Tick: Concurrent GC in Apache Harmony

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Acknowledgement:
Yunan He, Simon Zhou
Agenda

• Concurrent GC phases and transition
• Concurrent marking scheduling
• Concurrent GC algorithms
• Tick code in Apache Harmony
Concurrent GC Options

- At the moment, Tick supports only mark-sweep algorithm
  - #define USE_UNIQUE_MARK_SWEEP_GC

- Command line options
  - -XXgc.concurrent_gc = TRUE
    - Use concurrent GC (and default concurrent algorithm)
  - You can also specify concurrent phases separately
    - -XXgc.concurrent Enumeration
    - -XXgc.concurrent_mark
    - -XXgc.concurrent_sweep

- Write barrier (generate_barrier) is set TRUE for any concurrent collection
Mutator Object Allocation

- gc_alloc uses mark-sweep gc_ms_alloc
  - Thread local allocation
  - As normal, except that
    - It checks if a concurrent collection should start
Collection Triggering

• Case 1: heap is full
  – Has to trigger STW collection

• Case 2: trigger collection at proper time so as to avoid STW
  – Check at allocation site
  – Actually also trigger collection phase transition at allocation site
  – Then schedule proper phase
Collection Phases

- Tick uses a state graph to guide the phase transitions
  - ②, Enum: suspend and enumerate rootset
  - ③, Mark: trace and mark the live objects
  - ④, Collect: recycle the dead objects
  - Note: All of the three phases can be executed in a STW manner
    - When the heap is full, the collection transitions to STW manner
Phase Transition

1: No collection
5: Wrap up collection
6: STW collection

1 → 2 Time to collect
2 → 3 Finish enumerating
3 → 4 Finish marking
4 → 5 Finish collecting
1, 2, 3, 4 → 6 STW if heap is full
5, 6, 1 → 1 Finish concurrent/STW collection, or keep no collection

- Global gc->gc_concurrent_status tracks the states
• Entry point: gc_sched_collection()
  – Invoked in every gc_alloc()
  – Calls gc_con_perform_collection() when command line option specifies concurrent GC
  – Every mutator invokes the scheduler
    • Use atomic operation so that only one mutator makes the state transition

• Protocol between mutator and collector
  – Mutator drives the state transition between phases
  – Collector reports its state back to mutator
Phase Interactions

Time

1. Mutator Collector
   - State transitioned by mutator
   - State transitioned by collector

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enum GC_CONCURRENT_STATUS {
    GC_CON_NIL = 0x00,
    GC_CON_STW_ENUM = 0x01,
    GC_CON_START_MARKERS = 0x02,
    GC_CON_TRACING = 0x03,
    GC_CON_TRACE_DONE = 0x04,
    GC_CON_BEFORE_SWEEP = 0x05,
    GC_CON_SweepING = 0x06,
    GC_CON_Sweep_DONE = 0x07,
    GC_CON_BEFORE_FINISH = 0x08,
    GC_CON_RESET = 0x09,
    GC_CON_DISABLE = 0x0A //STW collection
};
gc_con_perform_collection()

in src/common/concurrent_collection_scheduler.cpp

switch( gc->gc_concurrent_status ) {
    case GC_CON_NIL :
        if( !gc_con_start_condition(gc) )
            return FALSE;
        state_transformation( gc, NIL, ENUM );
        gc->num_collections++;
        gc_start_con Enumeration(gc); //now it is a stw enumeration
        state_transformation( gc, ENUM, START_MARKERS );
        gc_start_con_marking(gc);
        break;

    (continued in next slide)
gc_con_perform_collection()

• case GC_CON_BEFORE_SWEEP :
  • state_transformation( gc, BEFORE_SWEEP, SWEEPING );
  • gc_ms_start_con_sweep(gc);
  • break;

• case GC_CON_BEFORE_FINISH :
  • state_transformation( gc, BEFORE_FINISH, RESET );
  • gc_reset_after_con_collection(gc);
  • state_transformation( gc, RESET, NIL );
  • break;

• default :
  • return FALSE;
Agenda

- Concurrent GC phases and transition
- Concurrent marking scheduling
- Concurrent GC algorithms
- Tick code in Apache Harmony
• Tick uses write barrier to track heap modifications
  – Remember set (or called dirty set sometimes)
• Write barrier is instrumented by JIT, so it is enabled at Harmony startup
  – NULL method if no collection (state ①)
  – NULL method if STW collection (state ⑥)
  – In other states, a specified method for its respective algorithm
• Write barrier also catches object_clone and array_copy
Remember Set

