APL as a Shared Library

Version 17.1

Dyalog Limited

Minchens Court, Minchens Lane
Bramley, Hampshire
RG26 5BH
United Kingdom

tel: +44 1256 830030
fax: +44 1256 830031
email: support@dyalog.com
https://www.dyalog.com
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1 About This Document

This document describes the API that can be used to call APL code in a shared library (that is, .dll, .so and .dylib files). It describes the SDK to create such a shared library and includes samples of how to call it.

1.1 Audience

It is assumed that the reader has a working knowledge of Dyalog (for information on the resources available to help develop your Dyalog knowledge, see http://www.dyalog.com/introduction.htm) as well as knowledge of the C programming language. Awareness of Dyalog's "Direct Workspace Access" SDK is also beneficial.
2 Introduction

On the Microsoft Windows operating system, it is possible for third-party code and applications to call APL code in shared libraries using the COM and .NET interfaces. However, these mechanisms are proprietary to Windows and are not available on all the operating systems supported by Dyalog. In addition, these interfaces impose restrictions and data formats that might not be optimal for use with APL code and the APL interpreter.

The SDK described in this document is implemented end-to-end with code and libraries (owned and implemented by Dyalog Ltd) that are efficient and portable across operating systems. They are also extensible, both by Dyalog Ltd and by end users.

The SDK comprises a number of C header files and libraries that can be used to produce a self-contained native shared library; this can then be called by any language or program that can access native shared libraries.

The current (Dyalog version 17.1) SDK requires the author of the library to write some simple C source code to provide a strongly typed exportable interface to APL functions in a workspace or script.

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On Microsoft Windows, shared libraries typically have a .dll extension.
On Linux and UNIX, shared libraries typically have a .so extension.
On macOS, shared libraries typically have a .dylib extension.

Although this SDK is intended to produce a shared library containing APL code (as described in this document), it is also possible to produce a static library or a self-contained application containing APL code.
3 Installation

3.1 Pre-requisites

To build and execute the samples, the host computer must have an installed C development environment.

On Microsoft Windows, Visual Studio 2015 or later is required to build and execute the sample VS solutions.

On Linux and macOS, the default C development and make tools should be sufficient to build and execute the samples. Additional developer libraries may be required along with those already installed on a developer machine, for example, the ncurses library. This can be installed with:

```
sudo apt-get install libncurses5 (or equivalent)
```

3.2 Installation

The required header files and libraries are installed as part of the normal installation of Dyalog. The destination directory varies according to the target operating system.
# Architecture

## 4.1 The Binary

The SDK can be used to produce a library (shared or static) that contains both APL code and the Dyalog interpreter required to run the APL code.

The APL code, some interface C code and the Dyalog interpreter (as a static library) are all combined into a single, shared, binary.

On Microsoft Windows, the APL code is embedded in the binary as a Windows resource. On Linux and macOS, the APL code is embedded as static data.

### 4.1.1 The Interpreter

The SDK includes an implementation of the Dyalog interpreter as a static library.

For each shared library, the first time the `call_apl` function is called an embedded Dyalog interpreter is started and any APL code in the shared library is loaded into that interpreter. The interpreter instance persists for as long as the shared library is loaded into the host process. This makes it possible to persist data between calls in the APL workspace. By default, the interpreter is started as a runtime, meaning that a development environment is never presented. The interpreter is started with default values of MAXWS and other configuration parameters.

To tailor the properties of the APL interpreter, call the `load_apl` function before calling the `call_apl` function:

```c
extern int load_apl(unsigned int flags, int argc, wchar_t **argv);
```

The first argument to the `load_apl` function can be one of the following:

- 0 (zero) – on Microsoft Windows, any untrapped errors in the APL code will cause the Dyalog Development Environment to be displayed. On Linux/macOS, the interpreter will suspend until the RIDE is attached.
- ENGINE_F_RUNTIME – the interpreter behaves like a runtime system and will never display a development environment.

The `argv` argument to the `load_apl` function is an array of pointers to options (for example, "MAXWS=512Mb" or "/Dcw"). These parameters should be passed as wide character strings.

