Short-term Memory for Self-collecting Mutators

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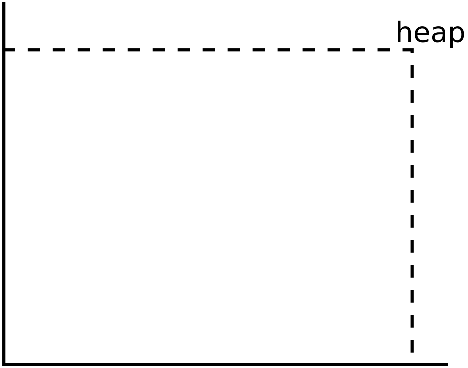
Heap Management



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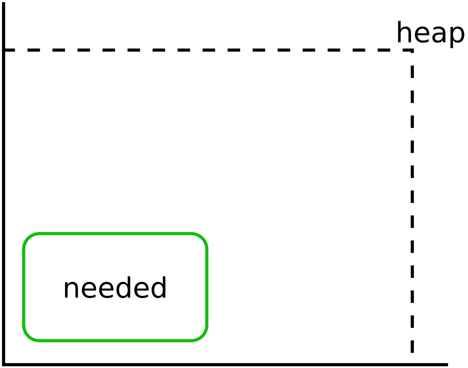

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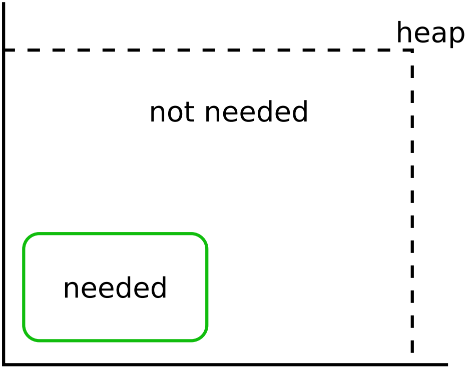

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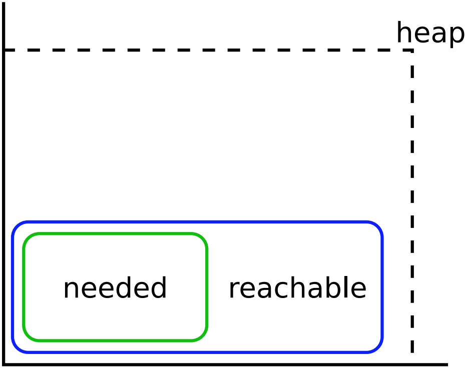

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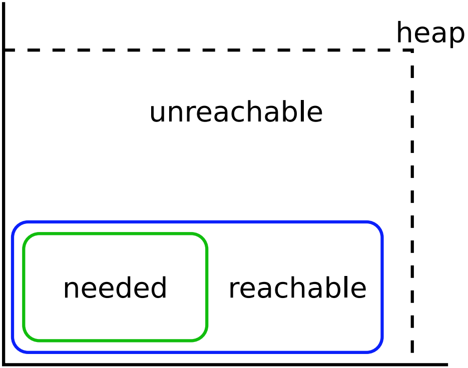

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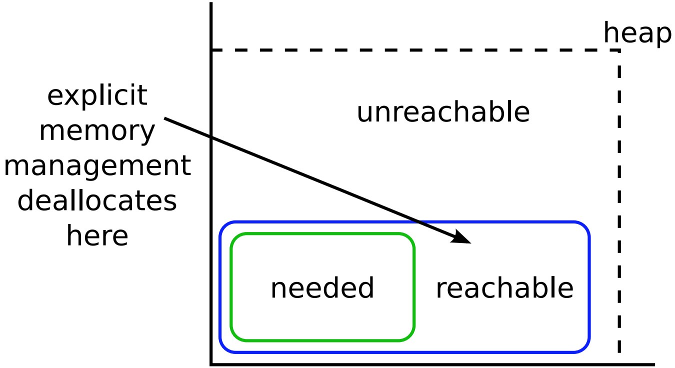