- Mutator holds a local RemSet (or dirty_set)
  - Implemented as an array (Vector_Block)
  - Mutator grabs an empty set from global free pool
  - Mutator puts a full set to global rem set pool

- During marking, root set and rem set are processed together
  - At the same time, global rem set pool is growing
  - So, concurrent access to the pool by mutators and markers
1. Shared pool for task sharing
2. One reference is a task
3. Collector grabs task block from pool
4. Pop one task from task block, push into mark stack
5. Scan object in mark stack in DFS order
6. If stack is full, grow into another mark stack, put the full one into pool
7. If stack is empty, take another task from task block
Marking Termination

• In some algorithm, it requires all the data sets are consumed to terminate
  – Root set
  – Rem set (mutator local, global pool)
  – Task set (marker local stack, global pool)

• Since marking and remembering are concurrent, how to ensure mutators’ local rem sets are empty? Tick’s solution:
  1. Marker copies mutators’ local sets to global pool
     – gc_copy_local_dirty_set_to_global()
  2. Marker scans the global pool
  3. Check if any mutator local set is non-empty, goto 1; or terminate.
     – dirty_set_is_empty()
Trigger Collection

- Collection consumes system resource
  - Avoid collection if possible

- Trigger strategy
  - Can not be too late
    - Otherwise has to STW, no concurrent
  - Can not be too early
    - Otherwise waste system resource
  - Ideally, trigger at a time point T, so that
    - When marking finishes, heap becomes full
At time $T$, heap has free size $S$
  - Assuming mutators allocation rate is $\text{AllocRate}$, markers tracing rate is $\text{TraceRate}$, Then ideally,
    - $S = \text{AllocRate} \times \text{MarkingTime}$
    - $H = \text{TraceRate} \times \text{MarkingTime}$
    - $\Rightarrow S = H \times \frac{\text{AllocRate}}{\text{TraceRate}}$
    - I.e., when heap has free size $S$, collection is triggered
    - I.e., it takes time $S/\text{AllocRate}$ to conduct a full marking
  - If current free size is $S_{\text{now}}$, collection after time
    - $T_{\text{delay}} = (S_{\text{now}} - S)/\text{AllocRate}$
  - Tick does not check heap free size in every allocation
    - It checks after time $T_{\text{delay}}/2$. (I.e., binary approximation)
Agenda

- Concurrent GC phases and transition
- Concurrent marking scheduling
- Concurrent GC algorithms
- Tick code in Apache Harmony
Tick Concurrent Algorithms

• Known concurrent mark-sweep GCs
  – Mostly concurrent (Boehm, Demers, Shenker PLDI 91)
  – Snapshot-at-the-beginning
    • DLG on-the-fly (Doligez, Leroy, Gonthier, POPL93, POPL94)
    • Sliding-view on-the-fly (Azatchi, et al. OOPSLA03)

• Harmony Tick implemented three algorithms, similar to those listed above
  – XXgc.concurrent_algorithm
    • MOSTLY_CON: similar to mostly concurrent
    • OTF_SLOT: similar to DLG on-the-fly
    • OTF_OBJ: similar to sliding-view on-the-fly
Tick 1: MOSTLY_CON

- Steps
  1. Rootset enumeration (optionally STW). WB turn on.
  2. WB rem updated objects; Con marking from roots.
  3. WB keep remembering; Con rescan from rem set; Repeat 3.
  4. WB turn off. STW re-enumeration and marking
  5. Concurrent sweeping

- Write barrier
  ```
  { *slot = new_ref;
    if( obj is marked && obj is clean){
      dirty obj;
      remember(obj);
    }
  }
  ```

- New object handling: nothing
Tick 2: OTF SLOT

Steps
1. Root set enumeration (optionally STW). WB turn on.
2. WB rem overwritten ref; Con marking from root set and rem set
3. WB turn off. Con sweeping

Write barrier

\[
\text{old ref} = *\text{slot};
\]

\[
\text{if}(*\text{old ref} \text{ is unmarked})\{
\]

\[
\text{remember}(*\text{old ref});
\]

\[
*\text{slot} = \text{new ref};
\]

New object handling: created marked (black)
Tick 3: OTF_OBJ

• **Steps**
  1. Root set enumeration (optionally STW). WB turn on.
  2. WB rem overwritten ref; Con marking from root set and rem set
  3. WB turn off. Con sweeping

