

Java SPEC designed for 32-bit implementations ?

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Abstract— The platform-agnostic nature of Java is made possible thanks to the presence of the Java Virtual Machine (JVM) with a well defined set of bytecodes and library routines. This requires the availability of a JVM for many different platforms, 32-bit as well as 64-bit wide. During an effort to port the Jikes Research Virtual Machine (RVM) to the 64-bit PowerPC, we stumbled into a number of problems that prove that the Java specification was designed with a 32-bit platform in mind and that prevent an efficient implementation on a 64-bit platform. All described problems boil down to the fact that all types have a fixed size, while it is in the nature of some types to automatically adapt to the word-size of the current platform. We would like to share those issues with the community, so that future SPEC designers can take into account these flaws. While Java declares to be platform independent, we believe some aspects of the Java SPEC are designed too specific for a 32-bit platform.

Keywords— Java, JVM SPEC, 64-bit platform, porting experience

I. INTRODUCTION

The 64-bit world is not new to a variety of back-end server applications, but its growing popularity towards consumer products will make it the major universe *tout court* in a few years. The main reason that the market for consumer applications is running behind, is that this market is the x86-market and in this segment there is only recently 64-bit hardware available. This is in contrast with the back-end application market, for which special (64-bit) hardware gets developed for many years. With the availability of the 64-bit hardware on the x86-market, soon everyone will be confronted with 64-bit applications.

In order to be able to explore the new opportunities in the 64-bit world, we cooperated on a 64-bit port of the Jikes Research Virtual Machine. It is during this experience that we encountered some limitations of Java that either have a negative influence on the performance, or that force us to write separate code for each platform even when semantic similarity exists.

The rest of this paper is organized as follows. In the next section we'll touch some limitations and performance bottlenecks. Section III will present some proposed improvements, and at the end some conclusions in section IV will summarize this paper.

II. PERFORMANCE ISSUES AND LIMITATIONS

A. No natural sized type

The Java SPEC is defined as if all types have a fixed size. However, in practice we experience a whole different world

if we shift between 32-bit platforms and 64-bit platforms. Some types (should) automatically adapt to the word size of the machine. What is missing in Java is an integral type of natural size. Probably the best reason to have a natural sized type is for performance. Let's say we define a type that corresponds to the size of the machine word, as long as a minimum size is guaranteed (e.g. 32-bit). Such a type would be ideal for all small ranges used by programmers, such as in for-loops. If we would use another type, then unless the ISA has a set of 32-bit ALU-instructions, most results of ALU-operations will have to be masked to mimic the 32-bit operation. We believe that adding such a type would not break the platform independence of Java as long as we can guarantee that overflow is of no concern.

B. 4GiB limitations

Who wants limitations? As long as something is physically possible, it should be allowed as much as possible. Unfortunately, many Java constructs are limited in size by the Java SPEC itself. Those limitations are not visible on 32-bit platforms, because the physical resources have the same scope. On 64-bit platforms, physical borders are stretched much further. The Java SPEC is obvious once more designed with a 32-bit platform in mind.

For example the size of an array is defined as an int, which is bound to a 32-bit value. If we take into account the fact that this is a signed value (which btw is complete nonsense), the largest possible byte-array can never exceed the 2GiB border. This probably is not an acute problem yet, but with the shift towards the 64-bit world this will become an unavoidable issue in time.

C. Wasted Stack Space

All actual Java types are divided into 2 categories as seen in table I: category I&II computational types. Each category is defined in terms of 1 or 2 stack slots respectively. Now a performance problem arises when we'd like to make a simple implementation of the Java stack model. A lot of space gets wasted on the 64-bit version. The reason for this is that a reference has become larger, but still has to take one stack slot. So a stack slot will become 64 bits. All other types that do not need this extension, are forced to use the same stack slot definition. So int-like types take one stack slot of 64 bits even though it would suffice to

