPL

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sort(l : [a], cmp : a -> a -> Int) : [a] { ...  }
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How to store this?

- Function objects
- Function pointer in C
- Function as argument
- Straightforward in SSM

SPL

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- Partially applied function
- Remember **bsr** versus **jsr**?

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Haskell

```
ap :: (a -> b) -> a -> b
ap f a = f a

main = ap (ap (+) 4) 38
```

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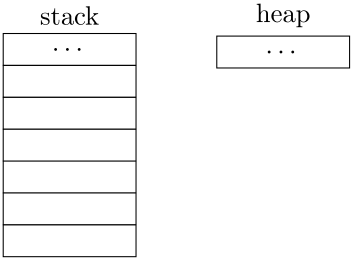

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ap (f : a -> b, a : a) : b {
  return f(a);
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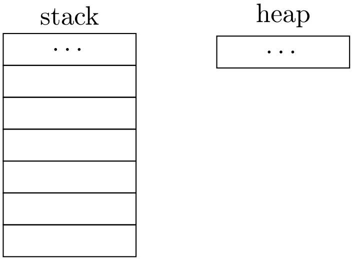

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jsr versus bsr

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SP_post = SP_pre
PC_post = M_pre[
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M_post[SP_post] =
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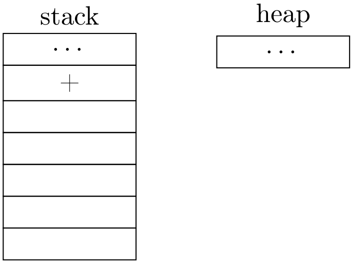

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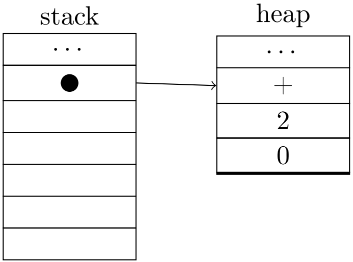

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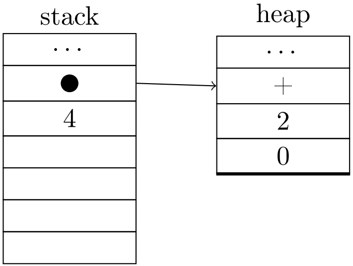

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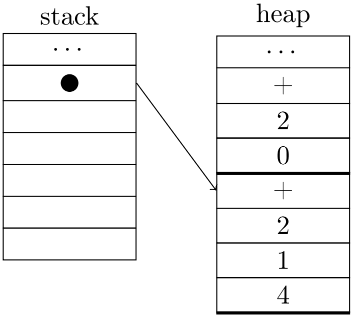

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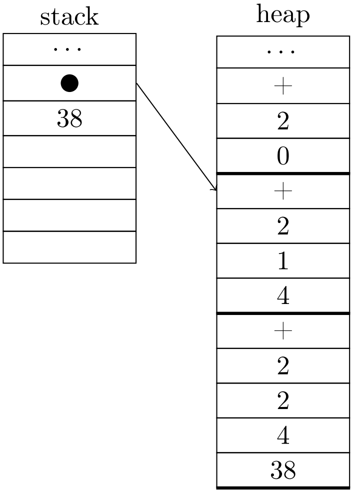

SPL

```
ap (f : a -> b, a : a) : b {
  return f(a);
}
main () {
  print(ap(ap(+, 4), 38));
}
```

jsr versus bsr

```
SP_post = SP_pre
PC_post = M_pre[
    SP_pre]
M_post[SP_post] =
    PC_pre + 1
```

```
SP_post = SP_pre + 1
M_post[SP_post] = PC_pre + 2
PC_post = PC_pre +
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Thunks

- Thunks
- Curried arguments
- Partially applied function
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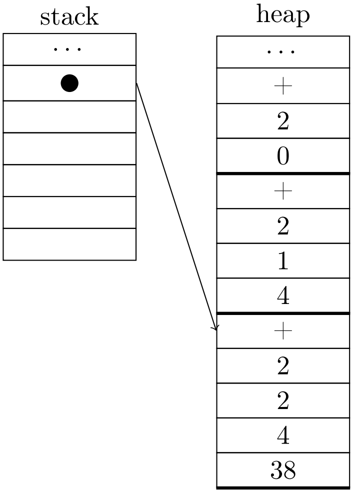

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Closures

- Closure
- Environment
- Anonymous function
- Only thunks needed when lambda lifting

What is lambda lifting

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plus38(x : Int) : Int -> Int {
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    return y + x;
  }
  return ret;
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plus38(x : Int) : Int -> Int {
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    return y + x;
  }
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}
```

```
plus38_ret(x : Int, y : Int) : Int{
  return y + x;
}
plus38(x : Int) : Int -> Int {
  return plus38_ret(x);
}
```

