BASIS Software Manual

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Andreas Schuh

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Contents

The **CMake Build system And Software Implementation Standard (BASIS)** makes it easy to create sharable software and libraries that work together. This is accomplished by combining and documenting some of the best practices and utilities available. More importantly, BASIS supplies a fully integrated suite of functionality to make the whole process seamless!

1 Features

Project Creation

- Quick project setup with mad-libs style text substitution
- Customizable project templates

Standards

- Filesystem layout standards
- Basic software implementation standards
- Command-line parsing standards
- Guidelines on coding style

Build system utilities

- New CMake Module APIs
- Version Control Integration
- Automatic Packaging

Documentation

- Documentation generation tools
- Manuals
- PDF and HTML output of each
- Integrated with CMake APIs

Testing

- Unit testing
- Continuous integration
- Executable testing frameworks

Program Execution

- Parsing library
- Command execution library
- Unix philosophy and tool chains

Supported Languages:

- C++, BASH, Python, Perl, MATLAB

Supported Packages:

- CMake, CPack, CTest/CDash, Doxygen, Sphinx, Git, Subversion, reStructuredText, gtest, gflags, Boost, and many more, including custom packages.

2 Quick Start

2.1 First Steps

The following steps will show you how to

- download and install BASIS on your system.
- use the so-called "basisproject" command line tool to create a new empty project.
- add some example source files and edit the build configuration files to build the executable and library files.
- build and test the example project.

You need to have a Unix-like operating system such as Linux or Mac OS X installed on your machine in order to follow these steps. At the moment, there is no separate tutorial available for Windows users, but you can install CygWin as an alternative. Note, however, that BASIS can also be installed and used on Windows. Only the tools for *automated software tests* will not be available then. These tools are for advanced users who want to set up an automated software build and test on dedicated test machines. The testing tools are not needed for what follows.

Install BASIS

Get a copy of the source code

Download either a pre-packaged `.tar.gz` of the latest BASIS release and unpack it using the following command:

```
mkdir -p ~/local/src
cd ~/local/src
tar xzf /path/to/downloaded/cmake-basis-$version.tar.gz
cd cmake-basis-$version
```

or clone the Git repository as follows:

```
mkdir -p ~/local/src
cd ~/local/src
git clone https://github.com/schuhschuh/cmake-basis.git
cd cmake-basis
```

Configure the build

Configure the build system using CMake 2.8.4 or a more recent version:

```
mkdir build && cd build
ccmake ..
```

- Press `c` to configure the project.
- Change `CMAKE_INSTALL_PREFIX` to `~/local`.
- Set option `BUILD_EXAMPLE` to `ON`.
- Make sure that option `BUILD_PROJECT_TOOL` is enabled.
- Press `g` to generate the Makefiles.

Build and install BASIS

CMake has generated Makefiles for GNU Make. The build is thus triggered by the make command:

```
make
```

To install BASIS after the successful build, run the following command:

```
make install
```

As a result, CMake copies the built files into the installation tree as specified by the `CMAKE_INSTALL_PREFIX` variable.

Set up the environment

For the following tutorial steps, set up your environment as follows. In general, however, only the change of the `PATH` environment variable is recommended. The other environment variables are only needed for the tutorial sessions.

Using the C or TC shell (csh/tcsh):

```
setenv PATH "~/local/bin:${PATH}"
setenv BASIS_EXAMPLE_DIR "~/local/share/basis/example"
setenv HELLOBASIS_RSC_DIR "${BASIS_EXAMPLE_DIR}/hellobasis"
```

Using the Bourne Again SHell (bash):

```
export PATH="~/local/bin:${PATH} "
export BASIS_EXAMPLE_DIR="~/local/share/basis/example"
export HELLOBASIS_RSC_DIR="${BASIS_EXAMPLE_DIR}/hellobasis"
```

Create an Example Project

Create a new and empty project as follows:

```
basisproject --name HelloBasis --description "This is a BASIS project."
             --root ~/local/src/hellobasis
```

The next command demonstrates that you can modify a previously created project by using the project tool again:

```
basisproject --root ~/local/src/hellobasis --noexample --config-settings
```

Here we removed the `example/` subdirectory and added some configuration file used by BASIS. These options could also have been given to the initial command above instead.

See Also:

The guide on how to *Create/Modify a Project*.

Install Your Project

The build and installation of the just created empty example project is identical to the build and installation of BASIS itself:

```
mkdir ~/local/src/hellobasis/build
cd ~/local/src/hellobasis/build
cmake -D CMAKE_INSTALL_PREFIX=~/local ..
make
```

See Also:

The guide on how to *Install any Software*.

Add an Executable

Copy the source file from the example to `src/`:

```
cd ~/local/src/hellobasis
cp ${HELLOBASIS_RSC_DIR}/helloc++.cxx src/
```

Add the following line to `src/CMakeLists.txt` under the section "executable target(s)":

```
basis_add_executable(helloc++.cxx)
```

Alternatively, you can use the implementation of this example executable in Python, Perl, BASH or MATLAB. In case of MATLAB, add also a dependency to MATLAB:

```
basisproject --root ~/local/src/hellobasis --use MATLAB
```

Change target properties

- The name of the output file is given by the `OUTPUT_NAME` property.
- To change this property, add the following line to the `src/CMakeLists.txt` file (**after** `basis_add_executable`):

```
basis_set_target_properties(helloc++ PROPERTIES OUTPUT_NAME "hellobasis")
```

If you used another source file, you need to replace "helloc++" by its name (excl. the extension).

Test the Executable

Now build the executable from the previously added source code. As the build system has been configured before using CMake, only GNU `make` has to be invoked. It will recognize the change of the `CMakeLists.txt` file and therefore reconfigure the build system before re-building the software.

```
cd ~/local/src/hellobasis/build
make
bin/hellobasis
How is it going?
```

Install the executable and test it:

```
make install
hellobasis
How is it going?
```

Note that the `hellobasis` executable was installed into the `~/local/bin/` directory as we set the installation root directory to `~/local` using the `CMAKE_INSTALL_PREFIX` CMake variable. This directory should be listed in your *PATH* environment variable when you followed the *environment set up* steps at the begin of this tutorial.

Add Libraries

Next, you will add three kinds of libraries, i.e., collections of binary or script code, to your example project. We distinguish here between private, public, and script libraries. A private library is a library without public interface which is only used by other libraries and in particular executables of the project itself. A public library provides a public interface for users of your software. Therefore, the declarations of the interface given by `.h` files in case of C/C++ are copied to the installation directory along with the binary library file upon installation. Another kind of library is one written in a scripting language such as Python, Perl, or BASH. Such library is more commonly referred to as *module*.

Add a private library

Copy the files from the example to `src/`:

```
cd ~/local/src/hellobasis
cp ${HELLOBASIS_RSC_DIR}/foo.* src/
```

Add the following line to `src/CMakeLists.txt` under the section "library target(s)":

```
basis_add_library(foo.cxx)
```

Add a public library

Create the subdirectory tree for the public header files declaring the public interface:

```
cd ~/local/src/hellobasis
basisproject --root . --include
mkdir include/hellobasis
```

Copy the files from the example. The public interface is given by `bar.h`.

```
cp ${HELLOBASIS_RSC_DIR}/bar.cxx src/
cp ${HELLOBASIS_RSC_DIR}/bar.h include/hellobasis/
```

Add the following line to `src/CMakeLists.txt` under the section "library target(s)":

```
basis_add_library(bar.cxx)
```

Add a scripted module

Copy the example Perl module to `src/`:

```
cd ~/local/src/hellobasis
cp ${HELLOBASIS_RSC_DIR}/FooBar.pm.in src/
```

Add the following line to `src/CMakeLists.txt` under the section "library target(s)":

```
basis_add_library(FooBar.pm)
```

The .in suffix

- Note that some of these files have a `.in` file name suffix.
- This suffix can be omitted in the `basis_add_library` statement. It has however an impact on how this function treats this file.
- The .in suffix indicates that the file is not usable as is, but contains patterns such as `@PROJECT_NAME@` which BASIS should replace during the build of the module.
- The substitution of these `@*@` patterns is what we refer to as "building" script files.

Install the libraries

Now build the libraries and install them:

```
cd ~/local/src/hellobasis/build
make && make install
```

Next Steps

Congratulations! You just finished your first BASIS tutorial.

So far you have already learned how to install BASIS on your system and set up your own software project. You have also seen how you can add your own source files to your newly created project and build the respective executables and libraries. The essentials of any software package! Thanks to BASIS, only few lines of CMake code are needed to accomplish this.

Now check out the *Advanced Tutorials* for more details regarding each of the above steps and in-depth information about the used BASIS commands if you like, or move on to the various *How-to Guides* which will introduce you to even more BASIS concepts and best practices.

2.2 Advanced Tutorials

The tutorial slides linked here for download give a slide-by-slide introduction to BASIS and its use including in-depth information and references to further documentation. For a less comprehensive tutorial-like introduction, please refer to the *First Steps* above.

0. Download `BASIS Introduction` for an explanation of the components and purpose of BASIS (ref).
1. Download `Getting Started` (ref)

3 How-to Guides

The how-to guides describe BASIS concepts and best practices which help to conform with the *Standards* defined by BASIS, and explain common tasks such as creating a new project or its installation.

3.1 Create/Modify a Project

This how-to guide introduces the `basisproject` command-line tool which is installed as part of BASIS. This tool is used to create a new project based on BASIS or to modify an existing BASIS project. The creation of a new project based on BASIS is occasionally also referred to as instantiating the *Project Template*.

For a detailed description and overview of the available command options, please refer to the output of the following command:

```
basisproject --help
```

Create a New Project

The fastest way to create a new project is to call `basisproject` with the name of the new project and a brief project description as arguments:

```
basisproject --name MyProject \
        --description "This is a brief description of the project."
```

This will create a subdirectory called `MyProject` under the current working directory and populate it with the standard project directory structure and BASIS configuration. No CMake commands to resolve dependencies to other software packages will be added. These can be added later either manually or as described *below*. However, if you know already that your project will depend, for example, on ITK and optionally make use of VTK if available, you can specify these dependencies when creating the project using the `--use` or `--useopt` option, respectivley:

```
basisproject --name MyProject \
        --description "This is a brief description of the project." \
        --use ITK --useopt VTK
```

The basisproject tool will in turn modify the `BasisProject.cmake` file to add the named packages to the corresponding lists of dependencies.

Note: In order for `basisproject` to be able to find the correct place where to insert the new dependencies, the `#<dependency>` et al. placeholders have to be present. See the `BasisProject.cmake` template file.

Modify an Existing Project

`basisproject` allows a detailed selection of the features included in the project template for a particular BASIS project. Which of these features are needed will often not be known during the creation of the project, but change during the work on the project. Therefore, an existing BASIS project which was created as described *above* can be modified using `basisproject` to add or remove certain project features and to conveniently add CMake commands to resolve further dependencies on other software packages. How this is done is described in the following.

General Notes

The two project attributes which cannot be modified using `basisproject` are the project name and its description. These attributes need to be modified manually by editing the project files. Be aware that changing the project name may require the modification of several project files including source files. Furthermore, the project name is used to identify the project within the lab and possibly even externally. Therefore, it should be fixed as early as possible. In order to change the project description, simply edit the `BasisProject.cmake` file which you can find in the top directory of the source tree. Specifically, the argument for the `DESCRIPTION` option of the basis_project() function.

Hence, in order to modify an existing project, the `--name` and `--description` options cannot be used. Instead, use the `--root` option to specify the root directory of the source tree of the project you want to modify or run the command without either of these options with the root directory as current working directory.

Adding Features

By features, we refer here to the set of directories and contained CMake/BASIS configuration files for which template files exist in the BASIS project template. For a list of available project features, please have a look at the help output of `basisproject`. You can either select a pre-configured project template consisting of a certain set of directories and configuration files and optionally modify these sets by removing features from them and/or adding other features, or you can simply remove and/or add selected features only from/to the current set of directories and configuration files which already exist in the project's source tree.

For example, if you created a project using the standard project template (i.e., by supplying no particular option or the option `--standard` during the project creation), but your software requires auxiliary data such as a pre-computed lookup table or a medical image atlas, you can add the `data/` directory in which these auxiliary files should be stored in the source tree using the command:

```
basisproject --data
```

As another example, if you want to extend the default *script configuration file* which is used to configure the build of scripts written in Python, Perl, BASH, or any other scripting language (even if not currently supported by BASIS will it likely still be able to "build" these), use the command:

```
basisproject --config-script
```

Removing Features

For example, in order to remove the `conf/Settings.cmake` file and the `example/` directory tree, run the command:

```
basisproject --noconfig-settings --noexample
```

If any of the project files which were initially added during the project creation differ from the original project file, the removal of such files will fail with an error message. If you are certain that the changes are not important and still want to remove those files from the project, use the `--force` option. Moreover, if a directory is not empty, it will only be removed if the `--force` option is given. Note that a directory is also considered empty if it only contains hidden subdirectories which are used by the revision control software to manage the revisions of the files inside this directory, i.e., the `.svn/` subdirectory in case of Subversion or the `.git/` subdirectory in case of Git. Before using the `--force` option, you should be certain which directories would be removed and if their content is no longer needed. Thus, run any command first without the `--force` option, and only if it failed consider to add the `--force` option.

Adding Dependencies

A dependency is either a program required by your software at runtime or an external software package such as the nifticlib or ITK. `basisproject` can be used to add the names of packages your project depends on to the lists of dependencies which are given as arguments to the basis_project() command. For each named package in this list, the basis_find_package() command is called to look for a corresponding package installation. In order to understand how CMake searches for external software packages, please read the documentation of CMake's find_package() command.

The BASIS package provides so-called Find modules (e.g., FindMATLAB.cmake or FindNiftiCLib.cmake) for external software packages which are commonly used at SBIA and not (yet) part of CMake or improve upon the standard modules. If you have problems resolving the dependency on an external software package required by your software due to a missing corresponding Find module, please contact the maintainer of the BASIS project and state your interest in a support by BASIS for this particular software package. Alternatively, you can write such Find module yourself and save it in the PROJECT_CONFIG_DIR of your project.

As an example on how to add another dependency to an existing BASIS project, consider the following scenario. We created a project without any dependency and now notice that we would like to make use of ITK in our implementation. Thus, in order to add CMake code to the build configuration to resolve the dependency on ITK, which also includes the so-called Use file of ITK (named `UseITK.cmake`) to import its build configuration, run the command:

```
basisproject --use ITK
```

If your project can optionally make use of the features of a certain external software package, but will also built and run without this package being installed, you can use the `--useopt` option to exploit CMake code which tries to find the software package, but will not cause CMake to fail if the package was not found. In this case, you will need to consider the `<Pkg>_FOUND` variable in order to decide whether to make use of the software package or not. Note that the package name is case sensitive and that the case must match the one of the first argument of basis_find_package().

