

Efficient Implementation of Smalltalk Activation Records in Language Implementation Frameworks

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ABSTRACT

Language implementation frameworks such as RPython or Truffle help to build runtimes for dynamic languages. For this, they make certain design decisions and trade-offs upfront to make common language concepts easy to implement. Because of this, however, some language-specific concepts may be rather tedious to support, especially the modification of activation records. For example, Smalltalk provides reification of activations through *context* objects. Since they are used to implement other mechanisms such as exception handling on the language level, contexts need to be entirely supported by the underlying runtime. We present an approach for efficiently implementing Smalltalk context objects in frameworks that do not support unrestricted modification of activation records.

CCS CONCEPTS

- Software and its engineering → Interpreters; Runtime environments; Just-in-time compilers.

KEYWORDS

Squeak, Smalltalk, RPython, Truffle, RSqueak/VM, GraalSqueak

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1 INTRODUCTION

Virtual machines (vms) for dynamic languages commonly manage activation records in the form of a stack of call frames. Depending on the implemented language, a VM may have to expose some of the

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internal data structures it uses for this to the language. Language implementation frameworks such as Truffle [15] or RPython [1] provide facilities to manage call frames in an efficient way. Neither framework, however, supports unrestricted modification of activation records (such as returning to a different sender) which are required to implement Smalltalk-80 [5]. We present an approach for implementing full support for Squeak/Smalltalk context objects in both Truffle and RPython.

2 BACKGROUND

Smalltalk exposes activation records as first-class objects to the language. Unlike in many other languages, these *context* objects are arbitrarily modifiable and can therefore be used as continuations [14]. Control flow can be manipulated by changing a context's instruction pointer or its sender context. This allows, for example, a language-level implementation of exception handling and other mechanisms. In Truffle, a dedicated frame implementation must be used to represent an activation record of the guest language while in RPython, language implementers have to designate one interpreter-level class to allow it to be stack-allocated. In the remainder of this paper, we will use the term "frame" for an activation record in both frameworks, and "context" in Squeak/Smalltalk. Moreover, the two frameworks provide a Just-in-time compiler (JIT) to improve runtime performance. A common optimization applied by these JITs is to avoid the allocation of frames on the heap by reusing the machine stack. For this reason, Truffle differentiates between *virtual* and *materialized* frames, which are allocated on the machine stack and heap, respectively. Furthermore, Truffle allows language implementers to request the materialization of a virtual frame, consequently forcing it to heap. In RPython, on the other hand, fields of the frame class must be marked as *virtualizable* and special references ("virtualrefs") must be used to chain them. Only then the framework's JIT may decide to allocate these fields on the stack.

3 APPROACH

For an efficient Smalltalk implementation, it is worthwhile to optimize the representation of context objects [2]. In frameworks like Truffle and RPython, we suggest to use two different representations: A *stack-allocated* context is represented by a frame on the

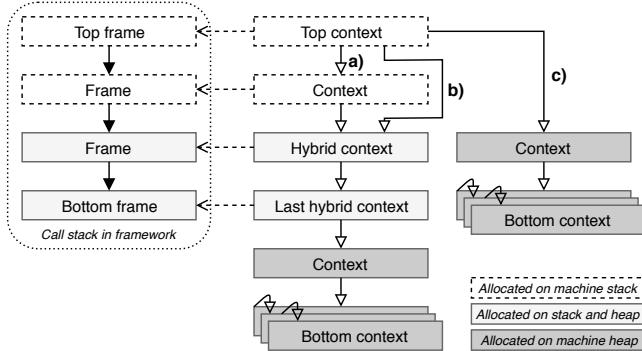


Figure 1: The framework-level frames can be in sync with contexts (a), or out of sync after a sender has been changed to a context of the current stack (b) or a different stack (c).

