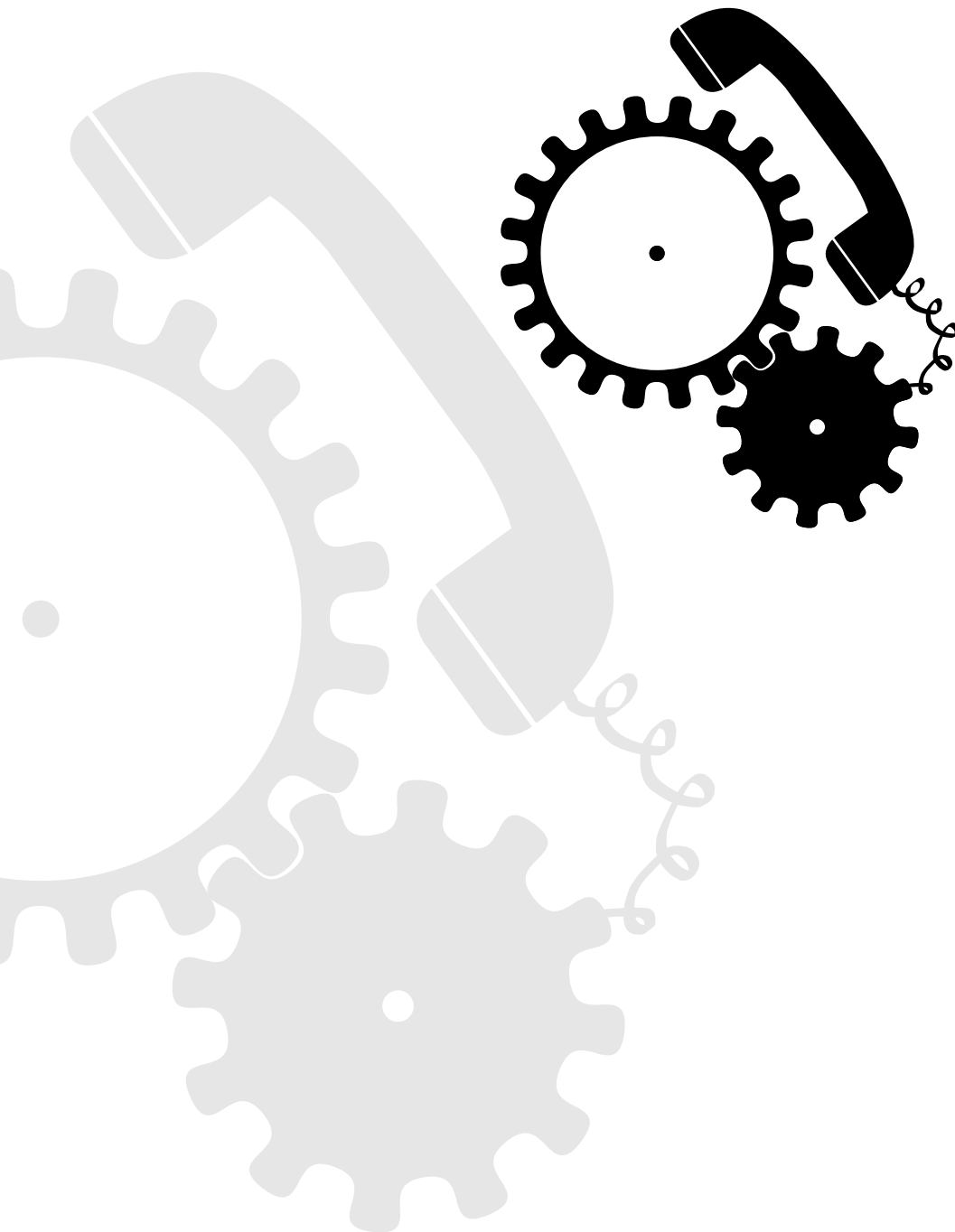


# dyncall

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Daniel ADLER ([dadler@uni-goettingen.de](mailto:dadler@uni-goettingen.de))  
Tassilo PHILIPP ([tphilipp@potion-studios.com](mailto:tphilipp@potion-studios.com))

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**Contents**



**List of Tables**

**List of Figures**

**Listings**



# 1 Motivation

Interoperability between programming languages is a desirable feature in complex software systems. While functions in scripting languages and virtual machine languages can be called in a dynamic manner, statically compiled programming languages such as C, C++ and Objective-C lack this ability. The majority of systems use C function interfaces as their system-level interface. Calling these (foreign) functions from within a dynamic environment often involves the development of so called "glue code" on both sides, the use of external tools generating communication code, or integration of other middleware fulfilling that purpose. However, even inside a completely static environment, without having to bridge multiple languages, it can be very useful to call functions dynamically. Consider, for example, message systems, dynamic function call dispatch mechanisms, without even knowing about the target.

The *dyncall* library project provides a clean and portable C interface to dynamically issue calls to foreign code using small call kernels written in assembly. Instead of providing code for every bridged function call, which unnecessarily results in code bloat, only a modest number of instructions are used to invoke all the calls.

## 1.1 Static function calls in C

The C programming language and its direct derivatives are limited in the way function calls are handled. A C compiler regards a function call as a fully qualified atomic operation. In such a statically typed environment, this includes the function call's argument arity and type, as well as the return type.

## 1.2 Anatomy of machine-level calls

The process of calling a function on the machine level yields a common pattern:

1. The target function's calling convention dictates how the stack is prepared, arguments are passed, results are returned and how to clean up afterwards.
2. Function call arguments are loaded in registers and on the stack according to the calling convention that take alignment constraints into account.
3. Control flow transfer from caller to callee.
4. Process return value, if any. Some calling conventions specify that the caller is responsible for cleaning up the argument stack.

The following example depicts a C source and the corresponding assembly for the X86 32-bit processor architecture.

```
extern void f(int x, double y, float z);  
void caller()  
{  
    f(1,2.0,3.0f);  
}
```

Listing 1: C function call

```
.global f          ; external symbol 'f'  
caller:  
    push  40400000H ; 3.0f (32 bit float)  
                ; 2.0 (64 bit float)  
    push  40000000H ;          low  DWORD  
    push  0H        ;          high DWORD  
    push  1H        ; 1      (32 bit integer)  
    call  f          ; call 'f'  
    add   esp, 16    ; cleanup stack
```

Listing 2: Assembly X86 32-bit function call

## 2 Overview

The *dyncall* library encapsulates architecture-, OS- and compiler-specific function call semantics in a virtual

*bind argument parameters from left to right and then call*

interface allowing programmers to call C functions in a completely dynamic manner. In other words, instead of calling a function directly, the *dyncall* library provides a mechanism to push the function parameters manually and to issue the call afterwards.

Since the idea behind this concept is similar to call dispatching mechanisms of virtual machines, the object that can be dynamically loaded with arguments, and then used to actually invoke the call, is called CallVM. It is possible to change the calling convention used by the CallVM at run-time. Due to the fact that nearly every platform comes with one or more distinct calling conventions, the *dyncall* library project intends to be a portable and open-source approach to the variety of compiler-specific binary interfaces, platform specific subtleties, and so on...

The core of the library consists of dynamic implementations of different calling conventions written in assembler. Although the library aims to be highly portable, some assembler code needs to be written for nearly every platform/compiler/OS combination. Unfortunately, there are architectures we just don't have at home or work. If you want to see *dyncall* running on such a platform, feel free to send in code and patches, or even to donate hardware you don't need anymore. Check the **supported platforms** section for an overview of the supported platforms and the different calling convention sections for details about the support.

### 2.1 Features

- A portable and extendable function call interface for the C programming language.
- Ports to major platforms including Windows, Mac OS X, Linux, BSD derivatives, iPhone and embedded devices and more, including lesser known and/or older platforms like Plan 9, Playstation Portable, Nintendo DS, etc..
- Add-on language bindings to Python, R, Ruby, Java, Lua, sh, ...
- High-level state machine design using C to model calling convention parameter transfer.
- One assembly *hybrid* call routine per calling convention.
- Formatted call, vararg function API.
- Comprehensive test suite.

## 2.2 Showcase

### Foreign function call in C

This section demonstrates how the foreign function call is issued without, and then with, the help of the *dyncall* library and scripting language bindings.

```
double call_as_sqrt(void* funptr, double x)
{
    return ( ( double (*)(double) )funptr)(x);
}
```

Listing 3: Foreign function call in C

### Dyncall C library example

The same operation can be broken down into atomic pieces (specify calling convention, binding arguments, invoking the call) using the *dyncall* library.

```
#include <dyncall.h>
double call_as_sqrt(void* funptr, double x)
{
    double r;
    DCCallVM* vm = dcNewCallVM(4096);
    dcMode(vm, DC_CALL_C_DEFAULT);
    dcReset(vm);
    dcArgDouble(vm, x);
    r = dcCallDouble(vm, funptr);
    dcFree(vm);
    return r;
}
```

Listing 4: Dyncall C library example

As you can see, this is more code after all, but completely dynamic. And definitely less than generated glue-code for each function call, if used correctly.

The following are examples from script bindings:

### Python example

```
import pydc
def call_as_sqrt(funptr,x):
    return pydc.call(funptr,"d)d", x)
```

Listing 5: Dyncall Python bindings example

### R example

```
library(rdyncall)
call.as.sqrt <- function(funptr,x)
    .dyncall(funptr,"d)d", x)
```

Listing 6: Dyncall R bindings example

## 2.3 Supported platforms/architectures

The feature matrix below gives a brief overview of the currently supported platforms. Different colors are used, where a green cell indicates a supported platform, yellow a platform that might work (but is untested) and red a platform that is currently unsupported. Gray cells are combinations that don't exist at the time of writing, or that are not taken into account.