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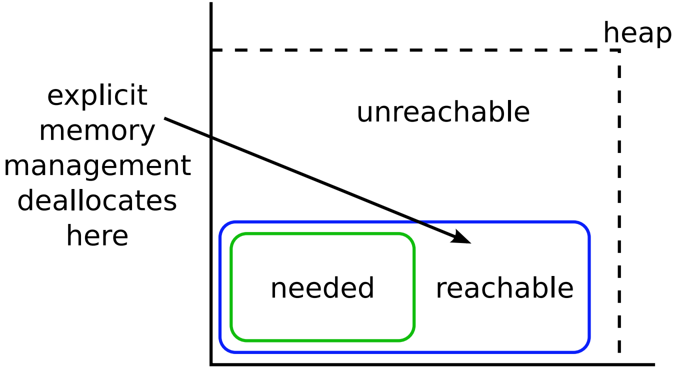
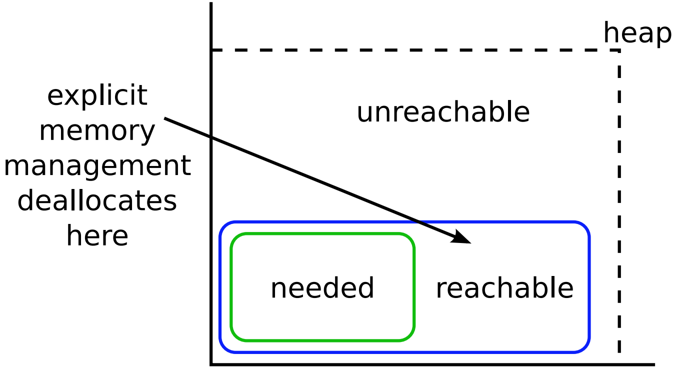


