Declarative Computation Model

Memory management (VRH 2.5)

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October 18, 2007

Adapted with permission from:
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Memory Management

- Semantic stack and store sizes during computation
  - analysis using operational semantics
  - recursion used for looping
    - efficient because of last call optimization
  - memory life cycle
  - garbage collection

Last call optimization

- Consider the following procedure

```
proc {Loop10 I}
   if I ==10 then skip
   else
      {Browse I}
      {Loop10 I+1}
   end
end
```

Recursive call is the last call

- This procedure does not increase the size of the STACK
- It behaves like a looping construct

Last call optimization

```
proc {Loop10 I}
   if I ==10 then skip
   else
      {Browse I}
      {Loop10 I+1}
   end
end
```

ST: **[** ({Loop10 0}, E_0) **]**

ST: **[**({Browse I}, {I→i_0,...})
({Loop10 I+1}, {I→i_0,...}) **]**
σ : {i_0=0, ...}

ST: **[**({Loop10 I+1}, {I→i_0,...}) **]**
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ST: **[**({Browse I}, {I→i_1,...})
({Loop10 I+1}, {I→i_1,...}) **]**
σ : {i_0=0, i_1=1,...}

Stack and Store Size

```
proc {Loop10 I}
   if I ==10 then skip
   else
      {Browse I}
      {Loop10 I+1}
   end
end
```

ST: **[**({Browse I}, {I→i_k,...})
({Loop10 I+1}, {I→i_k,...}) **]**
σ : {i_0=0, i_1=1,..., i_{k-i}=k-1, i_k=k,... }

The semantic stack size is bounded by a constant.
But the store size keeps increasing with the computation.

Notice that at $(k+1)^{th}$ recursive call, we only need i_k
If we can keep the store size constant, we can run indefinitely with a constant memory size.

Garbage collection

```
proc {Loop10 I}
   if I ==10 then skip
   else
      {Browse I}
      {Loop10 I+1}
   end
end
```

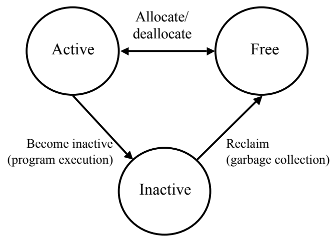
ST: **[**({Browse I}, {I→i_k,...})
({Loop10 I+1}, {I→i_k,...}) **]**
σ : {i_0=0, i_1=1,..., i_{k-i}=k-1, i_k=k,... }

Garbage collection is an algorithm (a task) that removes from memory (store) all cells that are not accessible from the stack

ST: **[**({Browse I}, {I→i_k,...})
({Loop10 I+1}, {I→i_k,...}) **]**
σ : { i_k=k, ... }

The memory life cycle

- Active memory is what the program needs to continue execution (semantic stack + reachable part of store)
- Memory that is no longer needed is of two kinds:
  - Can be immediately deallocated (i.e., semantic stack)
  - Simply becomes inactive (i.e., store)
- Reclaiming inactive memory is the hardest part of memory management
  - Garbage collection is automatic reclaiming



Garbage Collection

- Lower-level languages (C, C++) do not have automatic garbage collection.
- Manual memory management can be more efficient but it is also more error-prone, e.g.:
  - Dangling references
    - Reclaiming reachable memory blocks
  - Memory leaks
    - Not reclaiming unreachable memory blocks
- Higher-level languages (Erlang, Java, Lisp, Smalltalk) typically have automatic garbage collection.
- Modern algorithms are efficient enough---minimal memory and time penalties.

Garbage Collection Algorithms

- Reference Counting algorithms
  - Keep track of number of references to memory blocks
  - When count is 0, memory block is reclaimed.
  - Cannot collect cycles of garbage.
- Mark-and-Sweep algorithms
  - Phase 1: Determine active memory
    - Following *pointers* (in Oz, referenced store variables) from a *root set* (in Oz, the semantic stack).
  - Phase 2: Compact memory in one contiguous region.
    - Everything outside this region is free.
  - Generally must briefly pause the application memory mutation while collecting.

Avoiding memory leaks

- Consider the following function

```
fun {Sum X L1 L}
     case L1 of Y|L2 then {Sum X+Y L2 L}
     else X end
end

L= [1 2 3 … 1000000]
{Sum 0 L L}
```

- Since it keeps a pointer to the original list L, L will stay in memory during the whole execution of Sum.

Avoiding memory leaks

- Consider the following function

```
fun {Sum X L1}
     case L1 of Y|L2 then {Sum X+Y L2}
     else X end
end

L= [1 2 3 … 1000000]
{Sum 0 L}
```

- Here, the reference to L is lost immediately and its space can be collected as the function executes.

Managing external references

- External resources are data structures outside the current O.S. process.
- There can be pointers from internal data structures to external resources, e.g.
  - An open file in a file system
  - A graphic entity in a graphics display
  - If the internal data structure is reclaimed, then the external resource needs to be cleaned up (e.g., remove graphical entity, close file)
- There can be pointers from external resources to internal data structures, e.g.
  - A database server
  - A web service
  - If the internal data structure is reachable from the outside, it should not be reclaimed.

Local Mozart Garbage Collector

- Copying dual-space algorithm
- Advantage : Execution time is proportional to the active memory size, not total memory size.
- Disadvantage : Half of the total memory is unusable at any given time

Exercises

59. What do you expect to happen if you try to execute the following statement? Try to answer without actually executing it!

```
local T = tree(key:A left:B right:C value:D) in
   A = 1
   B = 2
   C = 3
   D = 4
end
```

60. VRH Exercise 2.9.9 (page 109).
61. *Any realistic computer system has a memory cache for fast access to frequently used data. Can you think of any issues with garbage collection in a system that has a memory cache?