

## User Manual:

# Python code for generating C code for piecewise Chebyshev approximation

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This user guide documents Python and C software that supports the piecewise polynomial approximation of real-valued functions as described in our article “Algorithm 1062: Code generation for piecewise Chebyshev approximation”.

## 1 Introduction

The free and open-source Python package *ppapp* (piecewise polynomial approximation) contains Python and C code for piecewise polynomial function approximation. This manual addresses the approximation of a real-valued function of a real variable as described in our article “Algorithm 1062: Code generation for piecewise Chebyshev approximation” [1]. The software is released under the GNU General Public License Version 3 or higher; other licensing is negotiable.

The package is available through three distribution channels:

- the **project repository** at the GitLab instance of Forschungszentrum Jülich [2];
- the **PyPI package** `ppapp` [3], installable via `pip install ppapp`;
- the **archival zip package** in the Collected Algorithms of the ACM (CALGO) [4], which contains release 1.3.0 as described in [1], with project root in directory `src/`.

Section 2 describes the code generator that produces C source files containing tables of polynomial coefficients that approximate a specific function  $f$ . Section 3 describes how the generated C code is used.

## 2 Code generator

### 2.1 Install and run

The generator code is written in the programming language Python3. It depends on the arbitrary-precision library *Arb* that is part of *FLINT*, Fast Library for Number Theory [5]. A Python wrapper of FLINT is available from [pypi.org](https://pypi.org) as package *python-flint* [6].

The software can be installed from PyPI with:

```
pip install ppapp
```

This automatically installs the *python-flint* dependency and provides the command:

```
ppapp
```

Alternatively, when working from source, run the `ppapp` module from the root directory indicated in Sect 1:

```
cd <ppapp root directory>
python -m ppapp <mode> <arguments>
```

Running `ppapp` without arguments prints a summary of available modes:

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No mode given

Usage:

```
ppapp i <f_module>           - run initial tests from my_testcases
ppapp v <f_module> <x>       - print function value f(x)
ppapp n <f_module> <M> <Nmax> <E> - print N_min(M',E), up to given Nmax
ppapp e <f_module> <M> <N>   - print maximum relative error, in units of epsilon
ppapp c <f_module> <M> <N> [<E>] - print plain table of Chebyshev coefficients c_n
ppapp p <f_module> <M> <N> [<E>] - print plain table of economized coefficients p_m
ppapp s <f_module> <M> <N> [<E>] - print C source defining economized coefficients p_m
ppapp t <f_module> <M> <Nx0> <E> - print C source defining test cases
ppapp r <f_module> <M> <N> <n>   - print deviation in units of epsilon, for <n> points
ppapp H <f_module> <M> <N> <n>   - print deviation histogram, for <n> random points
```

where

```
<f_module> - path to function definition file (e.g., 'mydir/f_imwofx.py')
<M>        - integer M >= 0 specifies 2^M subdomains per octave
<N>        - integer N >= 1 is the polynomial degree
<E>        - double E > 0 is the maximum relative error, in units of epsilon=2^-53
<Nx0>     - number of extra (non-Chebyshev) octaves on each side of the Chebyshev range
<n>        - integer n >= 1 is the total number of test points
```

Installation info:

```
- Invoked via:      /G/sw/ppapp/ppapp/___main___.py
- Running from:    source
- Package directory: /G/sw/ppapp/ppapp, with subdirectories:
  - docs/          user manual (PDF)
  - demo_functions/ example high-precision function definitions
```

## 2.2 Function argument

All commands require a function definition file as the second argument:

```
ppapp v /path/to/my_function.py 1.0
```

The function definition file specifies the interface between the generic approximation machinery and the specific target function that is to be approximated. It defines one function and two global objects:

```
def my_arb_f(X: Arb, prec: int) -> Arb:
    """Evaluates f(x) with given precision"""
    ...

my_domain: Tuple[float, float] = (a, b)
my_testcases: List[Tuple[float, float, float]] = [
    (x, f_expected, tolerance),
    ...
]
```