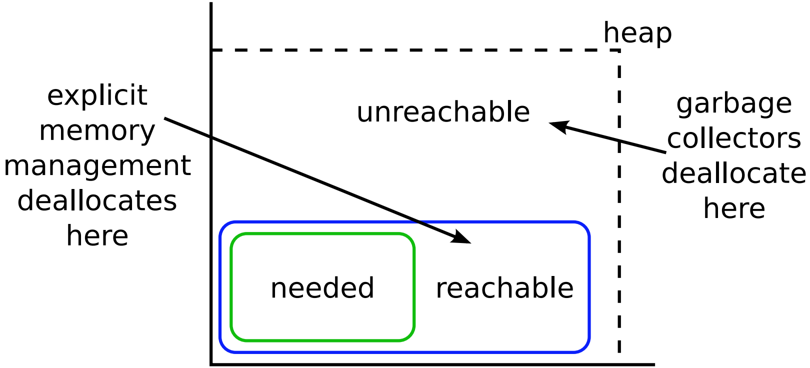
- memory leaks

Heap Management



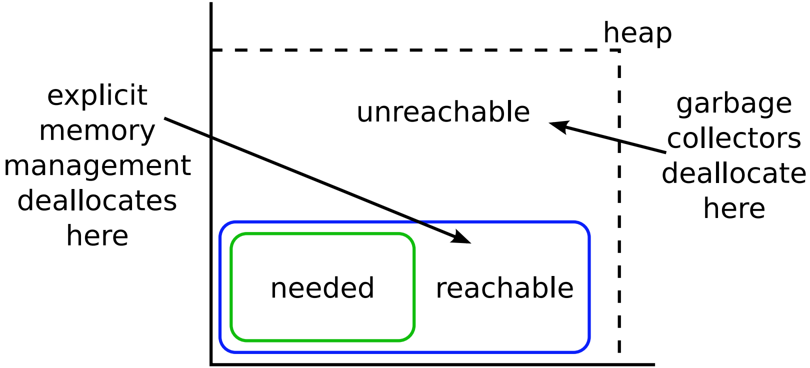
- memory leaks
- dangling pointers

Heap Management



- memory leaks
- dangling pointers

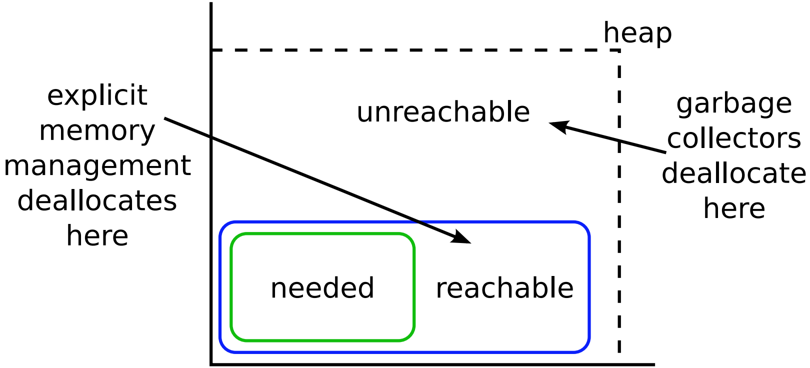
Heap Management



- memory leaks
- dangling pointers

- tracing

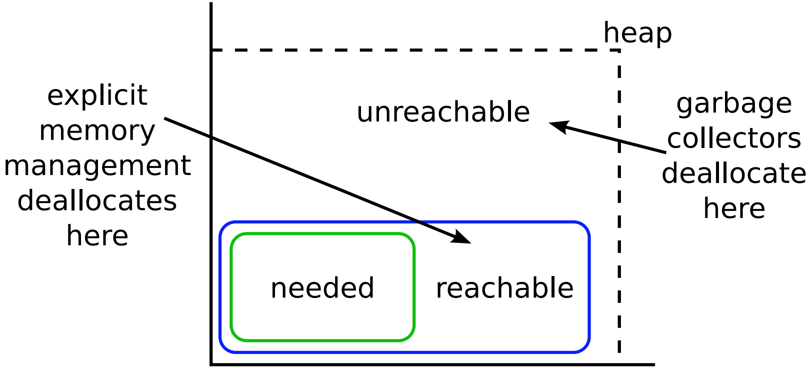
Heap Management



- memory leaks
- dangling pointers

- tracing
- reference counting

Heap Management



- memory leaks
- dangling pointers

- tracing
- reference counting
- reachable memory leaks

Persistent Memory Model

- Allocated memory objects are guaranteed to exist until deallocation
- Explicit deallocation is not safe (dangling pointers) and can be space-unbounded (memory leaks)
- Implicit deallocation (unreachable objects) is safe but may be slow or space-consuming (proportional to the size of live memory) and can still be space-unbounded (memory leaks)

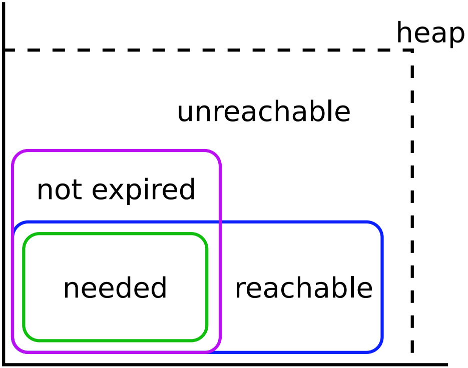
Short-term Memory

- Memory objects are only guaranteed to exist for a finite amount of time
- Memory objects are allocated with a given expiration date
- Memory objects are neither explicitly nor implicitly deallocated but may be refreshed to extend their expiration date

