Guide to Documentation

Documentation for esys.escript comes in a number of parts. Here is a rough guide to what goes where.

install.pdf  "Installation guide for esys-Escript": Instructions for compiling escript for your system from its source code.

cookbook.pdf  "The escript COOKBOOK": An introduction to escript for new users from a geophysics perspective.


sphinx_api directory  Documentation for escript Python libraries.

escript_examples(.tar.gz)/(.zip)  Full example scripts referred to by other parts of the documentation.

doxygen directory  Documentation for C++ libraries (mostly only of interest for developers).
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Introduction

This document describes how to install esys-Escript\(^1\) on to your computer. To learn how to use Escript please see the Cookbook, User’s guide or the API documentation.

Escript is primarily developed on Linux desktop, SGI ICE and MacOS X systems. It can be installed in several ways:

1. Binary packages – ready to run with no compilation required. These are available in Debian and Ubuntu repositories, so just use your normal package manager (so you don’t need this guide). They are also available for Anaconda Python 3.

2. Using flatpak

3. From source – that is, it must be compiled for your machine. This is the topic of this guide.

See the site https://answers.launchpad.net/escript-finley for online help. Chapter 5 covers installing from source. Appendix A lists some c++ features which your compiler must support in order to compile escript. This version of escript has the option of using Trilinos in addition to our regular solvers. Appendix B covers features of Trilinos which escript needs.

\(^1\)For the rest of the document we will drop the esys-
Installing from Flatpak

To install `esys.escript` on any linux distribution using flatpak\(^1\), type

```
flatpak install flathub au.edu.uq.esys.escript
```

This will download and install `esys.escript` on your machine. The `esys.escript` build installed utilises both the Trilinos and PASO solver libraries, with openMP but without OPENMPI.

After flatpak has finished downloading and installing `esys.escript`, you can launch an `esys.escript` window from the menu or run `esys.escript` in a terminal with the command:

```
flatpak run au.edu.uq.esys.escript [other arguments to pass to escript]
```

Finally, to uninstall `esys.escript` from your machine, type

```
flatpak uninstall escript
```

\(^1\)For most linux distributions this can be installed from the repository. Otherwise, flatpak is available at https://flathub.org/home
Installing inside Anaconda

There are precompiled binaries of esys.escript available for Anaconda python (for Linux), available in the conda-forge channel on Anaconda cloud. They can be installed using the command

```
conda install esys-escript -c conda-forge
```
Installing from Docker

To install an esys.escript Docker container on your machine, first install Docker and then type:

docker pull esysescript/esys-escript
This chapter assumes you are using a unix/posix like system (including MacOSX).

5.1 Parallel Technologies

It is likely that the computer you run esys.escript on, will have more than one processor core. Escript can make use of multiple cores [in order to solve problems more quickly] if it is told to do so, but this functionality must be enabled at compile time. Section 5.1.1 gives some rough guidelines to help you determine what you need.

There are two technologies which esys.escript can employ here.

• OpenMP – the more efficient of the two [thread level parallelism].
• MPI – Uses multiple processes (less efficient), needs less help from the compiler.

Escript is primarily tested on recent versions of the GNU and Intel suites (“g++” / “icpc”). However, it also passes our tests when compiled using “clang++”. Escript now requires compiler support for some features of the C++11 standard. See Appendix A for a list.

Our current test compilers include:
• g++ 8
• clang++ 7
• intel icpc v17

Note that:
• OpenMP will not function correctly for g++ ≤ 4.2.1 (and is not currently supported by clang).
• icpc v11 has a subtle bug involving OpenMP and C++ exception handling, so this combination should not be used.

5.1.1 What parallel technology do I need?

If you are using any version of Linux released in the past few years, then your system compiler will support OpenMP with no extra work (and give better performance); so you should use it. You will not need MPI unless your computer is some form of cluster.

