Compiler Practical 2013

Storage Administration: Overview

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Structure

1. Heap Administration
2. Automatic Garbage Collection
3. Reference Countin
4. Mark and Sweep Collectors
5. Copying Collectors
6. Mark and Compact Collectors

Heap Administration: Push-Only Stack

- Can be implemented very fast and easy
- Standard implementation in LOOP-0
- Full, some time ... ;-)
- Cannot be used if the program shall run for some time, and works with data on the heap.

Heap Aministration: Free Lists

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- For programming languages mit explicit (manual) allocation/de-allocation:
  - Keeping one or several lists that link free blocks on the heap
    - Allocation in these lists
    - De-allocated blocks are added to one of these lists
  - Fragmentation (and counter measures)
    - Bigger blocks are no longer available
    - Allocation: *First-fit* vs. *Best-fit*
    - De-allocation: Joining adjacent blocks to bigger blocks

Automatic Garbage Collection I

- Explicit storage management is error-prone
  - Storage leaks
  - Multiple de-allocation
  - Dereferencing of „dangling pointers“
- Automatic storage management can be faster
  (Benjamin Zorn, The Measured Cost of Conservative Garbage Collection, *Software - Practice and Experience*)
  - Using times of low activity
  - Generational garbage collection

Autom. Garb. Collection II

Drawbacks

- Temporary suspension of program execution during garbage collection
- Some operations are slowed down, e.g., assignments, by reference counting
- Possibly additional initialization of variables that are otherwise useless

De-Allocation of Unused Storage

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With simple de-allocation:

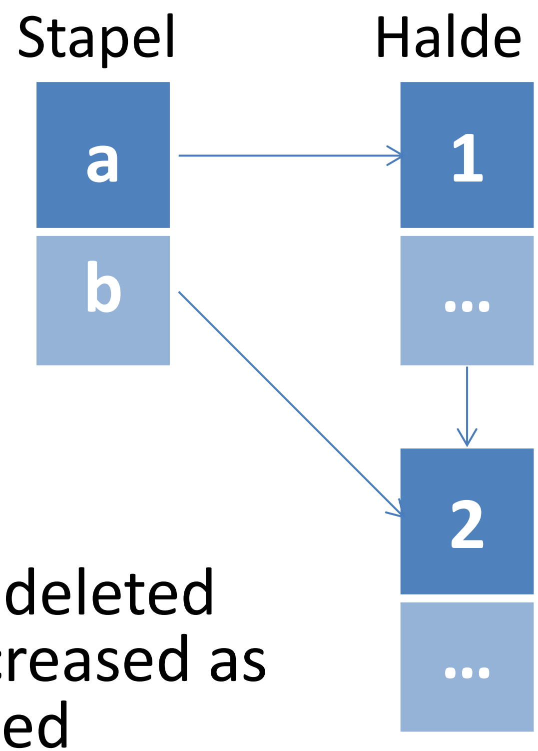
- Used storage is untouched
- All pointers / references stay valid
- Can be done in parallel with program execution
- Does not solve fragmentation

Compactification

- Used storage is pushed together
- All pointers / references have to be adjusted
  - On the stack
  - Within objects on the heap
- Cannot be done in parallel to program execution

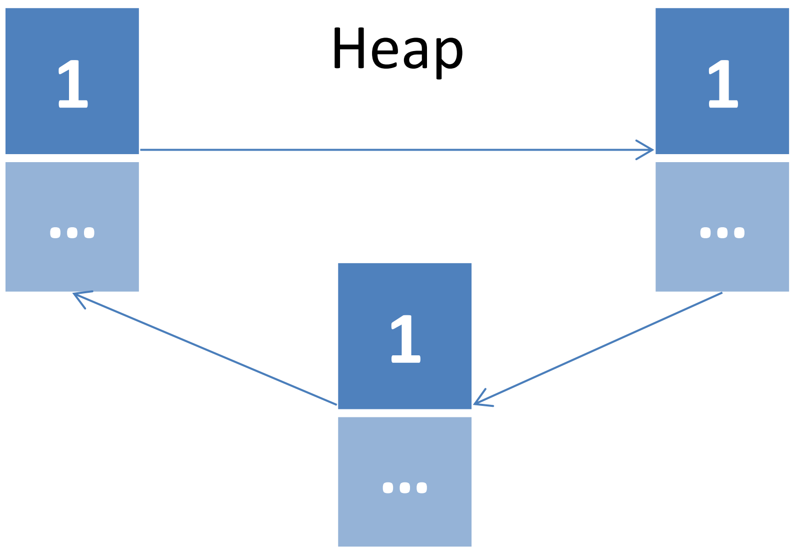
Reference Counters

- Every object on the heap gets a reference count
- The counter is set to 0 during allocation
- With every assignment to a reference
  - The counter of the newly assigned object is increased, and the counter of the object held previously is decreased
  - If this count equals 0, the object is deleted
  - For every object reference of the deleted object, the reference count is decreased as well, and the object may be deleted