machine stack. In contrast, a *heap-allocated* context is used when all fields of the context need to be allocated on the heap, for example when they are needed outside of the current scope. As an effect of the framework’s JIT, a context may actually be represented in a hybrid manner in case escape analysis is able to allocate only some fields of the corresponding frame on the stack. Furthermore, a complete implementation also needs to support sender modifications. Both frameworks, however, try to aggressively allocate frames on the stack for performance reasons. For this, they assume that senders are immutable which is a valid assumption for most languages, but not for Smalltalk. In the prevalent case that activation records are not modified, each context is ideally represented by a corresponding stack-allocated frame (cf. Figure 1a). The sender of a context can change, which happens frequently for example when an exception is handled. In this case, the chain of contexts and the stack-allocated frames may get out of sync (cf. Figure 1b). The sender of the current context may be changed to a different parent context which is further away from the original sender in the chain. The two stacks can be brought back in sync by unwinding all stack-allocated frames until the frame representing this parent context is reached. Moreover, the new sender of a context can also be a new materialized context from a different stack of contexts (cf. Figure 1c). Then, all frames of the framework need to be unwound and the return value needs to be passed to the new context.

4 IMPLEMENTATION

An implementation of our approach has proven to work well in RSqueak/VM [3], a Squeak/Smalltalk VM written in RPython. Contexts are represented by `ContextPartShadow` which has virtualizable attributes and its sender field references another `ContextPartShadow` through a `virtualref`. To keep Squeak/Smalltalk contexts in sync with their shadows, we use exceptions to signal both non-virtual returns and process switches in RPython. Similarly, we have implemented our approach in GraalSqueak [12], a Truffle-based Squeak/Smalltalk implementation for the GraalVM. Since Truffle’s `VirtualFrames` must not be referenced by other objects, we identify them using thin marker objects that are stored in the first frame slot. If access to a context object is requested, GraalSqueak allocates and pushes a `ContextObject` which references a

materialized Truffle frame. Further optimization is then left to the Graal compiler. To find a specific sender, Truffle’s `iterateFrames` API is used to determine the corresponding frame. Again, we use exceptions to keep `ContextObjects` and Truffle frames in sync. Additionally, `ContextObjects` are fully materialized if they are marked as escaped, that is when they have been stored in some other object or when a process switch occurs.

5 DISCUSSION

Following our approach, we were able to implement support for Squeak/Smalltalk context objects in RSqueak/VM using RPython and GraalSqueak using Truffle. When contexts are allocated on the machine stack, the user interface is refreshed at normal frame rates (around 40 to 50 fps, capped by the programming system) while otherwise the frame rate is around one or two fps. Moreover, our approach enables another key feature with regard to contexts: the chain of contexts can grow, at least in theory, infinitely. Since the two frameworks are based on Python and Java, it is possible that the framework-level stack overflows. In both vms, we use the materialization mechanism to unwind all frames just before this happens, so that context chains are supported that exceed the framework’s stack size. Implementing our approach in RSqueak/VM required fewer optimizations and was relatively straightforward compared with Truffle, which matches previous observations [8]. In case of sender modifications, for example, we had to avoid materialization of contexts as much as possible in GraalSqueak. Instead, we had to carefully use Truffle’s `iterateFrames` frame-walking facility which triggers deoptimizations in the JIT under poorly documented conditions. This made parts of our approach cumbersome to implement.

6 RELATED WORK

The vm used for VisualWorks 5i [9] also uses different context representations and applied further optimizations to reduce run-time overhead. The OpenSmalltalk vm [11] is the state-of-the-art vm for Squeak/Smalltalk, is still under active development, and uses “married contexts” [10], which are also used in SqueakMaxine [13]. The original “interpreter” vm [7], SqueakJS [4], and Potato [6] for Squeak/Smalltalk always allocate contexts on the heap. None of these vms are written in and constrained by a language implementation framework. The OpenSmalltalk vm which optimizes context objects is significantly more complex (300k+ SLOC) compared with RSqueak/VM (\approx 22k SLOC) and GraalSqueak (\approx 36k SLOC), which in turn are more complex than SqueakJS (\approx 8k SLOC) and Potato (\approx 6k SLOC). These two vms and the interpreter vm, however, are significantly slower in performance compared with our vms.

7 CONCLUSION AND FUTURE WORK

We presented an approach for implementing full support for Smalltalk context objects in Truffle and RPython, both of which do not support unrestricted alterations of activation records out of the box. Our implementation strategy played an important role in making the Smalltalk programming system usable. In the future, it would be interesting to see how our approach can be incorporated into language implementation frameworks as well as to measure performance implications in more detail.

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