Garbage collection

Storing stuff in the heap

Semantics: **sth**

Nr of inline Opnds	Nr of stack Opnds	Nr of stack Results	Instr code (hex)
0	1	1	`0xd6`

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Store into Heap. Pops 1 value from the stack and stores it into the heap. Pushes the heap address of that value on the stack.

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ldc 5
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Load via Address. Dereferencing. Pushes the value pointed to by the value at the top of the stack. The pointer value is offset by a constant offset.

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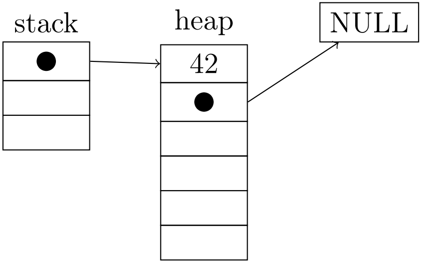

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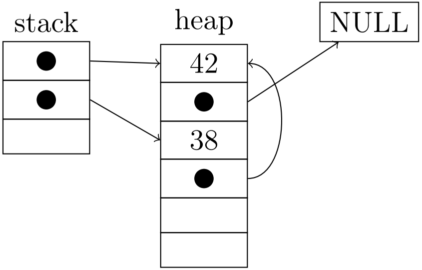

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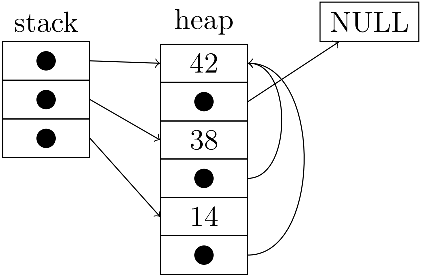

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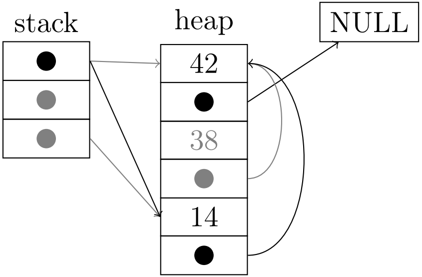

Garbage collection

Burden the programmer

`malloc`, `free`, **new**, **delete**

Garbage collection

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- GC on alloc
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Intuition

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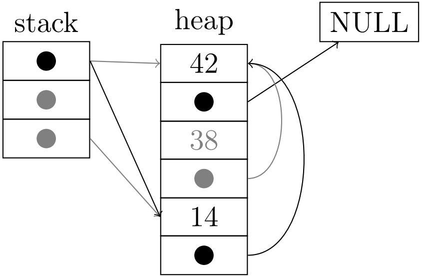

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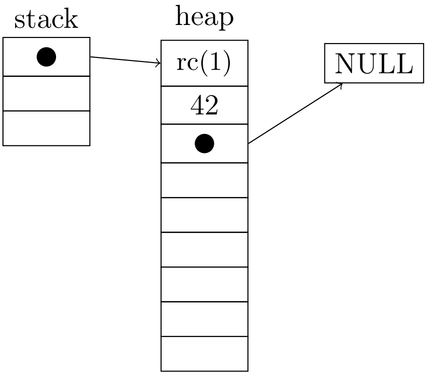

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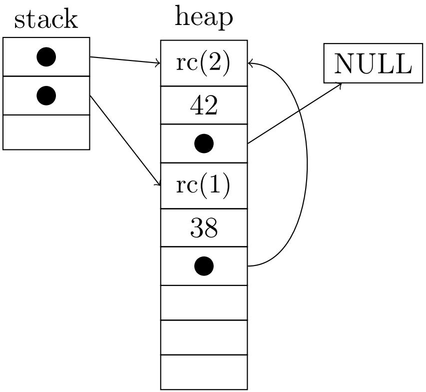

