FlexiBLAS

Switching BLAS libraries made easy

Martin Köhler

joint work with Jens Saak, Christian Himpe, and Jörn Papenbroock

January 29, 2018
**Basic Linear Algebra Subprograms (BLAS)**

“The BLAS (Basic Linear Algebra Subprograms) are routines that provide standard building blocks for performing basic vector and matrix operations. … Because the BLAS are efficient, portable, and widely available, they are commonly used in the development of high quality linear algebra software, LAPACK for example.”

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4From: [http://www.netlib.org/blas/faq.html](http://www.netlib.org/blas/faq.html) – What and where are the BLAS?
Let $\alpha, \beta$ be scalars, $x, y$ be vectors, $A, B, C$ be matrices.

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<thead>
<tr>
<th>level</th>
<th>included operations</th>
<th>data</th>
<th>flops</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>$\alpha x, \alpha x + y, x^*y, |x|_2, |x|<em>1, |x|</em>\infty$</td>
<td>$O(n)$</td>
<td>$O(n)$</td>
</tr>
<tr>
<td>2</td>
<td>$\alpha Ax + \beta y, \alpha A^<em>x + \beta y, A + \alpha xy^</em>, A + \alpha xx^<em>, A + \alpha xy^</em> + \beta yx^*$</td>
<td>$O(n^2)$</td>
<td>$O(n^2)$</td>
</tr>
<tr>
<td>3</td>
<td>$\alpha AB + \beta C, \alpha AB^* + \beta C, \alpha A^<em>B + \beta C, \alpha AA^</em> + \beta C, \alpha A^*A + \beta C$ rank $k$ updates $\alpha A^*B + \beta C$, $\alpha B^*A + \beta C$ rank $2k$ updates</td>
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Level 3 BLAS especially attractive for communication avoidance and parallelism.
What is BLAS?
Some important BLAS implementations

Open Source

- **NetLib BLAS**: [http://www.netlib.org/blas/](http://www.netlib.org/blas/) (the reference)
- **OpenBLAS**: [http://www.openblas.net/](http://www.openblas.net/) (uses assembler level optimization)
- **BLIS (BLAS-like Library Instantiation Software Framework)**: [https://github.com/flame/blis](https://github.com/flame/blis) (alternative approach to BLAS, with wrappers available)

Hardware Vendor Implementations

- **AMD Core Math Library (ACML)**: ... discontinued
- **Apple Accelerate, IBM ESSL**, ...
Why do we need yet another BLAS library?

Linker Problems

Figure: A sample application using BLAS

```
gcc -o application app.o -lumfpack -llapack -lblas
```
Why do we need yet another BLAS library?

Linker Problems

Application
libblas.so
liblapack.so
libumfpack.so
libblas.so

Figure: A sample application using BLAS

```
gcc -o application app.o -lumfpack -llapack -lblas
```

```
$ ldd ./application
linux-vdso.so.1 => (0x00007ffc2d1de000)
libumfpack.so.5.7.1 => /.../libumfpack.so.5.7.1
liblapack.so.3 => /.../liblapack.so.3
libblas.so.3 => /.../libblas.so.3
libc.so.6 => /.../libc.so.6
...
```
Why do we need yet another BLAS library?

Linker Problems

---

Figure: ...after linking with a different BLAS-implementation

```
gcc -o application app.o -lumfpack -llapack -lopenblas
```
Why do we need yet another BLAS library?