The `argc` argument to the `load_apl` function specifies how many entries there are in the `argv` array. The `load_apl` function starts the APL interpreter with the specified configuration.

If the appropriate settings are provided and the appropriate shared library files are installed with the shared library, then the Dyalog Development Environment (on
Microsoft Windows) or the RIDE can be used to debug the APL code in the shared library.

4.1.1.1 Multithreading

Multiple threads can call APL code concurrently. This is achieved by mapping threads in the host application to multiple APL threads within the interpreter. If only a single thread is used to call APL code then it will run on APL thread one. APL thread zero is not used to run any APL code. For an example of multiple threads calling APL, see section 6.6.

4.2 The Source

Each entry point in a shared library that will call APL code needs to be exported from the library. This is achieved by writing a C function that is declared as being callable from outside the library. (Note that in the SDK header files, this platform-specific mechanism is largely abstracted out). Each such function will typically contain a line of code for each of its parameters and for its result. This line tells the underlying library how to marshal the data from the native code to/from APL arrays.

For example, to call the APL function inAPL with a scalar integer argument:

```c
extern int call_apl(const wchar_t *name, APL_PARAM *first,...);
EXPORT int LIBCALL inAPL(int month)
{
    APL_INT32_PARAM(Month,month);
    return call_apl(L"inAPL", &Month, PARAM_END);
}
```

In this example, the `APL_INT32_PARAM` statement (which is a macro from one of the SDK include files) declares that the `month` parameter to the function is to be passed as an `INT32` (int32_t) scalar to the APL code. The parameter is passed in a structure defined as a local variable called `Month`.

The `call_apl` function calls the APL function `inAPL`, passing the value of `month` (contained within the `Month` structure) as `inAPL`'s argument. The `call_apl` function takes a variable number of parameters; the special macro `PARAM_END` marks the end of the parameter list.

The result of the `call_apl` function is an error code:

- A return of 0 (zero) indicates that the call to the APL function (`inAPL` in this example) completed successfully.
- A non-zero return indicates that an error occurred during the invocation of the APL function (including marshalling the parameters, executing the APL code and marshalling the result):
  - Positive error codes have the same numeric value and meaning as APL error codes.
  - Negative error codes are reserved.

Parameters are passed in the right argument of the APL function (it is not possible to pass parameters in the left argument of an APL function).

In this example the APL function does not return a result. However, the return of `call_apl` can still indicate an error.
5 Implementation

5.1 Parameter and Result Macros

The SDK supports the following C data types:

- signed integers: 8, 16 and 32-bit
- floating point numbers: 32 and 64-bit
- unsigned characters: 8, 16 and 32-bit
- characters: char and wchar_t
- arrays of each of the above
- Null terminated arrays of the above characters
- arrays of the above characters containing JSON text

These types can be the input to, output of, or the result of an APL function.

C arrays will always be passed to the APL function as vectors.

Each of these parameters can be declared using a predefined macro. The names of these macros include the type that they are marshalling (see [DYALOG]\DWASamples\call_apl.h and Appendix A for the full list):

- *_INT8_* marshals int8_t
- *_INT16_* marshals int16_t
- *_INT32_* marshals int32_t
- *_FLOAT_* marshals float
- *_DOUBLE_* marshals double
- *_CHAR_* marshals char (as character(s))
- *_CHAR8_* marshals uint8_t (as character(s))
- *_CHAR16_* marshals uint16_t (as character(s))
- *_CHAR32_* marshals uint32_t (as character(s))
- *_WCHAR_* marshals wchar_t (as character(s))

These macros define local variables that encapsulate the value to be passed and other information that is necessary for the API to convert the data to an APL array. If it is not possible to marshal the specified value, then the call_apl function returns a non-zero error code.

A subset of the provided macros is described in the following sub-sections.

5.1.1 Scalar Parameters
APL_INT32_PARAM(name,v)

(also  APL_INT8_PARAM, APL_INT16_PARAM, APL_DOUBLE_PARAM, and so on)

This macro defines a local variable called name which will marshal the value v (which is an int32_t) to the APL function.