Please note that a green cell doesn't imply that all existing calling conventions/features/build tools are supported for that platform (but the most important). For details about the support consult the appendix.

	Alpha	ARM	MIPS (32)	MIPS (64)	SuperH	PowerPC (32)	PowerPC (64)	m68k	m88k	x86	x64	Itanium	SPARC	SPARC64
Windows family														
Minix														
Linux														
Mac OS X/iOS/Darwin														
FreeBSD														
NetBSD														
OpenBSD														
DragonFlyBSD														
Solaris														
Plan 9														
Haiku/BeOS														
Playstation Portable														
Nintendo DS														

Table 1: Supported platforms



## 3 Building the library

The library has been built and used successfully on several platform/architecture configurations and build systems. Please see notes on specific platforms to check if the target architecture is currently supported.

### 3.1 Requirements

The following tools are supported directly to build the *dyncall* library. However, as the number of source files to be compiled for a given platform is small, it shouldn't be difficult to build it manually with another toolchain.

- C compiler to build the *dyncall* library (GCC, Clang, SunPro or Microsoft C/C++ compiler)
- C++ compiler to build the optional test cases (GCC, Clang, SunPro or Microsoft C/C++ compiler)
- BSD make, GNU make, Microsoft nmake or mk (on Plan9) as automated build tools
- Python (optional - for generation of some test cases)
- Lua (optional - for generation of some test cases)
- CMake (optional support)

### 3.2 Supported/tested platforms and build systems

Building *dyncall* is a straightforward two-step process, first configure, then make. The library should be able to be built with the default operating systems' build tools, so BSD make on BSD and derived systems, GNU make on GNU and compatible, mk on Plan9, nmake on Windows, etc.. This is a detailed overview of platforms and their build tools that are known to build *dyncall*:

Platform	Build Tool(s)	Compiler, SDK
Windows	nmake, Visual Studio	cl, cygwin (gcc), mingw (gcc)
Unix-like	GNU/BSD/Sun make	gcc, clang, sunc
Plan9	mk	8c
Haiku/BeOS	GNU make	gcc
iOS/iPhone	GNU make	gcc and iPhone SDK on Mac OS X
Nintendo DS	nmake	devkitPro[?] tools on Windows
Playstation Portable	GNU make	psptoolchain[?] tools

### 3.3 Build instructions

1. Configure the source (not needed for Makefile.embedded)

#### \*nix flavour

```
./configure [--option ...]
```

Available options (omit for defaults):

--help	display help
--prefix= <i>path</i>	specify installation prefix (Unix shell)
--target= <i>platform</i>	MacOSX,iOS,iPhoneSimulator,PSP,...
--sdk= <i>version</i>	SDK version

#### Windows flavour, and cross-build from Windows (PSP, NDS, etc.)

```
.\configure [/option ...]
```

Available options:

/?	display help
/prefix <i>path</i>	set installation prefix (GNU make only)
/prefix-bd <i>path</i>	set build directory prefix (GNU make only)
/target-x86	build for x86 architecture (default)
/target-x64	build for x64 architecture
/target-psp	build for PlayStation Portable (homebrew SDK)
/target-nds-arm	build for Nintendo DS (devkitPro, ARM mode)
/target-nds-thumb	build for Nintendo DS (devkitPro, THUMB mode)
/tool-msvc	use Microsoft Visual C++ compiler (default)
/tool-gcc	use GNU Compiler Collection
/asm-ml	use Microsoft Macro Assembler (default)
/asm-as	use the GNU Assembler
/asm-nasm	use NASM Assembler
/config-release	build release version (default)
/config-debug	build debug version

#### Plan 9 flavour

```
./configure.rc [--option ...]
```

Available options (none, at the moment):

--help	display help
--------	--------------

2. Build the static libraries *dyncall*, *dynload* and *dyncallback*

```
make          # for {GNU,BSD} Make
nmake /f Nmakefile  # for NMake on Windows
mk            # for mk on Plan9
```

3. Install libraries and includes (supported for GNU and BSD make based builds, only)

```
make install
```

#### 4. Optionally, build the test suite

```
make tests           # for {GNU,BSD} Make
nmake /f Nmakefile tests # for NMake on Windows
mk tests             # for mk on Plan9
```

### 3.4 Build-tool specific notes

Some platforms require some manual tweaks:

Problem: Build fails because CC and/or related are not set, or different compiler, linker, etc. should be used.

Solution: Set the 'CC' and other environment variables explicitly to the desired tools. E.g.:

```
CC=gcc make
```

Problem: On windows using mingw and msys/unixutils 'Make', the make uses 'cc' for C compilation, which does not exist in mingw.

Solution: Set the 'CC' environment variable explicitly to 'gcc' (as in the example above).

### 3.5 Build with CMake

```
cmake -DCMAKE_INSTALL_PREFIX=<location>
make
```

## 4 Bindings to programming languages

Through binding of the *dyncall* library into a scripting environment, the scripting language can gain system programming status to a certain degree.

The *dyncall* library provides bindings to Java[?], Lua[?], Python[?], R[?], Ruby[?] and the command line.

However, please note that some of these bindings are work-in-progress and not automatically tested, meaning it might require some additional work to make them work.

### 4.1 Common Architecture

The binding interfaces of the *dyncall* library to various scripting languages share a common set of functionality to invoke a function call.

#### 4.1.1 Dynamic loading of code

The helper library *dynload* which accompanies the *dyncall* library provides an abstract interface to operating-system specific mechanisms for loading and accessing executable code out of, but not limited to, shared libraries.

#### 4.1.2 Functions

All bindings are based on a common interface convention providing a common set of the following 4 functions (exact spelling depending on the binding's scripting environment):

**load** - load a module of compiled code

**free** - unload a module of compiled code

**find** - find function pointer by symbolic names

**call** - invoke a function call

### 4.1.3 Signatures

A signature is a character string that represents a function's arguments and return value types. It is used in the scripting language bindings invoke functions to perform automatic type-conversion of the languages' types to the low-level C/C++ data types. This is an essential part of mapping the more flexible and often abstract data types provided in scripting languages conveniently to the strict machine-level data types used by C-libraries. The high-level C interface functions `dcCallF()` and `dcCallFV()` of the *dyncall* library also make use of this signature string format.

The format of a *dyncall* signature string is as depicted below:

#### **dyncall signature string format**

`<input parameter type signature character>* ')' <return type signature character>`

The `<input parameter type signature character>` sequence left to the `)'` is in left-to-right order of the corresponding C function parameter type list.

The special `<return type signature character>` `'v'` specifies that the function does not return a value and corresponds to void functions in C.

Signature character	C/C++ data type
'B'	_Bool, bool
'c'	char
'C'	unsigned char
's'	short
'S'	unsigned short
'i'	int
'I'	unsigned int
'j'	long
'J'	unsigned long
'l'	long long, int64_t
'L'	unsigned long long, uint64_t
'f'	float
'd'	double
'p'	void*
'Z'	const char* (pointing to C string)
'v'	void

Table 2: Type signature encoding for function call data types

Please note that using a `'('` at the beginning of a signature string is possible, although not required. The character doesn't have any meaning and will simply be ignored. However, using it prevents annoying syntax highlighting problems with some code editors.

## Examples of C function prototypes

	C function prototype	dyncall signature
void	f1();	")v"
int	f2(int, int);	"ii)i"
long long	f3(void*);	"p)L"
void	f3(int**);	"p)v"
double	f4(int, bool, char, double, const char*);	"iBcdZ)d"

Table 3: Type signature examples of C function prototypes

## 4.2 Python language bindings

The python module pydc implements the Python language bindings, namely `load`, `find`, `free`, `call`.

Signature character	accepted Python data types
'B'	bool
'c'	if string, take first item
's'	int, check in range
'i'	int
'j'	int
'l'	long, casted to long long
'f'	float
'd'	double
'p'	string or long casted to void*
'v'	no return type

Table 4: Type signature encoding for Python bindings

## 4.3 R language bindings

The R package `rdyncall` implements the R language bindings providing the function `.dyncall()`.  
Some notes on the R Binding:

- Unsigned 32-bit integers are represented as signed integers in R.
- 64-bit integer types do not exist in R, therefore we use double floats to represent 64-bit integers (using only the 52-bit mantissa part).

Signature character	accepted R data types
'B'	coerced to logical vector, first item
'c'	coerced to integer vector, first item truncated char
'C'	coerced to integer vector, first item truncated to unsigned char
's'	coerced to integer vector, first item truncated to short
'S'	coerced to integer vector, first item truncated to unsigned short
'i'	coerced to integer vector, first item
'I'	coerced to integer vector, first item casted to unsigned int
'j'	coerced to integer vector, first item
'J'	coerced to integer vector, first item casted to unsigned long
'l'	coerced to numeric, first item casted to long long
'L'	coerced to numeric, first item casted to unsigned long long
'f'	coerced to numeric, first item casted to float
'd'	coerced to numeric, first item
'p'	external pointer or coerced to string vector, first item
'Z'	coerced to string vector, first item
'v'	no return type

Table 5: Type signature encoding for R bindings

## 4.4 Ruby language bindings

The Ruby gem rdbc implements the Ruby language bindings.