If you are using BSD or MacOSX and you are just experimenting with esys.escript, then performance is probably not a major issue for you at the moment so you don’t need to use either OpenMP or MPI. This also applies if you write and polish your scripts on your computer and then send them to a cluster to execute. If in the future you find escript useful and your scripts take significant time to run, then you may want to recompile esys.escript with more options.
Note that even if your version of esys.escript has support for OpenMP or MPI, you will still need to tell the system to use it when you run your scripts. If you are using the run-escript launcher, then this is controlled by the \(-t\), \(-p\), and \(-n\) flags. If not, then consult the documentation for your MPI libraries (or the compiler documentation in the case of OpenMP). If you are using MacOSX, then see the next section, if not, then skip to Section 5.3.

5.2 MacOS

This release of esys.escript has only been tested on OSX 10.13. For this section we assume you are using either homebrew or MacPorts as a package manager. You can of course install prerequisite software in other ways. For example, we have had some success changing the default compilers used by those systems. However this is more complicated and we do not provide a guide here.

Both of those systems require the XCode command line tools to be installed.

5.3 Building

Escript is built using SCons. To simplify the installation process, we have prepared SCons _options.py files for a number of common systems. The options files are located in the scons/templates directory. We suggest that the file most relevant to your OS be copied from the templates directory to the scons directory and renamed to the form XXXX.options.py where XXXX should be replaced with your computer’s (host-)name. If your particular system is not in the list below, or if you want a more customised build, see Section 5.3.9 for instructions.

- Debian - 5.3.1
- Ubuntu - 5.3.2
- OpenSuse - 5.3.3
- Centos - 5.3.4
- Fedora - 5.3.5
- MacOS (macports) - 5.3.6
- MacOS (homebrew) - 5.3.7
- FreeBSD - 5.3.8

Once these are done proceed to Section 5.4 for cleanup steps.

All of these instructions assume that you have obtained the esys.escript source (and uncompressed it if necessary).

5.3.1 Debian

These instructions were prepared on Debian 10 Buster.

As a preliminary step, you should install the dependencies that Escript requires from the repository. If you intend to use Python 2.7, then you should install the following

```
sudo apt-get install python-dev python-numpy python-pyproj python-gdal
sudo apt-get install python-sympy python-matplotlib python-scipy
sudo apt-get install libboost-python-dev libboost-random-dev
sudo apt-get install libnetcdf-dev libnetcdf-cxx-legacy-dev libnetcdf-c++4-dev
sudo apt-get install scons lsb-release libsuitesparse-dev gmsh
```

1 It may be enough to set the OMP_NUM_THREADS environment variable.

2 Note that package managers will make changes to your computer based on programs configured by other people from various places around the internet. It is important to satisfy yourself as to the security of those systems.

3 As of OSX10.9, the command xcode-select --install will allow you to download and install the commandline tools.

4 These are correct a time of writing but later versions of those systems may require tweaks. Also, these systems represent a cross section of possible platforms rather than meaning those systems get particular support.
If you intend to use Python 3.0+, then you should install the following:

```bash
sudo apt-get install python3-dev python3-numpy python3-pyproj python3-gdal
sudo apt-get install python3-mpi4py python3-matplotlib python3-scipy
sudo apt-get install libboost-python-dev libboost-random-dev
sudo apt-get install libnetcdf-dev libnetcdf-cxx-legacy-dev libnetcdf-c++4-dev
sudo apt-get install libboost-python-dev libboost-iostreams-dev
```

In the source directory execute the following (substitute `buster_py2` or `buster_py3` for `XXXX`):

```bash
scons -j1 options_file=scons/templates/XXXX_options.py
```

If you wish to test your build, you can use the following:

```bash
scons -j1 py_tests options_file=scons/templates/XXXX_options.py
```

### 5.3.2 Ubuntu

These instructions were prepared on Ubuntu 20.04 LTS *Focal Fossa*.