For example, let's assume your software can optionally make use of CUDA. Therefore, as CMake includes already a `FindCUDA.cmake` module, we can run the following command in order to have CMake look for an installation of the CUDA libraries:

```
basisproject --useopt CUDA
```

If this search was successful, the CMake variable `CUDA_FOUND` will be `TRUE`, and `FALSE` otherwise.

Another example of a dependency on an external package is the compilation of MATLAB source files using the MATLAB Compiler (MCC). In this case, you need to add a dependency on the MATLAB package. Please note that it is important to capitalize the package name and not to use `Matlab` as this would refer to the `FindMatlab.cmake` module included with CMake. The FindMATLAB.cmake module which we are using is included with BASIS. It improves the way CMake looks for a MATLAB installation and furthermore looks for executables required by BASIS, such as in particular `matlab`, `mcc`, and `mex`. Use the following command to add a dependency on MATLAB:

```
basisproject --use MATLAB
```

Removing Dependencies

`basisproject` does at the moment not support the removal of previously added dependencies. Therefore, please edit the `BasisProject.cmake` file manually and simply remove all CMake code referring to the particular package you do no longer require or use.

Add Modules

BASIS supports the *modularization* of a project similar to the ITK 4 Modularization, where each module is itself a BASIS project which may depends on other modules of the top-level project or other external packages. As each

module itself is a project, modules are created just the same way as projects are created. The only difference might be that modules may include different sets of features (directories and files) than the top-level project. A project which uses such modularization in turn often does not include source files by its own, but is a collection of the projects (i.e., subprojects) which are its modules.

Therefore, the top-level project often excludes the `src/` subdirectory, but includes the `modules/` directory instead, in which the project's modules reside. First create the top-level project as follows (or simply add a `modules/` directory to an existing project):

```
basisproject --name MyToolkit --description "A modularized project." --toplevel
```

To now add modules to your modularized project, i.e., one which has a `modules/` subdirectory, change to the modules/ subdirectory of the top-level project, and run the command:

```
basisproject --name MyModule --description "A module of MyToolkit." --module
```

Update a Project

Occasionally, the project template of BASIS may be modified as the development of BASIS progresses. In such case, you may want or need to update the files of a project which have been created from a previous version of the project template. In order to help updating a project to a newer project template version, the project tool uses a three-way file comparison similar to Subversion to merge changes in the template files with those changes you have made to the corresponding files of your project. If such merge fails because both the template as well as the project file have been changed at the same lines, a merge conflict occurs which has to be resolved manually. In no case, however, `basisproject` will discard your changes. There will always be a backup of your current project file, before the automatic file merge is performed.

To update the project files, run the following command in the root directory of your project's source tree:

```
basisproject --update
```

If the project template has not been changed since the last update, no files will be modified by this command.

Resolving Merge Conflicts

When the same lines of the template file as well as the project file have been modified since the creation or last update of the project, you will get a merge conflict. A merge conflict results in a merged project file which contains the changes of both the template and your current project file. Markers such as the following are used to highlight the lines of the merged file which are in conflict with each other.

Marker	Description
`<<<<<<<`	Marks the start of conflicting lines. This marker is followed by your changes from the corresponding lines of your project file.
`|||||||`	Marks the start of the corresponding lines from the original template file which was used to create the project or which the project has been updated to last.
`=======`	Marks the start of the corresponding lines from the current template file, i.e., the one the project file should be updated to.
`>>>>>>>`	Marks the end of the conflicting lines.

In order to resolve the conflicts in one file, you have to edit the merged project file manually. For reference, `basisproject` writes the new template file to a file named like the project file in conflict with this project file, using .template as file name suffix. It further keeps a backup of your current project file before the update. The file name suffix for this backup file is `.mine`. For example, if conflicts occured when updating the `README.txt` file, the following files are written to your project's directory.

File Name	Description
`README.txt.mine`	A copy of the project file before the update.
`README.txt.template`	A copy of the current template file which differs from the template file used to create the project or corresponds to the version of the template file of the last update.
`README.txt`	The file containing changes from both the `README.txt.template` and `README.txt.mine` file, where conflicts have been highlighted using above markers.

After you edited the project files which contain conflicts, possibly using merge tools installed on your system, you need to remove the `.template` and `.mine` files to let `basisproject` know that the conflicts are resolved. Otherwise, when you run the update command again, it will fail with an error message indicating that there are unresolved merge conflicts. You can delete those files either manually or using the following command in the root directory of your project's source tree.

```
basisproject --cleanup
```

3.2 Create a Custom Template

In addition to creating new projects from an existing project template, the `basisproject` command-line tool can also be used to generate a new *Project Template* customized for your needs.

For a detailed description and overview of the available command options, please refer to the output of the following command:

```
basisproject --help
```

Create a New Template

The fastest way to create a new template is to call `basisproject` with the name of the new template and the option `--new-template`:

```
basisproject --name MyTemplate --new-template
```

This will create a subdirectory called `MyTemplate/1.0` under the current working directory and populate it with the current default project template structure and BASIS configuration. With this you can modify the the default substitutions and file contents for your needs, and create new versions so that users can update their source tree automatically as you improve and update your customized template.

Note: Use the template options of the existing template to specify which features of this template to copy when creating the new template.

Use a Custom Template

To use a custom template that you have created, specify the path to the template including the version subdirectory as part of the `basisproject` command as follows:

```
basisproject --name MyProject --template path/to/MyTemplate/1.0
```

Other than that you can use your custom template in the same manner as described in *The How-To on Creating and Modifying a Project*.

Make Custom Template the Default

During the installation of BASIS, it is possible to specify a custom template as the default used by `basisproject` when called without the `--template` argument. See the *BasisInstallationOptions* for details.

Template Layout

```
- template_name/
    - 1.0/
        + _config.py
        + src/
        + config/
        + data/
        + doc/
        + example/
        + modules/
        + test/
    - 1.1/
    - 2.0/
    - 2.1/
    - .../
```

Note: Only the files which were modified or added have to be present in the new template. The `basisproject` tool will look in older template directories for any missing files.

Template Versions

The template system is designed to help automate updates of existing libraries to new template versions. Whenever a template file is modified or removed, the previous project template has to be copied to a new directory with an updated template version! Otherwise, the three-way diff merge used by the `basisproject` tool to update existing projects to this newer template will fail.

Custom Substitutions

The template configuration file named `_config.py` and located in the top directory of each project template defines not only which files constitute a project, but also the available substitution parameters and defaults used by `basisproject`. The template configuration file requires a basic understanding of Python syntax, but is fairly easy to understand even without much experience. To get an idea of the syntax, take a look at the example below. A complete example can be found in the BASIS source package in `data/templates/basis/1.0/_config.py`.

```
# project template configuration script for basisproject tool

# ----------------------------------------------------------------------------
# required project files
required = [
  'AUTHORS.txt',
  'README.txt',
  'INSTALL.txt',
  'COPYING.txt',
  'CMakeLists.txt',
  'BasisProject.cmake'
]
```

```
# ------------------------------------------------------------------------------
# optional project files
options = {
  'config-settings' : {
    'desc' : 'Include/exclude custom Settings.cmake file.',
    'path' : [ 'config/Settings.cmake' ]
  },
  'config' : {
    'desc' : 'Include/exclude all custom configuration files.',
    'deps' : [
               'config-settings'
             ]
  },
  'data' : {
    'desc' : 'Add/remove directory for auxiliary data files.',
    'path' : [ 'data/CMakeLists.txt' ]
  }
}

# ------------------------------------------------------------------------------
# preset template options
presets = {
  'minimal' : {
    'desc' : 'Choose minimal project template.',
    'args' : [ 'src' ]
  },
  'default' : {
    'desc' : 'Choose default project template.',
    'args' : [ 'doc', 'doc-rst', 'example', 'include', 'src', 'test' ]
  },
  'toplevel' : {
    'desc' : 'Create toplevel project.',
    'args' : [ 'doc', 'doc-rst', 'example', 'modules' ]
  },
  'module' : {
    'desc' : 'Create module of toplevel project.',
    'args' : [ 'include',   'src',   'test' ]
  }
}

# ------------------------------------------------------------------------------
# additional substitutions besides <project>, <template>,...
from datetime import datetime as date

substitutions = {
  # fixed computed substitutions
  'date'  : date.today().strftime('%x'),
  'day'   : date.today().day,
  'month' : date.today().month,
  'year'  : date.today().year,
  # substitutions which can be overridden using a command option
  'vendor' : {
    'help'    : "Package vendor ID (e.g., acronym of provider and/or division).",
    'default' : "SBIA"
  },
  'copyright' : {
    'help'    : "Copyrigth statement optionally including years, but not \". All rights reserved.\".'
    'default' : str(date.today().year) + " University of Pennsylvania"
```

```
},
'license' : {
  'help'    : "Software license statement, e.g., \"Simplified BSD\" or reference to license text.",
  'default' : "See http://www.rad.upenn.edu/sbia/software/license.html or COPYING file."
},
'contact' : {
  'help'    : "Package contact information.",
  'default' : "SBIA Group <sbia-software at uphs.upenn.edu>"
}
```

3.3 Managing Test Data

Note: This how-to guide has to be written yet.

This document describes how example and test data can be stored outside the source tree.

See Also:

http://www.cmake.org/Wiki/ITK/Git/Develop/Data#ExternalData

See Also:

http://vtk.org/Wiki/ITK_Release_4/Testing_Data

3.4 Documenting Software

Note: This how-to guide is yet not complete.

BASIS supports two well-known and established documentation generation tools: Doxygen and Sphinx.

Since version 1.8.0, Doxygen can natively generate documentation from C/C++, Java, Python, Tcl, and Fortran. The markup language used to format documentation comments was originally a set of commands inherited from Javadoc. More recently, Doxygen further adopted Markdown and elements from Markdown Extra. To extend the reportoire of programming languages processed by Doxygen, so-called custom Doxygen filters can be provided which transform any source code into the syntax of one of the languages well understood by Doxygen. The target language used is commonly C/C++ as this is the language best understood by Doxygen. The goal of BASIS is to provide one such filter for each programming language supported by it but not by Doxygen, i.e., Bash, Perl, and MATLAB. Moreover, a Doxygen filter for Python allows the use of Doxygen tags within doc strings as well by converting doc strings to Doxygen-style comments.

Besides Doxygen, BASIS makes use of Sphinx for the alternative documentation generation from Python source code and corresponding doc strings. The markup language used by Sphinx is reStructuredText (reST). The wide spectrum of output formats, including in particular, HTML, LaTeX, and man pages, supported by the Docutils which include the tools to process reST and are further utilized by Sphinx, the preferred way of writing a software manual, developer's guide, tutorial slides, and a project web site is by providing text files marked up using reST which are then processed by Sphinx to generate documentation in the desired output format.

The two Sphinx extensions breathe and doxylink which are included with BASIS can be used to include, respectively, link to the the documentation generated by Doxygen from the documentation generated by Sphinx. The latter only for the HTML output, which, however, is the most commonly used and preferred output format. Given that the project web site and manuals are generated by Sphinx and only the more advanced reference documentation is generated by Doxygen, this one directional linking of documentation pages is sufficient for most use cases.

Last but not least, Markdown and Markdown Extra can be used as an alternative to reStructuredText for additional documentation pages. This is in particular of interest for the root package documentation files such as the AUTHORS, README, INSTALL, and COPYING files. Many online hosting platforms for the distribution of open source software such as SourceForge and GitHub can display such files on the project page with the marked up formatting.

Note: At the moment, not all of these documentation tools are supported for all the programming languages considered.

ChangeLog

Generated from revision history.

Software Manual

Introduces users to software tools and guides them through example application.

Developer's Guide

Describes implementation details.

API Documentation

Documentation generated from source code and in-source comments.

Software Web Site

A web site can be created using the documentation generation tool Sphinx. The main input to this tool are text files written in the lightweight markup language reStructuredText. A default theme for use at SBIA has been created which is part of BASIS. This theme together with the text files that define the content and structure of the site, the HTML pages of the software web site can be generated by `sphinx-build`. The CMake function basis_add_doc() provides an easy way to add such web site target to the build configuration. For example, the template `doc/CMakeLists.txt` file contains the following section:

```
# ----------------------------------------------------------------------------
# web site (optional)
if (EXISTS "${CMAKE_CURRENT_SOURCE_DIR}/site/index.rst")
  basis_add_doc (
    site
    GENERATOR     Sphinx
    BUILDER       html dirhtml pdf man
    MAN_SECTION   7
    HTML_THEME    sbia
    HTML_SIDEBARS globaltoc
    RELLINKS      installation documentation publications people
    COPYRIGHT     "<year> University of Pennsylvania"
    AUTHOR        "<author>"
  )
endif ()
```

where <year> and <author> should be replaced by the proper values. This is usually done by the *basisproject* command-line tool upon creation of a new project.

This CMake code adds a build target named `site` which invokes `sphinx-build` with the proper default configuration to generate a web site from the reST source files with file name extension `.rst` found in the `site/` subdirectory. The source file of the main page, the so-called master document, of the web site must be named `index.rst`. The main pages which are linked in the top navigation bar are named using the `RELLINKS` option of basis_add_sphinx_doc(), the CMake function which implements the addition of a Sphinx documentation target. The corresponding source files must be named after these links. For example, given above CMake code, the reStructuredText source of the page with the download instructions has to be saved in the file `site/download.rst`.

See the *corresponding section* of the `../install` guide for details on how to generate the HTML pages from the reST source files given the specification of a Sphinx documentation build target such as the `site` target defined by above template CMake code.

3.5 Branch and Release

This guide defines the process of creating a new development branch other than the trunk and the creation of a release version of a software. Before reading this document, you should be familiar with the basic structure of any revision controlled software project as described in the *Filesystem Layout*.

Branching and Merging

Please read the corresponding SVN Book article.

Releasing Software

Whenever the software of a project is to be used by another project or user, the following steps have to be performed in order to create a new release version of the software.

1. If the development was carried out in a branch other than the trunk, the changes which shall be part of the release version have to be merged back to the trunk. Therefore, use the `svn merge` command as described in the SVN Book.

2. Then the trunk is copied to a branch which is used to apply release specific adjustments such as setting the version number or to apply bug fixes to this particular release version. Therefore, name this branch "<project>-<major>.<minor>" (note that the patch number is excluded!) to indicate that this branch represents the "<major>.<minor>" series of software releases.

   See *Branching and Merging* for details on how to create a new branch.

3. Edit the `BasisProject.cmake` file of the new release branch and change the `VERSION` argument to the proper version as described below.

   The version number consists of three components: the major version number, the minor version number, and the patch number. The format of the version number is "<major>.<minor>.<patch>", where the minor version number and patch number default to 0 if not given. Only digits are allowed except of the two separating dots.