Reference Counters: Cycles

- Cyclic structures cannot be de-allocated



Separate Storage Adjustment

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- When?
  - If no heap space is available
  - If there is time
- How?
  - Determining which blocks on the heap can be reached from the stack
  - De-allocation of all not reachable blocks
  - Compactification of the heap

Mark and Sweep Collector

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- Mark every block on the heap as *not reachable*
- Construct the *RootSet*: all blocks on the heap that are directly referenced from the stacl
- For every block *b* in the RootSet that is marked as unreachable:
  - Mark *b* as *reachable*
  - Check, recursively, every block *b'* that is still unreachable, and is referenced from block *b*
- De-allocate every block on the heap that is still marked as *unreachable*
- Cost: *O*(number of blocks on the heap)

Bakers Mark and Sweep Collector

- Every block belongs always to exactly one of the following lists
  - *free*: list of free blocks
  - *unreached*: **list of occupied blocks** (additional mark within the blocks)
  - *unscanned*: temporry list of unscanned blocks
  - *scanned*: temporary list of scanned blocks
- Cost: O(number of reachable blocks)

Bakers Mark and Sweep Collector

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```
scanned := Ø
unscanned := blocks in RootSet
WHILE unscanned # Ø DO
    WITH b ∈ unscanned DO
        unscanned := unscanned \ b
        scanned := scanned ∪ {b}
        FOR EACH b‘ referenced from b DO
            IF b‘ ∈ unreached THEN
                unreached := unreached \ b‘
                unscanned := unscanned ∪ {b‘}
            END IF
        END FOR
    END WITH
END WHILE
free := free ∪ unreached
unreached := scanned
```

Conservative Storage Administration

- A storage block is *reachable* if the stack or a reachable heap blocks contain numbers that *might be* heap addresses
- Works without information about the structure of data on stack and heap
- Compactification is not possible
- May miss to de-allocate some blocks

Non-Cons. Storage Administration

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- Structure information is used to identify references on the stack and within heap blocks
- Only these are checked for reachability
- Language must be *type-safe*
  - References always point to compatible objects

Cheney's Mark and Sweep Collector

- Blocks are copied from one heap to a second one, and back
- Drawback: Halves the storage capacity
- Cost *O*(size of reachable blocks
  + number of heap)

```
FOR EACH b ϵ Heap DO
	b.newAddr := NULL
END FOR
```

```
free := start address of target heap
FOR EACH b ϵ RootSetDO
	b := lookupNewAddr(b)
END FOR
b := start address of target heap
WHILE b < free DO
	FOR EACH Reference b.r aus b DO
		b.r := lookupNewAddr(b.r)
	END FOR
	b := b + b.size
END WHILE
```

```
METHOD lookupNewAddr(b) IS
	IF b.newAddr = NULL THEN
		b.newAddr := free
		free := free + b.size
		Copyb to b.newAddr
	END IF
	RETURN b.newAddr
END METHOD
```

Mark and Compact Collector

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- Determine reachable blocks (as with *Mark and Sweep*)
- Allocate new addresses
- Correct references
- Copy blocks
- Cost: *O*(size of reachable blocks + number of heap blocks)

```
FOR EACH b ϵ RootSetDO
    b := b.newAddr;
END FOR
```

```
FOR EACH b ϵ Heap (ascending) DO
    IF b.reached THEN
        FOR EACH reference b.r aus b
        DO b.r := b.r.newAddr
        END FOR
    END IF
END FOR
```

```
free := start address of heap
FOR EACH b ϵ Heap (ascending) DO
    IF b.reached THEN
        b.newAddr := free
        free := free + b.size
    END IF
END FOR
```

```
FOR EACH b ϵ Heap (ascending) DO
    IF b.reached THEN
        Copyb to b.newAddr
    END IF
END FOR
```