Memory Management

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Programming Concepts using Java

Week 1

Keeping track of variables

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    - Typically these are local to a function
    - Can also refer to global variables outside the function
    - Dynamically created data, like nodes in a list

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  - In the following code, the `x` in `f()` is not in scope within call to `g()`

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def f(l):
  ...
  for x in l:
    y = y + g(x)
  ...
```

```
def g(m):
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  for x in range(m):
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  for x in l:                  for x in range(m):
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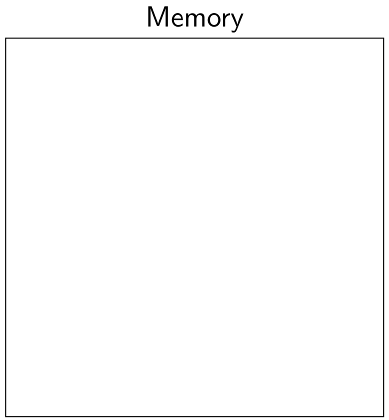
```

- Lifetime of a variable
  - How long the storage remains allocated
  - Above, lifetime of `x` in `f()` is till `f()` exits
  - “Hole in scope” — variable is alive but not in scope

Memory stack

- Each function needs storage for local variables



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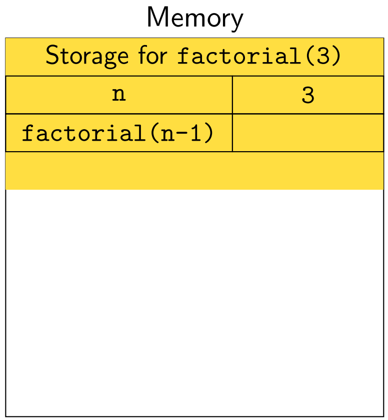

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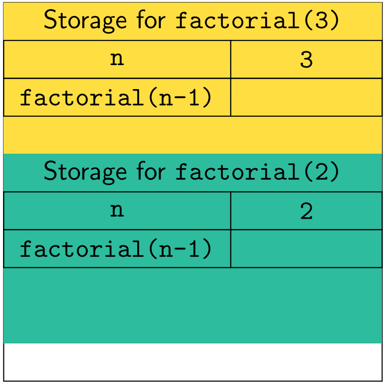

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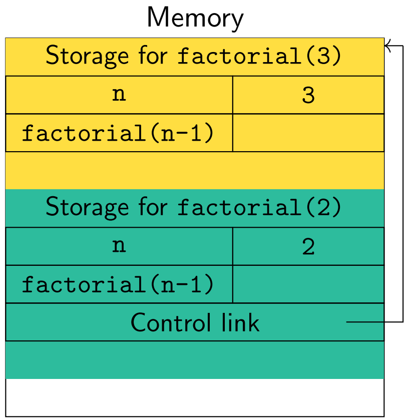

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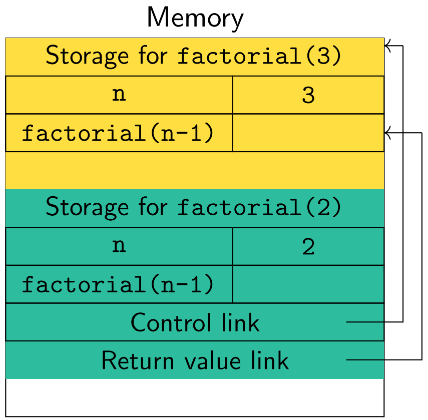

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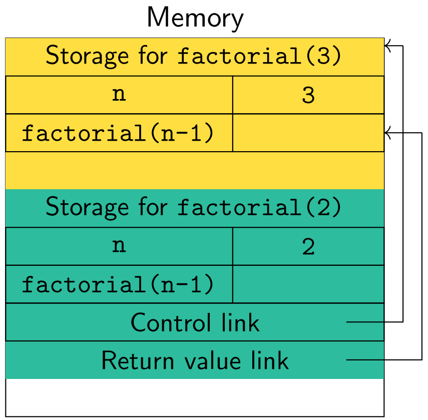

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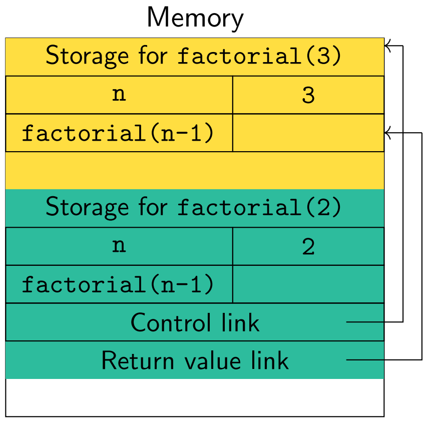
- Lifetime of a variable
  - Storage allocated is still on the stack



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Passing arguments to functions

- When a function is called, arguments are substituted for formal parameters

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def f(a,l):         x = 7
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  - Like having implicit assignment statements at the start of the function
- Two ways to initialize the parameters
  - Call by value — copy the value
    - Updating the value inside the function has no side-effect
  - Call by reference — parameter points to same location as argument
    - Can have side-effects
    - Be careful: can update the contents, but cannot change the reference itself

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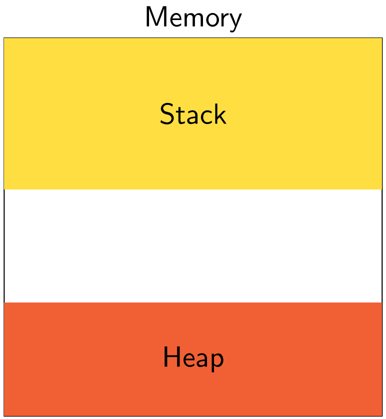

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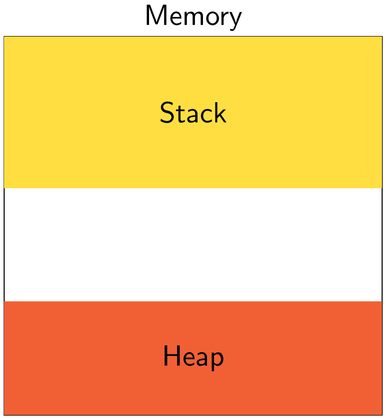
  - Conceptually, allocate heap storage from "opposite" end with respect to stack
- Heap storage outlives activation record
  - Access through some variable that is in scope



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- Manual memory management
  - Programmer explicitly requests and returns heap storage
    - `p = malloc(...)` and `free(p)` in C
  - Error-prone — memory leaks, invalid assignments
- Automatic garbage collection (Java, Python, . . .)
  - Run-time environment checks and cleans up dead storage — e.g., mark-and-sweep
    - Mark all storage that is reachable from program variables
    - Return all unmarked memory cells to free space
  - Convenience for programmer vs performance penalty

Summary

- Variables have scope and lifetime
    - Scope — whether the variable is available in the program
    - Lifetime — whether the storage is still allocated
- Activation records for functions are maintained as a stack
    - Control link points to previous activation record
    - Return value link tells where to store result
- Heap is used to store dynamically allocated data
    - Outlives activation record of function that created the storage
    - Need to be careful about deallocating heap storage
    - Explicit deallocation vs automatic garbage collection