   For release candidates which are made available for review, on the other side, instead of the patch number, prepend "rc<N>" to the release version, where N is the number of the release candidate. For example, the first release candidate of the first stable release will have the version number "1.0.0rc1", the second release candidate which is tagged after bug fixes have been applied, will have the version "1.0.0rc2", etc. Once the 1.0 version was reviewed and is ready for final release, change the version to "1.0.0". From now on, the patch number will be increased by one for each consecutive maintenance release of the 1.0 version.

- Beta releases have the major version number 0. The first stable release the major version number 1, the second major stable release the number 2, etc.
- A change of the major version number indicates changes of the software API (and often ABI) and/or its behavior and/or the change or addition of major features.
- A change of the minor version number indicates changes that are not only bug fixes and no major changes. Hence, changes of the API, but not ABI.
- A change of the patch number indicates changes only related to bug fixes which did not change the software API nor ABI. It is the least important component of the version number.

4. After setting the version number, tag the release branch as "<project>-<version>", i.e., copy the branch "branches/<project>-<major>.<minor>" to "tags/<project>-<version>".
5. Now select the reviewers and ask them to retrieve a copy of the tagged release candidate. According to the reviewers feedback, the release branch is bug fixed and a new release candidate is tagged (after increasing the N in "<major>.<minor>rc<N>") and made available for the next review iteration.
6. The prvieous step is iterated until the release candidate passed all reviews. Once this is the case, set the version to "<major>.<minor>.0" and create a corresonding tag.
7. Optionally, binary and source distribution packages are generated from the tagged release branch and uploaded to the public domain. See the *Packaging Software* guide for details on how to create such distribution packages.
8. Inform the users that a new release is available and update any internal and external documentation related to the software package.
9. Finally, make sure that all bug fixes which were applied to the release branch are merged back to the trunk where the development continues. Do not implement new features in the created release branch. This branch will only be used for maintenance of the "<major>.<minor>" series of the software.

Note: The trunk is not associated with a version other than the revision number as it is always in development. Therefore, the trunk always uses the invalid version 0.0.0.

Do not forget to commit all changes to the release branch, not the trunk. In particular the adjustment of the version number shall not be applied to the trunk as it will always keep the invalid version 0.0.0.

3.6 Packaging Software

This document describes the packaging of BASIS projects.

Distribution of Sources

A source package for distribution which only includes basic tests and selected modules can be generated using CPack. In particular, the build target `package_source` is used to generate a `.tar.gz` file with the source files of the distribution package. This package will include all source files except those which match one of the patterns in the `CPACK_SOURCE_IGNORE_FILES` CMake list which is set to common default patterns in the BasisPack.cmake module. Additional exclude patterns for a particular package shall be added to the `Settings.cmake` file of the project. Moreover, if the project contains different *modules*, only the enabled modules are included. For general steps on how to configure a build tree, see the *common build instructions*. Given a configured build tree with a generated `Makefile`, run the following command to generate the source distribution package:

```
make package_source
```

3.7 Install any Software

The following contains general build and installation instructions which apply to any project which is developed using CMake BASIS.

Build Steps Overview

See *Prerequisites* below for information on dependencies.

Build Steps

The common steps to build, test, and install software from source code based on CMake are as follows:

1. Extract source files.
2. Create build directory and change to it.
3. Run CMake to configure the build tree.
4. Build the software using selected build tool.
5. Test the built software.
6. Install the built files.

On Unix-like systems with GNU Make as build tool, these build steps can be summarized by the following sequence of commands executed in a shell, where $package and $version are shell variables which represent the name of this package and the obtained version of the software.

```
$ tar xzf $package-$version-source.tar.gz
$ mkdir $package-$version-build
$ cd $package-$version-build
$ ccmake ../$package-$version-source
```

- Press 'c' to configure the build system and 'e' to ignore warnings.
- Set CMAKE_INSTALL_PREFIX and other CMake variables and options.
- Continue pressing 'c' until the option 'g' is available.
- Then press 'g' to generate the configuration files for GNU Make.

```
$ make
$ make test    (optional)
$ make install (optional)
```

An exhaustive list of minimum build dependencies, including the build tools along detailed step-by-step build, test, and installation instructions can be found in the corresponding "Building from Sources" section of the BASIS how-to guide on software installation [2].

Please refer to the rest of this guide first if you are uncertain about above steps or have problems to build, test, or install the software on your system. If this guide does not help you resolve the issue, please contact the provider of the respective software package. In case of failing tests, please attach the output of the following command to your email:

```
$ ctest -V >& test.log
```

Prerequisites

The following software packages are prerequisites for any software that is based on BASIS. Note that the stated package versions are usually the minimum versions for which it is known that the software is working with. Newer versions will usually be fine as well if not otherwise stated by the particular software documentation, but less certainly older versions.

See the installation instructions of the specific software package for details on what is required and which optional software is being used if available. For instructions on how to build or install any of the following software packages, please refer to the documentation of the respective package.

Required Packages

Package	Version	Description
CMake	2.8.4	A cross-platform, open-source build tool used to generate platform specific build configurations. It configures the system for the various build tools which perform the actual build of the software. If your operating system such as certain Linux distribution does not include a pre-build binary package of the required version yet, download a more recent CMake version from the CMake download page and build and install it from sources. Often this is easiest accomplished by using the CMake version provided by the Linux distribution in order to configure the build system for the more recent CMake version. To avoid conflict with native CMake installation, it is recommended to install your own build of CMake in a different directory.
`BASIS`		The CMake Build system And Software Implementation Standard (BASIS) among other features defines the project directory structure and provides CMake implementations to ease and standardize the packaging, build, testing, and installation. Refer to the `INSTALL` document of the software package you want to build for information on which particular BASIS version is required by this package.
GNU Make, ninja, etc.		All build tools supported by the CMake generator
GNU Compiler Collection, Clang, etc.		A C++ compiler is required to compile the BASIS source code.

Optional Packages

Package	Version	Description
Doxygen	1.8.0	This tools is required for the generation of the API documentation from in-source comments in C++, CMake, Bash, Python, and Perl. Note that only since version 1.8.0, Python and the use of Markdown (Extra) are support by Doxygen.
Python	2.7	Python is used by the basisproject tool that generates template projects. Python is also generally supported for the implementation of tools and libraries following the BASIS standard.
Sphinx	1.1.3	This tool can be used for the generation of the documentation from in-source Python comments and in particular from reStructuredText.
LaTeX		The LaTeX tools may be required for the generation of the software manuals. Usually these are, however, already included in PDF in which case a LaTeX installation is only needed if you want to regenerate these from the LaTeX sources (if available after all).
MATLAB	R2009b	The MATLAB tools such as, in particular, the MEX script are used to build MEX-Files from C++ source code. A MEX-File is a loadable module for MATLAB which implements a single function. If the software package you are building does not define any MEX build target, MATLAB might not be required.
MATLAB Compiler	R2009b	The MATLAB Compiler (MCC) is required for the build of standalone executables and shared libraries from MATLAB source files. If the software package you are building does not include any MATLAB sources (`.m` files), you do not need the MATLAB Compiler to build it.

Build and Installation

These are the build, test, and installation steps common to any BASIS based software, including BASIS itself. See *BasisInstallationSteps* for installation instructions specific to the CMake BASIS package itself.

If you obtained a binary distribution package for a supported platform, please follow the installation instructions corresponding to your operating system. The build step can be omitted in this case.

Note: The commands given in this guide have to be entered in a terminal, in particular, the Bourne Again Shell (Bash). If you are not using the Bash, see the documentation of your particular shell for information on how to perform these actions using this shell instead.

Package Names

The file names of the distribution packages follow the convention `<package>-<version>-<arch><ext>`, where `<package>` is the name of the package in lowercase letters, and `<version>` is the package version in the format `<major>.<minor>.<patch>`. The `<arch>` file name part specifies the operating system and hardware architecture, i.e.,

<arch>	Description
linux-x86	Linux, 32-bit
linux-x86_64	Linux, 64-bit
darwin-i386	Darwin x86 Intel
darwin-ppc	Darwin Power PC
win32	Windows, 32-bit
win64	Windows, 64-bit
source	Source files

The file name extension <ext> is .tar.gz for a compressed tarball, .deb for a Debian package, and .rpm for a RPM package.

Binary Distribution Package

Debian Package This package can be installed on Debian and its derivatives such as Ubuntu using the Advanced Package Tool (APT):

```
sudo apt-get install <package>-<version>-<arch>.deb
```

RPM Package This package can be installed on Red Hat Enterprise Linux and its derivatives such as CentOS and openSUSE using the Yellowdog Updater, Modified (YUM):

```
sudo yum install <package>-<version>-<arch>.rpm
```

Mac OS Bundles for Mac OS might be available for some software packages, but this is not supported by default. Please refer to the INSTALL file which is located in the top directory of the respective software package.

Windows Currently, Microsoft Windows has limited support as an operating system. The most tested platform is the Linux platform CentOS, in particular, and most software packages are therefore dependent on a Unix-based operating system. Thus, building and executing SBIA software under Windows will most likely require an installation of Cygwin and the build of the software from sources as described below. Some packages, on the other side, can be build on Windows as well, using, for example, Microsoft Visual Studio as build tool. The Visual Studio project files have to be generated using CMake (see *Building From Sources*).

As an alternative, consider the use of a Live Linux Distribution, a dual boot installation of Linux or an installation of a Linux operating system in a virtual machine using virtualization tools such as VirtualBox or proprietary virtualization solutions available for your host operating system.

Building From Sources

In the following, we assume you obtained a copy of the source package as compressed tarball (.tar.gz). The name and version part of the package file is referred to as Bash variable:

```
package=<package>-<version>
```

Extract sources At first, extract the downloaded source package, e.g.:

```
tar -xzf $package-source.tar.gz ~
```

This will extract the sources to a new diretory in your home directory named "<package>-<version>-source".

Configure Create a directory for the build tree of the package and change to it, e.g.:

```
mkdir ~/$package-build
cd ~/$package-build
```

Note: An in-source build, i.e., building the software within the source tree is not supported to force a clear separation of source and build tree.

To configure the build tree, run CMake's graphical tool ccmake:

```
ccmake ~/$package-source
```

Press `c` to trigger the configuration step of CMake. Warnings can be ignored by pressing `e`. Once all CMake variables are configured properly, which might require the repeated execution of CMake's configure step, press `g`. This will generate the configuration files for the selected build tool (i.e., GNU Make Makefiles in our case) and exit CMake.

Variables which specify the location of other required or optionally used packages if available are named `<Package>_DIR`. These variables usually have to be set to the directory which contains a file named `<Package>Config.cmake` or `<package>-config.cmake`. Alternatively, or if the package does not provide such CMake package configuration file, the installation prefix, i.e., root directory should be specified. See the build instructions of the particular software package you are building for more details on the particular `<Package>_DIR` variables that may have to be set if the packages were not found automatically by CMake.

See the documentation of the available *CMake Options* for more options that can be used to configure the build of any project developed with BASIS. Please refer also to the package specific build instructions given in the `INSTALL` file or software manual of the corresponding package for information on available additional project specific configuration options.

Note: The ccmake tool also provides a brief description to each variable in the status bar.

CMake Options The following standard CMake options/variables can be configured, see the documentation of CMake itself for more details:

`-DBASIS_DIR:``PATH`
: Directory where the `BASISConfig.cmake` file is located. Alternatively, the installation prefix used to install BASIS can be specified instead.

`-DBUILD_DOCUMENTATION:``BOOL`
: Whether build and installation instructions for the documentation should be added. If OFF, the build configuration of the doc/ directory is skipped. Otherwise, the `doc` target is added which can be used to build the documentation. You may still need to run make doc, make manual, make site, etc. by hand, this option enables those settings.

Note: Though surprising at first glance, the build of the documentation may often be preceeded by the build of the software itself. The reason is that the documentation can in general only be generated after script files have been configured. Thus, do not be surprised if `make doc` will actually first build the software if not up to date before generating the API documentation.

`-DBUILD_EXAMPLE:``BOOL`
: Whether the examples should be built (if required) and/or installed.

`-DBUILD_TESTING:``BOOL`
: Whether the testing tree should be built and system tests, i.e., tests that execute the installed programs and compare the outputs to the expected results should be installed (if done so by the software package).

-DCMAKE_BUILD_TYPE:STRING
Specify the build configuration to build. If not set, the `Release` configuration will be build. Common values are `Release` or `Debug`.

-DCMAKE_INSTALL_PREFIX:PATH
Prefix used for package *installation*. See also the CMake reference.

-DUSE_<Package>**:**BOOL
If the software you are building has declared optional dependencies, i.e., software packages which it makes use of only if available, for each such optional package a `USE_<Package>` option is added by BASIS if this package was found on your system. It can be set to OFF in order to disable the use of this optional dependency by this software.

The following BASIS specific options are available when building packages. For the full set of options and descriptions use the ccmake tool. For CMake specific options see the documentation for your CMake installation.

Advanced CMake Options Advanced users may further be interested in the settings of the following options which in most cases are automatically derived from the non-advanced CMake options summarized above. To view these options in the CMake GUI, press the `t` key in `ccmake` (Unix) or check the `Show Advanced Values` box (Windows).

-DBASIS_ALL_DOC:BOOL
Request the build of all documentation targets as part of the `ALL` target if `BUILD_DOCUMENTATION` is `ON`.

-DBASIS_COMPILE_SCRIPTS:BOOL
Enable compilation of Python modules. If this option is enabled, only the compiled `.pyc` files are installed.

-DBASIS_COMPILE_MATLAB:BOOL
Whether to compile MATLAB sources using the MATLAB Compiler (mcc) if available. If set to `OFF`, the MATLAB source files are copied as part of the installation and a Bash script for the execution of `matlab` with the `-c` option is generated on Unix or a Windows NT Command script on Windows, respectively. This allows the convenient execution of the executable implemented in MATLAB even without having a license for the MATLAB Compiler. Each instance of the built executable will take up one MATLAB license, however. Moreover, the startup of the executable is longer every time, not only the first time it is launched as is the case for mcc compiled executables. It is therefore recommended to enable this option and to obtain a MATLAB Compiler license if possible. By default, this option is `ON`.

-DBASIS_DEBUG:BOOL
Enable debugging messages during build configuration.

-DBASIS_INSTALL_APIDOC_DIR:PATH
Installation directory of the API documentation relative to the installation prefix.

-DBASIS_INSTALL_SCHEME:STRING
Installation scheme, i.e., filesystem hierarchy, to use for the installation of the software files relative to the installation prefix specified by the *-DCMAKE_INSTALL_PREFIX*. Valid values are `default`, `usr`, `opt`, or `win`. See *Installation Tree* as defined by the *Filesystem Layout* of BASIS for more details.