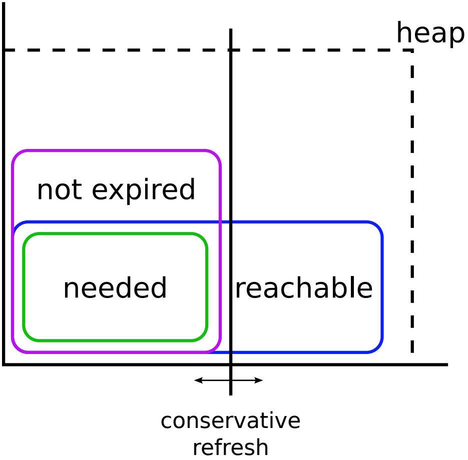
Short-term Memory

With short-term memory programmers or algorithms
specify which memory objects are still needed
and not
which memory objects are
not needed anymore!

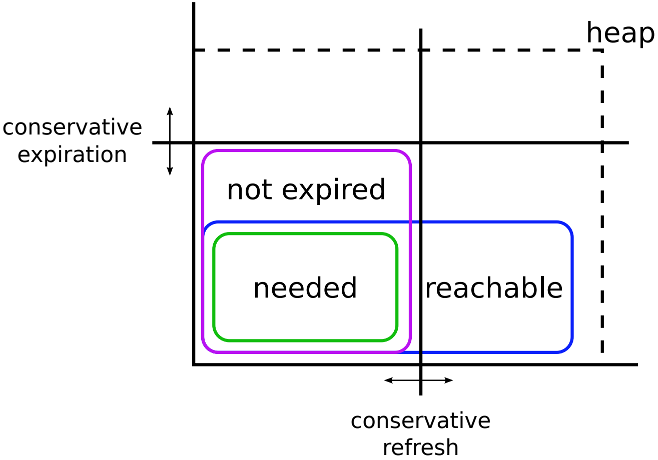
Short-term Memory



Short-term Memory



Short-term Memory



Short-term Memory - Sources of Errors

- Memory leaks
  - When not-needed objects are continuously refreshed
  - When time does not advance
- Dangling Pointers
  - When needed objects are not refreshed

Self-collecting Mutators

Programming Model

- Explicit memory management
  - The programmer (or an algorithm) adds memory management calls to the program code
- Hybrid approach for backward compatibility
  - Per default objects are allocated as persistent and managed by the existing memory management (malloc/free, garbage collection)
  - A refresh-call makes an object short-term, e.g. the objects gets an expiration date

Programming Model - Expiration Date

- An object gets an expiration date when it gets refreshed and is then managed by our system
- A programmer refreshes objects explicitly
  - Every refresh-call creates a new expiration date for an object
    - The object expires when all its expiration dates are expired

Programming Model - Time

- A software clock is used for object expiration
  - An integer counter which is increased by tick-calls
  - An expiration date has expired when its value is less than the time of the software clock
- Every thread has its own thread-local clock
  - Expiration dates expire according to the clock of the thread which created the expiration date

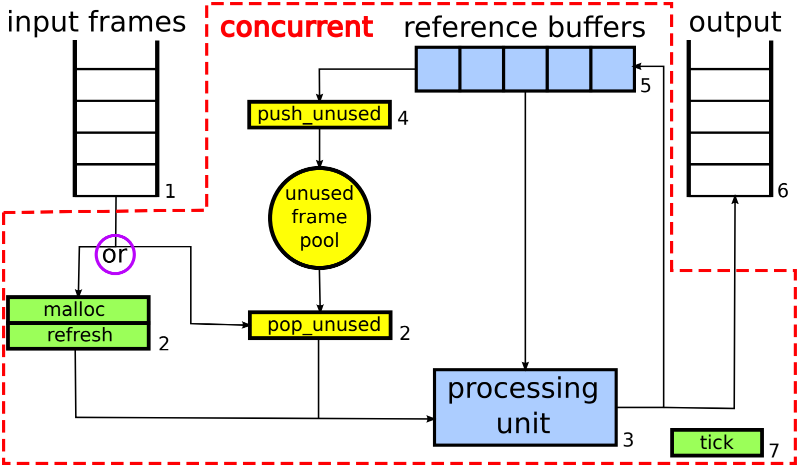
Example - Monte Carlo

```
monteCarlo(int repetitions)
{
    Vector results = new Vector(repetitions);
    for(int i = 0; i < repetitions; i++)
    {
        RandomWalk walk = createRandomWalk();

        results.add(doCalculation(walk);

    }

    evaluateResults(results);
}
```

