SUMATRA NEW FEATURES
COORDINATING BETWEEN THE GPU AND THE JVM

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AGENDA

- Brief Review of HSA and Sumatra Project Organization

- Look at some features added to Sumatra over the last year that involve cooperation with the JVM
  - Deoptimization
  - Allocation
  - Safepoints

- Along the way, point out challenges presented by HSA targets

- This code is available in the Sumatra JDK and Graal repository
  - http://hg.openjdk.java.net/sumatra/sumatra-dev/jdk/
  - http://hg.openjdk.java.net/graal/graal/

HSA ARCHITECTURE, QUICK OVERVIEW

- Heterogeneous System Architecture standardizes CPU/GPU functionality
- Unified address space for GPU and CPU
  - A pointer is a pointer
- GPU can access pageable system memory using CPU pointers
- Fully cache coherent memory between CPU and GPU
- HSAIL is a virtual ISA for parallel programs
  - Finalized to native GPU ISA at runtime
- Explicitly parallel model
- HSA Foundation Home page: http://hsafoundation.com/

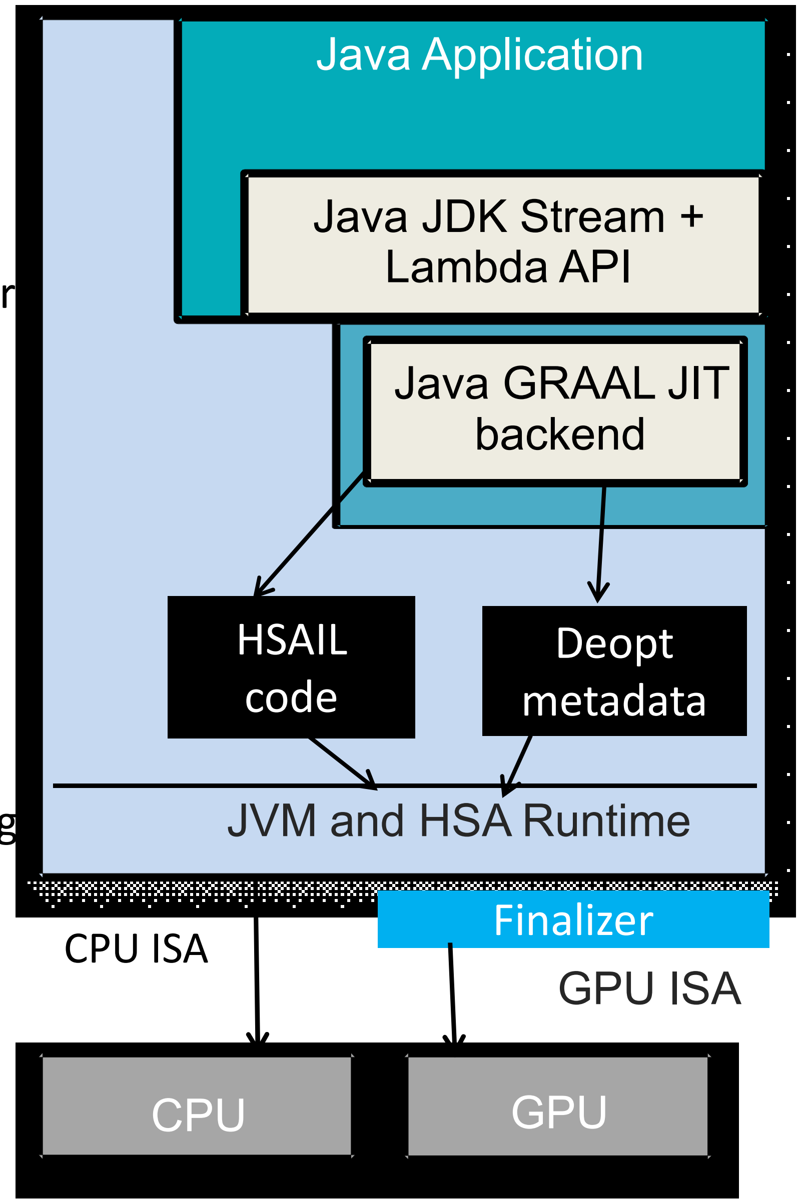
HSA ARCHITECTURE, QUICK OVERVIEW

- Kernel code is dispatched across range of workitems
  - Think of it as hundreds of threads, each running the same function per invocation
  - HSAIL instruction to get workitemabsid, e.g. can be used as array index
  - Example: out[n] = in[n] * in[n];

```
kernel &run(kernarg_u64 %_out,  kernarg_u64 %_in) {
   ld_kernarg_u64 $d0, [%_out];
   ld_kernarg_u64 $d1, [%_in];
   workitemabsid_u32 $s2, 0;  // id for this workitem
   cvt_s64_s32 $d2, $s2;
   mad_u64 $d3, $d2, 4, $d1;
   ld_global_f32 $s3, [$d3];
   mul_f32 $s5, $s3, $s3;
   mad_u64 $d4, $d2, 4, $d0;
   st_global_f32 $s5, [$d4];
   ret;
}
```

SUMATRA PROJECT OVERVIEW

- Using slightly modified JDK (sumatra-dev), collect the lambda target method at `ForEachOp` diversion point
  - Send lambda method to Graal HSAIL compiler
  - Graal emits HSAIL text, then sent to HSA Finalizer for kernel creation
  - Kernel is cached for subsequent executions
- Native code in the JVM
  - Part of Graal's hotspot
  - Passes arguments to HSA Runtime and runs kernel
  - Handles any post-kernel-execution processing



DEOPTIMIZATION

DEOPTIMIZATION, MOTIVATION