-DBASIS_INSTALL_SITE_DIR:PATH
Installation directory of the web site relative to the installation prefix.

-DBASIS_INSTALL_SITE_PACKAGES:BOOL
Whether to install public module libraries written in a scripting language such as Python or Perl in the system-wide default locations for site packages. This option is disabled by default as write permission to these directories are required otherwise.

-DBASIS_MCC_FLAGS:STRING
Additional flags for MATLAB Compiler separated by spaces.

-DBASIS_MCC_MATLAB_MODE:BOOL
: Whether to call the MATLAB Compiler in MATLAB mode. If ON, the MATLAB Compiler is called from within a MATLAB interpreter session, which results in the immediate release of the MATLAB Compiler license once the compilation is done. Otherwise, the license is reserved for a fixed amount of time (e.g. 30 min).

-DBASIS_MCC_RETRY_ATTEMPTS:INT
: Number of times the compilation of MATLAB Compiler target is repeated in case of a license checkout error.

-DBASIS_MCC_RETRY_DELAY:INT
: Delay in number of seconds between retries to build MATLAB Compiler targets after a license checkout error has occurred.

-DBASIS_MCC_TIMEOUT:INT
: Timeout in seconds for the build of a MATLAB Compiler target. If the build of the target could not be finished within the specified time, the build is interrupted.

-DBASIS_MEX_FLAGS:STRING
: Additional flags for the MEX script separated by spaces.

-DBASIS_MEX_TIMEOUT:INT
: Timeout in seconds for the build of MEX-Files.

-DBASIS_REGISTER:BOOL
: Whether to register installed package in CMake's package registry. This option is enabled by default such that packages are found by CMake when required by other packages based on this build tool.

-DBASIS_VERBOSE:BOOL
: Enable verbose messages during build configuration.

-DBUILD_CHANGELOG:BOOL
: Request build of ChangeLog as part of the ALL target. Note that the ChangeLog is generated either from the Subversion history if the source tree is a SVN working copy, or from the Git history if it is a Git repository. Otherwise, the ChangeLog cannot be generated and this option is disabled again by BASIS. In case of Subversion, be aware that the generation of the ChangeLog takes several minutes and may require the input of user credentials for access to the Subversion repository. It is recommended to leave this option disabled and to build the changelog target separate from the rest of the software package instead (see *Build the Software*).

-DITK_DIR:PATH
: Path to the directory of your ITK installation, if applicable.

-DMATLAB_DIR:PATH
: Path to the directory of your MATLAB installation, if applicable.

-DSPHINX_DIR:PATH
: Path to the directory of your Sphinx installation, if applicable.

Build the Software To build the executables and libraries, run GNU Make in the root directory of the configured build tree:

```
make
```

In order to build the documentation, the *-DBUILD_DOCUMENTATION* option has to be set to ON. If not set before, this option can be enabled using the command:

```
cmake -D BUILD_DOCUMENTATION:BOOL=ON ~/$package-build
```

Note that the build of the documentation may require the build of the software beforehand. If the software was not build before, the build of the documentation will also trigger the build of the software.

Each software package provides different documentation. In general, however, each software has a manual, which by default is being build by the manual target if the software manual is not already included as PDF document. In the

latter case, the manual does not have to be build. Instead, the PDF file will simply be copied (and renamed) during the installation. Otherwise, in order to build the manual from source files such as reStructuredText or LaTeX, run the command:

```
make manual
```

If the software provides a software library for use in your own code, the API documentation may be useful which can be build using the `apidoc` target:

```
make apidoc
```

The advanced *-DBASIS_INSTALL_APIDOC_DIR* configuration option can be set to an absolute path or a path relative to the *-DCMAKE_INSTALL_PREFIX* directory in order to modify the installation directory for the API documentation which is generated from the in-source comments using tools such as Doxygen and Sphinx. This can be useful, for example, to install the documentation in the document directory of a web server.

Some software packages further generate a project web site from text files marked up using a lightweight markup language such as reStructuredText. This web site can be build using the `site` target:

```
make site
```

This will generate the HTML pages and corresponding static files of the web site in `doc/site/html/`. If you prefer a single directory per document which results in prettier URLs without the `.html` extension, run the following command instead:

```
make site_dirhtml
```

The resulting web site can then be found in `doc/site/dirhtml/`. Optionally, the advanced *-DBASIS_INSTALL_SITE_DIR* configuration option can be set to an absolute path or a path relative to the *-DCMAKE_INSTALL_PREFIX* directory in order to modify the installation directory for the generated web site. This can be useful, for example, to install the web site in the document directory of a web server.

For maintainers of the software, a developer's guide may be provided which would then be build by the `guide` target if not included as PDF document:

```
make guide
```

If the source tree is a Subversion working copy and you have access to the Subversion repository of the project or if the project source tree is a Git repository, a ChangeLog file can be generated from the commit history by building the `changelog` target:

```
make changelog
```

In case of Subversion, be aware that the generation of the ChangeLog takes several minutes and may require the input of your user credentials for access to the Subversion repository. Moreover, if the command svn2cl is installed on your system, it will be used to format the ChangeLog prettier. Otherwise, the plain output of the `svn log` command is written to the `ChangeLog` file.

Note: Not all of the above build targets are provided by each software package. You can see a list of available build targets by running `make help`. All available documentation targets, except the ChangeLog, can be build by executing the command `make doc`.

Test the Software In order to run the software tests, execute the command:

```
make test
```

For more verbose test output, which in particularly is of importance when submitting an issue report, run CTest directly with the `-V` option instead:

```
ctest -V >& $package-test.log
```

and attach the file `$package-test.log` to the issue report.

Note: If the software package does not include tests, follow the steps in the software manual to test the software manually with the provided example dataset.

Install the Software First, make sure that the CMake configuration options *-DCMAKE_INSTALL_PREFIX*, *-DBASIS_INSTALL_SCHEME*, and *-DBASIS_INSTALL_SITE_PACKAGES* are set properly, where for normal use cases only *-DCMAKE_INSTALL_PREFIX* may be modified. These variables can be set as follows:

```
cmake -D "CMAKE_INSTALL_PREFIX:PATH=<prefix>" ~/$package-build
```

or:

```
cmake -D "CMAKE_INSTALL_PREFIX:PATH=<prefix>" \
      -D "BASIS_INSTALL_SCHEME:STRING=default|usr|opt|win" \
      -D "BASIS_INSTALL_SITE:BOOL=ON|OFF" \
      ~/$package-build
```

This can be omitted if these variables were set already during the configuration of the build tree or if the default values should be used. On Linux, *-DCMAKE_INSTALL_PREFIX* is by default set to `/opt/<provider>/<package>[-<version>]` and on Windows to `C:/Program Files/<Provider>/<Package>[-<version>]`.

The advanced *-DBASIS_INSTALL_SCHEME* option specifies how to install the files relative to this installation prefix. If it is set to `default` (the default), BASIS will decide the appropriate directory structure based on the set installation prefix. On Unix, if the installation prefix contains the package name, the `opt` installation scheme is selected which skips the addition of subdirectories named after the package within the different installation subdirectories. This corresponds to the suggested Linux Filesystem Hierarchy for Add-on Packages , where the installation prefix is set to `/opt/<package>` or `/opt/<provider>/<package>`. Otherwise, the `usr` installation scheme is chosen which will append the package name to each installation directory to avoid conflicts between software packages installed in the same location. This installation scheme follows the Linux Filesystem Hierarchy Standard for /usr. Given the installation prefix `/usr/local`, for example, the package library files will be installed into `/usr/local/lib/<package>`. On Windows, the `win` scheme is used which does not add any package specific subdirectories to the installation path similar to the `opt` scheme. Furthermore, the directory names are more Windows-like and start with a capital letter. For example, the default installation directory for package library files on Windows given the installation prefix `C:\Program Files\<Provider>\<Package>` is `C:\Program Files\<Provider>\<Package>\Lib`.

If the *-DBASIS_INSTALL_SITE_PACKAGES* option is `ON`, module libraries written in a scripting language such as Python or Perl are installed to the system-wide default directories for site packages of these languages. As this requires write permission to these directories, this option is disabled by default.

Note: The binary executables which are intended to be called by the user are copied to the `bin/` directory, where no package subdirectory is created regardless of the installation scheme. It is in the responsibility of the package provider to choose names of the executables that are unique enough to avoid conflicts with other available software packages. Auxiliary executables, on the other side, i.e., executables which are called by the executables in the `bin/` directory, are installed in the directory for library files.

The executables and auxiliary files can be installed using either the command:

```
make install
```

or:

```
make install/strip
```

in the top directory of the build tree. The available install targets copy the files intended for installation to the directories specified during the configuration step. The `install/strip` target additionally strips installed binary executable and shared object files, which can save disk space.

If more than one version of a software package shall be installed, include the package version in the installation prefix by setting *-DCMAKE_INSTALL_PREFIX* to `/opt/[<provider>/]/<package>[-<version>]`, for example (the default). Otherwise, you may choose to install the package in `/usr/local`, which will by default make the executables in the `bin/` directory and the header files available to other packages without the need to change any environment settings.

Besides the installation of the built files of the software package to the named locations, the directory where the CMake configuration file of the package was installed is added to CMake's package registry if the advanced option *-DBASIS_REGISTER* is set to `ON` (the default). This helps CMake to find the installed package when used by another software package based on CMake.

After the successful installation, the build tree can be deleted. It should be verified before, however, that the installation indeed was successful.

Set up the Environment

PATH

In order to ease the execution of the main executable files, we suggest to add the path `<prefix>/bin/` to the search path for executable files, i.e., the `PATH` environment variable. This is, however, generally not required. It only eases the execution of the command-line tools provided by the software package.

For example, if you use Bash add the following line to the `~/.bashrc` file:

```
export PATH="<prefix>/bin:${PATH}"
```

PYTHONPATH

To be able to use any provided Python modules of the software package in your own Python scripts, you need to add the path `<prefix>/lib/[<package>/]python<version>/` to the search path for Python modules if such path exists after installation:

```
export PYTHONPATH=${PYTHONPATH}:/opt/<provider>/<package>-<version>/lib/python2.7
```

or, alternatively, insert the following code at the top of your Python scripts:

```
#! /usr/bin/env python
import sys
sys.path.append('/opt/<provider>/<package>-<version>/lib/python2.7')
from package import module
```

PERL5LIB

To be able to use the provided Perl modules of the software package in your own Perl scripts, you need to add the path `<prefix>/perl5/` to the search path for Perl modules if such path exists after installation:

```
export PERL5LIB=${PERL5LIB}:/opt/<provider>/<package>-<version>/lib/perl5
```

or, alternatively, insert the following code at the top of your Perl scripts:

```
use lib '/opt/<provider>/<package>-<version>/lib/perl5';
use Package::Module;
```

Deinstallation

Makefile-based Uninstall

In order to undo the installation of the package files built from the sources, run the following command in the root directory of the build tree which was used to install the package:

```
cd ~/$package-build
make uninstall
```

> **Warning:** This command will only delete all files which were installed during the **last** build of the install target (`make install`).

Uninstaller Script

During the installation, a manifest of all installed files and a CMake script which reads in this list in order to remove these files again is generated and installed in `<prefix>/lib/cmake/<package>/`.

The uninstaller is located in `<prefix>/bin/` and named `uninstall-<package>`. In order to remove all files installed by this package as well as the empty directories left behind inside the installation root directory given by `<prefix>`, run the command:

```
uninstall-$package
```

assuming that you added `<prefix>/bin/` to your `PATH` environment variable.

Note: The advantage of the uninstaller is, that the build tree is no longer required in order to uninstall the software package. Thus, you do not need to keep a copy of the build tree once you installed the software only to be able to uninstall the package again.

3.8 Automated Testing

This how-to guide describes the implementation and configuration of automated tests of software implemented on top of BASIS. Note that this guide is mainly of interest for software maintainers who have permissions to change the configuration of the software testing process and system administrators. Other lab members and software developers generally do not need to bother with these details. Note, however, that the automated tests can generally also be setup on any machine outside the lab. But in order for CTest to be able to submit test results to the CDash server, a VPN connection to the University of Pennsylvania Health System (UPHS) network is required.

Note: This how-to guide details the automated software testing at SBIA and is therefore specific to the lab's computing environment.

The basistest family of scripts

The BASIS package comes with a family of scripts whose name starts with the prefix `basistest`. All these scripts respond to the usual command-line options such as `--help` and `--version` to provide detailed information regarding usage and version. Further, a wrapper script named `basistest` is available which understands the subcommands `cron`, `master`, `slave` (the default), and `svn`.

- ***basistest-cron*:** The command executed by the scheduled cron job.

- ***basistest-master*:** The master script which runs the scheduled tests.
- ***basistest-slave*:** The test execution command which is executed by the master script for each test job.
- ***basistest-svn*:** The wrapper for the svn command which can be run non-interactively.

basistest-cron

This command is run by a cron job. The configuration of the test execution command is coded into this script, optionally including the submission command used to submit test jobs to the batch-queuing system such as the Oracle Grid Engine, formerly known as Sun Grid Engine (SGE), in particular. Moreover, the location of the test configuration file and test schedule file, both used by the `basistest-master` script, are specified here. Another reason for implementing this script is the setup of the environment for the execution of the master script because cron jobs are run with a minimal configuration of environment variables. Therefore, the `basistest-cron` script sources the `~swtest/.bashrc` file of the `swtest` user which is used at our lab for the automated software testing in order to, for example, add the `~swtest/bin/` directory where all the `basistest` scripts are installed to the `PATH` environment variable.

basistest-master

This so-called master script is executed by the `basistest-cron` command. On each run, it reads in the configuration file given by the `--config` option line-by-line. Each line in the configuration file specifies one test job to be executed. The format of the configuration file is detailed here. Comments within the configuration file start with a pound (#) character at the beginning of each line.

For each test of a specific branch of a project, the configuration file contains a line following the format:

```
<m> <h> <d> <project> <branch> <model> <options>
```

where:

```
<m>         Interval in minutes between consecutive test runs.
            Defaults to "0" if "*" is given.
<h>         Interval in hours between consecutive test runs.
            Defaults to "0" if "*" is given.
<d>         Interval in days (i.e., multiples of 24 hours) between consecutive
            test runs. Defaults to "0" if "*" is given.
<project>   Name of the BASIS project.
<branch>    Branch within the project's SVN repository, e.g., "tags/1.0.0".
            Defaults to "trunk" if a "*" is given.
<model>     Dashboard model, i.e., either one of "Nightly", "Continuous",
            and "Experimental". Defaults to "Nightly".
<options>   Additional options to the CTest script.
            The "basisctest" script of BASIS is used by default.
            Run "ctest -S <path>/basistest.ctest,help" to get a list of
            available options. By default, the default options of the
            CTest script are used. Note that this option can in particular
            be used to define CMake variables for the build configuration.
```

Note that either <m>, <h>, or <d> needs to be a positive number such that the interval is valid. Otherwise, the master script will report a configuration error and skip the test.

