Algebraic Transformation of Descriptive Vector Byte-code Sequences

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Both high-productivity and high-performance are two often sought after aspects of scientific programming. Python gives the programmer high-productivity, but even with NumPy it is often not high-performant because of the GIL\(^1\), which makes it inherently single threaded.

Bohrium intercepts NumPy calls and generates an intermediate language, Bohrium byte-code, before being compiled to OpenCL kernels. It thus grants Python/NumPy the ability to be easily run on multicore systems or GPUs, without changing the source code.

The Bohrium byte-code can be optimized, by transforming byte-code sequences into more performant ones. This way, the scientific programmer will not need to change her code to utilize special performant constructs.

### 2. ALGEBRAIC TRANSFORMATIONS

A transformation can be thought of as a rewriting of elements from one set to another. An example of such a transformation could be to realize
\[
\begin{align*}
\mathbf{x}^n &\mapsto \mathbf{x} \cdot \mathbf{x} \cdot \ldots \cdot \mathbf{x} = \prod_n^n x \\
\text{if } n \in \mathbb{N}
\end{align*}
\]

We can thus exchange the power-function for a series of multiplications or vice versa. This also holds true for tensors, such that
\[
\mathbf{x}^{10} = \prod_{10} \mathbf{x}
\]

Another example of a transformation, one that requires a more context-aware transformation, could be transforming a solution of
\[
\mathbf{Ax} = \mathbf{B} \iff \mathbf{A}^{-1} \mathbf{Ax} = \mathbf{A}^{-1} \mathbf{B} \iff \mathbf{x} = \mathbf{A}^{-1} \mathbf{B}
\]

Instead one could do a LU-factorization [1] of the same problem, which would usually be faster to compute. Note that this is of course only faster, if we do not use the \(\mathbf{A}^{-1}\) tensor for anything else in our computations.

The transformations can thus be small loop-fusion-like contractions of byte-codes, or it can detect the semantic meaning of the code, thus being more specialized and context-aware.

\(^1\text{Global Interpreter Lock}\)

\(^2\text{Also known as array-programming.}\)
3. BOHIRUM BYTE-CODE

Even though Python is an interpreted language, with Bohrium we actually get a JIT-compiled intermediate language. We can thus manipulate the byte-code before executing it.

In this byte-code language a single line encapsulates one byte-code. A byte-code consists of an op-code, e.g. BH_ADD, a result tensor, and up to two parameter registers or constants.

In Listing 1 we have a Python program adding three ones together in a one-dimensional vector of size 10.

```python
import bohrium as np
a = np.zeros(10)
a += 1
a += 1
print a
```

Listing 1: Adding three ones in Python.

In Listing 2 the same program is shown in the Bohrium byte-code language.

```bohrium
BH_IDENTITY a0 [0:10:1] 0
BH_ADD a0 [0:10:1] a0 [0:10:1] 1
BH_ADD a0 [0:10:1] a0 [0:10:1] 1
BH_ADD a0 [0:10:1] a0 [0:10:1] 1
BH_SYNC a0 [0:10:1]
```

Listing 2: Adding three ones with Bohrium.

Here, a0 is a vector register where our view is always from 0 to 10 with a step of 1. In further listings I assume the view is the same for all registers, and thus will not write it out.

What this means is that we three times add 1 to all elements of our a0 tensor’s full view and store it back into the full view.

3.1 Transforming the Byte-code

In the code example in Listing 2, we see each of the three additions being their own byte-code. In reality our a0 tensor could be very large, so large in fact that adding one to each element would take a long time. Instead the constants of the three byte-codes can be merged into one by simply adding them together. After transforming the byte-code sequence, we thus end up with only one BH_ADD op-code adding 3 to each element, as shown in Listing 3.

```bohrium
BH_IDENTITY a0 0
BH_ADD a0 a0 3
BH_SYNC a0
```

Listing 3: Optimized adding three ones with Bohrium.

By transforming we can also generate more byte-codes. In the power-to-multiplication example we start with one byte-code, BH_POWER, and can potentially end up with many. Here it is important to know, that we usually only have access to the origin and result tensors, since copying data to create temporary tensors would be time consuming for large tensors. For the power example from (1), we can get better performance, still only using BH_MULTIPLY, by utilizing the result tensor multiple times, instead of only seeing it as the end-result. To do this, we can realize that

\[ x^{10} = x^8 \cdot x^2 \]

\[ = x^4 \cdot x^4 \cdot x \]

\[ = x^2 \cdot x^2 \cdot x^2 \cdot x^2 \cdot x \]

If we thus first calculate \( x^2 \), we can then multiply it with itself to get \( x^4 \). Multiplying this with itself grants us \( x^8 \) and then multiplying this with \( x \) twice gives us the result \( x^{10} \).

In Listing 4 we have calculated \( x^{10} \) by multiplying first our origin tensor by \( x \) and then 9 more times multiplying the result tensor with \( x \).

```bohrium
BH_IDENTITY a0 ... # initialize the tensor, x
BH_MULTIPLY a1 a0 a0 # x^2
... (x 7) # x^3...x^9
BH_MULTIPLY a1 a1 a0 # x^10
BH_SYNC a1
```

Listing 4: \( x \) to the power of ten, using nine BH_MULTIPLYs.

We could actually do better. Since we own the result tensor, we are allowed to use it as we see fit. In Listing 5 a better \( x^{10} \) is shown.

```bohrium
BH_IDENTITY a0 ... # x
BH_MULTIPLY a1 a0 a0 # x^2
BH_MULTIPLY a1 a1 a1 # x^4
BH_MULTIPLY a1 a1 a1 # x^8
BH_MULTIPLY a1 a1 a0 # x^9
BH_MULTIPLY a1 a1 a0 # x^10
BH_SYNC a1
```

Listing 5: \( x \) to the power of ten, using just five BH_MULTIPLYs.

4. CONCLUSIONS

Some of these rudimentary transformations have already been implemented into the Bohrium runtime system. Bohrium already supports merging integer addition, by adding the constants, before adding it to the actual tensors. It also does power expansion by default, since benchmarks have shown, that for values close to a power of 2, multiplying multiple times is faster than doing an actual BH_POWER.

A further study of real examples, such as (2), from imaging software and benchmark suites is planned. If resulting sequences is found to be too slow, a study on how to make them faster will be made.

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6. REFERENCES