Linker Problems

$ ldd ./application
linux-vdso.so.1 => (0x00007ffc2d1de000)
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liblapack.so.3 => /.../liblapack.so.3
libopenblas.so.0 => /.../libopenblas.so.0
libc.so.6 => /.../libc.so.6
libm.so.6 => /.../libm.so.6
libblas.so.3 => /.../libblas.so.3
...

gcc -o application app.o -lumfpack -llapack -lopenblas
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Linker Problems: Existing Solutions

- **LD_LIBRARY_PATH / LD_PRELOAD**
  only applicable for single file implementations
  (i.e. **NOT** Intel® MKL, or ATLAS)

- **static libraries**
  drastically increased binary sizes, often complicated linking, painful in large projects

- **update-alternatives** (Debian/Ubuntu/Suse)
  requires super-user privileges and has similar restrictions as **LD_LIBRARY_PATH / LD_PRELOAD**

- **eselect / pkg-config** (Gentoo)
  requires super-user privileges and switches at **build-time only**

- **BSD ports/pkgsrg/dports**
  Links agains libblas.so if already installed otherwise installs some BLAS implementation depending on the maintainer.

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### gfortran vs g77/intel interface style

- **different calling sequences:**
  - *gfortran* and *g77/f2c/intel* return complex numbers as additional function parameters.

- **affected routines:** *zdotc, zdotu, cdotc, cdotu* (level 1)
Why do we need yet another BLAS library?
Compatibility Issues

**gfortran vs g77/intel interface style**

- **different calling sequences:**
  gfortran and g77/f2c/intel return complex numbers as additional function parameters.
- **affected routines:** zdotc, zdotu, cdotc, cdotu (level 1)

**auxiliary routine treatment**

- Routines sc/dzabs1 are missing in ATLAS and derived implementations, such as Apple Accelerate / AMD ACML.
- Intel® MKL and OpenBLAS extend the BLAS routine set by: xAXPBY, xOMATCOPY, .....
Why do we need yet another BLAS library?

Compatibility Issues

dependency detection problems

Correct/reliable detection of alternative BLAS implementations not guaranteed for many software packages:

- faulty autotools scripts,
- old CMake versions,
- hard-coded library names,
- non-standard library locations.
Profiling usually requires additional compiler settings,
Profiler data requires additional (sometimes confusing) tools for evaluation,
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Often only execution times and numbers of calls of single routines are of interest.
Our Solution – FlexiBLAS

- Initial idea: Summer 2013 after struggling with the linking issue.
- First release: December 2013 (BLAS and CBLAS only)
- Presented at GAMM ’14, PMAA ’14, OctConf ’15.
- Current Public Version: 2.0 (April 2017)
- Provides interfaces for BLAS, CBLAS, and LAPACK.
Long Story Short

We employ a plugin-like framework on top of the POSIX features for dynamic loading of shared libraries at runtime.
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We employ a plugin-like framework on top of the POSIX features for dynamic loading of shared libraries at runtime.

### POSIX.1 2001 `dl*-family`

- **`dlopen`**: add a shared library and its dynamic dependencies to the current address space.
- **`dlsym`**: search for symbols in the current address space beginning in the handle retrieved by `dlopen`.
- **`dlclose`**: close a previously opened shared library if no other references to the library exist.
- **`dlerror`**: provide human readable error messages.
**dlopen based issues to solve**

1. **dlopen** only integrates selected parts of the library: Each required BLAS call needs to be initialized separately.
2. Dynamically (runtime) loaded symbols can not be resolved while linking a program.
3. **dlopen** only loads a single file: Multi-file implementations require additional treatment.
```c
_attribute__((constructor))
```

- automatically executed before the program starts.
- replaces deprecated `init()`.
- Here used to read configuration and explicitly resolve all BLAS-routines to make sure they get loaded by `dlopen` as an initialization stage.
## How does it work?

### Initialization

**attribute (constructor)**

- automatically executed before the program starts.
- replaces deprecated `init()`.
- Here used to read configuration and explicitly resolve all BLAS-routines to make sure they get loaded by `dlopen` as an initialization stage.

**attribute (destructor)**

- automatically executed after the main program exits.
- replaces deprecated `fini()`.
- Here used to cleanly close the loaded shared library and potentially print profiling data.
<table>
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Provide a 100% Netlib-BLAS compatible API and ABI for use in user applications.