Example - Monte Carlo

```
monteCarlo(int repetitions)
{
    Vector results = new Vector(repetitions);
    for(int i = 0; i < repetitions; i++)
    {
        RandomWalk walk = createRandomWalk();
        SCM.refresh(walk, 0);
        results.add(doCalculation(walk));
        SCM.tick();
    }

    evaluateResults(results);
}
```

Example - x264 Video Encoder



Other Use Cases

benchmark	LoC	tick	refresh	free	aux	total
mpg123	16043	1	0	(-)43	0	44
JLayer	8247	1	6	0	2	9
Monte Carlo	1450	1	3	0	2	6
LuIndex	74584	2	15	0	3	20

Table: Use cases of short-term memory: lines of code of the benchmark, number of tick-calls, number of refresh-calls, number of free-calls, number of auxiliary lines of code, and total number of modified lines of code.

Implementation

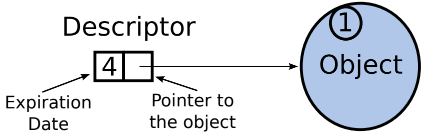
Implementation

- Our implementation is called self-collecting mutators (SCM)
  - The threads (mutators) of a program collect their expired objects by themselves
  - At memory management calls a constant number of expired objects are collected
- We have implementations in C, Java and Go
- The C implementation is based on ptmalloc2
- The Java implementation is based on the Jikes RVM
- For the Go implementation we extended the 6g Go runtime

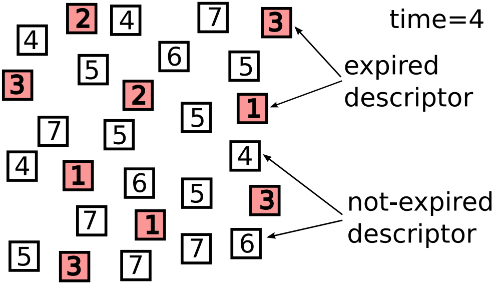
Available at: tiptoe.cs.uni-salzburg.at/short-term-memory

Implementation - Descriptors

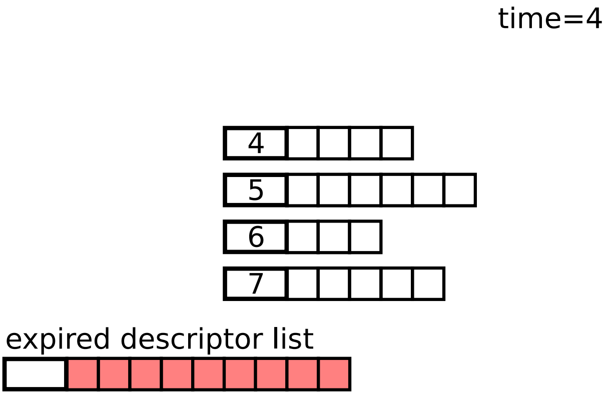
- An Object can have multiple expiration dates
  - An expiration date is represented by a descriptor, which stores the expiration date and a pointer to the object
- For each expiration date of an object there exists one descriptor
  - Every object contains a descriptor counter (1 word) in its header which counts the number of descriptors pointing to it