Note: Neither of these entries may contain any whitespace character!

For example, nightly tests of the main development branch (trunk) of the project BASIS itself which are run once every day including coverage analysis are scheduled by:

```
* * 1 BASIS trunk Nightly coverage,memcheck
```

Besides the configuration file, which has to be edited manually, a test schedule file is maintained by the testing master. For each configured test job, the master consults the current schedule to see whether the test is already due for execution given the testing interval specified in the configuration file and the last time the test was executed. If the test is due for execution, the testing command, i.e., by default the *basistest-slave*, is executed and the test schedule updated by the testing master. Otherwise, the execution of the test is skipped.

basistest-slave

This script wraps the execution of the CTest script used for the automated testing of BASIS projects including the submission of the test results to the CDash server. It mainly converts the command-line arguments to the correct command-line for the invocation of the CTest script.

The basistest.ctest script performs the actual testing of a BASIS project, i.e., the

- initial check out of the sources from the Subversion controlled repository,
- update of an existing working copy,
- build of the test executables,
- execution of the tests,
- optional coverage analysis,
- optional memory checks,
- submission of test results to the CDash server.

Run the following command in a shell to have the CTest script print its help to screen and exit. However, the `basistest-slave` script should be used instead of executing this CTest script directly. The help displayed by this command can be used in order to determine which additional options are available (such as `coverage` and `memcheck`).

```
ctest -S basistest.ctest,help
```

basistest-svn

This script simply wraps the execution of the svn command as the `svnuser` user as this allows for non-interactive check outs and updates of working copies without the need to provide a user name and password. The code of the script is at the moment the single line:

```
exec sudo -u svnuser /bin/sh /sbia/home/svn/bin/svnwrap "$@"
```

Note: There is another wrapper script named `svnwrap` owned by the `svnuser` involved which does the actual invocation of the `svn` command.

Administration of Software Testing

The following describes the setup and configuration of the automated software tests at SBIA. Hence, these instructions are only of interest for the administrators of the automated software testing at our lab. Other users do not have the permission to become the `swtest` user. To become the `swtest` user execute:

```
sudo -u swtest sudosh
```

Note: If you want to start with a clean setup, keep in mind that the directories `~swtest/etc/` and `~swtest/var/` contain files which are not part of the BASIS project. These need to be preserved and backed up separately.

Initial BASIS Installation

The testing scripts described above are part of the BASIS project. As long as this project is not installed system-wide, it has to be installed locally for use by the `swtest` user. Executing the following commands as this testing user will install BASIS locally in its home directory.

1. Check-out the BASIS sources into the directory `~swtest/src/`:

```
cd
svn --username <your own username> co "https://sbia-svn/projects/BASIS/trunk" src
```

2. Create a directory for the build tree and configure it such that BASIS will be installed in the home directory of the `swtest` user:

```
mkdir build
cd build
ccmake -DINSTALL_PREFIX:PATH=~ -DINSTALL_SINFIX:BOOL=OFF \
       -DINSTALL_LINKS:BOOL=OFF \
       -DBUILD_DOCUMENTATION:BOOL=OFF \
       -DBUILD_EXAMPLE:BOOL=OFF \
       -DBUILD_TESTING:BOOL=OFF \
       ../src
```

3. Build and install BASIS with `~swtest` as installation prefix:

```
make install
```

The testing scripts described above are then installed in the directory `~swtest/bin/` and the CTest script is located in `~swtest/share/cmake/`.

Updating the BASIS Installation

In order to update the testing scripts, run the following commands as the `swtest` user on `olympus` (this is important because the cron job which executes the tests will run on `olympus`).

```
cd
svn up src
cmake build
make -C build install
make clean
```

This updates the working copy of the BASIS sources in `~swtest/src/` and builds the project in the build tree `~swtest/build/`. Finally, the updated BASIS project is installed. Note that the explicit execution of CMake might be redundant. However, some modifications may not re-trigger a configuration even though it is required. Thus, it is better to run CMake manually before the make. The final `make clean` is optional. It is done in order to remove the temporary object and binary files from the build tree and thus reduce the disk space occupied.

Configuring Test Jobs

Setting up the Test Environment All tests are executed by the `swtest` user. Therefore, the common test environment can be set up in the `~swtest/.bashrc` file. Here, the environment modules which are required by all tests should be loaded. Moreover, a particular project can depend on another project and should always be build using the most recent version of that other project. Every BASIS project, in particular, depends on BASIS. Thus, after each successful test of a project which is required by other projects, the files of this project are installed locally in the home directory of the `swtest` user. By setting the `<Pkg>_DIR` environment variable, CMake will use this reference installation if available. Otherwise, it will keep looking in the default system locations.

For an example on how the test environment can be set up, have a look at the following example lines of the `~swtest/.bashrc`:

```
# BASIS is required by all tested projects
module load basis
# ITK 3.* is required by BASIS (for the test driver), HardiTk, GLISTR
module unload itk
module load itk/3.20
# Boost (>= 1.45) is required by HardiTk
module load boost
# TRILINOS is required by HardiTk
module load trilinos

# root directory for installation of project files after successful test execution
#
# Note: When logged in on olympus, we usually want to configure
#       the setup of the test environment such as updating the BASIS
#       installation used by the automated testing infrastructure itself.
#       In this case, we actually want to install the files in ~swtest/
#       and not in the DESTDIR set here.
if ! [[ `hostname` =~ "olympus" ]]; then
        export DESTDIR="${HOME}/comp_space/destdir"
fi

# Set <Project>_DIR environment variables such that the most recent
# installations in DESTDIR are used. If a particular installation is
# not available yet, the default installation as loaded by the module
# commands above will be used instead.
export BASIS_DIR="${DESTDIR}/usr/local/lib/cmake/basis"
```

Note: The environment set up this way is common for the build of all tested projects. Hence, all projects which use ITK will use ITK version 3.20 in this example. If certain projects would require a different ITK version, the environment for these test jobs would need to be adjusted before the execution of `ctest`. This is currently not further supported by BASIS, but is an open feature to be implemented.

Adding Test Job to basistest Configuration The automated tests of BASIS projects are configured in the test configuration file of the *basistest-master* script. The format of this configuration file is detailed *here*. Where this file is located and how it is named is configured in the *basistest-cron* script. By default, the `basistest-master` script looks for the file `/etc/basistest.conf`, but the current installation is setup such that the configuration is located in `~swtest/etc/`. The current test schedule file which is maintained and updated by the *basistest-master* script is at the moment saved as `~swtest/var/run/basistest.schedule`. The log files of the test executions are saved in the directory `~swtest/var/log/`. Note that these paths are configured in the *basistest-cron* script. Old log files are deleted by the *basistest-cron* script after each execution of the test master.

An example test jobs configuration file is given below:

```
# MM HH DD   Project Name      Branch   Dashboard   Arguments
#                                                   (e.g., build configuration)
# ------------------------------------------------------------------------------
# Note: The destination directory for installations is specified by the DESTDIR
#       environment variable as set in the ~swtest/.bashrc file as well as the
#       default CMAKE_INSTALL_PREFIX.
# ------------------------------------------------------------------------------
  0  1  0    BASIS            trunk    Continuous
  0  0  1    BASIS            trunk    Nightly     doxygen,coverage,memcheck,install
# ------------------------------------------------------------------------------
  0  6  0    DRAMMS           trunk    Continuous
  0  0  1    DRAMMS           trunk    Nightly     doxygen,coverage,memcheck,install
# ------------------------------------------------------------------------------
  0  0  1    GLISTR           trunk    Continuous  include=sbia
  0  0  7    GLISTR           trunk    Nightly     doxygen,memcheck,coverage,install
  0  0 61    GLISTR           trunk    Nightly     exclude=sbia  # non-parallel
# ------------------------------------------------------------------------------
  0  1  0    HardiTk          trunk    Continuous  BUILD_ALL_MODULES=ON
  0  0  1    HardiTk          trunk    Nightly     install,BUILD_ALL_MODULES=ON
# ------------------------------------------------------------------------------
  0  0  1    MICO             trunk    Continuous
  0  0  7    MICO             trunk    Nightly     doxygen,memcheck,coverage,install
```

Adjustment of Test Schedule The current implementation of the *basistest-master* script does not allow to specify specific times at which a test job is to be executed. It only allows for the specification of the interval between test executions. Hence, if the test master script is executed the first time with a job that should be executed every day, the job will be executed immediately and then every 24 hours later. For nightly tests, it is however often desired to actually run these tests after midnight (more specifically after the nightly start time configured in CDash such that the test results are submitted to the dashboard of the current day). To adjust the time when a test job is executed, one has to edit the test schedule file (i.e., `~swtest/var/run/basistest.schedule`) manually. This file lists in the first two columns the date and time after when the next execution of the test job corresponding to the particular row should be run. Note that the actual execution time depends on when the *basistest-cron* script is executed. So for the example of nightly test jobs, the time in the second column for this test job should be changed to "3:30:00" for example. Choosing a time after midnight will show the nightly test results on the dashboard page of CDash for the "following" work day. The nightly test of BASIS itself which is used by the other projects should be executed first such that the updated BASIS installation is already used by the other tests.

Note: As the test schedule file is generated by the *basistest-master* script, run either this script or the *basistest-cron* script with the `--dry` option if this file is missing or was not generated yet. This will skip the immediate execution of all tests, but only create the test schedule file which then can be edited manually to adjust the times.

The following is an example of such test schedule file:

```
2012-01-11 13:55:04 BASIS trunk Continuous
2012-01-11 13:55:05 HardiTk trunk Continuous BUILD_ALL_MODULES=ON
2012-01-11 18:55:04 DRAMMS trunk Continuous
2012-01-12 03:00:00 BASIS trunk Nightly doxygen,coverage,memcheck,install
2012-01-12 02:00:00 DRAMMS trunk Nightly doxygen,coverage,memcheck,install
2012-01-12 12:55:04 GLISTR trunk Continuous include=sbia
2012-01-12 02:00:00 HardiTk trunk Nightly install,BUILD_ALL_MODULES=ON
2012-01-12 12:55:05 MICO trunk Continuous
2012-01-18 03:30:00 GLISTR trunk Nightly doxygen,memcheck,coverage,install
2012-01-18 03:30:00 MICO trunk Nightly doxygen,memcheck,coverage,install
2012-03-12 03:30:00 GLISTR trunk Nightly exclude=sbia
```

Remember that the test schedule is processed by the *basistest-master* script on every script invocation. It will output the scheduled tests in chronic order of their next due date. If a test has been removed from the test configuration file, it will also no longer show up in the test schedule.

Setting up a Cron Job for Automated Testing Before you schedule a cron job for the automated software testing, open the *basistest-cron* script located in the `~swtest/bin/` directory and ensure that the settings are correct.

Then run crontab -e as `swtest` user on `olympus` and add an entry such as:

```
*/5 * * * * /sbia/home/swtest/bin/basistest cron
```

This will run the *basistest-cron* script and hence the testing master script every 5 minutes on `olympus`. Note that the actual interval for executing the test jobs in particular depends on the test configuration. Hence, even when the cron job is executed every 5 minutes, the actual tests may only be run once a night, a week, a month,... depending on the *configuration file* which is provided for the *basistest-master* script, no matter if any files were modified or not.

4 Standards

The following sections detail the Build system (i.e., the **B** in BASIS) and Software Implementation (i.e., the **SI** in BASIS) Standard.

4.1 Filesystem Layout

This document describes the filesystem hierarchy of BASIS projects, which is based on the Filesystem Hierarchy Standard of Linux. It has a goal of supporting:

- Unix and Windows
- Installation of multiple versions of each package on a single system
- Seamless integration of BASIS software packages
- A superproject, or super-build, concept based on a bundle build

Please note that the variable names used below are defined by BASIS using CMake, and will often refer to particular directories of a software project. These variables should be used where possible, so that directories can be renamed without breaking the build system.

The *Project Template* provides a reference implementation of this standard. See the *Create/Modify a Project* How-to Guide for details on how to make use of this template to create a new project which is conform with the filesystem hierarchy standard detailed in this section.

Legend

- `<project>` (`<package>`) is a placeholder for the lowercase project (or package) name
- `<Project>` is the case-sensitive project name.
- `<major>` is the major release number
- `<minor>` is the minor update number
- `<patch>` is the patch number
- `<version>` is a placeholder for the project version string `<major>.<minor>.<patch>`
- `<source>` is the root directory of a particular project source tree
- `<build>` is the root directory of the project's build or binary tree

Source Code Repository

Git

BASIS recommends that Git distributed version control users follow the nvie git-flow branching model. The Atlassian Gitflow Workflow Tutorial is another excellent source for this information.

Mercurial

BASIS recommends that Mercurial (hg) distributed version control users follow the hg-flow branching model. This is identical to the git-flow branching model explained in *Source Code Repository*, but uses mercurial as the version control system. The hg-flow extension is useful for assisting with development, but not required.

Subversion

Each Subversion (SVN) repository contains the top-level directories `trunk/`, `branches/`, and `tags/`. No other directories may be located next to these three top-level directories.

The root directory of a development branch, typically the trunk (see *Subversion*), is denoted by `<tag>` and considered relative to the base URL of the project repository. The base URL is referred to as `<url>`.

Repository Path	Description
`trunk/`	The current development version of the project. Most development is done in this master branch.
`branches/<name>/`	Separate branches named `<name>` are developed in subdirectories under the branches directory. One reason for branching is, for example, to develop new features separate from the main development branch, i.e., the trunk, and merging the desired changes back to the trunk once the new feature is implemented and tested.
`branches/<project>-<major>.<minor>/`	This particular branch is used prior to releasing a new version of the project. This branch is commonly referred to as release candidate of version `<major>.<minor>` of the project. It is used to adjust the project files prior to tagging a particular release. For example, to set the correct version number in the project files. This branch is further be used to apply bug fixes to a previous release of this version, in which case the patch number has to be increased before tagging a new release of this software version. See the *Branch and Release* guide for further details.
`tags/<project>-<version>/`	Tagged release version of the project. The reason for including the project name in the name of the tagged branch is, that SVN uses the last URL part as name for the directory to which the URL's content is checked out or exported to if no name for this directory is specified.

See the *Branch and Release* guide for details on how to create new branches and the process of releasing a new version of a software project.

Below the trunk and the release branches a version of the entire source tree should be present. Other branches below the `branches/` directory may contain a subset of the trunk such as the source code of the software without the examples and tests.

Source Code Tree

The Soruce Code Tree refers to the filesystem directory structure of all source code that is managed by version control. The build and intallation trees are separate entities created and populated from the source tree, so the source tree is essentially the "beating heart" of a software project.