- Handle cases where compile time assumptions are violated
  - For example, class hierarchy assumptions
- Throw exceptions back to CPU
  - For instance, null reference in an input object stream
- Handle cases where GPU needs CPU to take some action before proceeding
  - Example: allocation when no space left on heap, GC required
  - Similarly for safepoints

DEOPTIMIZATION OVERVIEW

- If kernel cannot complete on the GPU, revert to the interpreter on the CPU
- As with CPU deoptimization, keep track of reasons for deoptimization
  - Decide whether kernel should be recompiled
  - Or not offloaded in the future.
  - The logic for deciding to recompile or stop offloading is not implemented yet

HSA FEATURES AFFECTING DEOPTIMIZATION DESIGN

- No HSAIL “stack”, registers saved as stores to global memory
- Registers do not live across function calls
  - Register saving must be inlined into each function
- The total number of HSAIL registers used in a kernel affects the code quality when code is finalized
  - Even if registers are used on a "cold" path
  - Thus should not just “save all registers”
- We currently have one deopt exit point per kernel
  - Save the union of the actual registers and stack slots that are live at any of the deopt points

DEOPTIMIZATION, COMPILATION PHASE

- We fully utilize Graal features to provide HSA deoptimization
- Compiler keeps track of the deoptimization state at each deopt point
  - Indicates which HSAIL registers or stackslots need to be saved
  - Indicates which saved values contain oops, etc.

DEOPT, EXECUTION PHASE

AMD

- Kernel dispatch to GPU is done when all workitems have returned
  - It might have set a flag indicating it is deoptimizing and returned early
- Workitems that do not deoptimize have finished as they normally would
- Each deoptimizing workitems must save its state so the interpreter can finish
- Can be very large number of workitems
  - Each of which has its own HSAIL state
  - Because of divergence, different workitems can have different deopt points

```
if (condition) {
   output = myObjArray[k].getValue();    // possible NPE or IndexOutOfBounds
} else {
   output = new MyObj().getValue();      // possible deopt from out of memory.
}
```