As a preliminary step, you should install the dependencies that Escript requires from the repository.

For Python 3.0+, you should instead install the following packages:

```bash
sudo apt-get install python3-dev python3-numpy python3-pyproj python3-gdal
sudo apt-get install python3-mpi4py python3-matplotlib python3-scipy
sudo apt-get install libboost-python-dev libboost-random-dev
sudo apt-get install libnetcdf-dev libnetcdf-cxx-legacy-dev libnetcdf-c++4-dev
sudo apt-get install libboost-python-dev libboost-iostreams-dev
```

Then navigate to the source directory and execute the following:

```bash
scons -j1 options_file=scons/templates/focus_options.py
```

### 5.3.3 OpenSuse

These instructions were prepared using OpenSUSE Leap 15.2.

As a preliminary step, you should install the dependencies that Escript requires from the repository. If you intend to use Python 2.7, then you should install the following packages:

```bash
sudo zypper in python-devel python2-numpy python2-gdal
sudo zypper in python2-scipy python2-matplotlib
sudo zypper in gcc gcc-c++ scons netcdf-devel libnetcdf_c++-devel
sudo zypper in libboost_python2-py2_7-1_66_0-devel libboost_numpy2-py2_7-1_66_0-devel
```

If you intend to use Python 3.0, then you should instead install the following packages:

```bash
sudo zypper in python3-devel python3-numpy python3-GDAL
sudo zypper in python3-scipy python3-matplotlib
sudo zypper in gcc gcc-c++ scons netcdf-devel libnetcdf_c++-devel
sudo zypper in libboost_python3-py3-1_66_0-devel libboost_numpy3-py3-1_66_0-devel
```

Now to build escript itself. In the escript source directory execute the following (substitute `opensuse_py2` or `opensuse_py3` as appropriate for `XXXX`):

```bash
scons -j1 options_file=scons/templates/XXXX_options.py
```

If you wish to test your build, you can use the following:

```bash
scons -j1 py_tests options_file=scons/templates/XXXX_options.py
```

Now go to Section 5.4 for cleanup.
5.3.4 CentOS

It is possible to install esys.escript on both CentOS releases 7 and 8. We include separate instructions for each of these CentOS releases in this section.

CentOS release 7

The core of escript works, however some functionality is not available because the default packages for some dependencies in CentOS are too old. At present, it is not possible to compile esys.escript using Python 3.0+ on CentOS 7 as Python 3.0+ versions of many of the dependencies are not currently available in any of the CentOS repositories, but this may change in the future. In this section we only outline how to install a version of esys.escript that uses Python 2.7.

First, add the EPEL repository.

```bash
yum install epel-release.noarch
```

Install packages:

```bash
yum install netcdf-devel netcdf-cxx-devel gdal-python
yum install python-devel numpy scipy sympy python2-scons
yum install python-matplotlib gcc gcc-c++ boost-devel
yum install boost-python gdal-devel suitesparse-devel pyproj
```

Now to build escript itself. In the escript source directory:

```bash
scons -j1 options_file=scons/templates/centos7_0_options.py
```

Now go to Section 5.4 for cleanup.

CentOS release 8

The core of escript works in CentOS 8, however some functionality is not available because the default packages for some dependencies in CentOS are too old. This install is for Python 3.

First, add the EPEL, PowerTools and Okay repositories:

```bash
yum update
yum install epel-release.noarch dnf-plugins-core
yum config-manager --set-enabled PowerTools
yum update
```

Now, install the packages:

```bash
yum install python3-devel python3-numpy python3-scipy python3-pyproj
yum install boost-devel boost-python3 boost-python3-devel
yum install gcc gcc-c++ scons
yum install suitesparse suitesparse-devel
```

Finally, you can compile esys.escript with the command

```bash
scons -j1 options_file=scons/templates/centos8_0_options.py
```

5.3.5 Fedora

These instructions were prepared using Fedora 31 Workstation.