Source Categories Source files can fall under the categories of software, build, configuration, documentation, or testing. Any files essential to the execution of the software are also considered to be part of the software source. Examples of essential files include a pre-computed lookup table and a medical image atlas.

Documentation Examples within a software project are considered to be part of both documentation and testing.

Testing The testing category can be divided into system testing and unit testing. It is important to note the difference of system tests and unit tests. As testing can often require a huge amount of image data, these datasets may be stored and managed outside the source tree. Please refer to the *Managing Test Data* guide for details on this topic.

- **System Tests** System tests are usually implemented in a scripting language such as Python, Perl, or BASH. System tests simply run the built executables with different test input data and compare the output to the expected results. Therefore, system tests can also be performed on a target system using the installed software where both the software and system tests are distributed as separate binary distribution packages. Large data sets, such as medical image data sets in their entirety, should only be required for system tests and downsampled to a very low resolution for practical reasons whenever possible.
- **Unit Tests** Unit tests, provide a specialized test of a single software module such as a C++ class or Python module. Generally, the size and amount of additional data required for unit tests is kept reasonably small. The unit tests are compiled into separate executable files called test drivers. These executable files are not essential for the functioning of the software and are solely build for the purpose of testing.

Source Code Filesystem Heirarchy The filesystem hierarchy of a software project's source tree is defined below. The names of the CMake variables defined by BASIS are on the left, while the actual names of the directories are listed on the right:

```
- PROJECT_SOURCE_DIR              - <source>/
    + PROJECT_CODE_DIR                + src/
    + PROJECT_CONFIG_DIR              + config/
    + PROJECT_DATA_DIR                + data/
    + PROJECT_DOC_DIR                 + doc/
    + PROJECT_EXAMPLE_DIR             + example/
    + PROJECT_MODULES_DIR             + modules/
    + PROJECT_TESTING_DIR             + test/
```

Here are CMake variables defined in place of the default name for each of the following directories:

Directory Variable	Description
PROJECT_SOURCE_DIR	Root directory of source tree.
PROJECT_CODE_DIR	All source code files.
PROJECT_CONFIG_DIR	BASIS configuration files.
PROJECT_DATA_DIR	Software configuration files including auxiliary data such as medical atlases.
PROJECT_DOC_DIR	Software documentation.
PROJECT_EXAMPLE_DIR	Example application of software.
PROJECT_MODULES_DIR	*Project Modules*, each residing in its own subdirectory.
PROJECT_TESTING_DIR	Implementation of tests and test data.

Build Tree

CMake supports but recommends against in-source builds. Therefore, BASIS requires that the build tree be outside the source tree. Only the files in the source tree are considered to be important.

Directories in the build tree are separate from the source tree, and they are created and populated when CMake configuration and the build step are run.

```
- PROJECT_BINARY_DIR                - <build>/
    + RUNTIME_OUTPUT_DIRECTORY         + bin/
    + LIBRARY_OUTPUT_DIRECTORY         + lib/
    + ARCHIVE_OUTPUT_DIRECTORY         + lib/
    + TESTING_RUNTIME_DIR              + Testing/bin/
    + TESTING_LIBRARY_DIR              + Testing/lib/
    + TESTING_OUTPUT_DIR               + Testing/Temporary/
```

Here are CMake variables defined in place of the default name for each of the following directories:

Directory Variable	Description
RUNTIME_OUTPUT_DIRECTORY	All executables and shared libraries (Windows).
LIBRARY_OUTPUT_DIRECTORY	Shared libraries (Unix).
ARCHIVE_OUTPUT_DIRECTORY	Static libraries and import libraries (Windows).
TESTING_RUNTIME_DIR	Directory of test executables.
TESTING_LIBRARY_DIR	Directory of libraries only used for testing.
TESTING_OUTPUT_DIR	Directory used for test results.

Installation Tree

The following directory structure is used when installing the software package, either by building the install target with "make install", extracting a binary distribution package, or running an installer.

Different installation hierarchies are defined in order to account for different installation schemes depending on the location and target system on which the software is being installed.

The first installation scheme is referred to as the `usr` scheme which is in compliance with the Linux Filesystem Hierarchy Standard for /usr:

```
- CMAKE_INSTALL_PREFIX              - <prefix>/
    + INSTALL_CONFIG_DIR               + lib/cmake/<package>/
    + INSTALL_RUNTIME_DIR              + bin/
    + INSTALL_LIBEXEC_DIR              + lib/<package>/
    + INSTALL_LIBRARY_DIR              + lib/<package>/
    + INSTALL_ARCHIVE_DIR              + lib/<package>/
    + INSTALL_INCLUDE_DIR              + include/<package>/
    + INSTALL_SHARE_DIR                + share/
        + INSTALL_DATA_DIR                 + <package>/data/
        + INSTALL_DOC_DIR                  + doc/<package>/
        + INSTALL_EXAMPLE_DIR              + <package>/example/
        + INSTALL_MAN_DIR                  + man/
        + INSTALL_INFO_DIR                 + info/
```

Another common installation scheme, here referred to as the `opt` scheme and the default used by BASIS packages, follows the Linux Filesystem Hierarchy Standard for Add-on Packages:

```
- CMAKE_INSTALL_PREFIX              - <prefix>/
    + INSTALL_CONFIG_DIR               + lib/cmake/<package>/
    + INSTALL_RUNTIME_DIR              + bin/
    + INSTALL_LIBEXEC_DIR              + lib/
    + INSTALL_LIBRARY_DIR              + lib/
    + INSTALL_ARCHIVE_DIR              + lib/
    + INSTALL_INCLUDE_DIR              + include/<package>/
    + INSTALL_SHARE_DIR                + share/
        + INSTALL_DATA_DIR                 + data/
```

```
    + INSTALL_DOC_DIR                + doc/
    + INSTALL_EXAMPLE_DIR            + example/
    + INSTALL_MAN_DIR                + man/
    + INSTALL_INFO_DIR               + info/
```

The installation scheme for Windows is:

```
- CMAKE_INSTALL_PREFIX           - <prefix>/
    + INSTALL_CONFIG_DIR             + CMake/
    + INSTALL_RUNTIME_DIR            + Bin/
    + INSTALL_LIBEXEC_DIR            + Lib/
    + INSTALL_LIBRARY_DIR            + Lib/
    + INSTALL_ARCHIVE_DIR            + Lib/
    + INSTALL_INCLUDE_DIR            + Include/<package>/
    + INSTALL_SHARE_DIR              + Share/
    + INSTALL_DATA_DIR               + Data/
    + INSTALL_DOC_DIR                + Doc/
    + INSTALL_EXAMPLE_DIR            + Example/
```

In order to install different versions of a software, choose an installation prefix that includes the package name and software version, for example, `/opt/<package>-<version>` (Unix) or `C:/Program Files/<Package>-<version>` (Windows).

Note that the directory for CMake package configuration files is chosen such that CMake finds these files automatically given that the `<prefix>` is a system default location or the `INSTALL_RUNTIME_DIR` is in the `PATH` environment.

It is important to note that the include directory always contains the package name. This way, project header files must use an include path that avoids conflicts with other packages that use identical header names. Here is a usage example:

```
#include <package/header.h>
```

Thus, the include directory that is added to the search path must be set to the `include/` directory, but not the `<package>` subdirectory.

Here are CMake variables defined in place of the default name for each of the following directories:

Directory Variable	**Description**
`CMAKE_INSTALL_PREFIX`	Common prefix (`<prefix>`) of installation directories. Defaults to `/opt/<provider>/<package>-<version>` on Unix and `C:/Program Files/<Provider>/<Package>-<version>` on Windows. All other directories are specified relative to this prefix.
`INSTALL_CONFIG_DIR`	CMake package configuration files.
`INSTALL_RUNTIME_DIR`	Main executables and shared libraries on Windows.
`INSTALL_LIBEXEC_DIR`	Utility executables which are called by other executables only.
`INSTALL_LIBRARY_DIR`	Shared libraries on Unix and module libraries.
`INSTALL_ARCHIVE_DIR`	Static and import libraries on Windows.
`INSTALL_INCLUDE_DIR`	Public header files of libraries.
`INSTALL_DATA_DIR`	Auxiliary data files required for the execution of the software.
`INSTALL_DOC_DIR`	Documentation files including the software manual in particular.
`INSTALL_EXAMPLE_DIR`	All data required to follow example as described in manuals.
`INSTALL_MAN_DIR`	Man pages.
`INSTALL_MAN_DIR/man1/`	Man pages of the executables in `INSTALL_RUNTIME_DIR`.
`INSTALL_MAN_DIR/man3/`	Man pages of libraries.
`INSTALL_SHARE_DIR`	Shared package files including required auxiliary data files.

4.2 Project Template

The BASIS Project Template defines a standardized project directory and file structure for consistency and interoperability that is required to follow the BASIS standard. The idea is to make projects easier for developers to create, share, and use. It provides template files for the configuration of the build, testing, installation, and packaging, as well as a common directory structure which can be found at *Filesystem Layout*. The Software Project Template also defines how CMake, `CMakeLists.txt` files are set up and the basic build flags that are required. The easiest way to get started is by using the `basisproject` utility to generate a completed template for your project that follows this standard, see the *Quick Start* section for more details on getting started.

Required Project Files

The following files have to be part of any project which follows the *Filesystem Layout*. These are thus the minimal set of project files which need to be selected when instantiating a new software project. Besides these files, a project will have either a `src/` directory or a `modules/` directory, or even both of them. See below for a description of these directories.

README.txt This is the main (root) documentation file. Every user is assumed to first read this file, which in turn will refer them to the more extensive documentation. This file in particular introduces the software package shortly, including a summary of the package files. Moreover, it refers to the *INSTALL.txt* and *COPYING.txt* files for details on the build and installation and software license, respectively. Furthermore, references to scientific articles related to the software package shall be included in this file.

AUTHORS.txt Names the authors of the software package. People who notably contributed to the software directly should also be named here as well, even if they did not actually edit any project file. Others, who mostly contributed indirectly should be named in the *README.txt* file instead. No author names shall be given in any particular source code file, as these are generally edited by multiple persons and updating the authors information within each source file is tedious.

COPYING.txt Contains copyright and license information. If some files of the project were copied from other sources, the copyright and license information of these files shall be stated here as well. It is important to clearly state which copyright and license text corresponds to which project files.

INSTALL.txt Contains build and installation instructions. As the build of all projects which follow BASIS is very similar, this file shall only describe additional steps/CMake variables which are not described in the *Install any Software* guide.

BasisProject.cmake This file contains the meta-data of the project such as the project name and release version, its brief description which is used for the packaging, and the dependencies. Note that additional dependencies may be given by the CMake code in the *config/Depends.cmake* file, if such file is present. This file mainly consists of a call to the basis_project() command. If the project is a module of another project, this file is read by the top-level project to be able to identify its modules and the dependencies among them.

CMakeLists.txt The root CMake configuration file. **Do not edit this file.**

Common Project Files

build/CMakeLists.txt CMake configuration file for bundle build (also referred to as super-build) of the project and all or some of its prerequisites. The source packages of the prerequisites are either downloaded during the bundle build or may be included with the distribution package. In the latter case, these source packages shall be placed in the build/ directory next to this CMake configuration file.

CTestConfig.cmake The CTest configuration file. This file in particular specifies the URL of the CDash dashboard of the project where test results should be submitted to.

config/Settings.cmake This is the main CMake script file used to configure the build system, and BASIS in particular. Any CMake code required to configure the build system, such as adding common compiler flags, or adding common definitions which have not yet been added by the generic code used by BASIS to utilize a found dependency should go into this file.

config/ScriptConfig.cmake.in See the documentation on the *build of script targets* for details on how this *script configuration* is used.

data/CMakeLists.txt This CMake configuration file contains code to simply install every file and directory from the source tree into the `INSTALL_DATA_DIR` directory of the installation tree.

doc/CMakeLists.txt This CMake configuration file adds rules to build the documentation from, for example, the in-source comments using Doxygen or reStructuredText sources using Sphinx. Moreover, for every documentation file, such as the software manual, the basis_add_doc() command has to be added to this file.

doc/index.rst The main page of the *comprehensive* software manual which may also serve as project web site at the same time.

doc/manual/index.rst The main page of the *condensed* software manual, i.e., a manual which focuses on the use of the software rather than it's installation and detailed reference.

doc/guide/index.rst The main page of the developer's guide which is intended for those who continue development or maintenance of the software.

doc/site/indes.rst The main page of the project web site.

example/CMakeLists.txt This CMake configuration file contains by default code to install every file and directory from the source tree into the `INSTALL_EXAMPLE_DIR` directory of the installation tree. It may be modified to configure and/or build certain files of the example if applicable or required.

src/CMakeLists.txt The definition of all software build targets shall be added to this file, using the commands basis_add_library() to add a shared, static, or module library, which can also be a module written in a scripting language, and basis_add_executable() to add an executable target, which can be either a binary or a script file. If appropriate, the source code files may be further organized in subdirectories of the `src/` directory, in which case either separate `CMakeLists.txt` files can be used for each subdirectory, or yet all targets are added to the `src/CMakeLists.txt` file using relative paths which include the subdirectory in which the source files are found. In general, if the number of source code files is low, i.e., close to or below 20, no subdirectory structure is required.

test/CMakeLists.txt Tests are added to this build configuration file using the basis_add_test() command. The test input files are usually put in a subdirectory named `test/input/`, while the baseline data of the expected test output is stored inside a subdirectory named `test/baseline/`. Generally, however, the *Filesystem Layout* of BASIS does not dictate how the test sources, input, and baseline data have to be organized inside the `test/` directory.

test/internal/CMakeLists.txt More elaborate and extended tests which are intended for internal use only and which shall be excluded from the public source distribution package are configured using this CMake configuration file. Reasons for excluding tests from a public distribution are that some tests may depend on the internal software environment to succeed and further the particular machine architecture. Moreover, the size of the downloadable distribution packages shall be kept as small as possible and therefore some of the more specialized tests may be excluded from this distribution.

modules/ If the project files are organized into conceptual cohesive groups, similar to the modularization goal of the ITK 4, this directory contains these conceptual modules of the project. The files of each module reside in a subdirectory named after the module. Note that each module itself is a project derived from this project template.