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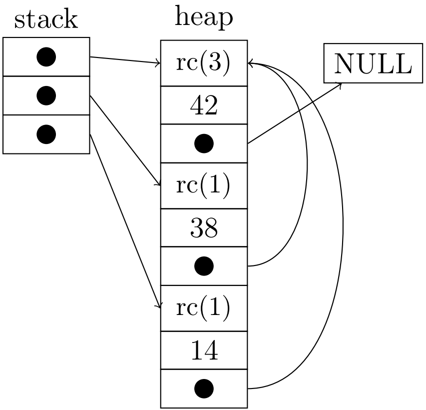

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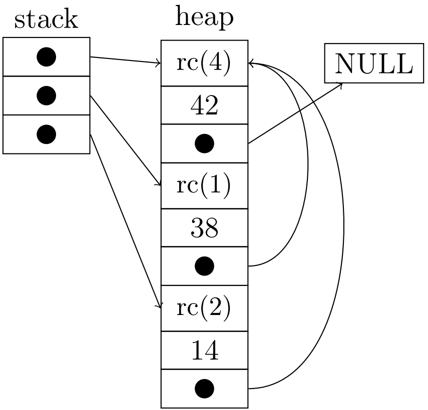

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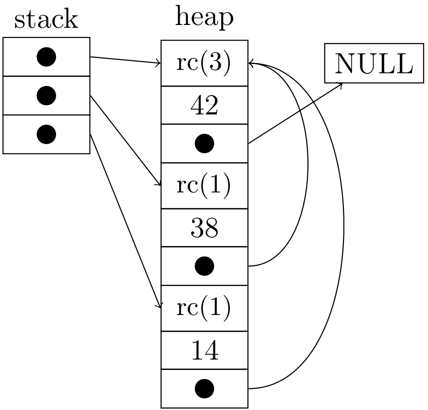

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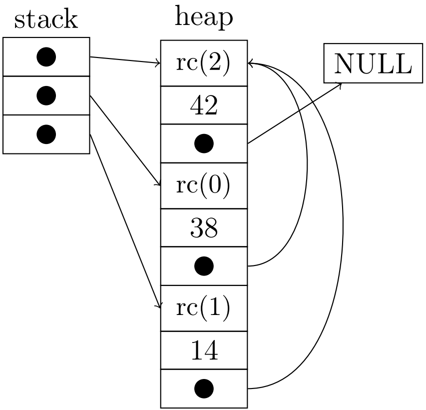

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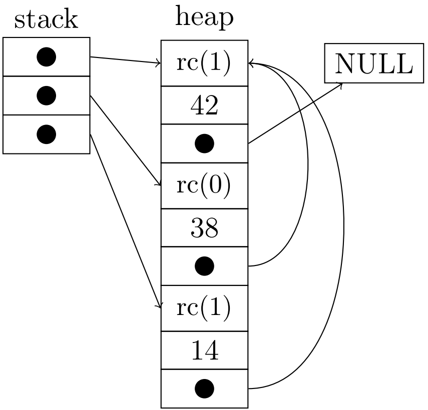

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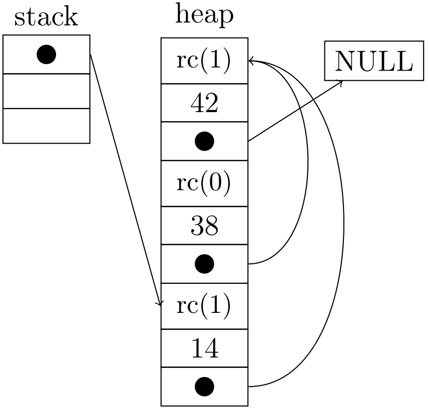

Garbage collection in SPL

- Remember the start of the heap

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- Copying is more difficult but possible
- Compressing is easy since all objects are of the same size

Real architectures

Instruction sets

Instruction sets

Name	Word	Registers	Endianness
x86	32	8	Little
x86_64	64	16	Little
ARM/A32	32	15	Big*
ARM/A64	64	32	Big*
AVR	8	32	Little
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Intermediate languages

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- Java bytecode
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Conclusion

Your project

Send in your extension proposal

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Do not hesitate to discuss ideas