Figure: Calling $\text{sdot}$ from an application via FlexiBLAS.
Python based code-gen

- NumPy’s f2py module allows to parse f77/f90 function headers.
- Extracted function headers are translated into Fortran-ABI compatible C functions containing the wrapper.
How does it work?
Wrapper Functions

Python based code-gen

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From

\texttt{SUBROUTINE DAXPY(N, ALPHA, X, INCX, Y, INCY)}

we obtain

\begin{verbatim}
void daxpy_(Int *N, double *ALPHA, double *X, Int *INCX, double *Y, Int * INCY) {
    ...
    fncall_daxpy(N,ALPHA,X,INCX,Y,INCY);
    ...
}
\end{verbatim}
All BLAS routines can be overloaded to:

- build a deep profiling framework, (work in progress)
- dynamically offload them to accelerators, (work in progress)
- introduce faulty behavior for debugging purpose,
- original BLAS implementation is callable by a separate pointer.

Example - **DASUM with perturbed output**

```c
double hook_dasum(Int *N, double *X, Int *INCX) {
    double res = fncall_real_dasum(N,X,INCX);
    return res + ((*N)*eps());
}
```
How does it work?
Profiling Framework

Functionality
- Collects all arguments, excluding arrays, of all BLAS calls.
- Measures the runtime of each BLAS call.
- Detects multi-threaded execution of the BLAS library.
- Stores all results in an SQLITE database.

Implementation
- Using NumPy’s f2py again.
- Include a hook function for each BLAS call collecting the information.
- Uses the constructor and destructor routine for pre/post-processing.
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**Why?:**

- Replay all BLAS calls to find errors in BLAS implementations. (e.g. OpenBLAS bugs #1332, #237, #1191)
- See how good “blackbox” codes utilizes the BLAS library.

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How does it work?
Multi-file BLAS treatment

Remaining Question

How do we treat BLAS libraries consisting of multiple files (e.g. MKL and some versions of ATLAS), when the \texttt{dl}\_\texttt{-family} can only use single file shared object libraries?

Simple trick
Place an additional surrogate library between FlexiBLAS and, e.g., MKL that references all necessary symbols in MKL and behaves like a netlib-BLAS interface from the view of the dynamic linker.

Intel MKL provides a set of Makefiles to create such dummy libraries containing arbitrary BLAS symbols.

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How does it work?

What else is implemented in version 2.0?

- Wrappers around some additional functions from OpenBLAS,
- Wrappers for all routines of LAPACK 3.6.1,
- Command line tool for easy management,
- API to change the BLAS backend at runtime,
- GNU Octave interface for the API.
- Library to manage the configuration files,
- Packaging scripts for Ubuntu/Debian.

Planed for version 3.0:

- Fine grained profiling.
- Increased LAPACK compatibility.
We provide a tool that closely follows Gentoo’s `eselect` syntax. To check for backends, do

```
flexiblas list
```

To select the active backend, use

```
flexiblas default BLAS_BACKEND_NAME
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Alternatively we use an environment variable as in:

```
export FLEXIBLAS=/usr/lib/libopenblas.so
```

Or

```
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```
How is it used?

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or

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```

Both rely on configuration files generated automatically in `/etc/flexiblasrc` and `~/.flexiblasrc`
New BLAS libraries can be added by:

```
flexiblas add BLASNAME sharedlibrary.so
```

or other runtime properties, like verbosity or easy profiling, can be set:

```
flexiblas set PROPERTY VALUE
```
Future Plans?

- Tests with the LLVM/CLang/FLang Compiler Suite,
- Tests with IBM XLC/XLF on ppc64le,
- Keep track of the BLAS enhancements,
- Ongoing update of LAPACK,
- Extend the profiling framework,
- Get the automatic offloading ready, AutoBLAS
- Get into the distributions!!! (at the moment only Arch/AUR).

Details

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Thank you very much for your attention!

for the software package visit: http://www.mpi-magdeburg.mpg.de/projects/flexiblas

Wishes? Ideas? What do you need?