Advanced Project Files

The customization of the following files is usually not required, and hence, in most cases, most of these files need not to be part of a project.

config/Components.cmake Contains CMake code to configure the components used by component-based installers. Currently, component-based installers are not very well supported by BASIS, and hence this file is mostly unused and is yet subject to change.

config/Config.cmake.in This is the template of the package configuration file. When the project is configured/installed using CMake, a configured version of this file is copied to the build or installation tree, respectively, where the information about the package configuration is substituted as appropriate for the actual build/installation of the package. For example, the configured file contains the absolute path to the installed public header files such that other packages can easily add this path to their include search path. The find_package() command of CMake, in particular, will look for this file and automatically import the CMake settings when this software package was found. For many projects, the default package configuration file of BASIS which is used if this file is missing in the project's `config/` directory, is sufficient and thus this file is often not required.

config/ConfigSettings.cmake This file sets CMake variables for use in the *config/Config.cmake.in* file. As the package configuration for the final installation differs from the one of the build tree, this file has to contain CMake code to set the variables used in the *config/Config.cmake.in* file differently depending on whether the variables are being set for use within the build tree or the installation tree. This file only needs to be present if the project uses a custom *config/Config.cmake.in* file, which in turn contains CMake variables whose value differs between build tree and installation.

config/ConfigUse.cmake.in This file is provided for convenience of the user of the software package. It contains CMake code which uses the variables set by the package configuration file (i.e., the file generated from the file *config/Config.cmake.in*) in order to configure the build system of packages which use this software packages properly such that they can make use of this software. For example, the package configuration sets a variable to a list of include directories have to be added to the include search path. This file would then contain CMake instructions to actually add these directories to the path.

config/ConfigVersion.cmake.in This file accompanies the package configuration file generated from the *config/Config.cmake.in* file. It is used by CMake's find_package() command to identify versions of this software package which are compatible with the version requested by the dependent project. This file needs almost never be customized by a project and thus should generally not be included in a project's source tree.

config/Depends.cmake If the generic code used by BASIS to resolve the dependencies on external packages is not sufficient, add this file to your project. CMake code required to find and make use of external software packages properly shall be added to this file. In order to only make use of the variables set by the package configuration of the found dependency, consider to add a dependency entry to the *BasisProject.cmake* file instead and code to use these variables to *config/Settings.cmake*.

config/Package.cmake Configures CPack, the package generator of CMake. The packaging of software using CPack is currently not completely supported by BASIS. This template file is yet subject to change.

CTestCustom.cmake.in This file defines CTest variables which customize CTest.

4.3 Project Modularization

This article details the design and implementation of the project modularization, where a project, also referred to as top-level project (note that BASIS only allows one level of submodularization), can have other projects as subprojects (referred to as modules in this context to distinguish them from the superproject/subproject relationship in case of the superbuild approach, see below). The project modules are conceptual cohesive groups of the project files.

A top-level project can also be described as a modularized project, where each module of this project may depend on other modules of the same project or external projects (also referred to as packages). Note that an external project can

also be another top-level project which utilizes the same project modularization as discussed herein. The idea, and partly the CMake implementation, has been borrowed from the ITK 4 project. See the Wiki of this project for details on the ITK 4 Modularization.

Implementation

The modularization is mainly implemented by the ProjectTools.cmake module, in particular, the basis_project_modules() function which is called at the very top of the basis_project_impl() macro, which is the foundation for the root CMake configuration file (`CMakeLists.txt`) of every BASIS project. The basis_project_modules() function searches the subdirectories in the `modules/` directory for the presence of the BasisProject.cmake file. It then loads this file, to retrieve the meta-data of each module, i.e., its name and dependencies. It then adds for each module a `MODULE_<module>` option to the build configuration. When this option is set to `OFF`, the module is excluded from both the project build and any package generated by CPack. Otherwise, if it is set to `ON`, the module is build as part of the top-level project. These options are superceded by the `BUILD_ALL_MODULES` option if this option is set to `ON`, however.

Besides adding these options, the basis_project_modules() function ensures that the modules are configured and build in the right order, such that a module which is needed by another module is build prior to this dependent module. Moreover, it helps the basis_find_package() function to find the other modules, in particular their configured package configuration files, which are either generated from the default Config.cmake.in file or a corresponding file found in the `config/` directory of each module.

The other BASIS CMake functions may further change their actual behaviour depending on the `PROJECT_IS_MODULE` variable which specifies whether the project that is currently being configured is a module of another project (i.e., `PROJECT_IS_MODULE` is `TRUE`) or a top-level project (i.e., `PROJECT_IS_MODULE` is `FALSE`).

4.4 Build of Script Targets

Unlike source files written in non-scripting languages such as C++ or Java, source files written in scripting languages such as Python, Perl, or BASH do not need to be compiled before their execution. They are interpreted directly and hence do not need to be build (in case of Python, however, they are as well compiled by the interpreter itself to improve speed). On the other side, CMake provides a mechanism to replace CMake variables in a source file by their respective values which are set in the `CMakeLists.txt` files (or an included CMake script file). As it is often useful to introduce build specific information in a script file such as the relative location of auxiliary executables or data files, the basis_add_executable() and basis_add_library() commands also provide a means of building script files. How these functions process scripts during the build of the software is discussed next. Afterwards it is described how the build of scripts can be configured.

Prerequisites and Build Steps

During the build of a script, the CMake variables as given by `@VARIABLE_NAME@` patterns are replaced by the value of the corresponding CMake variable if defined, or by an empty string otherwise. Similar to the configuration of source files written in C++ or MATLAB, the names of the script files which shall be configured by BASIS during the build step have to end with the `.in` suffix. Otherwise, the script file is not modified by the BASIS build commands and simply copied to the build tree or installation tree, respectively. Opposed to configuring the source files already during the configure step of CMake, as is the case for C++ and MATLAB source files, script files are configured during the build step to allow for the used CMake variables to be set differently depending on whether the script is intended for use inside the build tree or the installation tree. Moreover, certain properties of the script target can still be modified after the basis_add_executable() or basis_add_library() command, respectively, using the basis_set_target_properties() or basis_set_property() command. Hence, the final values of these variables are not known before the configuration of the build system has been completed. Therefore, all CMake variables which are defined when the basis_add_executable() or basis_add_library() command is called, are dumped to a CMake script file to preserve their value at this moment

and the dump of the variables is written to a file in the build tree. This file is loaded again during the build step by the custom build command which eventually configures the script file using CMake's configure_file() command with the `@ONLY` option. This build command configures the script file twice. The first "built" script is intended for use within the build tree while the second "built" script will be copied upon installation to the installation tree.

Before each configuration of the (template) script file (the `.in` source file in the source tree), the file with the dumped CMake variable values and the various script configuration files are included in the following order:

1. Dump file of CMake variables defined when the script target was added.
2. Default script configuration file of BASIS (`BasisScriptConfig.cmake`).
3. Default script configuration file of individual project (`ScriptConfig.cmake`, optional).
4. Script configuration code specified using the `CONFIG` argument of the basis_add_executable() or basis_add_library() command.

Script Configuration

The so-called script configuration is CMake code which defines CMake variables for use within script files. This code is either saved in a CMake script file with the `.cmake` file name extension or specified directly as argument of the `CONFIG` option of the basis_add_executable() or basis_add_library() command used to add a script target to the build system. The variables defined by the script configuration are substituted by their respective values during the build of the script target. Note that the CMake code of the script configuration is evaluated during the build of the script target, not during the configuration of the build system. During the configuration of the build systems, the script configuration is, however, configured in order to replace `@VARIABLE_NAME@` patterns in the configuration by their respective values as defined by the build configuration (`CMakeLists.txt` files). Therefore, the variables defined in the script configuration can be set differently for each of the two builds of the script files. If the script configuration is evaluated before the configuration of the script file for use inside the build tree, the CMake variable `BUILD_INSTALL_SCRIPT` is set to `FALSE`. Otherwise, if the script configuration is evaluated during the build of the script for use in the installation tree, this variable is set to `TRUE` instead. It can therefore be used to set the variables in the script configuration depending on whether or not the script is build for use in the build tree or the installation tree.

For example, the project structure differs for the build tree and the installation tree. Hence, relative file paths to the different directories of data files, for instance, have to be set differently depending on the value of `BUILD_INSTALL_SCRIPT`, i.e.,

```
if (BUILD_INSTALL_SCRIPT)
  set (DATA_DIR "@CMAKE_INSTALL_PREFIX@/@INSTALL_DATA_DIR@")
else ()
  set (DATA_DIR "@PROJECT_DATA_DIR@")
endif ()
```

Avoid the use of absolute paths, however! Instead, use the `__DIR__` variable which is set in the build script to the directory of the output script file to make these paths relative to this directory which contains the configured script file. These relative paths which are defined by the script configuration are then used in the script file as follows:

```
#! /usr/bin/env bash
. ${BASIS_BASH_UTILITIES} || { echo "Failed to import BASIS utilities!" 1>&2; exit 1; }
exedir EXEDIR && readonly EXEDIR
[ $? -eq 0 ] || { echo 'Failed to determine directory of this executable!'; exit 1; }
readonly DATA_DIR="${EXEDIR}/@DATA_DIR@"
```

where `DATA_DIR` is the relative path to the required data files as determined during the evaluation of the script configuration. See documentation of the basis_set_script_path() function for a convenience function which can be used therefore. Note that this function is defined in the custom build script generated by BASIS for the build of each

script target and hence can only be used within a script configuration. For example, use this function as follows in the `PROJECT_CONFIG_DIR/ScriptConfig.cmake.in` script configuration file of your project:

```
basis_set_script_path(DATA_DIR "@PROJECT_DATA_DIR@" "@INSTALL_DATA_DIR@")
```

Note that most of the more common variables which are useful for the development of scripts are already defined by the default script configuration file of BASIS. Refer to the documentation of the BasisScriptConfig.cmake file for a list of available variables.

4.5 Command-line Parsing

Most of the software developed in a research environment is based on the command-line, as command-line tools are easier and thus faster implemented then tools with graphical user interface. To help the developer, who wants to focus on the actual image processing algorithm rather than the parsing of the command-line arguments, BASIS intends to provide a command-line parsing library for each of the commonly used programming languages. The following sections document the usage of these libraries for each respective programming language:

Parsing the Command-line Arguments in C++

For the parsing of command-line arguments in C++, BASIS includes a slightly extended version of the Templatized C++ Command Line Parser (TCLAP) Library. For details and usage of this library, please refer to the TCLAP documentation. It is in particular recommended to read the TCLAP manual. Further, the *TCLAP API documentation* is a good reference on the available command-line argument classes. The API documentation of the TCLAP classes can also be found as part of this documentation.

Note: BASIS provides its own subclass of the `TCLAP::CmdLine` class which is also named `CmdLine`, but in the `basis` namespace, i.e., `basis::CmdLine`. Most of the argument implementations are, however, simply typedefs of the commonly used `TCLAP::Arg` subclasses. See the API documentation for a list of command-line arguments which are made available as part of the `basis` namespace.

The usage of the command-line parsing library shall be demonstrated in the following on the implementation of an example command-line program. It should be noted that the try-catch block in the `main()` function will only help to track errors in the command-line specification, but once the `cmd` instance is initialized properly, all runtime exceptions related to the parsing of the command-line are handled by BASIS.

```
/**
 * @file  smoothimage.cxx
 * @breif Smooth image using Gaussian or anisotropic diffusion filtering.
 *
 * Copyright (c) 2011 University of Pennsylvania. All rights reserved.<br />
 * See http://www.rad.upenn.edu/sbia/software/license.html or COPYING file.
 *
 * Contact: SBIA Group <sbia-software at uphs.upenn.edu>
 */

#include <package/basis.h> // include BASIS C++ utilities


// acceptable in .cxx file
using namespace std;
using namespace basis;


// ============================================================================
```

```cpp
// smoothing filters
// ============================================================================

// ----------------------------------------------------------------------------
int gaussianfilter(const string&                imagefile,
                   const vector<unsigned int>& r,
                   double                       std)
{
    // [...]
    return 0;
}

// ----------------------------------------------------------------------------
int anisotropicfilter(const string& imagefile)
{
    // [...]
    return 0;
}

// ============================================================================
// main
// ============================================================================

// ----------------------------------------------------------------------------
int main(int argc, char* argv[])
{
    // ------------------------------------------------------------------------
    // define command-line arguments
    SwitchArg gaussian(                          // option switch
        "g", "gaussian",                         // short and long option name
        "Smooth image using a Gaussian filter.", // argument help
        false);                                  // default value

    SwitchArg anisotropic(                       // option switch
        "a", "anisotropic",                      // short and long option name
        "Smooth image using anisotropic diffusion filter.", // argument help
        false);                                  // default value

    MultiUIntArg gaussian_radius(                // unsigned integer values
        "r", "radius",                           // short and long option name
        "Radius of Gaussian kernel in each dimension.", // argument help
        false,                                   // required?
        "<rx> <ry> <rz>",                        // value type description
        3,                                       // number of values per argument
        true);                                   // accept argument only once

    DoubleArg gaussian_std(                      // floating-point argument value
        "", "std",                               // only long option name
        "Standard deviation of Gaussian in voxel units.", // argument help
        false,                                   // required?
        2.0,                                     // default value
        "<float>");                              // value type description

    // [...]

    PositionalArg imagefile(                     // positional, i.e., unlabeled
        "image",                                 // only long option name
        "Image to be smoothed.",                 // argument help
```

```
        true,                                   // required?
        "",                                     // default value
        "<image>");                             // value type description

    // --------------------------------------------------------------------
    // parse command-line
    try {
        vector<string> examples;

        examples.push_back(
                "EXENAME --gaussian --std 3.5 --radius 5 5 3 brain.nii\n"
                "Smooths the image brain.nii using a Gaussian with standard"
                " deviation 3.5 voxel units and 5 voxels in-slice radius and"
                " 3 voxels radius across slices.");

        examples.push_back(
                "EXENAME  --anisotropic brain.nii\n"
                "Smooths the image brain.nii using an anisotropic diffusion filter.");

        CmdLine cmd(
                // program identification
                "smoothimage", PROJECT,
                // program description
                "This program smooths an input image using either a Gaussian "
                "filter or an anisotropic diffusion filter.",
                // example usage
                examples,
                // version information
                RELEASE, "2011 University of Pennsylvania");

        // The constructor of the CmdLine class has already added the standard
        // arguments --help, --helpshort, --helpxml, --helpman, and --version.

        cmd.xorAdd(gaussian, anisotropic);
        cmd.add(gaussian_std);
        cmd.add(gaussian_radius);
        cmd.add(imagefile);

        cmd.parse(argc, argv);
    } catch (CmdLineException& e) {
        // invalid command-line specification
        cerr << e.error() << endl;
        exit(1);
    }

    // --------------------------------------------------------------------
    // smooth image - access parsed argument value using Arg::getValue()
    unsigned int r[3];

    if (gaussian.getValue()) {
        return gaussianfilter(imagefile.getValue(),
                              gaussian_radius.getValue(),
                              gaussian_std.getValue());
    } else {
        return anisotropicfilter(imagefile.getValue());
    }
}
```

Running the above program with the `--help` option will give the output:

```
SYNOPSIS
    smoothimage [--std <float>] [--radius <rx> <ry> <rz>] [--verbose|-v]
                {--gaussian|--anisotropic} <image>
    smoothimage [--help|-h|--helpshort|--helpxml|--helpman|--version]

DESCRIPTION
    This program smooths an input image using either a Gaussian filter or
    an anisotropic diffusion filter.

OPTIONS
    Required arguments:
       -g or --gaussian
            Smooth image using a Gaussian filter.
       or -a or --anisotropic
            Smooth image using anisotropic diffusion filter.

       <image>
            Image to be smoothed.

    Optional arguments:
       -s or --std <float>
            Standard deviation of Gaussian in voxel units.

       -r or --radius <rx> <ry> <rz>
            Radius of Gaussian kernel in each dimension.

    Standard arguments:
       -- or --ignore_rest
            Ignores the rest of the labeled arguments following this flag.

       -v or --verbose
            Increase verbosity of output messages.

       -h or --help
            Display help and exit.

       --helpshort
            Display short help and exit.

       --helpxml
            Display help in XML format and exit.

       --helpman
            Display help as man page and exit.

       --version
            Display version information and exit.

EXAMPLE
    smoothimage --gaussian --std 3.5 --radius 5 5 3 brain.nii

        Smooths the image brain.nii using a Gaussian with standard
        deviation 3.5 voxel units and 5 voxels in-slice radius and 3 voxels
        radius across slices.

    smoothimage --anisotropic brain.nii
```

```
        Smooths the image brain.nii using an anisotropic diffusion filter.

CONTACT
    SBIA Group <sbia-software at uphs.upenn.edu>
```

The `--helpshort` output contains the synopsis of the full help only:

```
smoothimage [--std <float>] [--radius <rx> <ry> <rz>] [--verbose|-v]
            {--gaussian|--anisotropic} <image>
smoothimage [--help|-h|--helpshort|--helpxml|--helpman|--version]
```

Parsing the Command-line Arguments in Bash

Note: This how-to guide has to be written yet. See the shflags.sh module as a reference until this guide is completed, keeping in mind, though, that this module will have to be revised.