Signature character	accepted Ruby data types
'B'	TrueClass, FalseClass, NilClass, Fixnum casted to bool
'c', 'C'	Fixnum cast to (unsigned) char
's', 'S'	Fixnum cast to (unsigned) short
'i', 'I'	Fixnum cast to (unsigned) int
'j', 'J'	Fixnum cast to (unsigned) long
'l', 'L'	Fixnum cast to (unsigned) long long
'f'	Float cast to float
'd'	Float cast to double
'p', 'Z'	String cast to void*
'v'	no return type

Table 6: Type signature encoding for Ruby bindings

## 5 Library Design

### 5.1 Design considerations

The *dyncall* library encapsulates function call invocation semantics that depend on the compiler, operating system and architecture. The core library is driven by a function call invocation engine, named *CallVM*, that encapsulates a call stack to foreign functions and manages the following three phases that constitute a truly dynamic function call:

1. Specify the calling convention. Some run-time platforms, such as Microsoft Windows on a 32-bit X86 architecture, even support multiple calling conventions.
2. Specify the function call arguments in a specific order. The interface design dictates a *left to right* order for C and C++ function calls in which the arguments are bound.
3. Specify the target function address, expected return value and invoke the function call.

The calling convention mode entirely depends on the way the foreign function has been compiled and specifies the low-level details on how a function actually expects input parameters (in memory, in registers or both) and how to return its result(s).





## 6 Developers

### 6.1 Noteworthy files in the project root

```
configure      -- pre-make configuration tool (unix-shell)
configure.bat  -- pre-nmake configuration tool (windows batch)
configure.rc   -- pre-mk configuration tool (Plan 9's rc)
CMakeLists.txt -- top-level project information for CMake
Makefile       -- GNU/BSD makefile (output of ./configure)
Nmakefile      -- MS nmake makefile
mkfile         -- Plan 9 mkfile
LICENSE        -- license information
buildsys/      -- build system details and extras
doc/           -- platform specific readme's and manual
dyncall/       -- dyncall library source code
dyncallback/   -- dyncallback library source code
dynload/       -- dynload library source code
test/          -- test suites
```

### 6.2 Test suites

**plain** Simple, identity, unary function calls for all supported return types and calling conventions.

**plain.c++** Similar to plain, but for C++ thiscalls (GNU and MS calling convention).

**suite** All combinations of parameter types and counts are tested on void function calls. A script written in Python (`mkcase.py`) generates the tests up to an upper MAXARG limit.

**suite.floats** Based on suite. Test double/float variants with up to 10 arguments.

**suite.x86win32std** All combinations of parameter types and counts are tested on `__stdcall` void function calls. A script written in Python (`mkcase.py`) generates the tests up to an upper MAXARG limit. This is a x86/Windows only test.

**suite.x86win32fast** All combinations of parameter types and counts are tested on `__fastcall` (MS or GNU, depending on the build tool) void function calls. A script written in Python (`mkcase.py`) generates the tests up to an upper MAXARG limit. This is a x86/Windows only test.

**ellipsis** All combinations of parameter types and counts are tested on void ellipsis function calls. A script written in Python (`mkcase.py`) generates the tests up to an upper MAXARG limit.

**suite2** Designed mass test suite for void function calls. Tests individual void functions with a varying count of arguments and type.

**suite2.win32std** Designed mass test suite for `__stdcall` void function calls. Tests individual void functions with a varying count of arguments and type. This is a x86/Windows only test.

**suite2.win32fast** Designed mass test suite for `__fastcall` (MS or GNU, depending on the build tool) void function calls. Tests individual void functions with a varying count of arguments and type. This is a x86/Windows only test.

**suite3** All combinations of parameter types integer, long long, float and double and counts are tested on void function calls. A script written in Python (`mkcase.py`) generates the tests up to an upper MAXARG limit. This is a modified version of suite.

**call.suite** General purpose test suite combining aspects from all others suites (usually enough for testing non-callback calls). A script written in Lua generates the tests.

**callf** Tests the *formatted call dyncall* C API.

**malloc\_wx** Tests *writable and executable memory allocation* used by the *dyncallback* C API.

**thunk** Tests *callbacks* for the *dyncallback* C API.

**callback\_plain** Simple callback function test (useful for easy debugging of new ports).

**callback\_suite** Mass test suite for callback function testing. Uses random function argument number and type. A script written in Lua generates the tests up to a given number of calls and type combinations.

**resolv\_self** Test for dynload library to resolve symbols from application image itself.



## 7 Epilog

### 7.1 Stability and security considerations

Since the *dyncall* library doesn't know anything about the called function itself (except its address), no parameter-type validation is done. This means that in order to avoid crashes, data corruption, etc., the user is required to ascertain the number and types of parameters. It is strongly advised to double check the parameter types of every function to be called, and not to call unknown functions at all.

Consider a simple program that issues a call by directly passing some unchecked command line arguments to the call itself, or even worse, by indirectly choosing a library and a function to call without verification. Such unchecked input data can quite easily be used to intentionally crash the program or to hijack it by taking over control of the program flow.

To put it in a nutshell, if not used with care, programs depending on the *dyncall*, *dyncallback* and *dynload* libraries, can be exploited as arbitrary function call dispatchers through manipulating of their input data. Successful exploits of programs like the example outlined above can be used as very powerful tools for a wide variety of malicious attacks, ...

### 7.2 Embedding

The *dyncall* library strives to have a minimal set of dependencies, meaning no required runtime dependencies and usually only the necessary tools to build the library as build-time dependencies. The library uses some heap-memory to store the CallVM and uses by default the platform's `malloc()` and `free()` calls. However, providing custom `dcAllocMem()` and `dcFreeMem()` functions will override the default behaviour. See `dyncall/dyncall_alloc.h` for details.

### 7.3 Multi-threading

The *dyncall* library is thread-safe and reentrant, by means that it works correctly during execution of multiple threads if, and only if there is at most a single thread pushing arguments to one CallVM (invoking the call is always thread-safe, though). Since there's no limitation on the number of created CallVM objects, it is recommended to keep a copy for each thread if multiple thread make use of *dyncall* at once.

### 7.4 Supported types

Currently, the *dyncall* library supports all of ANSI C's integer, floating point and pointer types as function call arguments as well as return values. Additionally, C++'s `bool` and C99's `_Bool` types are supported. Due to the still rare and often incomplete support of the `long double` type on various platforms, the latter is currently not officially supported.

### 7.5 Roadmap

The *dyncall* library should be extended by a wide variety of other calling conventions and ported to other and more esoteric platforms. With its low memory footprint it surely might come in handy on embedded systems. Furthermore, the authors plan to provide more scripting language bindings, examples, and other projects based on *dyncall*.

Besides *dyncall* and *dyncallback*, the *dynload* library needs to be extended with support for other shared library formats (e.g. AmigaOS `.library` or GEM `[?]` files).

### 7.6 Related libraries

Besides the *dyncall* library, there are other free and open projects with similar goals. The most noteworthy libraries are `libffi` `[?]`, `C/Invoke` `[?]` and `libffi` `[?]`.

## A Dyncall C library API

The library provides low-level functionality to make foreign function calls from different run-time environments. The flexibility is constrained by the set of supported types.

### C interface style conventions

This manual and the *dyncall* library's C interface "dyncall.h" use the following C source code style.

Subject	C symbol	Details	Example
Types	DC<type name>	lower-case	DCint, DCfloat, DClong, ...
Structures	DC<structure name>	camel-case	DCCallVM
Functions	dc<function name>	camel-case	dcNewCallVM, dcArgInt, ...

Table 7: C interface conventions

### A.1 Supported C/C++ argument and return types

Type alias	C/C++ data type
DCbool	_Bool, bool
DCchar	char
DCshort	short
DCint	int
DClong	long
DClonglong	long long
DCfloat	float
DCdouble	double
DCpointer	void*
DCvoid	void

Table 8: Supported C/C++ argument and return types

## A.2 Call Virtual Machine - CallVM

This *CallVM* is the main entry to the functionality of the library.

### Types

```
typedef void DCCallVM; /* abstract handle */
```

### Details

The *CallVM* is a state machine that manages all aspects of a function call from configuration, argument passing up the actual function call on the processor.

## A.3 Allocation

### Functions

```
DCCallVM* dcNewCallVM (DCsize size);  
void      dcFree(DCCallVM* vm);
```

`dcNewCallVM` creates a new *CallVM* object, where `size` specifies the max size of the internal stack that will be allocated and used to bind arguments to. Use `dcFree` to destroy the *CallVM* object.

This will allocate memory using the system allocators or custom ones provided custom `dcAllocMem` and `dcFreeMem` macros are defined to override the default behaviour. See `dyncall_alloc.h` for details.

## A.4 Error Reporting

### Function

```
DCint dcGetError(DCCallVM* vm);
```

Returns the most recent error state code out of the following:

### Errors

Constant	Description
<code>DC_ERROR_NONE</code>	No error occurred.
<code>DC_ERROR_UNSUPPORTED_MODE</code>	Unsupported mode, caused by <code>dcMode()</code>

Table 9: CallVM calling convention modes

## A.5 Configuration

### Function

```
void dcMode (DCCallVM* vm, DCint mode);
```

Sets the calling convention to use. Note that some mode/platform combination don't make any sense (e.g. using a PowerPC calling convention on a MIPS platform) and are silently ignored.