To build the a version of esys.escript that uses Python 2.7, install the following packages:

```bash
yum install gcc-c++ scons suitesparse-devel
yum install python2-devel boost-python2-devel
yum install python2-scipy
yum install netcdf-devel netcdf-cxx-devel netcdf-cxx4-devel
```

To build the a version of esys.escript that uses Python 3.0+, install the following packages:
yum install gcc-c++ scons suitesparse-devel
yum install python3-devel boost-python3-devel
yum install python3-scipy python3-pyproj python3-matplotlib
yum install netcdf-devel netcdf-cxx-devel netcdf-cxx4-devel

In the source directory execute the following (substitute fedora.py2 or fedora.py3 for XXXX):
scons -j1 options_file=scons/templates/XXXX_options.py

Now go to Section 5.4 for cleanup.

5.3.6 MacOS 10.10 and later (macports)

The following will install the capabilities needed for the macports_10.10_options.py file (later versions can use the same options file).
sudo port install scons
sudo port select --set python python27
sudo port install boost
sudo port install py27-numpy
sudo port install py27-sympy
sudo port select --set py-sympy py27-sympy
sudo port install py27-scipy
sudo port install py27-pyproj
sudo port install py27-gdal
sudo port install netcdf-cxx
sudo port install silo
scons -j1 options_file=scons/templates/macports_10.10options.py

5.3.7 MacOS 10.13 and later (homebrew)

The following will install the capabilities needed for the homebrew_10.13_options.py file.
brew install scons
brew install boost-python
brew install netcdf

There do not appear to be formulae for sympy or pyproj so if you wish to use those features, then you will need to install them separately.
scons -j1 options_file=scons/templates/homebrew_10.13_options.py

5.3.8 FreeBSD

At time of writing, numpy does not install correctly on FreeBSD. Since numpy is a critical dependency for esys.escript, we have been unable to test on FreeBSD.

5.3.9 Other Systems / Custom Builds

esys.escript has support for a number of optional packages. Some, like netcdf need to be enabled at compile time, while others, such as sympy and the projection packages used in esys.downunder are checked at run time. For the second type, you can install them at any time (ensuring that python can find them) and they should work. For the first type, you need to modify the options file and recompile with scons. The rest of this section deals with this.

To avoid having to specify the options file each time you run scons, copy an existing _options.py file from the scons/ or scons/templates/ directories. Put the file in the scons directory and name it your-machinename_options.py. For example: on a machine named toybox, the file would be scons/toybox_options.py.

Individual lines can be enabled/disabled, by removing or adding # (the python comment character) to the beginning of the line. For example, to enable OpenMP, change the line

Chapter 5. Installing from Source
#openmp = True

to

openmp = True

If you are using libraries which are not installed in the standard places (or have different names) you will need
to change the relevant lines. A common need for this would be using a more recent version of the boost::python
library. You can also change the compiler or the options passed to it by modifying the relevant lines.

MPI

If you wish to enable or disable MPI, or if you wish to use a different implementation of MPI, you can use the
mpi configuration variable. You will also need to ensure that the mpi_prefix and mpi_libs variables are
uncommented and set correctly. To disable MPI use, mpi = 'none'.

Testing

As indicated earlier, you can test your build using scons py_tests. Note however, that some features like
netCDF are optional for using esys.escript, the tests will report a failure if they are missing.

5.4 Cleaning up

Once the build (and optional testing) is complete, you can remove everything except:

• bin
• esys
• lib
• doc
• CREDITS
• LICENSE
• README

The last three aren’t strictly required for operation. The doc directory is not required either but does contain
eamples of escript scripts.

You can run escript using path_to_escript_files/bin/run-escript.
Where path_to_escript_files is replaced with the real path.

Optional step
You can add the escript bin directory to your PATH variable. The launcher will then take care of
the rest of the environment.