Function `my_arb_f` computes  $f(x)$  in interval arithmetic with a precision of `prec` binary digits, using the python-flint wrapper for Arb [5]. The tuple `my_domain` contains the limits of the total domain  $[a, b)$ . The entries in the list

`my_testcases` are triples  $(x, f_{\text{expected}}(x), \text{tol})$ . The test suite will fail unless for each test case, the function value  $f(x)$ , computed by our arbitrary-precision function `my_arb_f`, agrees with  $f_{\text{expected}}(x)$  with a relative error not larger than `tol`.

As an example, the package includes `ppapp/demo_functions/imwofx.py` that implements the function

$$f(x) := \exp(-x^2) \operatorname{erfi}(x) \equiv \operatorname{Im} w(x) \quad (1)$$

introduced in [1, Sect 1.3]. The arbitrary-precision computation of  $f$  is straightforward because Arb supports `erfi(x)` as built-in method `arb.erfi()`. The domain is  $[a, b] = [0.5, 12)$ . The test cases allow a tolerance of  $10^{-5}$ , i. e. they are meant to ensure the basic correctness of the high-precision implementation but not its accuracy. The latter is not a concern because of the intrinsic accuracy control of Arb. To support any other function  $f$ , one needs to write a new implementation file, based on the model provided by `ppapp/demo_functions/imwofx.py`.

### 2.3 Run modes

The program `ppapp` operates in different modes that are selected by a letter provided as first command-line argument. All output is written to `stdout`; use redirection to save it in a file.

#### Mode i: initial test of high-precision function.

```
ppapp i <f_module>
```

Tests the function implementation against the test cases defined in `my_testcases`. This verifies that the high-precision reference function is basically correct before using it for coefficient generation.

#### Mode f: compute function value.

```
ppapp v <f_module> <x>
```

Computes a single function value  $f(x)$ .

#### Mode n: compute minimal polynomial degree.

```
ppapp n <f_module> <M> <Nmax> <relerr>
```

Computes the minimal polynomial degree for which the relative error, in units of  $\epsilon$ , is not larger than the given `relerr`. This mode has been used to produce Table 1 in [1].

#### Mode e: estimate error bound.

```
ppapp e <f_module> <M> <N>
```

Prints an upper bound for the total relative error in units of  $\epsilon$ . Based on results from modes `n` and `e`, make your choice of  $M$  and  $N$ , as discussed in [1, Sect 4.4].

#### Modes c, p: Compute coefficient tables.

```
ppapp c <f_module> <M> <N> [<relerr>]
```

```
ppapp p <f_module> <M> <N> [<relerr>]
```

Prints a table of Chebyshev coefficients  $c_n$  (mode `c`) or of economized polynomial coefficients  $p_n$  (mode `p`). These modes have been used to produce Fig 3 of [1]. The optional `relerr` argument, in units of  $\epsilon$ , activates tests that ensure that the relative error never exceeds this bound.

**Mode s: Generate target C source code.**

```
ppapp s <f_module> <M> <N> [<relerr>]
```

Prints C source code with arrays that hold the  $p_n$ .

**Mode t: Generate test C source code.**

```
ppapp t <f_module> <M> <Nx0> <relerr>
```

Prints C source code with test cases, covering a range  $a2^{-N_{x0}} \dots b2^{N_{x0}}$  that extends beyond the Chebyshev domain if  $N_{x0} > 0$ .

**Mode r: Tabulate representative deviations.**

```
ppapp r <f_module> <M> <N> <n>
```

Computes and prints the relative deviation  $\delta f$  between the polynomial approximation and the high-precision reference function, in units of  $\epsilon$ , for  $n$  points regularly spaced on a logarithmic scale. This mode has been used to produce Fig 4a in [1].