APL_CHAR8_PARAM(name,v)

(also APL_CHAR16_PARAM, APL_CHAR32_PARAM, and so on)

This macro defines a local variable called name which will marshal the value v (which is an 8 bit unsigned char) to the APL function.

APL_WCHAR_PARAM(name,v)

This macro defines a local variable called name which will marshal the value v (which is a wchar_t) to the APL function.

5.1.2 (Rank 1) Numeric Array Parameters

APL_INT32_ARRAY_PARAM(name,v,l)

(also APL_INT8_ARRAY_PARAM, APL_INT16_ARRAY_PARAM, and so on)

This macro defines a local variable called name which will marshal the array v (which is an int32_t *, of length l) to the APL function. The APL function will receive a vector of length l).

5.1.3 (Rank 1) Character Array Parameters

APL_WCHAR_ARRAY_PARAM(name,v,l,f)

This macro defines a local variable called name which will marshal the array v (which is a wchar_t *) to the APL function.

The argument f specifies additional information about the array v:

• If f includes the flag AP_NULLTERM, then v is null terminated, otherwise the length is provided by the parameter l.

• If f includes AP_JSON, then s is JSON text, in which case the API will deserialize the JSON (using ⎕JSON) before passing the array to the APL function:
  APL_WCHAR_ARRAY_PARAM(var,param1,AP_NULLTERM|AP_JSON);
  The above macro passes param1, (a null terminated JSON string) as a deserialized object (or array) to the APL function.

5.1.4 "Z" Format Data

APL_ZFORMAT_PARAM(name,v)

This macro defines a local variable called name which will marshal the binary data v (which of type unsigned char*) to the interpreter. The format of the data is the "Z" format of APL arrays as used by ⎕NA and TCPIP socket support. See the relevant
documentation for more details of this format. Note that the length of the data is encoded within it so there is no length parameter to this macro.

5.1.5 Results

APL_INT32_ARRAY_RESULT (name, v, l, f) (and others)

This macro defines a local variable called name which will marshal the (vector) RESULT of the APL function to an array of int32_t *.

The argument f specifies additional information about how the array is allocated:

- If f includes AP_SIZED then v is a pre-allocated array, the size of which is specified by l.
- If f includes AP_ALLOC then the API will allocate space for the array before returning. It is the caller's responsibility to call dwa_free() on the array in v when the data is no longer required.

There are _RESULT versions of most of the macros previously described.

5.1.6 "Input and Output Parameters"

Sometimes it is convenient to use a single parameter as both INPUT to a function and as a placeholder for an additional "result" from a function. The * _INOUT macros provide this functionality. There are * _INOUT versions of the macros for all of the data types.

EXPORT void getsign_object(wchar_t *json,size_t len)
{  
  APL_WCHAR_ARRAY_INOUT(JSON,json,len,AP_NULLTERM|AP_JSON|AP_SIZED);
  CHECK_ERR(call_apl(L"GetSignObject",&JSON,PARAM_END));
}

Here, the macro APL_WCHAR_ARRAY_INOUT is used to pass an AP_NULLTERM JSON string to the interpreter (the array will be deserialised before being passed to GetSignObject). The same macro specifies that the result of the function will be returned as an AP_NULLTERM JSON string. The use of the AP_SIZED macro will cause the function to fail if the RESULT array is larger than the specified size.

5.1.7 "Structures"

The macros STRUCT_PARAM, STRUCT_INOUT and STRUCT_RESULT can be used to create a nested array argument to an APL function. These macros combine multiple APL_PARAM structures into a single array.