5.5 Optional Extras

Some other packages which might be useful include:

• Lapack and UMFPACK — direct solvers (install the relevant libraries and enable them in the options file).
• support for the Silo file format (install the relevant libraries and enable them in the options file).
• VisIt — visualisation package. Can be used independently but our weipa library can make a Visit plug-in
to allow direct visualisation of escript simulations.
• gmsh — meshing software used by our pycad library.
• Mayavi2 — another visualisation tool.
5.5.1 Trilinos

esys.escript now has some support for Trilinos\textsuperscript{6} solvers and preconditioners. The most significant limitation is that the current Trilinos release does not support block matrices so esys.escript can only use Trilinos solvers for single PDEs (i.e. no PDE systems).

If your distribution does not provide Trilinos packages you can build a working version from source. (See Appendix B)

5.6 Testing esys.escript

esys.escript has extensive testing that can be used to confirm that the program is working correctly. To run the unit testing, compile esys.escript with the flag build\_full. This will build esys.escript normally and then create a shell script named utest.sh. Once this file has been created, you can run unit testing using the command

\begin{verbatim}
sh utest.sh path_to_build_folder '-tT -nN -pP'
\end{verbatim}

where T, N and P represent the number of threads, nodes and processes to run the testing on. Some of these terms can be omitted. For example, to run the testing in serial, you would run

\begin{verbatim}
sh utest.sh path_to_build_folder '-t1'
\end{verbatim}

Note that a careless selection of these parameters may cause the testing program to skip many of the tests. For example, if you compile esys.escript with OpenMP enabled but then instruct the testing program to run on a single thread, many of the OpenMP tests will not be run.

\footnote{https://trilinos.org/}
Required compiler features

Building escript from source requires that your c++ compiler supports at least the following features:

- `std::complex<>`
- Variables declared with type `auto`
- Variables declared with type `decltype(T)`
- `extern template class` to prevent instantiation of templates.
- `template class classname<type>`, to force instantiation of templates
- `isnan()` is defined in the `std::` namespace

The above is not exhaustive and only lists language features which are more recent that our previous baseline of c++99 (or which we have recently begun to rely on). Note that we test on up to date versions of `g++`, `icpc` & `clang++` so they should be fine.

Note that in future we may use c++14 features as well.
In order to solve PDEs with complex coefficients, escript needs to be compiled with Trilinos support. This requires that your version of Trilinos has certain features enabled. Since some precompiled distributions of Trilinos are not built with these features, you may need to compile Trilinos yourself as well.

While we can’t provide support for building Trilinos, we provide here two configuration files which seem to work for Debian 10 “buster”. One of these cmake script builds Trilinos with MPI support and one builds Trilinos without MPI support.

B.1 Debian “buster” configuration

B.1.1 Required packages

The following packages should be installed to attempt this build:

- cmake
- g++
- libsuitesparse-dev
- libmumps-dev
- libboost-dev
- libscotchparmetis-dev
- libmetis-dev
- libcppunit-dev

B.1.2 Example configuration file (without MPI)

```
#!/bin/bash

# Set this to the root of your Trilinos source directory.
TRILINOS_PATH=../trilinos_source

rm -f CMakeCache.txt

EXTRAARGS=--

cmake \
   -D CMAKE_C_COMPILER='which gcc' \
   -D CMAKE_C_COMPILER='which g++'
```
B.1.3 Example configuration file (with MPI)

```bash
#!/bin/bash

# Set this to the root of your Trilinos source directory.
```
# You can invoke this shell script with additional command-line arguments. They will be passed directly to CMake.
# EXTRA_ARGS=$@