### Modes

Constant	Description
DC_CALL_C_DEFAULT	C default function call for current platform
DC_CALL_C_ELLIPSIS	C ellipsis function call (named arguments (before '...'))
DC_CALL_C_ELLIPSIS_VARARGS	C ellipsis function call (variable/unnamed arguments (after '...'))
DC_CALL_C_X86_CDECL	C x86 platforms standard call
DC_CALL_C_X86_WIN32_STD	C x86 Windows standard call
DC_CALL_C_X86_WIN32_FAST_MS	C x86 Windows Microsoft fast call
DC_CALL_C_X86_WIN32_FAST_GNU	C x86 Windows GCC fast call
DC_CALL_C_X86_WIN32_THIS_MS	C x86 Windows Microsoft this call
DC_CALL_C_X86_WIN32_THIS_GNU	C x86 Windows GCC this call
DC_CALL_C_X86_PLAN9	C x86 Plan9 call
DC_CALL_C_X64_WIN64	C x64 Windows standard call
DC_CALL_C_X64_SYSV	C x64 System V standard call
DC_CALL_C_PPC32_DARWIN	C ppc32 Mac OS X standard call
DC_CALL_C_PPC32_OSX	alias for DC_CALL_C_PPC32_DARWIN
DC_CALL_C_PPC32_SYSV	C ppc32 SystemV standard call
DC_CALL_C_PPC32_LINUX	alias for DC_CALL_C_PPC32_SYSV
DC_CALL_C_ARM_ARM	C arm call (arm mode)
DC_CALL_C_ARM_THUMB	C arm call (thumb mode)
DC_CALL_C_ARM_ARM_EABI	C arm eabi call (arm mode)
DC_CALL_C_ARM_THUMB_EABI	C arm eabi call (thumb mode)
DC_CALL_C_ARM_ARMHF	C arm call (arm hardfloat - e.g. raspberry pi)
DC_CALL_C_MIPS32_EABI	C mips32 eabi call
DC_CALL_C_MIPS32_PSPSDK	alias for DC_CALL_C_MIPS32_EABI (deprecated)
DC_CALL_C_MIPS32_O32	C mips32 o32 call
DC_CALL_C_MIPS64_N64	C mips64 n64 call
DC_CALL_C_MIPS64_N32	C mips64 n32 call
DC_CALL_C_SPARC32	C sparc32 call
DC_CALL_C_SPARC64	C sparc64 call
DC_CALL_SYS_DEFAULT	C default syscall for current platform
DC_CALL_SYS_X86_INT80H_BSD	C syscall for x86 BSD platforms
DC_CALL_SYS_X86_INT80H_LINUX	C syscall for x86 Linux

Table 10: CallVM calling convention modes

### Details

DC\_CALL\_C\_DEFAULT is the default standard C call on the target platform. It uses the standard C calling convention. DC\_CALL\_C\_ELLIPSIS is used for C ellipsis calls which allow to build up a variable argument list. On many platforms, there is only one C calling convention. The X86 platform provides

a rich family of different calling conventions.

## A.6 Machine state reset

```
void dcReset(DCCallVM* vm);
```

Resets the internal stack of arguments and prepares it for the selected mode. This function should be called after setting the call mode (using `dcMode`), but prior to binding arguments to the `CallVM`. Use it also when reusing a `CallVM`, as arguments don't get flushed automatically after a function call invocation.

## A.7 Argument binding

### Functions

```
void dcArgBool      (DCCallVM* vm, DCbool      arg);
void dcArgChar      (DCCallVM* vm, DCchar      arg);
void dcArgShort     (DCCallVM* vm, DCshort     arg);
void dcArgInt       (DCCallVM* vm, DCint       arg);
void dcArgLong      (DCCallVM* vm, DClong      arg);
void dcArgLongLong  (DCCallVM* vm, DClonglong  arg);
void dcArgFloat     (DCCallVM* vm, DCfloat     arg);
void dcArgDouble    (DCCallVM* vm, DCdouble    arg);
void dcArgPointer   (DCCallVM* vm, DCpointer   arg);
```

### Details

Used to bind arguments of the named types to the `CallVM` object. Arguments should be bound in *left-to-right* order regarding the C function prototype.

## A.8 Call invocation

### Functions

```
DCvoid      dcCallVoid      (DCCallVM* vm, DCpointer funcptr);
DCbool      dcCallBool      (DCCallVM* vm, DCpointer funcptr);
DCchar      dcCallChar      (DCCallVM* vm, DCpointer funcptr);
DCshort     dcCallShort     (DCCallVM* vm, DCpointer funcptr);
DCint       dcCallInt       (DCCallVM* vm, DCpointer funcptr);
DClong      dcCallLong      (DCCallVM* vm, DCpointer funcptr);
DClonglong  dcCallLongLong  (DCCallVM* vm, DCpointer funcptr);
DCfloat     dcCallFloat     (DCCallVM* vm, DCpointer funcptr);
DCdouble    dcCallDouble    (DCCallVM* vm, DCpointer funcptr);
DCpointer   dcCallPointer   (DCCallVM* vm, DCpointer funcptr);
```

### Details

Calls the function specified by *funcptr* with the arguments bound to the *CallVM* and returns. Use the function that corresponds to the dynamically called function's return value.

After the invocation of the foreign function call, the argument values are still bound and a second call using the same arguments can be issued. If you need to clear the argument bindings, you have to reset the *CallVM*.

## A.9 Formatted calls (ANSI C ellipsis interface)

### Functions

```
void dcCallF (DCCallVM* vm, DCValue* result, DCpointer funcptr,
              const DCsigchar* signature, ...);
void dcVCallF(DCCallVM* vm, DCValue* result, DCpointer funcptr,
              const DCsigchar* signature, va_list args);
```

### Details

These functions can be used to operate *dyncall* via a printf-style functional interface, using a signature string encoding the argument types and return type. The return value will be stored in what *result* points to.. For more information about the signature format, refer to *??*.



## B Dyncallback C library API

This library extends *dyncall* with function callback support, allowing the user to dynamically create a callback object that can be called directly, or passed to functions expecting a function-pointer as argument.

Invoking a *dyncallback* calls into a user-defined unified handler that permits iteration and thus dynamic handling over the called-back-function's parameters.

The flexibility is constrained by the set of supported types, though.

For style conventions and supported types, see *dyncall* API section. In order to use *dyncallback*, include "dyncall\_callback.h".

### B.1 Callback Object

The *Callback Object* is the core component to this library.

#### Types

```
typedef struct DCCallback DCCallback;
```

#### Details

The *Callback Object* is an object that mimics a fully typed function call to another function (a generic callback handler, in this case).

This means, a pointer to this object is passed to a function accepting a pointer to a callback function *as the very callback function pointer itself*. Or, if called directly, cast a pointer to this object to a function pointer and issue a call.

### B.2 Allocation

#### Functions

```
DCCallback* dcbNewCallback(const char*      signature ,
                           DCCallbackHandler* funcptr ,
                           void*            userdata);
void dcbFreeCallback(DCCallback* pcb);
```

*dcbNewCallback* creates and initializes a new *Callback* object, where *signature* is the needed function signature (format is the one outlined in the language bindings-section of this manual, see ??) of the function to mimic, *funcptr* is a pointer to a callback handler, and *userdata* a pointer to custom data that might be useful in the handler. Use *dcbFreeCallback* to destroy the *Callback* object.

As with *dcNewCallVM/dcFree*, this will allocate memory using the system allocators or custom overrides.

### B.3 Callback handler

The unified callback handler's declaration used when creating a *DCCallback* is:

```
char cbHandler(DCCallback* cb,  
              DCArgs*      args,  
              DCValue*     result,  
              void*        userdata);
```

cb is a pointer to the DCCallback object in use, args allows for dynamic iteration over the called-back-function's arguments (input) and result is a pointer to a DCValue object in order to store the callback's return value (output, to be set by handler).

Finally, userdata is a pointer to some user defined data that can be set when creating the callback object. The handler itself returns either 'i' or 'f' depending on whether the value stored in result is of integral or floating point type.



## C Dynload C library API

The *dynload* library encapsulates dynamic loading mechanisms and gives access to functions in foreign dynamic libraries and code modules.

### C.1 Loading code

```
void* dlLoadLibrary(const char* libpath);  
void dlFreeLibrary(void* libhandle);
```

`dlLoadLibrary` loads a dynamic library at `libpath` and returns a handle to it for use in `dlFreeLibrary` and `dlFindSymbol` calls.

`dlFreeLibrary` frees the loaded library with handle `pLib`.

### C.2 Retrieving functions

```
void* dlFindSymbol(void* libhandle, const char* symbol);
```

returns a pointer to a symbol with name `pSymbolName` in the library with handle `pLib`, or returns a null pointer if the symbol cannot be found.



## D Calling Conventions

Before we go any further...

It is important to understand that this section isn't a general purpose description of the present calling conventions. It merely explains the calling conventions **for the parameter/return types supported by dyncall**, not for aggregates (structures, unions and classes), SIMD data types (`__m64`, `__m128`, `__m128i`, `__m128d`), etc.

We strongly advise the reader not to use this document as a general purpose calling convention reference.

### D.1 x86 Calling Conventions

#### Overview

There are numerous different calling conventions on the x86 processor architecture, like `cdecl` [?], `MS fastcall` [?], `GNU fastcall` [?], `Borland fastcall` [?], `Watcom fastcall` [?], `Win32 stdcall` [?], `MS thiscall` [?], `GNU thiscall` [?], the pascal calling convention [?] and a `cdecl`-like version for Plan9 [?] (dubbed `plan9call` by us), etc.