**Mode H: Produce deviations histogram.**

```
ppapp H <f_module> <M> <N> <n>
```

Computes and prints a histogram of relative deviations for  $n$  random-drawn points. This mode has been used to produce Fig 4b in [1].

**2.4 Hexadecimal output**

The output files are self-explaining thanks to initial comment lines. Let us explain just one detail: In the auto-generated C source files, floating-point numbers are written in hexadecimal format, like

```
0x1.ef90904c7e99p-2, 0x1.461380c17af85p-8, -0x1.9d5e2f887fe99p-15, -0x1.35c476fb1ab4ap-24, ...
```

Note that the letter p is followed by the base 2 exponent in decimal notation, i.e.  $0x1.8p-13$  is  $1.5 \cdot 2^{-13}$ .

**2.5 Unit tests**

The PyPI package includes a comprehensive test suite. When working with the repository, the tests can be run with:

```
python3 -m pytest tests/ -v
```

The test suite covers mathematical helper functions, power law analysis, error bounds, subdomain computation, output formatting, function modules, Chebyshev coefficient computation, polynomial approximation accuracy, and full pipeline integration.

### 3 Usage demonstrator

The C source code generated by ppapp can be used in C or C++ projects to compute function values  $f(x)$ . In a typical application, this code would be integrated with other code that evaluates  $f$  outside the intermediate domain considered here, using expansions for small and large  $x$ .

A C demonstration implementation is available in subdirectory `ppapp/docs/target-C-code-demo`. It shows how to use the auto-generated coefficients for efficient function evaluation.

The target algorithm for evaluating the piecewise polynomial approximation is also illustrated in the Python module `ppapp.target_algorithm` (included in the PyPI package). This plain Python implementation is for illustration purposes only. The *ppapp* project is designed to generate C code for optimized high-throughput computation. For production use from Python, the evaluation code should be implemented as a C extension module or at least use NumPy for vectorized operations. The Python script should not be used as a template for production code.

#### 3.1 Alignment specifier

In order to minimize the number of cache loads, the auto-generated arrays that hold tables of polynomial coefficients must start at the beginning of a 64 bytes memory block [1, Sect 2.5]. This is achieved by defining these arrays as

```
alignas(64) static const double ppapp_Coeffs0[...] = { ... };
```

The specifier `alignas` is defined in the language standards C23 and C++11. For older versions of C it is not in the standard, but may be supported as a compiler extension. C11 has a specifier `_Alignas`. For even older language variants one would depend on compiler-specific attributes.

The Python code generator automatically inserts the correct alignment directives and pads coefficient tables with zeros when necessary to maintain proper alignment [1, Sect 2.5].

In the project repository, the C demonstration executable is built and run with the commands

```
cd <target C directory>
mkdir build
cd build
cmake ..
make
./test_computation
./run_computation
```

Program `test_computation` runs automated tests using test cases generated by ppapp mode `t`. It verifies that the polynomial approximation meets the specified error bounds. Program `run_computation` demonstrates the usage of the generated code by computing and printing function values at a set of sample points.

### References

- [1] Wuttke J and Kleinsorge A (2026) *Algorithm 1062: Code generation for piecewise Chebyshev approximation*. ACM Transactions on Mathematical Software (2026), <https://doi.org/10.1145/380569>.
- [2] Wuttke J et al. (2025) *PPAPP, Piecewise Polynomial APPROXimation generator*. <https://jugit.fz-juelich.de/mlz/ppapp>.
- [3] *Python Package Index. Project ppapp*. <https://pypi.org/project/ppapp>.
- [4] Wuttke J and Kleinsorge A (2026) *Code generating code for piecewise Chebyshev approximation. Code snapshot and user manual*. Collected Algorithms of the ACM. <https://calgo.acm.org/1062.zip>.
- [5] The FLINT team (2024) *FLINT: Fast Library for Number Theory*. <https://flintlib.org>. Version 3.1.2.
- [6] *Python Package Index. Project python-flint*. <https://pypi.org/project/ppapp>.