Java types	32 bit platform			64 bit platform		
	Logical size	Cat	Size on stack	Logical size	Cat	Size on stack
boolean	32 bit	I	32 bit	32 bit	I	64 bit
byte	32 bit	I	32 bit	32 bit	I	64 bit
char	32 bit	I	32 bit	32 bit	I	64 bit
short	32 bit	I	32 bit	32 bit	I	64 bit
int	32 bit	I	32 bit	32 bit	I	64 bit
float	32 bit	I	32 bit	32 bit	I	64 bit
reference	32 bit	I	32 bit	64 bit	I	64 bit
returnAddress	32 bit	I	32 bit	64 bit	I	64 bit
long	64 bit	II	64 bit	64 bit	II	128 bit
double	64 bit	II	64 bit	64 bit	II	128 bit

TABLE I
JAVA TYPES WITH THEIR SIZE INFORMATION

provide 32 bits and longs and doubles will take 2 slots (128 bits) instead of the necessary 64 bits. On a 64-bit platform, except for references, space is wasted for almost every type. Thus for int-like types, doubles and longs, we have half of the space wasted.

D. Wasted Space for Locals

For the allocation of the locals, we have no other choice¹ than allocating a long and a double twice the space as a computational type of category I. This is so because the Java-to-bytecode compilers automatically increase the local index with 2 units each time they encounter a long or a double. Due to the fact that a reference takes 64 bits on a 64-bit machine, a long or a double will occupy 128 bits instead of the normal 64. Another consequence is that (even on 32-bit platforms) the use of some specific bytecodes, prohibits the use of other bytecodes. e.g. `dload_0` takes local slot 0 and 1, so e.g. `dload_1`, `iload_0` and `aload_1` can never be used in the same function.

III. PROPOSED IMPROVEMENTS

A. New Type Category

If we have an other look at table I, we see two categories of computational types. So far so good: two different categories are probably essential to express some differences between some types. But by which motivations did those two type categories get created? Looking at table I, more specific to the side of the 32-bit platform, we see that all types that do not fit into 32 bits are separated of those that do. However, if we take a look at the other side of table I, it is clear that this is no longer the case on a 64-bit platform. In our opinion it is fine to isolate longs and doubles in a separate category, but to dump all the rest in a single category was less intuitive.

Considering different platforms, it would be a good idea to group together those types that change their size ac-

¹speaking for interpreters and JIT compilers that need to be fast. Optimizing compilers can do a better job, but they need to do extra work that isn't necessary on 32-bit platforms

ordingly. So we could create a category III computational type, next to the existing two types of the Java SPEC [LY99]. A reference and a `returnAddress` then should be a member of this new category III instead of category I computational type. If we introduce a new word sized type to solve the problems of section II-A and II-B, it would also belong in this new category III.

The current Java Specification, has lacked to treat the “word-sized” types properly. It is because of those types being dropped with the int-like types, that sizes get very unnatural on a 64-bit platform. In the next sections we'll discuss some steps to take to solve the issues of sections II-C and II-D. We will also come back on the issue covered in this section, namely the need for a third type category.

B. Independent Type Categories

As stated before, the separation of longs and doubles in a separate type category is probably a good thing to do. But worse is the dependencies that still exist between the different type categories. Because the Java SPEC e.g. explicitly says that a type of category I takes one stack slot and a type of category II takes two stack slots, a dependency gets created that states that a category II type always has to take twice the space of a type of category I. We believe it is possible to define all types independent of there actual size (or number of stack slots). If all types are independent of their size, then we can implement the stack model without the overhead of wasting space for almost every type.

B.1 Wasted Space for Locals

Probably the easiest solution to get rid of the double index, used for types of category II is to say don't use 2 index numbers, just assign one index for each local variable, no matter which type. This would be very convenient for the 64-bit implementation, discussed in section II-D, but would complicate the 32 bit implementation considerably. That can not be our intention, so something more general applicable would be appreciated. The cleanest solution to this is in our opinion to number the parameters independent by

computational type category.

Let's check with the bytecodes if this is possible. Well, some examples of bytecodes accessing the local variables are e.g. `iload_0`, `aload_<n>`, `dstore_2`. If we take a look to the complete set of bytecodes that can access the locals, we notice that they all include the type of the variable they want to access. This means that they also implicitly know the type category. So there are no further complications that stops us from using the new way of indexing.