Note: Yet there exist only libraries for C++ and BASH, but solutions for Java, Python, and Perl will be part of future releases.

4.6 Calling Conventions

This document discusses and describes the conventions for calling other executables from a program. The calling conventions address the question whether to use relative or absolute file paths when calling executables and introduce a name mapping from build target names to actual executable file paths. These calling conventions are, however, hidden to the developer through automatically generated utility functions for each supported programming language. See *Implementation* for details on the specific implementations in the different languages.

Relative vs. Absolute Paths

Relative paths such as only the executable file name require a proper setting of the `PATH` environment variable. If more than one version of a particular software package should be installed or in case of name conflicts with other packages, this is not trivial and it may not be guaranteed that the correct executable is executed. Absolute executable file paths, on the other side, restrict the relocatability and thus distribution of pre-build binary packages. Therefore, BASIS proposes and implements the following convention on how absolute paths of (auxiliary) executables are determined at runtime by taking the absolute path of the directory of the calling executable into consideration.

Main executables in the `bin/` directory call utility executables relative to their own location. For example, a Bash script called `main` that executes a utility script `util` in the `lib/` directory would do so as demonstrated in the following example code (for details on the `@VAR@` patterns, please refer to the *Build of Script Targets* page):

```
# among others, defines the get_executable_directory() function
. ${BASIS_Bash_UTILITIES} || { echo "Failed to import BASIS utilities!" 1>&2; exit 1; }
# get absolute directory path of auxiliary executable
exedir _EXEC_DIR && readonly _EXEC_DIR
_LIBEXEC_DIR=${_EXEC_DIR}/@LIBEXEC_DIR@
# call utility executable in libexec directory
${_LIBEXEC_DIR}/util
```

where LIBEXEC_DIR is set in the BasisScriptConfig.cmake configuration file to either the output directory of auxiliary executables in the build tree relative to the directory of the script built for the build tree or to the path of the

installed auxiliary executables relative to the location of the installed script. Note that in case of script files, two versions are build by BASIS, one that is working directly inside the build tree and one which is copied to the installation tree. In case of compiled executables, such as in particular programs built from C++ source code files, a different but similar approach is used to avoid the build of two different binary executable files. Here, the executable determines at runtime whether it is executed from within the build tree or not and uses the appropriate path depending on this.

If an executable in one directory wants to execute another executable in the same directory, it can simply do so as follows:

```
# call other main executable
${_EXEC_DIR}/othermain
```

File vs. Target Name

In order to be independent of the actual names of the executable files–which may vary depending on the operating system (e.g., with or without file name extension in case of script files) and the context in which a project was built–executables should not be called by their respective file name, but their build target name.

It is in the responsibility of the BASIS auxiliary functions to properly map this project specific and (presumably) constant build target name to the absolute file path of the built (and installed) executable file. This gives BASIS the ability to modify the executable name during the configuration step of the project, for example, to prepand them with a unique project-specific prefix, in order to ensure uniqueness of the executable file name. Moreover, if an executable should be renamed, this can be done simply through the build configuration and does not require a modification of the source code files which make use of this executable.

Search Paths

All considered operating systems–or more specifically the used shell and dynamic loader–provide certain ways to configure the search paths for executable files and shared libraries which are dynamically loaded on demand. The details on how these search paths can be configured are summarized next including the pros and cons of each method to manipulate these search paths. Following these considerations, the solution aimed at by BASIS is detailed.

Unix

On Unix-based systems (including in particular all variants of Linux and Mac OS) executables are searched in directories specified by the `PATH` environment variable. Shared libraries, on the other side, are first searched in the directories specified by the `LD_LIBRARY_PATH` environment variable, then in the directories given by the `RPATH` which is set within the binary files at compile time, and last the directories specified in the `/etc/ld.so.conf` system configuration file.

The most flexible method which can also easily be applied by a user is setting the `LD_LIBRARY_PATH` environment variable. It is, however, not always trivial or possible to set this search path in a way such that all used and installed software works correctly. There are many discussions on why this method of setting the search path is considered evil among the Unix community (see for example here). The second option of setting the `RPATH` seems to be the most secure way to set the search path at compile time. This, however, only for shared libraries which are distributed and installed with the software because only in this case can we make use of the `$ORIGIN` variable in the search path to make it relative to the location of the binary file. Otherwise, it is either required that the software is being compiled directly on the target system or the paths to the used shared libraries on the target system must match the paths of the system on which the executable was built. Hence, using the `RPATH` can complicate or restrict the relocatability of a software. Furthermore, unfortunately is the `LD_LIBRARY_PATH` considered before the `RPATH` and hence any user setting of the `LD_LIBRARY_PATH` can still lead to the loading of the wrong shared library. The system configuration `/etc/ld.so.conf` is not an option for setting the search paths for each individual software. This search path should only be set to a limited number of standard system search paths as changes affect all users. Furthermore,

directories on network drives may not be included in this configuration file as they will not be available during the first moments of the systems start-up. Finally, only an administrator can modify this configuration file.

The anticipated method to ensure that the correct executables and shared libraries are found by the system for Unix-based systems is as follows. As described in the previous sections, executables which are part of the same software package are called by the full absolute path and hence no search path needs to be considered. To guarantee that shared libraries installed as part of the software package are considered first, the directory to which these libraries where installed is prepended to the `LD_LIBRARY_PATH` prior to the execution of any other executable. Furthermore, the `RPATH` of binary executable files is set using the `$ORIGIN` variable to the installation directory of the package's shared libraries. This ensures that also for the execution of the main executable, the package's own shared libraries are considered first. To not restrict the administrator of the target system on where other external packages need to be installed, no precaution is taken to ensure that executables and shared libraries of these packages are found and loaded properly. This is in the responsibility of the administrator of the target system. However, by including most external packages into the distributed binary package, these become part of the software package and thus above methods apply.

Note: The inclusion of the runtime requirements should be done during the packaging of the software and thus these packages should still not be integrated into the project's source tree.

Mac OS bundles differ from the default Unix-like way of installing software. Here, an information property list file (Info.plist) is used to specify for each bundle separately the specific properties including the location of frameworks, i.e., private shared libraries (shared libraries distributed with the bundle). Most shared libraries required by the software will be included in the bundle.

Windows

On Windows systems, executable files are first searched in the current working directory. Then, the directories specified by the `PATH` environment variable are considered as search path for executable files where the extensions `.exe`, `.com`, `.bat`, and `.cmd` are considered by default and need not be included in the name of the executable that is to be executed. Shared libraries, on the other side, are first searched in the directory where the using module is located, then in the current working directory, the Windows system directory (e.g., `C:\WINDOWS\system32\`), and then the Windows installation directory (e.g., `C:\WINDOWS`). Finally, the directories specified by the `PATH` environment variable are searched for the shared libraries.

As described in the previous sections, executables which are part of the software package are called by the full absolute path and hence no search path is considered. Further, shared runtime libraries belonging to the software package are installed in the same directory as the executables and hence will be considered by the operating system before any other shared libraries.

Implementation

In the following the implementation of the calling conventions in each supported programming language is summarized.

Note that the BASIS Utilities provide an `execute()` function for each of these languages which accepts either an executable file path or a build target name as first argument of the command-line to execute.

C++

For C++ programs, the BASIS C++ utilities provide the function exepath() which maps a build target name to the absolute path of the executable file built by this target. This function makes use of an implementation of the basis::util::IExecutableTargetInfo interface whose constructor is automatically generated during the configuration of a

project. This constructor initializes the data structures required for the mapping of target names to absolute file paths. Note that BASIS generates different implementations of this module for different projects, the whose documentation is linked here is the one generated for BASIS itself.

The project implementations will, however, mainly make use of the execute() function which accepts either an actual executable file path or a build target name as first argument of the command-line to execute. This function shall be used in C++ code as a substitution for the commonly used system() function on Unix. The advantage of `execute()` is further, that it is implemented for all operating systems which are supported by BASIS, i.e., Linux, Mac OS, and Windows. The declaration of the `execute()` function can be found in the `basis.h` header file. Note that this file is unique to each BASIS project.

Java

The Java programming language is not yet supported by BASIS.

Python

A Python module named basis.py stores the location of the executables relative to its own path in a dictionary where the UIDs of the corresponding build targets are used as keys. The functions exename(), exedir(), and exepath() can be used to get the name, directory, or path, respectively, of the executable file built by the specified target. If no target is specified, the name, directory, or path of the calling executable itself is returned.

Perl

The Basis.pm Perl module uses a hash reference to store the locations of the executable files relative to the module itself. The functions exename(), exedir(), and exepath() can be used to get the name, directory, or path, respectively, of the executable file built by the specified target. If no target is specified, the name, directory, or path of the calling executable itself is returned.

Bash

The module basis.sh imitates associative arrays to store the location of the built executable files relative to this module. The functions exename(), exedir(), and exepath() can be used to get the name, directory, or path, respectively, of the executable file built by the specified target. If no target is specified, the name, directory, or path of the calling executable itself is returned.

Additionally, the basis.sh module can setup aliases named after the UID of the build targets for the absolute file path of the corresponding executables. The target names can then be simply used as aliases for the actual executables. The initialization of the aliases is, however, at the moment expensive and delays the load time of the executable which sources the basis.sh module. Note further that this approach requires the option `expand_aliases` to be set via `shopt -s expand_aliases` which is done by the `basis.sh` module if aliases were enabled. A `shopt -u expand_aliases` disables the expansion of aliases and hence should not be used in Bash scripts which execute other executables using the aliases defined by basis.sh.

Unsupported Languages

In the following, languages for which the calling conventions are not implemented are listed. Reasons for not supporting these languages regarding the execution of other executables are given for each such programming language. Support for all other programming languages which are not supported yet and not listed here may be added in future releases of BASIS.

MATLAB

Visit this MathWorks page for a documentation of external interfaces MathWorks provides for the development of applications in MATLAB. An implementation of the `execute()` function in MATLAB is yet not provided by BASIS.

5 Guidelines

The following sections define common guidelines for the formatting of documents such as in particular program code as well as other recommended coding guidelines. Each organization employing BASIS, however, may define their own guidelines, possibly using the following guidelines as reference.

5.1 Plain Text Format

Note: This guideline is out-dated and a new set of rules must be defined which is compatible with either Markdown or reStructuredText, nowadays the preferred lightweight markup languages for plain text files.

The following guideline, which itself is styled according to the plain text format it describes, details how plain text documentation files of a software project should be formatted.

```
Section of Biomedical Image Analysis
Department of Radiology
University of Pennsylvania
3600 Market Street, Suite 380
Philadelphia, PA 19104

Web:   http://www.rad.upenn.edu/sbia/
Email: sbia-software at uphs.upenn.edu

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See http://www.rad.upenn.edu/sbia/software/license.html or COPYING file.



INTRODUCTION
============

  This document defines guidelines on how to style plain text documentation
  files such as the readme file and the build and installation instructions.
  A common style makes it easier for users of software developed at SBIA to
  navigate through the documents and recognize what is of importance to them.
  Moreover, it serves as a branding of the software. Each individual software
  project shall finally be integrated with all the other software projects
  to form one unique software package. Here a common documentation style is
  desired such that the separate subprojects nicely integrate with each other.



HEADER
======

  Each plain text document has to start with the following header with one
  blank line before and each line indented by two space characters.

  Section of Biomedical Image Analysis
  Department of Radiology
  University of Pennsylvania
  3600 Market Street, Suite 380
  Philadelphia, PA 19104

  Web:   http://www.rad.upenn.edu/sbia/
```

Email: sbia-software at uphs.upenn.edu

HEADINGS

Headings of level 1 are capitalized as in this document. All other headings are spelled case-sensitive where the first letter of words with four or more characters are started with an uppercase letter. Headings of level 1 are not intended, while all other headings are intended by two space characters.

For headings of level 1, a line of = characters as long as the heading is used to underline it. For headings of level 2, - characters are used instead. All other headings are not underlined.

Before each heading of level 1, three blank lines are inserted.
Before each heading of level 2, two blank lines are inserted.
Before any other heading, one blank line is inserted.

A heading and its text block are indented by (level - 1) * 2 space characters. Hence, headings of level 1 are not indented, while headings of level 2 are indented by two space characters.

TEXT BLOCKS

The number of columns in a text block is limited to about 80 characters. Each text block is indented equally to the indentation of its heading, where at least two space characters are used to intend a text block. Hence, even though headings of level 1 are not indented, so are the corresponding text blocks.

There are no space characters on blank lines.

ENUMERATIONS

Use -, +, and * characters as bullet points.

6 Getting Help

Please report any issues with BASIS, including bug reports, feature requests, or support questions, on GitHub.

7 People

Software Development

- Andreas Schuh
- Andrew Hundt

Contributors

The following people notably helped to define and shape BASIS.

- Dominique Belhachemi
- Kayhan N. Batmanghelich
- Luke Bloy
- Yangming Ou

Former Advisors at SBIA

- Christos Davatzikos
- Kilian M. Pohl