#### dyncall support

Currently `cdecl`, `stdcall`, `fastcall` (MS and GNU), `thiscall` (MS and GNU) and `plan9call` are supported.

#### D.1.1 cdecl

##### Registers and register usage

Name	Brief description
<b>eax</b>	scratch, return value
<b>ebx</b>	permanent
<b>ecx</b>	scratch
<b>edx</b>	scratch, return value
<b>esi</b>	permanent
<b>edi</b>	permanent
<b>ebp</b>	permanent
<b>esp</b>	stack pointer
<b>st0</b>	scratch, floating point return value
<b>st1-st7</b>	scratch

Table 11: Register usage on x86 `cdecl` calling convention

## Parameter passing

- stack parameter order: right-to-left
- caller cleans up the stack
- all arguments are pushed onto the stack

## Return values

- return values of pointer or integral type ( $\leq 32$  bits) are returned via the `eax` register
- integers  $> 32$  bits are returned via the `eax` and `edx` registers
- floating point types are returned via the `st0` register

## Stack layout

Stack directly after function prolog:

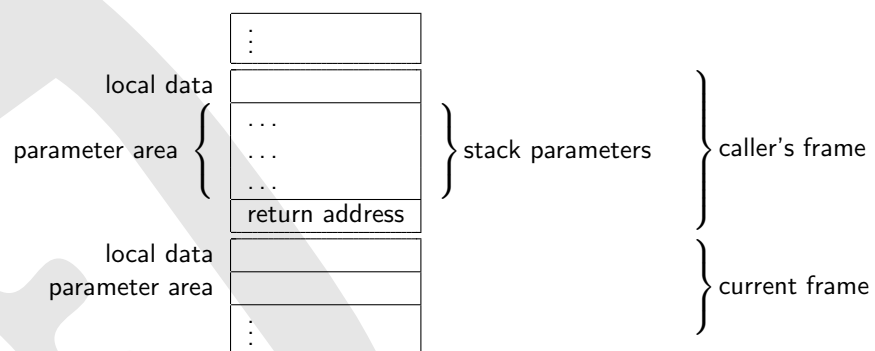


Figure 1: Stack layout on x86 cdecl calling convention

### D.1.2 MS fastcall

#### Registers and register usage

Name	Brief description
<b>eax</b>	scratch, return value
<b>ebx</b>	permanent
<b>ecx</b>	scratch, parameter 0
<b>edx</b>	scratch, parameter 1, return value
<b>esi</b>	permanent
<b>edi</b>	permanent
<b>ebp</b>	permanent
<b>esp</b>	stack pointer
<b>st0</b>	scratch, floating point return value
<b>st1-st7</b>	scratch

Table 12: Register usage on x86 fastcall (MS) calling convention



## Parameter passing

- stack parameter order: right-to-left
- called function cleans up the stack
- first two integers/pointers ( $\leq 32$ bit) are passed via ecx and edx (even if preceded by other arguments)
- integer types 64 bits in size @@@ ? first in edx:eax ?
- if first argument is a 64 bit integer, it is passed via ecx and edx
- all other parameters are pushed onto the stack

## Return values

- return values of pointer or integral type ( $\leq 32$  bits) are returned via the eax register
- integers  $> 32$  bits are returned via the eax and edx registers@@@verify
- floating point types are returned via the st0 register@@@ really ?

## Stack layout

Stack directly after function prolog:

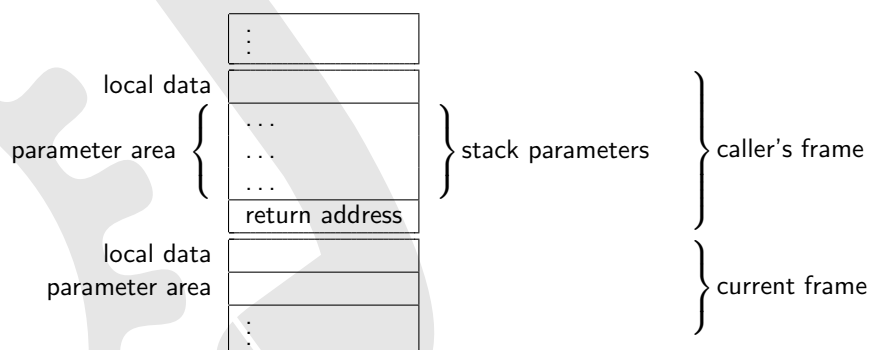


Figure 2: Stack layout on x86 fastcall (MS) calling convention

### D.1.3 GNU fastcall

#### Registers and register usage

Name	Brief description
<b>eax</b>	scratch, return value
<b>ebx</b>	permanent
<b>ecx</b>	scratch, parameter 0
<b>edx</b>	scratch, parameter 1, return value
<b>esi</b>	permanent
<b>edi</b>	permanent
<b>ebp</b>	permanent
<b>esp</b>	stack pointer
<b>st0</b>	scratch, floating point return value
<b>st1-st7</b>	scratch

Table 13: Register usage on x86 fastcall (GNU) calling convention

#### Parameter passing

- stack parameter order: right-to-left
- called function cleans up the stack
- first two integers/pointers ( $\leq 32$ bit) are passed via ecx and edx (even if preceded by other arguments)
- if first argument is a 64 bit integer, it is pushed on the stack and the two registers are skipped
- all other parameters are pushed onto the stack

#### Return values

- return values of pointer or integral type ( $\leq 32$  bits) are returned via the eax register.
- integers  $> 32$  bits are returned via the eax and edx registers.
- floating point types are returned via the st0.



## Stack layout

Stack directly after function prolog:

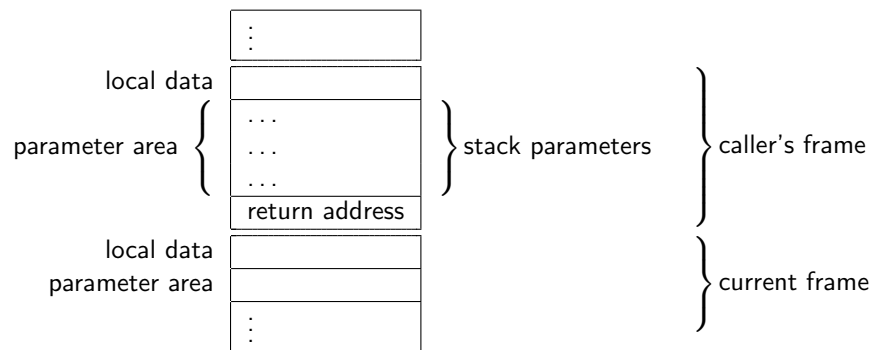


Figure 3: Stack layout on x86 fastcall (GNU) calling convention

## D.1.4 Borland fastcall

### Registers and register usage

Name	Brief description
<b>eax</b>	scratch, parameter 0, return value
<b>ebx</b>	permanent
<b>ecx</b>	scratch, parameter 2
<b>edx</b>	scratch, parameter 1, return value
<b>esi</b>	permanent
<b>edi</b>	permanent
<b>ebp</b>	permanent
<b>esp</b>	stack pointer
<b>st0</b>	scratch, floating point return value
<b>st1-st7</b>	scratch

Table 14: Register usage on x86 fastcall (Borland) calling convention

### Parameter passing

- stack parameter order: left-to-right
- called function cleans up the stack
- first three integers/pointers ( $\leq 32\text{bit}$ ) are passed via `eax`, `ecx` and `edx` (even if preceded by other arguments`@@@?`)
- integer types 64 bits in size `@@@ ?`
- all other parameters are pushed onto the stack

## Return values

- return values of pointer or integral type ( $\leq 32$  bits) are returned via the `eax` register
- integers  $> 32$  bits are returned via the `eax` and `edx` registers@@@ verify
- floating point types are returned via the `st0` register@@@ really ?

## Stack layout

Stack directly after function prolog:

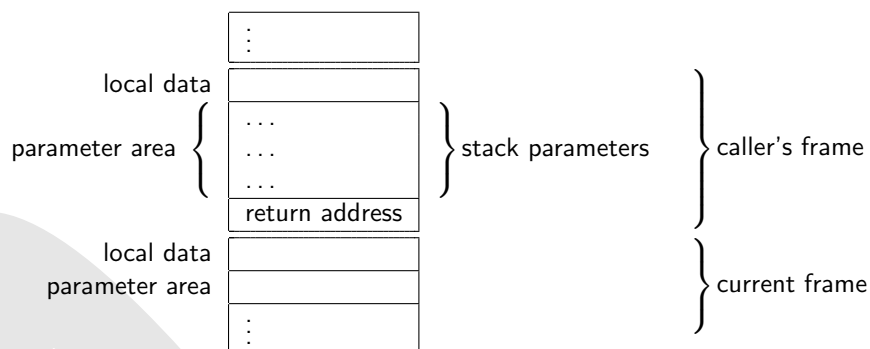


Figure 4: Stack layout on x86 fastcall (Borland) calling convention

## D.1.5 Watcom fastcall

### Registers and register usage

Name	Brief description
<b>eax</b>	scratch, parameter 0, return value@@@
<b>ebx</b>	scratch when used for parameter, parameter 2
<b>ecx</b>	scratch when used for parameter, parameter 3
<b>edx</b>	scratch when used for parameter, parameter 1, return value@@@
<b>esi</b>	scratch when used for return pointer @@@??
<b>edi</b>	permanent
<b>ebp</b>	permanent
<b>esp</b>	stack pointer
<b>st0</b>	scratch, floating point return value
<b>st1-st7</b>	scratch

Table 15: Register usage on x86 fastcall (Watcom) calling convention

### Parameter passing

- stack parameter order: right-to-left
- called function cleans up the stack

- first four integers/pointers ( $\leq 32$ bit) are passed via `eax`, `edx`, `ebx` and `ecx` (even if preceded by other arguments@@@?)
- integer types 64 bits in size @@@ ?
- all other parameters are pushed onto the stack

### Return values

- return values of pointer or integral type ( $\leq 32$  bits) are returned via the `eax` register@@@verify, I thnik its `esi`?
- integers  $> 32$  bits are returned via the `eax` and `edx` registers@@@ verify
- floating point types are returned via the `st0` register@@@ really ?