DEOPT EXECUTION PHASE, SAVING STATE

- Goal: avoid allocating state-saving space for the entire possibly very large range of workitems
- Compiler tells us size of the total union of saved registers
- Once we allow a workitem to start, we must have room to save its state
  - Because it might deoptimize
- Any HSA target has a maximum number of concurrent workitems
  - Only allocate state-saving space for this maximum number of possible concurrent workitems
- Deopting workitems set a "deopt happened" flag
  - And atomically bump an index of where to save in the save area
- Before beginning execution, workitems check this "deopt happened" flag.
  - If true, exit early without running at all.
  - And just set a flag that they never ran
  - Note: no saved state

DEOPT EXAMPLE

- Workitems 1 and 3 have deopted and saved their state. 2000 and up saw flag set and are never-rans.

id	action	Deopt PC	Saved State		
			$s0	$d2	$d3
0	Finished				
1	Deopted	1111	123	456	789
2	Finished				
3	Deopted	2222	234	567	890
4-1999..	Finished				
2000	NeverRan				
2001	NeverRan				
Etc.	NeverRan				

DEOPT PATH, POST-KERNEL EXECUTION PHASE

- When the GPU dispatch completes (still in thread in VM mode), each workitem will have either:
  - Finished normally
  - Deopted
  - Or exited early (never ran)
- If there was at least one deopt, then:
  - For the workitems that finished normally, there is nothing additional to do
  - For each deopting workitem, run through the interpreter starting from the byte code index of the deoptimization point
  - For each never-ran workitem, run on the CPU as a javaCall of the kernel method
  - Deopts and never-rans handled sequentially, although other policies are possible

SAVED HSAIL STATE TO THE INTERPRETER

- Workitems that deoptimize must run in the interpreter from the deopt bytecode
  - Using the per workitem saved state to fill in locals, bytecode stack, etc.
- We want to have a CPU stack with frames that the interpreter can handle
- Gilles Duboscq of the Graal team had a clever idea
  - Compile a deopt trampoline code graph, use it to generate host code
  - The trampoline host code takes the hsail deoptId and a pointer to the saved hsail frame as input
  - Generate code for each possible deopt id in this kernel to:
    - Move from each saved HSAIL register representing a local into a host local
    - Immediately deoptimize
  - It is this trampoline code that we invoke for each deoptimizing workitem

DEOPTIMIZATION AND GC

- While kernel is running, we are in "thread in VM" mode
  - So GC cannot happen
- However, post-kernel we run each deopting workitem through the interpreter
  - Transition back to Java mode which can cause GCs
- Oops in save area are properly handled as part of GC oops_do workflow

ALLOCATION FROM THE GPU

ALLOCATION FROM THE GPU, MOTIVATION

- Enable offload to the GPU lambda expressions that use object allocation
- Since HSA Device has a coherent view of system memory including Java Heap, this should be possible
  - GPU can access objects on heap
  - Can access data structures that control the heap
- Note: Graal compiler will avoid the actual allocation if can prove that the allocated objects do not escape
- This section will deal with allocating objects that really do escape

ALLOCATION IMPLEMENTATION, SNIPPETS

- Graal has a feature called Snippets
- In a lowering phase, nodes are replaced with the graph of the snippet
  - Which is written in java
- For HSAIL object allocation, we made our own modified versions of the standard object allocation snippets
- Snippets allowed us to write our new allocation fastpath and slowpath logic in java

ALLOCATION, FAST PATH

- In Hotspot JVM, each Java thread uses its own use Thread Local Allocation Buffers (TLAB) to allocate memory on the heap
- Important TLAB fields:
  - HeapWord* _start; // start of TLAB
  - HeapWord* _top; // address after last allocation, bumped with each allocation
  - HeapWord* _end; // end of TLAB

SHARING OF TLABS

- A TLAB per workitem would have meant too many TLABs
- Thus, we allow multiple workitems to allocate from a single TLAB
- HSAIL Kernels use special TLABs that are not used for allocation by any JavaThreads
- In other respects, treated like normal TLABs

ALLOCATION FAST PATH

- Normal single owner TLAB fastpath (as on CPU)

```
If (top + size < end) {
    oldtop = top;
   top += size;
   return oldtop;
}
```