For example:

typedef struct
{
  int a;
  char *c8;
  wchar_t *wc;
}test_str;

void test_struct(size_t len)
{  
  test_str str;
```
str.a=99;
str.c8="hello";
str.wc=L"world";

// extract str.a into A
APL_INT32_INOUT(A,str.a);
// extract str.c8 into C8
APL_CHAR8_ARRAY_INOUT(C8,str.c8,len,AP_SIZED|AP_NULLTERM);
// extract str.wc in WC
APL_WCHAR_ARRAY_INOUT(WC,str.wc,len,AP_SIZED|AP_NULLTERM);

// label as a separate parameter
char label[256]; strcpy(label,"John");
APL_CHAR8_ARRAY_INOUT(Label,label,256,AP_SIZED|AP_NULLTERM);

// combine a,c8 and wc into a nested array
APL_STRUCT_INOUT(Str,&A,&C8,&WC,PARAM_END);

// nested gets a 2 element vector
CHECK_ERR(call_apl(L"nested",&Label,&Str,PARAM_END));
```
The default makefile (simply called `makefile`) can be used to build an APL/SO project from a single call file. As `makefile` is the default filename used by `make`, it is possible to build the APL/SO called `sign` with:

```
make THING=sign
```

This processes `sign.c`, `sign.dyalog` and `sign.rc` to produce `sign.dll/sign.so/sign.dylib` (on Microsoft Windows/Linux/macOS respectively).

If you have written `call<THING>.c` or `call<THING>cpp`, then

```
make -f makefile.callapl THING=sign
```

can be used to make `callsign` (`callsign.exe` on Microsoft Windows).
6 Samples

Dyalog is provided with a number of samples that use this technology. Each of these samples comprises source code, a Visual Studio 2015 solution file (for use on Microsoft Windows only) and a makefile (for use on other platforms, or on Windows with Cygwin installed). The samples each build two components; a shared library with embedded APL code, and an executable program that calls the shared library.

6.1 Installation

Samples can be downloaded from https://my.dyalog.com/ (requires a DSS licence – see https://www.dyalog.com/support-dss.htm for more information).

6.2 Building

On Microsoft Windows:

Open the chosen solution in VS 2015 and select Build > Rebuild Solution from the menu. The binaries for the solution are built in the typical Visual Studio output directories.

On Linux/macOS:

> cd ~/DWASamples/<chosen sample>
> make

The make process builds the binaries in a subdirectory of <chosen sample>/obj

6.3Debugging

On all operating systems, C binaries can be debugged with the standard tools.

On Microsoft Windows, the APL code can be debugged by selecting the Show Session menu item from the Dyalog item in the system tray.

On Linux/macOS, the APL code can be debugged using the RIDE as long as RIDE_SERVE has been set appropriately. See the RIDE User Guide for more information.

6.4 Sample: HelloWorld

The HelloWorld sample calls into APL to display a simple "hello" message.

6.5 Sample: Sign

The Sign sample calls into APL using various different argument types to return the astrological star sign for a specific date.
6.6 Sample: Qa

The Qa sample uses and tests most (but not all) of the SDK and is provided for information only. It is used internally at Dyalog Ltd for QA purposes. Some elements of it might prove useful/interesting, for example, the Qa samples shows that the APL code can be called concurrently from multiple threads in the host application.

6.7 Sample: CallAPL

See The JSON_APL Shared Object document.
In the following definitions:

- **name**: The name of the local structure containing the value
- **first**: The first parameter of a var_arg list in a nested definition
- **v**: The value to be passed
- **l**: The length of an array (if required)
- **f**: AP_* flags one or more of:
  - **AP_END**: used in PARAM_END to indicate the end of a parameter list
  - **AP_OUT**: a parameter which will contain a value after the call to call_apl
  - **AP_IN**: a parameter which will contain a value before the call to call_apl
  - **AP_NULLTERM**: a null terminated character buffer
  - **AP_JSON**: a JSON encoded character buffer
  - **AP_SIZED**: the array size will be specified in l
  - **AP_ALLOC**: the array will be allocated by call_apl (use dwa_free() to deallocate)

Many of these macros are based on other macro definitions so it is possible to extend this list with new definitions:

- **APL_STRUCT_PARAM(name, first, ...)** // an IN nested array / structure
- **APL_STRUCT_RESULT(name, first, ...)** // a RESULT nested array / structure
- **APL_STRUCT_INOUT(name, first, ...)** // an IN and OUT nested array / structure
- **APL_DOUBLE_PARAM(name, v)** // an 8 byte double IN parameter
- **APL_DOUBLE_RESULT(name)** // an 8 byte double RESULT
- **APL_INT8_PARAM(name, v)** // a 1 byte SIGNED integer scalar for input
- **APL_INT8_INOUT(name, v)** // a 1 byte SIGNED integer scalar for input and output
- **APL_INT8_RESULT(name)** // a 1 byte SIGNED integer scalar for output
- **APL_CHAR_PARAM(name, v)** // a 1 byte (default) character for input
- **APL_CHAR_INOUT(name, v)** // a 1 byte (default) character for input and output
- **APL_CHAR_RESULT(name)** // a 1 byte (default) character for output
- **APL_CHAR16_PARAM(name, v)** // a 2 byte (unsigned) character for input
- **APL_CHAR16_INOUT(name, v)** // a 2 byte (unsigned) character for input and output
- **APL_CHAR16_RESULT(name)** // a 2 byte (unsigned) character for output
- **APL_WCHAR_PARAM(name, v)** // a unicode character (width determined by OS) for input
- **APL_WCHAR_RESULT(name)** // a unicode character (width determined by OS) for output
- **APL_INT8_ARRAY_PARAM(name, v, l)** // a 1 byte SIGNED integer ARRAY for input
- **APL_INT8_ARRAY_INOUT(name, v, l, f)** // a 1 byte SIGNED integer ARRAY for input and output
- **APL_INT8_ARRAY_RESULT(name, v, l, f)** // a 1 byte SIGNED integer ARRAY for output
- **APL_INT16_ARRAY_PARAM(name, v, l)** // a 2 byte SIGNED integer ARRAY for input
- **APL_INT16_ARRAY_INOUT(name, v, l, f)** // a 2 byte SIGNED integer ARRAY for input and output
- **APL_INT16_ARRAY_RESULT(name, v, l, f)** // a 2 byte SIGNED integer ARRAY for output
- **APL_INT32_ARRAY_PARAM(name, v, l)** // a 4 byte SIGNED integer ARRAY for input
- **APL_INT32_ARRAY_INOUT(name, v, l, f)** // a 4 byte SIGNED integer ARRAY for input and output
- **APL_INT32_ARRAY_RESULT(name, v, l, f)** // a 4 byte SIGNED integer ARRAY for output
- **APL_INT64_ARRAY_INOUT(name, v, l, f)** // a 8 byte SIGNED integer ARRAY for input and output
APL_INT64_ARRAY_RESULT(name,v,l,f) // a 8 byte SIGNED integer ARRAY for output

APL_DOUBLE_ARRAY_PARAM(name,v,l) // an 8 byte double ARRAY for input
APL_DOUBLE_ARRAY_INOUT(name,v,l,f) // an 8 byte double ARRAY for input and output
APL_DOUBLE_ARRAY_RESULT(name,v,l,f) // an 8 byte double ARRAY for output

APL_CHAR_ARRAY_PARAM(name,v,l,f) // a 1 byte (default) character ARRAY for input
APL_CHAR_ARRAY_INOUT(name,v,l,f) // a 1 byte (default) character ARRAY for input and output
APL_CHAR_ARRAY_RESULT(name,v,l,f) // a 1 byte (default) character ARRAY for output
APL_CHAR16_ARRAY_PARAM(name,v,l,f)
APL_CHAR16_ARRAY_RESULT(name,v,l,f)
APL_CHAR16_ARRAY_INOUT(name,v,l,f)
APL_CHAR32_ARRAY_PARAM(name,v,l,f)
APL_CHAR32_ARRAY_RESULT(name,v,l,f)
APL_CHAR32_ARRAY_INOUT(name,v,l,f)
APL_WCHAR_ARRAY_PARAM(name,v,l,f)
APL_WCHAR_ARRAY_RESULT(name,v,l,f)
APL_WCHAR_ARRAY_INOUT(name,v,l,f)