### Stack layout

Stack directly after function prolog:

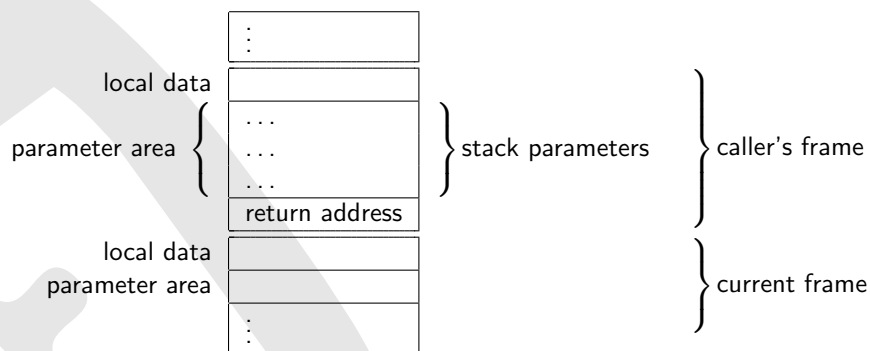


Figure 5: Stack layout on x86 fastcall (Watcom) calling convention

### D.1.6 win32 stdcall

#### Registers and register usage

Name	Brief description
<code>eax</code>	scratch, return value
<code>ebx</code>	permanent
<code>ecx</code>	scratch
<code>edx</code>	scratch, return value
<code>esi</code>	permanent
<code>edi</code>	permanent
<code>ebp</code>	permanent
<code>esp</code>	stack pointer
<code>st0</code>	scratch, floating point return value
<code>st1-st7</code>	scratch

Table 16: Register usage on x86 stdcall calling convention

## Parameter passing

- Stack parameter order: right-to-left
- Called function cleans up the stack
- All parameters are pushed onto the stack
- Stack is usually 4 byte aligned (GCC  $\geq 3.x$  seems to use a 16byte alignment@@@)
- Function name is decorated by prepending an underscore character and appending a '@' character and the number of bytes of stack space required

## Return values

- return values of pointer or integral type ( $\leq 32$  bits) are returned via the eax register
- integers  $> 32$  bits are returned via the eax and edx registers
- floating point types are returned via the st0 register

## Stack layout

Stack directly after function prolog:

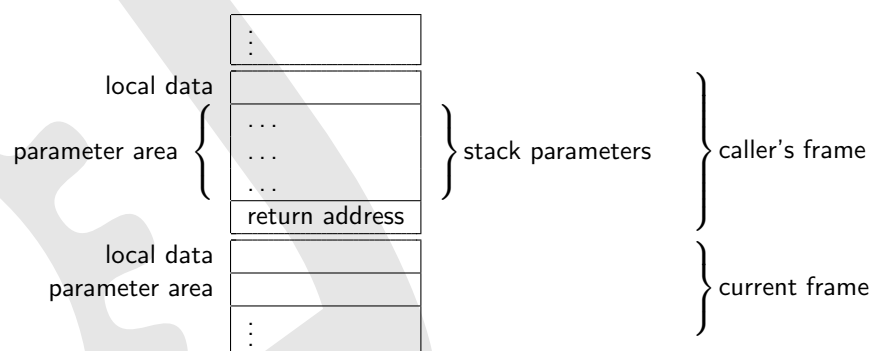


Figure 6: Stack layout on x86 stdcall calling convention

## D.1.7 MS thiscall

### Registers and register usage

Name	Brief description
<b>eax</b>	scratch, return value
<b>ebx</b>	permanent
<b>ecx</b>	scratch, parameter 0
<b>edx</b>	scratch, return value
<b>esi</b>	permanent
<b>edi</b>	permanent
<b>ebp</b>	permanent
<b>esp</b>	stack pointer
<b>st0</b>	scratch, floating point return value
<b>st1-st7</b>	scratch

Table 17: Register usage on x86 thiscall (MS) calling convention

### Parameter passing

- stack parameter order: right-to-left
- called function cleans up the stack
- first parameter (this pointer) is passed via ecx
- all other parameters are pushed onto the stack
- Function name is decorated by prepending a '@' character and appending a '@' character and the number of bytes (decimal) of stack space required

### Return values

- return values of pointer or integral type ( $\leq 32$  bits) are returned via the eax register
- integers  $> 32$  bits are returned via the eax and edx registers@@@verify
- floating point types are returned via the st0 register@@@ really ?

### Stack layout

Stack directly after function prolog:

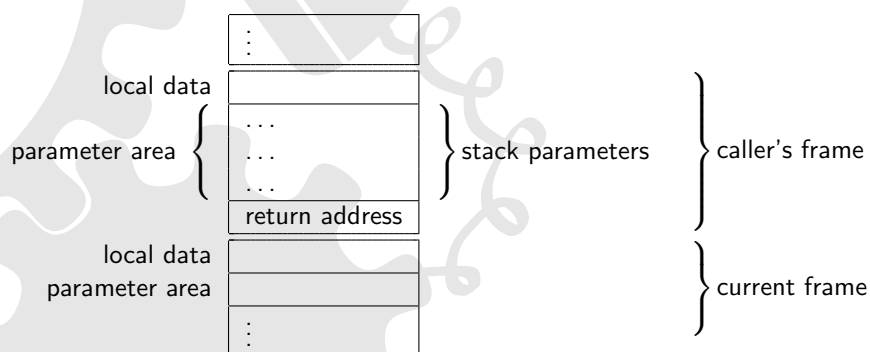


Figure 7: Stack layout on x86 thiscall (MS) calling convention

### D.1.8 GNU thiscall

#### Registers and register usage

Name	Brief description
<b>eax</b>	scratch, return value
<b>ebx</b>	permanent
<b>ecx</b>	scratch
<b>edx</b>	scratch, return value
<b>esi</b>	permanent
<b>edi</b>	permanent
<b>ebp</b>	permanent
<b>esp</b>	stack pointer
<b>st0</b>	scratch, floating point return value
<b>st1-st7</b>	scratch

Table 18: Register usage on x86 thiscall (GNU) calling convention

#### Parameter passing

- stack parameter order: right-to-left
- caller cleans up the stack
- all parameters are pushed onto the stack

#### Return values

- return values of pointer or integral type ( $\leq 32$  bits) are returned via the `eax` register
- integers  $> 32$  bits are returned via the `eax` and `edx` registers@@@verify
- floating point types are returned via the `st0` register@@@ really ?

#### Stack layout

Stack directly after function prolog:

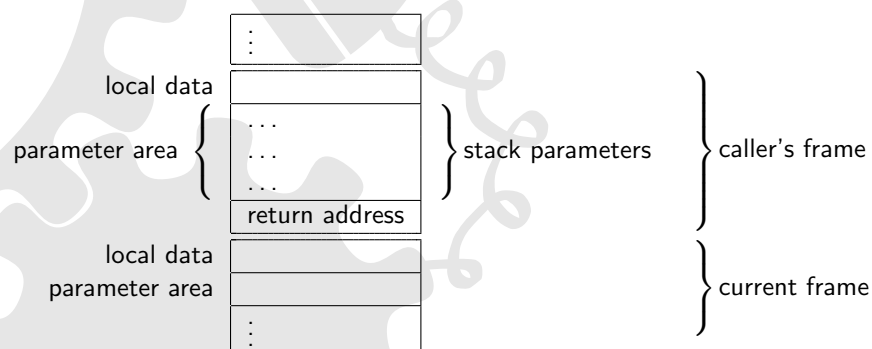


Figure 8: Stack layout on x86 thiscall (GNU) calling convention

### D.1.9 pascal

The best known uses of the pascal calling convention are the 16 bit OS/2 APIs, Microsoft Windows 3.x and Borland Delphi 1.x.