Implementation - Descriptors Buffer

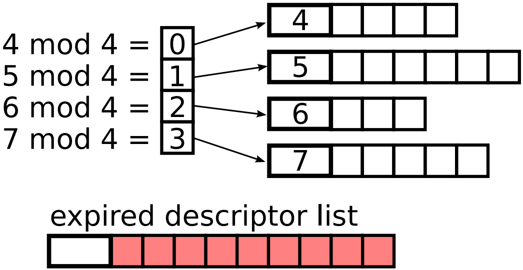


Implementation - Descriptor Buffer

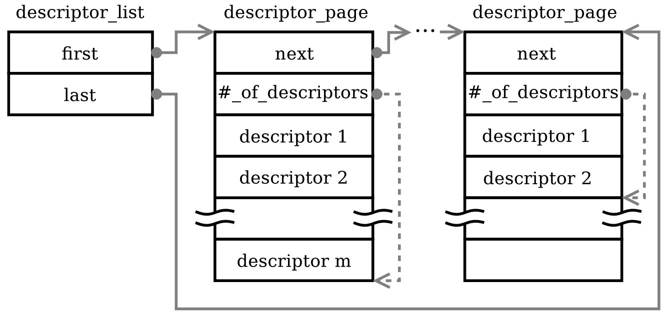


Implementation - Descriptor Buffer

time = 4
maximal expiration extension = 3



Implementation - Descriptor Buffer



Implementation - malloc/new

Definition

malloc(size)
new Object()

- The malloc/new call of SCM increases the requested amount of memory by one word and uses the underlying memory management then to allocate the memory
  - In C it is ptmalloc2
  - In Java and Go it is a mark-sweep garbage collector
- The additional header word of an object is used for the descriptor counter
- The descriptor counter is initialized with zero

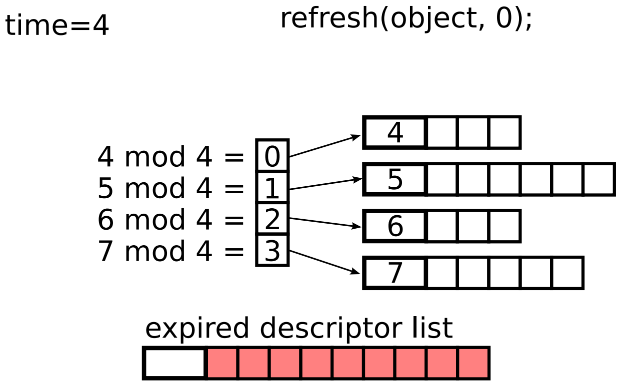
Implementation - refresh

Definition

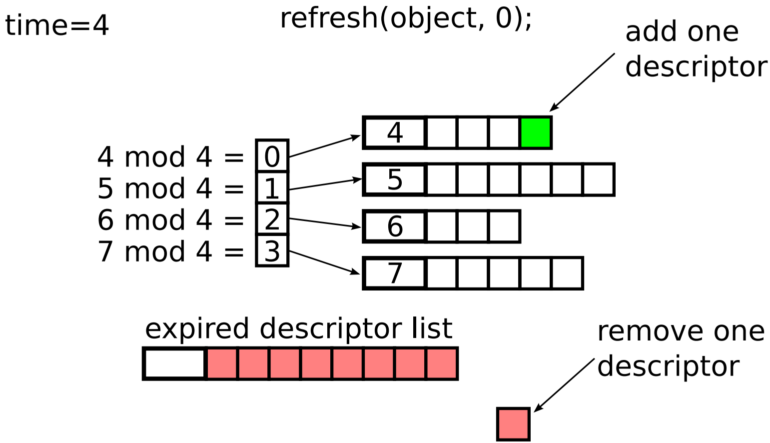
refresh(object, extension)

- The refresh-call creates a new descriptor for the considered object
- The refresh-call consists of four operations:
  1. Increase the descriptor counter of the specified object
  2. Create a new descriptor and store it in the descriptor buffer which corresponds to the given expiration extension.
  3. (Self-collection) Remove one descriptor from the expired_descriptors_list
  4. Decrease the descriptor counter of the object which corresponds to that descriptor
     - If the descriptor counter gets zero, the object is deallocated