rm -f CMakeCache.txt

cmake \
-D MPI_C_COMPILER=`which mpicc` \
-D MPI_CXX_COMPILER=`which mpic++` \
-D MPI_Fortran_COMPILER=`which mpif90` \
-D PYTHON_EXECUTABLE=/usr/bin/python3 \
-D CMAKE_INSTALL_PREFIX=/usr/local/ \
-D Trilinos_ENABLE_CXX11=ON \ 
-D CMAKE_C_FLAGS=-w -fopenmp \
-D CMAKE_CXX_FLAGS=-w -fopenmp \ 
-D Trilinos_ENABLE_Fortran=ON \ 
-D BUILD_SHARED_LIBS=ON \ 
-D TPL_ENABLE_BLAS=ON \ 
-D TPL_ENABLE_Boost=ON \ 
-D TPL_ENABLE_Cholmod=ON \ 
-D TPL_ENABLE_METIS=ON \ 
-D TPL_ENABLE_SuperLU=OFF \ 
-D TPL_ENABLE_UMFPACK=ON \ 
-D TPL_ENABLE_PARMETIS=ON \ 
-D TPL_ENABLE_SCALAPACK=ON \ 
-D TPL_ENABLE_MUMPS=OFF \ 
-D TPL_BLAS_INCLUDE_DIRS=/usr/include/suitesparse \ 
-D TPL_Cholmod_INCLUDE_DIRS=/usr/include/suitesparse \ 
-D TPL_Cholmod_LIBRARIES='libcholmod.so;libamd.so;libcolamd.so' \ 
-D TPL_UMFPACK_INCLUDE_DIRS=/usr/include/suitesparse \ 
-D TPL_Boost_INCLUDE_DIRS=/usr/local/boost/include/ \ 
-D TPL_Boost_LIBRARY_DIRS=lib/ \ 
-D TPL_MUMPS_INCLUDE_DIRS='/usr/include/mumps-seq-shared/' \ 
-D Trilinos_ENABLE_Amesos=ON \ 
-D Trilinos_ENABLE_Amesos2=ON \ 
-D Trilinos_ENABLE_AztecOO=ON \ 
-D Trilinos_ENABLE_Belos=ON \ 
-D Trilinos_ENABLE_Tpetra=ON \ 
-D Trilinos_ENABLE_ALL_OPTIONAL_PACKAGES=ON \ 
-D KOKKOS_ENABLE_AGGRESSIVE_VECTORIZATION=ON \ 
-D Tpetra_INST_COMPLEX_DOUBLE=ON \ 
-D Teuchos_ENABLE_COMPLEX=ON \ 
-D Tpetra_INST_INT_INT=ON \ 
-D Tpetra_ENABLE_DEPRECATED_CODE=ON \ 
-D Trilinos_ENABLE_Amesos=ON \ 
-D Trilinos_ENABLE_Amesos2=ON \ 
-D Trilinos_ENABLE_AztecOO=ON \ 
-D Trilinos_ENABLE_Belos=ON \ 
-D Trilinos_ENABLE_Tpetra=ON \ 
-D Trilinos_ENABLE_ALL_OPTIONAL_PACKAGES=ON \ 
-D KOKKOS_ENABLE_AGGRESSIVE_VECTORIZATION=ON \ 
-D Tpetra_INST_COMPLEX_DOUBLE=ON \ 
-D Teuchos_ENABLE_COMPLEX=ON \ 
-D Tpetra_INST_INT_INT=ON \ 
-D Tpetra_ENABLE_DEPRECATED_CODE=ON \ 

Appendix B. Trilinos
-D Trilinos_ENABLE_OpenMP=ON \ 
-D Trilinos_ENABLE_MPI=ON \ 
-D Trilinos_ENABLE_EXPLICIT_INSTANTIATION=ON \ 
-D KOKKOS_ENABLE_COMPILER_WARNINGS=ON \ 
-D Amesos2_ENABLE_Basker=ON \ 
-D Tpetra_INST_SERIAL:BOOL=ON \ 
-D Trilinos_ENABLE_TESTS=OFF \ 
$EXTRA_ARGS \ 
$TRILINOS_PATH