#### Registers and register usage

Name	Brief description
<b>eax</b>	scratch, return value
<b>ebx</b>	permanent
<b>ecx</b>	scratch
<b>edx</b>	scratch, return value
<b>esi</b>	permanent
<b>edi</b>	permanent
<b>ebp</b>	permanent
<b>esp</b>	stack pointer
<b>st0</b>	scratch, floating point return value
<b>st1-st7</b>	scratch

Table 19: Register usage on x86 pascal calling convention

#### Parameter passing

- stack parameter order: left-to-right
- called function cleans up the stack
- all parameters are pushed onto the stack

#### Return values

- return values of pointer or integral type ( $\leq 32$  bits) are returned via the `eax` register
- integers  $> 32$  bits are returned via the `eax` and `edx` registers
- floating point types are returned via the `st0` register

#### Stack layout

Stack directly after function prolog:

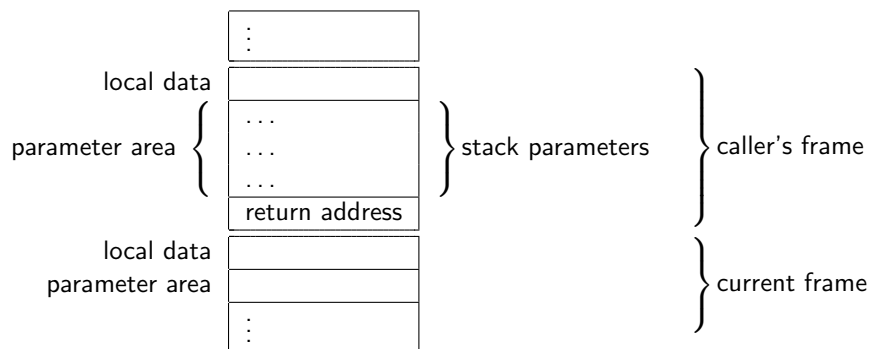


Figure 9: Stack layout on x86 pascal calling convention

#### D.1.10 plan9call

##### Registers and register usage

Name	Brief description
<b>eax</b>	scratch, return value
<b>ebx</b>	scratch
<b>ecx</b>	scratch
<b>edx</b>	scratch
<b>esi</b>	scratch
<b>edi</b>	scratch
<b>ebp</b>	scratch
<b>esp</b>	stack pointer
<b>st0</b>	scratch, floating point return value
<b>st1-st7</b>	scratch

Table 20: Register usage on x86 plan9call calling convention

##### Parameter passing

- stack parameter order: right-to-left
- caller cleans up the stack
- all parameters are pushed onto the stack



## Return values

- return values of pointer or integral type ( $\leq 32$  bits) are returned via the `eax` register
- integers  $> 32$  bits or structures are returned by the caller allocating the space and passing a pointer to the callee as a new, implicit first parameter (this means, on the stack)
- floating point types are returned via the `st0` register (called `F0` in plan9 8a's terms)

## Stack layout

Stack directly after function prolog:

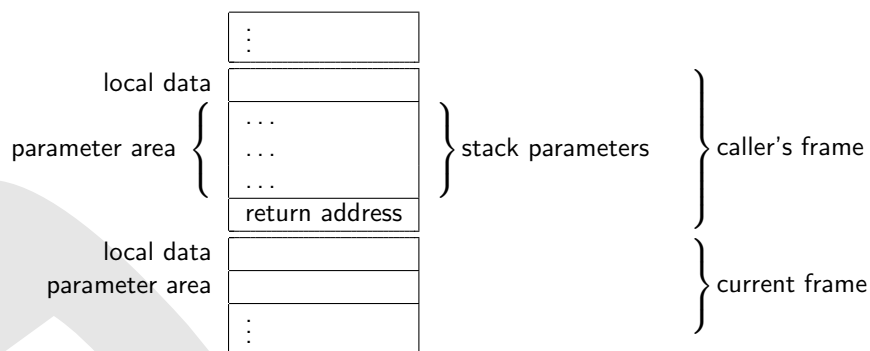


Figure 10: Stack layout on x86 plan9call calling convention

## D.2 x64 Calling Convention

### Overview

The x64 (64bit) architecture designed by AMD is based on Intel's x86 (32bit) architecture, supporting it natively. It is sometimes referred to as x86-64, AMD64, or, cloned by Intel, EM64T or Intel64. On this processor, a word is defined to be 16 bits in size, a dword 32 bits and a qword 64 bits. Note that this is due to historical reasons (terminology didn't change with the introduction of 32 and 64 bit processors).

The x64 calling convention for MS Windows [?] differs from the SystemV x64 calling convention [?] used by Linux/\*BSD/... Note that this is not the only difference between these operating systems. The 64 bit programming model in use by 64 bit windows is LLP64, meaning that the C types `int` and `long` remain 32 bits in size, whereas `long long` becomes 64 bits. Under Linux/\*BSD/... it's LP64.

Compared to the x86 architecture, the 64 bit versions of the registers are called `rax`, `rbx`, etc.. Furthermore, there are eight new general purpose registers `r8-r15`.

### dyncall support

*dyncall* supports the MS Windows and System V calling convention.

#### D.2.1 MS Windows

##### Registers and register usage

Name	Brief description
<b>rax</b>	scratch, return value
<b>rbx</b>	permanent
<b>rcx</b>	scratch, parameter 0 if integer or pointer
<b>rdx</b>	scratch, parameter 1 if integer or pointer
<b>rdi</b>	permanent
<b>rsi</b>	permanent
<b>rbp</b>	permanent, may be used as frame pointer
<b>rsp</b>	stack pointer
<b>r8-r9</b>	scratch, parameter 2 and 3 if integer or pointer
<b>r10-r11</b>	scratch, permanent if required by caller (used for <code>syscall/sysret</code> )
<b>r12-r15</b>	permanent
<b>xmm0</b>	scratch, floating point parameter 0, floating point return value
<b>xmm1-xmm3</b>	scratch, floating point parameters 1-3
<b>xmm4-xmm5</b>	scratch, permanent if required by caller
<b>xmm6-xmm15</b>	permanent

Table 21: Register usage on x64 MS Windows platform

##### Parameter passing

- stack parameter order: right-to-left
- caller cleans up the stack

- first 4 integer/pointer parameters are passed via rcx, rdx, r8, r9 (from left to right), others are pushed on stack (there is a preserve area for the first 4)
- float and double parameters are passed via xmm0l-xmm3l
- first 4 parameters are passed via the correct register depending on the parameter type - with mixed float and int parameters, some registers are left out (e.g. first parameter ends up in rcx or xmm0, second in rdx or xmm1, etc.)
- parameters in registers are right justified
- parameters < 64bits are not zero extended - zero the upper bits containing garbage if needed (but they are always passed as a qword)
- parameters > 64 bit are passed by reference
- if callee takes address of a parameter, first 4 parameters must be dumped (to the reserved space on the stack) - for floating point parameters, value must be stored in integer AND floating point register
- caller cleans up the stack, not the callee (like cdecl)
- stack is always 16byte aligned - since return address is 64 bits in size, stacks with an odd number of parameters are already aligned
- ellipsis calls take floating point values in int and float registers (single precision floats are promoted to double precision as defined for ellipsis calls)
- if size of parameters > 1 page of memory (usually between 4k and 64k), chkstk must be called

### Return values

- return values of pointer or integral type ( $\leq 64$  bits) are returned via the rax register
- floating point types are returned via the xmm0 register
- for types > 64 bits, a secret first parameter with an address to the return value is passed

### Stack layout

Stack frame is always 16-byte aligned. Stack directly after function prolog:

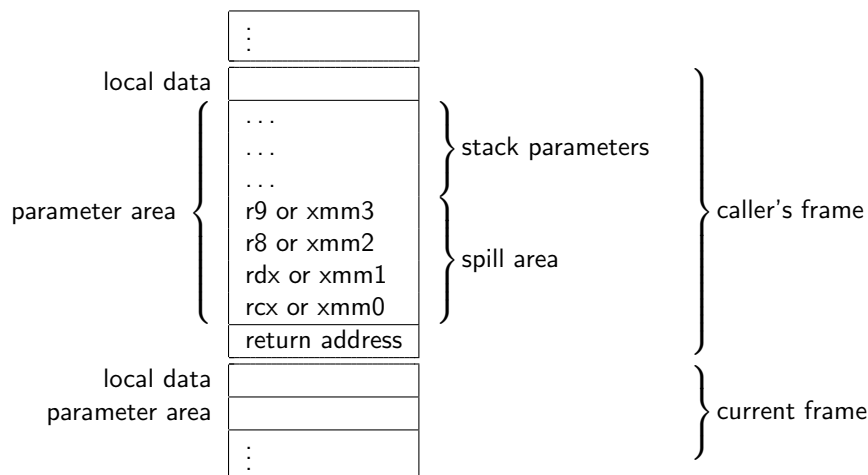


Figure 11: Stack layout on x64 Microsoft platform

## D.2.2 System V (Linux / \*BSD / MacOS X)

### Registers and register usage

Name	Brief description
<b>rax</b>	scratch, return value
<b>rbx</b>	permanent
<b>rcx</b>	scratch, parameter 3 if integer or pointer
<b>rdx</b>	scratch, parameter 2 if integer or pointer, return value
<b>rdi</b>	scratch, parameter 0 if integer or pointer
<b>rsi</b>	scratch, parameter 1 if integer or pointer
<b>rbp</b>	permanent, may be used as frame pointer
<b>rsp</b>	stack pointer
<b>r8-r9</b>	scratch, parameter 4 and 5 if integer or pointer
<b>r10-r11</b>	scratch
<b>r12-r15</b>	permanent
<b>xmm0</b>	scratch, floating point parameters 0, floating point return value
<b>xmm1-xmm7</b>	scratch, floating point parameters 1-7
<b>xmm8-xmm15</b>	scratch
<b>st0-st1</b>	scratch, 16 byte floating point return value
<b>st2-st7</b>	scratch

Table 22: Register usage on x64 System V (Linux/\*BSD)

### Parameter passing

- stack parameter order: right-to-left
- caller cleans up the stack
- first 6 integer/pointer parameters are passed via rdi, rsi, rdx, rcx, r8, r9
- first 8 floating point parameters ≤ 64 bits are passed via xmm0l-xmm7l
- parameters in registers are right justified