Before refresh



After refresh



Implementation - tick

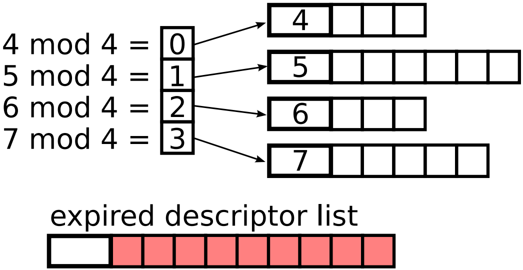
Definition

tick()

- The tick-call increases the thread-local time
- The descriptor list which expires by that time advance is appended to the expired descriptor list

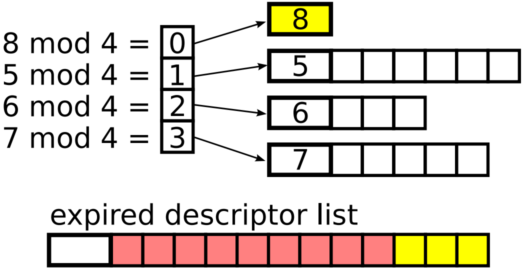
Before tick

time=4



After tick

time=5



Implementation - free

Definition

free(object)

- In C it is still possible to use the free-call for explicit deallocation
- When the descriptor counter of the object is zero, the object is deallocated
- Otherwise nothing is done
    - The object will be deallocated when its last descriptor expires

Implementation - Garbage Collector

- All objects are considered to compute reachability
- Short-term objects are not deallocated
    - They will be deallocated when their last descriptor expires

Experiments

What we want to show

- In C
  - Short-term memory is easier to use while not loosing temporal performance and with low memory overhead
- In Java and Go
  - Short-term memory is more difficult to use but improves temporal performance (e.g. reduce the number of garbage collection runs)

Experiments - System Configuration

CPU	2x AMD Opteron DualCore, 2.0 GHz
RAM	4GB
OS	Linux 2.6.32-21-generic
Java VM	Jikes RVM 3.1.0
C compiler	gcc version 4.4.3
C allocator	ptmalloc2-20011215 (glibc-2.10.1)

Table: System configuration.

Monte Carlo - Total Runtime

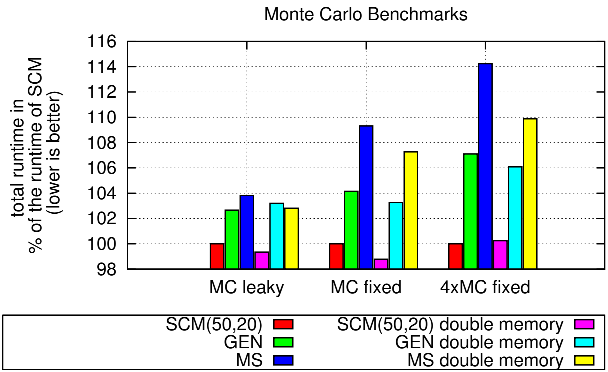


Figure: Total execution time of the Monte Carlo benchmarks in percentage of the total execution time of the benchmark using self-collecting mutators.

Monte Carlo - Latency and Free Memory

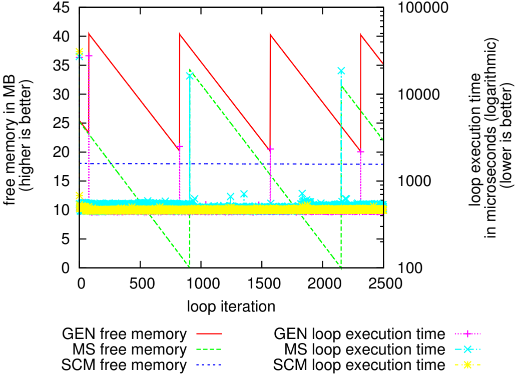


Figure: Free memory and loop execution time of the fixed Monte Carlo benchmark.