With this new way of indexing, the semantics of a `dload_3` would then be "load the 3th local variable of computational type category II". This way it is also no longer the case that the use of one bytecode obstructs the use of another. We can use the `dload_0` as well as the `dload_1`, `aload_0`, `iload_1`, ..., what leads to possible better usage of shorter bytecodes which will almost certain lead to shorter class files.

We could use the new indexing technique, for starters, only on the existing 2 type categories. This way we would recycle (on 64-bit machines of course) the wasted second stack slot for locals of type double and type long. If we agree on introducing a third type category, proposed in section III-A, we could go further and store the locals of the remaining type category I on 32-bit slots. The worst case will then be the remaining of one 32-bit slot of waste for the purpose of alignment.

B.2 Wasted Stack Space

The previous subsection concerned the local stack space. In this subsection we will focus on the operand stack. We will also start our discussion in assumption we have two type categories. How can we make both categories size independent? The condition that has to be met to make this possible, is that each bytecode that accesses the operand stack has to be defined in terms of manipulating (a subset of) only one computational type category.

If we take a look at the bytecodes, we notice most of them are argument specific (e.g. `aaload`, `fstore`, `dmul`) so the condition is met here because they explicitly know the type of the argument, which is more strict than only knowing the computational type category. Unfortunately, it is sad to notice that the Java SPEC is once again not consistent. This approach is not pursued for all the bytecodes. E.g. the `dup` bytecode family implicitly takes into account the number of stack slots. A nicer approach would have been to make separated variants for each computational type category. So it really is the bad design of the `dup` bytecode family which implicitly force longs and doubles to take 2 stack slots.

So in our approach we would need to introduce some extra bytecodes to make separate variants for each type category. This is not a great problem, because there are only about 200 out of 256 possibilities used. We will now consider each bytecode of the `dup` family and redefine and extend them, as we think should make a better specification. Following the Java SPEC, `dup` and `dup_x1` are bounded to category I computational types [LY99]. So we do not need to change the semantics of those bytecodes.

Bytecodes `dup_x2`, `dup2` and `dup2_x1` have 2 forms and will be bound to the form with all category I computational types. For the abandoned form, we will introduce 3 new bytecodes: `dup_xc2`, `dupc2` and `dupc2_x1` resp., where the `c2` indicates one type of category II in contrast to a single number 2 which indicates 2 times a type of category I. Finally the bytecode `dup2_x2` has four forms. We bound it to the form with all computational types of category I and introduce three new bytecodes to cover the three remaining forms: `dupc2_x2`, `dup2_xc2`, `dupc2_xc2`.

So with 6 extra bytecodes, we can make the type categories I and II independent of each other's size as far as the operand stack is concerned. With this little adjustment, it is no longer compulsory to give e.g. a double twice the stack space as e.g. a reference.

What in case of the third computational type category? Well in practice it will probably not be the case that, on the 64-bit machine, every type takes its minimal space. Due to alignment problems is it acceptable on a 64-bit platform to allocate 64-bit stack slots for every type. So by splitting the first computational type category, we will not be able to allocate the new category I types on 32-bit slots. So we could state that for practical reasons, we have no need for making the first and third type category independent of their size. But theoretically we think it would have been a cleaner design strategy to do so. So let us once again go to the bytecode level and see what needs to be done to do create the independence between the first and third type category. Of course the `dup` bytecode family now needs to be extended further to cover all three type categories. Besides this, only three other bytecodes needs to be extended, namely `ldc`, `ldc_w` and `swap`. Those three bytecodes do need to get an equivalent for the new type category.

IV. CONCLUSIONS

In this paper we have shown you some flaws in the Java Specification concerning platform independence. We would like to bring under attention the missing of a natural sized integral type. Second we would like to emphasize the inconsistent design of the bytecode set, which leads to difficulties regarding efficient implementations of the stack model on different platforms. With the proposed improvements to the Java SPEC, an implementation has more freedom in choosing sizes for every computational type category. A 64-bit implementation could for example allocate 64 bit for every category, without the need of sophisticated compiler analysis (which is the case now if you want to achieve the same performance gain).

REFERENCES

- [LY99] T. Lindholm and F. Yellin. *The Java Virtual Machine Specification*. Addison Wesley Longman, 2nd edition, 1999.