Declarative Computation Model

Memory management (CTM 2.5)

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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

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

• This procedure does **not** increase the size of the STACK
• It behaves like a looping construct
Last call optimization

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

\[
\text{ST: } [ (\{\text{Browse I} \}, \{I \rightarrow i_0, \ldots \}) \\
\quad (\{\text{Loop10 I+1} \}, \{I \rightarrow i_0, \ldots \}) ]
\]

\[
\sigma : \{i_0=0, \ldots \}
\]

\[
\text{ST: } [ (\{\text{Loop10 I+1} \}, \{I \rightarrow i_0, \ldots \}) ]
\]

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\text{ST: } [ (\{\text{Browse I} \}, \{I \rightarrow i_1, \ldots \}) \\
\quad (\{\text{Loop10 I+1} \}, \{I \rightarrow i_1, \ldots \}) ]
\]

\[
\sigma : \{i_0=0, i_1=1, \ldots \}
\]
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,...\})]

\(\sigma: \{i_0=0, i_1=1,..., i_{k-1}=k-1, i_k=k,...\}\)

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

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

\[
ST: [(\{Browse I\}, \{I \rightarrow i_k, \ldots\}) , \{\}]
\]

\[
\sigma : \{i_0=0, i_1=1, \ldots, i_{k-1}=k-1, i_k=k, \ldots\}
\]
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

local L in
    L= [1 2 3 … 1000000]
    {Sum 0 L L}
end

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

\[
\text{fun } \{\text{Sum } X \text{ L1}\}
\quad \begin{align*}
\text{case } \text{L1 of } Y|L2 \text{ then } & \{\text{Sum } X+Y \text{ L2}\} \\
\text{else } X \text{ end}
\end{align*}
\quad \text{end}
\]

\[
\text{local } L \text{ in} \\
\text{L} = [1 \ 2 \ 3 \ \ldots \ 1000000] \\
\{\text{Sum } 0 \text{ L}\}
\quad \text{end}
\]

• 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
55. 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

56. CTM Exercise 2.9.9 (page 109).

57. 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?