Monte Carlo - Tick Frequency - Latency

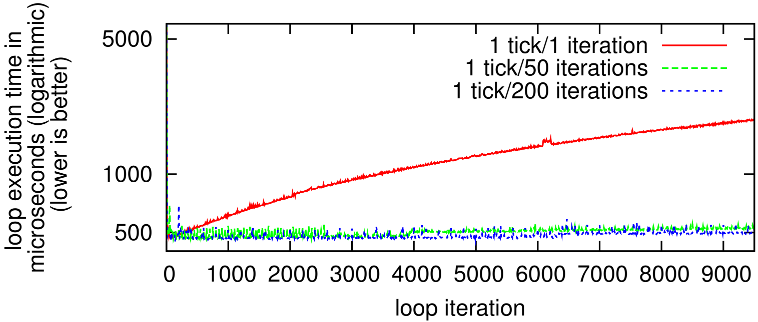


Figure: Loop execution time of the Monte Carlo benchmark with different tick frequencies. Self-collecting mutators is used.

Monte Carlo - Tick Frequency - Free Memory

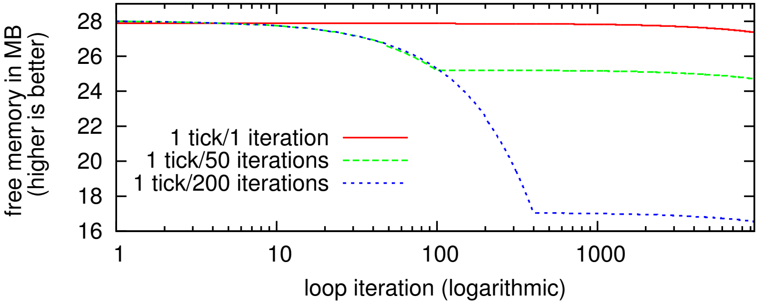


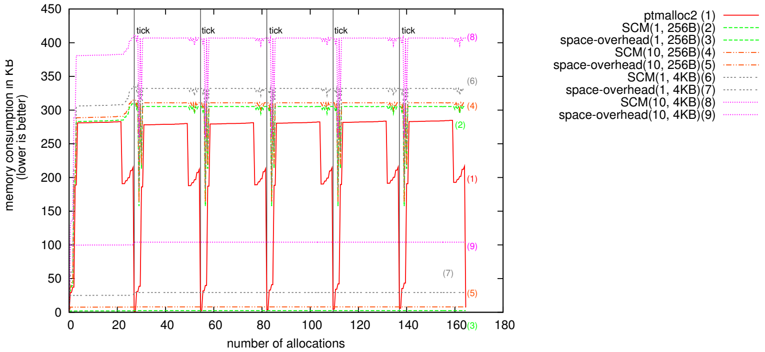
Figure: Free memory of the Monte Carlo benchmark with different tick frequencies. Self-collecting mutators is used.

mpg123 - Total Runtime

ptmalloc2	895.25ms	100.00%
ptmalloc2 through SCM	899.43ms	100.47%
SCM(1, 256B)	890.18ms	99.43%
SCM(10, 256B)	898.28ms	100.34%
SCM(1, 4KB)	892.18ms	99.66%
SCM(10, 4KB)	892.28ms	99.67%

Table: Total execution times of the mpg123 benchmark averaged over 100 repetitions. Here, SCM(n, m) stands for self-collecting mutators with a maximal expiration extension of n and descriptor page size m.

mpg123 - Memory Consumption



Memory overhead and consumption of the mpg123 benchmark. Again, SCM(n, m) stands for self-collecting mutators with a maximal expiration extension of n and descriptor page size m. We write space-overhead(n, m) to denote the memory overhead of the SCM(n, m) configurations for storing descriptors and descriptor counters.

Thank You

check out:

eurosys2011.cs.uni-salzburg.at