- HSAIL Multiple owner TLAB fastpath

```
oldtop = atomic_get_and_add(top, size);
If (oldtop + size < end) {
   return oldtop;   // fastpath success
} else {
   if (oldtop < end) {
      // overflowed but we were first overflower
      lastGoodTop = oldtop;
      //  continue slowpath, other workitems using this TLAB will also overflow
   }
}
```

ALLOCATION FAST PATH

- HSAIL-specific code here is really just the use of atomic_add on tlab.top
- The other logic in the fastpath allocation (formatting object, etc.) inherits from its superclass NewObjectSnippets

HSAIL ALLOCATION SLOW PATH

AMD

- What to do when the current TLAB overflows
- High level choices
  - Give up and deoptimize immediately
  - Do an “eden allocate” using CAS
    - Lots of CAS contention when many workitems overflow
  - Designate one workitem to allocate a new TLAB while still on the GPU
    - Other workitems overflowing on same TLAB will spin waiting for new TLAB
    - This is the current default

ALLOCATION SLOW PATH REFILL TLAB FROM GPU

- Several workitems overflow on TLAB, one needs to be the refiller

- TLAB refiller is the "first overflower" workitem as described above
  - Allocates TLAB from Eden using CAS

- Other workitems then wait for the first overflower to indicate that a new TLAB is ready

- If designated refiller cannot get a new TLAB
  - Workitems waiting on that TLAB will deoptimize
  - GC will presumably open up some space.

ALLOCATION EXAMPLE

AMD

- 1 TLAB shared by 8 workitems: top=1000, end=1450
- Each workitem needs 100 bytes

Fast Path

id	allocation	New top
1	1300	1400
2	1000	1100
3	X	1500
4	1100	1200
5	X	1600
6	1200	1300
7	X	1700
8	X	1800

Workitem 3, first overflower, gets new TLAB starting at 8000. 5,7,8 also overflow and wait for new TLAB then 3,5,7,8 try again

Slow Path

id	allocation
1	1300
2	1000
3	8100
4	1100
5	8000
6	1200
7	8200
8	8300

SAFEPOINTS

HSAIL SAFEPOINTS, MOTIVATION

- While kernel is running we are in "thread in VM" mode
  - So GC or other safepoints cannot happen
- Other Java threads (on CPU) that need to safepoint will be blocked waiting for GPU kernel thread
- Kernels can be long-running
  - Because they have a large grid size (lots of workitems)
  - Because each individual workitem is long running

HSAIL COMPILER SAFEPOINTS

- A global flag is set by the JVM indicating a safepoint is requested
- Checks of this flag are inserted in the HSAIL code by compiler at usual places, such as loop ends, etc.
  - The HSAIL backend implementation of Graal's SafePointNode
- When flag is seen set, workitem will deoptimize
- Post-kernel, during deoptimization handled in interpreter,
  - real safepoint takes place and GC or other activity can proceed
- Safepoint requested flag is also checked at workitem entry, producing a never-ran if detected

FUTURE WORK AND CONCLUSIONS

- Use CPU parallelism when handling deopters and never-rans
  - Or redispatch never-rans to GPU
- Investigate ways to spin on GPU rather than deopting for safepoints, GC
- Recompile or stop offloading for certain deoptimizations
- Investigate other shared TLAB allocation policies not requiring atomics

CONCLUSION

- With a coherent view of system memory, HSA targets can interact with the JVM in exciting ways that we have seen here.

LINKS AND REFERENCES

AMD

- Sumatra OpenJDK GPU/APU offload project
  - Project home page: http://openjdk.java.net/projects/sumatra/
  - Wiki: https://wiki.openjdk.java.net/display/Sumatra/Main/
- Graal JIT compiler and runtime project
  - Project home page: http://openjdk.java.net/projects/graal/
- HSA Foundation
  - Home page: http://hsafoundation.com/
  - Specifications at http://hsafoundation.com/standards/

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