• **Write barrier**

```c
{ if( obj is unmarked && obj is clean){
    remember(obj snapshot);
    dirty obj;
  }
  *slot = new_ref;
}
```

• **New object handling**: created marked (black)
MOSTLY_CON vs. SATB

Mostly-concurrent

Snapshot-at-the-beginning
# MOSTLY_CON vs. SATB

<table>
<thead>
<tr>
<th></th>
<th>SATB</th>
<th>Mostly-concurrent</th>
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</table>
| **Marking termination** | Terminate once no gray objs  
Pro: deterministic  
Con: snapshot may keep more floating garbage | Need STW final tracing  
Con: STW pause |
| **New objects handing** | Born marked  
Con: floating garbage (new-borns potentially die soon) | No special handling  
Con: rescans (new-borns normally active) |
| **Write barrier** | Care old values in snapshot  
Pro: sliding-view remembers small # objects | Care new values in execution  
Con: remembered # depends on marker thread priority |
OTF SLOT vs. OTF OBJ

Root Set

Rem Set

Rem Set

Rem Set

Rem Set

Rem Set

Rem Set
OTF SLOT vs. OTF OBJ

• OTF SLOT
  – Pro: remember only the updated slots
  – Con: check the old slot value if it is marked before remembering, causing cache misses

• OTF OBJ
  – Con: log the entire updated object
  – Pro: need log only once per object
Differences Between Tick GCs

• Implementation level
  – They share the same infrastructure
    • Collection scheduler
    • Rem set data structure
    • Mark-sweep algorithm

  – Differences are not big
    • Write barrier (already shown)
    • Termination condition (shown next)
MOSTLY_CON Marking Termination

- MOSTLY_CON marking process does not converge
  - Dirty objects are consumed and produced concurrently
  - Should terminate voluntarily or when heap is full
  - No strict termination condition. Try to mark most live objects

- Conditions for termination
  1. Root sets and mark stacks are empty
  2. A termination request from a mutator whose allocation fails
     - Markers then quit, and the requesting mutator triggers STW GC
     - STW re-enumeration and marking
     - Only scan unmarked objects, shorter pause time
  3. Marker also terminates voluntarily when not many tasks remain
SATB Marking Termination

• SATB marking process converges
  – Live object quantity is fixed at snapshot

• Conditions for termination
  1. Global rootset pool and mark stacks are empty
     • Implemented as “all markers finish marking”
  2. Mutator local remsets are empty
  3. Global remset pool are empty
     • Check 3 must precede 4, because mutator might put local remset to global pool

• Conditions must be satisfied
  – In order not to lose any live objects, i.e., to find the snapshot
Agenda

- Concurrent GC phases and transition
- Concurrent marking scheduling
- Concurrent GC algorithms
- Tick code in Apache Harmony
Tick Entry Point

- gc_alloc → gc_ms_alloc → wspace_alloc
  - wspace: space managed by mark-sweep
  - gc_gen\src\mark_sweep\wspace_alloc.cpp

- wspace_alloc → gc_sched_collection → gc_con_perform_collection
  - gc_gen\src\common\collection_scheduler.cpp

- gc_con_perform_collection → gc_con_start_condition
  - Check if a collection should trigger
  - Perform all the collection phases transition
    - gc_start_con Enumeration
    - gc_start_con Marking
    - gc_ms_start_con_sweep
Collectors Scheduling

- gc_start_con_marking → gc_ms_start_con_mark or gc_ms_start_mostly_con_mark
  - From general control to specific algorithms
  - gc_gen\src\common\gc_concurrent.cpp

- gc_ms_start_con_mark → conclctor_execute_task_con
  - notify_conclctor_to_work() triggers the idle concurrent collectors
  - gc_gen\src\mark_sweep\gc_ms.cpp

- conclctor_thread_func → conclctor_wait_for_task → task_func
  - Concurrent collectors are waken up and work on assigned task
  - gc_gen\src\thread\conclctor.cpp
  - Conclctors were initialized by conclctor_initialize in gc_init()
Summary

• Harmony Tick has implemented three concurrent GC algorithms
  – MOSTLY_CON, OTF_SLOT, OTF_OBJ
  – Tick has a common design infrastructure for phase control and collection scheduling
  – Experimental measurement showed very short pause time

• Next step to optimize and polish the code
  – More documents on the design and code to lower the entry barrier