- parameters that are not passed via registers are pushed onto the stack
- parameters  $< 64$ bits are not zero extended - zero the upper bits containing garbage if needed (but they are always passed as a qword)
- integer/pointer parameters  $> 64$  bit are passed via 2 registers
- if callee takes address of a parameter, number of used xmm registers is passed silently in al (passed number mustn't be exact but an upper bound on the number of used xmm registers)
- stack is always 16byte aligned - since return address is 64 bits in size, stacks with an odd number of parameters are already aligned

### Return values

- return values of pointer or integral type ( $\leq 64$  bits) are returned via the rax register
- floating point types are returned via the xmm0 register
- for types  $> 64$  bits, a secret first parameter with an address to the return value is passed - the passed in address will be returned in rax
- floating point values  $> 64$  bits are returned via st0 and st1

### Stack layout

Stack frame is always 16-byte aligned. Note that there is no spill area. Stack directly after function prolog:

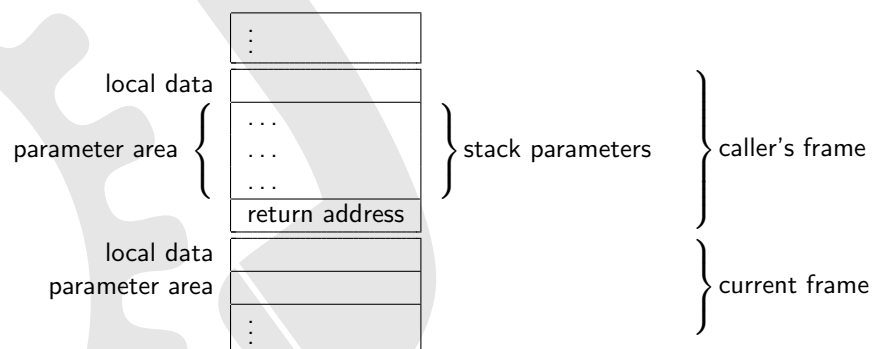


Figure 12: Stack layout on x64 System V (Linux/\*BSD)

## D.3 PowerPC (32bit) Calling Convention

### Overview

- Word size is 32 bits
- Big endian (MSB) and little endian (LSB) operating modes.
- Processor operates on floats in double precision floating point arithmetic (IEEE-754) values directly (single precision is converted on the fly)
- Apple Mac OS X/Darwin PPC is specified in "Mac OS X ABI Function Call Guide". It uses Big Endian (MSB).
- Linux PPC 32-bit ABI is specified in "LSB for PPC 2.1" which is based on "System V ABI". It uses Big Endian (MSB).
- PowerPC EABI is defined in the "PowerPC Embedded Application Binary Interface 32-Bit Implementation".

### dyncall support

*Dyncall* supports PowerPC (32bit) Big Endian (MSB) on Darwin (tested on Apple Mac OS X) and System V ABI systems (Linux, NetBSD, etc.).

#### D.3.1 Mac OS X/Darwin

##### Registers and register usage

Name	Brief description
<b>gpr0</b>	scratch
<b>gpr1</b>	stack pointer
<b>gpr2</b>	scratch
<b>gpr3</b>	return value, parameter 0 if integer or pointer
<b>gpr4-gpr10</b>	return value, parameter 1-7 for integer or pointer parameters
<b>gpr11</b>	permanent
<b>gpr12</b>	branch target for dynamic code generation
<b>gpr13-31</b>	permanent
<b>fpr0</b>	scratch
<b>fpr1-fpr13</b>	parameter 0-12 for floating point (always double precision)
<b>fpr14-fpr31</b>	permanent
<b>v0-v1</b>	scratch
<b>v2-v13</b>	vector parameters
<b>v14-v19</b>	scratch
<b>v20-v31</b>	permanent
<b>lr</b>	scratch, link-register
<b>ctr</b>	scratch, count-register
<b>cr0-cr1</b>	scratch
<b>cr2-cr4</b>	permanent
<b>cr5-cr7</b>	scratch

Table 23: Register usage on Darwin PowerPC 32-Bit

## Parameter passing

- stack parameter order: right-to-left@@@?
- caller cleans up the stack@@@?
- the first 8 integer parameters are passed in registers gpr3-gpr10
- the first 12 floating point parameters are passed in registers fpr1-fpr13
- if a float parameter is passed via a register, gpr registers are skipped for subsequent integer parameters (based on the size of the float - 1 register for single precision and 2 for double precision floating point values)
- the caller pushes subsequent parameters onto the stack
- for every parameter passed via a register, space is reserved in the stack parameter area (in order to spill the parameters if needed - e.g. varargs)
- ellipsis calls take floating point values in int and float registers (single precision floats are promoted to double precision as defined for ellipsis calls)
- all nonvector parameters are aligned on 4-byte boundaries
- vector parameters are aligned on 16-byte boundaries
- integer parameters < 32 bit occupy high-order bytes of their 4-byte area
- composite parameters with size of 1 or 2 bytes occupy low-order bytes of their 4-byte area. INCONSISTENT with other 32-bit PPC binary interfaces. In AIX and OS 9, padding bytes always follow the data structure
- composite parameters 3 bytes or larger in size occupy high-order bytes

## Return values

- return values of integer <= 32bit or pointer type use gpr3
- 64 bit integers use gpr3 and gpr4 (hiword in gpr3, loword in gpr4)
- floating point values are returned via fpr1
- structures <= 64 bits use gpr3 and gpr4
- for types > 64 bits, a secret first parameter with an address to the return value is passed

## Stack layout

Stack frame is always 16-byte aligned. Stack directly after function prolog:

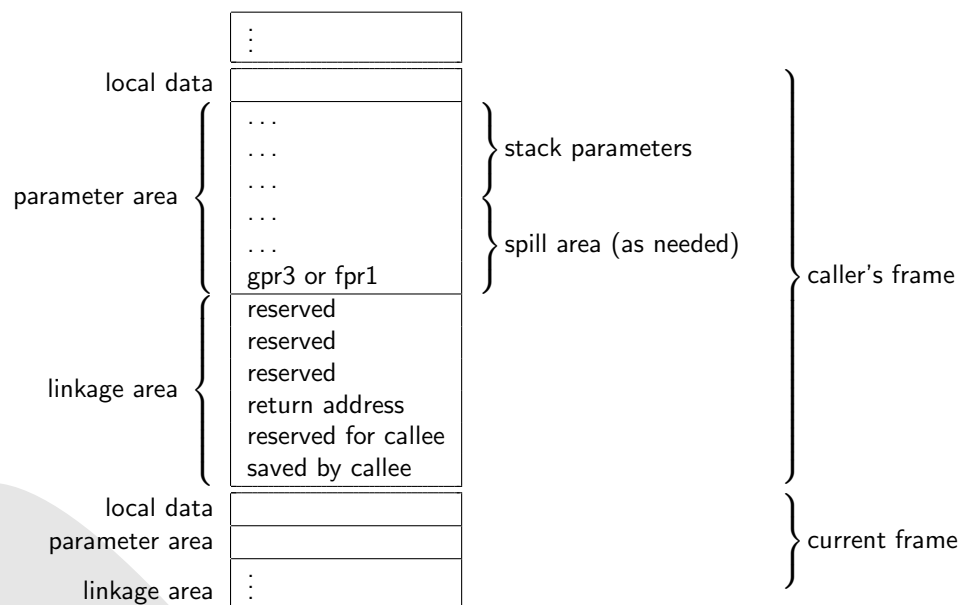


Figure 13: Stack layout on ppc32 Darwin

## D.3.2 System V PPC 32-bit

### Status

- C++ this calls do not work.
- *dyncallback* is buggy.

### Registers and register usage

#### Parameter passing

- Stack pointer (r1) is always 16-byte aligned. The EABI differs here - it is 8-byte alignment.
- 8 general-purpose registers (r3-r10) for integer and pointer types.
- 8 floating-point registers (f1-f8) for float (promoted to double) and double types.
- Additional arguments are passed on the stack directly after the back-chain and saved return address (8 bytes structure) on the callers stack frame.
- 64-bit integer data types are passed in general-purpose registers as a whole in two 32-bit general purpose registers (an odd and an even e.g. r3 and r4), probably skipping an even integer register. or passed on the stack. They are never splitted into a register and stack part.
- Ellipse calls set CR bit 6



Name	Brief description
<b>r0</b>	scratch
<b>r1</b>	stack pointer
<b>r2</b>	system-reserved
<b>r3-r4</b>	parameter passing and return value
<b>r5-r10</b>	parameter passing
<b>r11-r12</b>	scratch
<b>r13</b>	Small data area pointer register
<b>r14-r30</b>	Local variables
<b>r31</b>	Used for local variables or <i>environment pointer</i>
<b>f0</b>	scratch
<b>f1</b>	parameter passing and return value
<b>f2-f8</b>	parameter passing
<b>f9-13</b>	scratch
<b>f14-f31</b>	Local variables
<b>cr0-cr7</b>	Conditional register fields, each 4-bit wide (cr0-cr1 and cr5-cr7 are scratch)
<b>lr</b>	Link register (scratch)
<b>ctr</b>	Count register (scratch)
<b>xer</b>	Fixed-point exception register (scratch)
<b>fpscr</b>	Floating-point Status and Control Register

Table 24: Register usage on System V ABI PowerPC Processor

#### Return values

- 32-bit integers use register r3, 64-bit use registers r3 and r4 (hiword in r3, loword in r4).
- floating-point values are returned using register f1.

## Stack layout

Stack frame is always 16-byte aligned. Stack directly after function prolog:

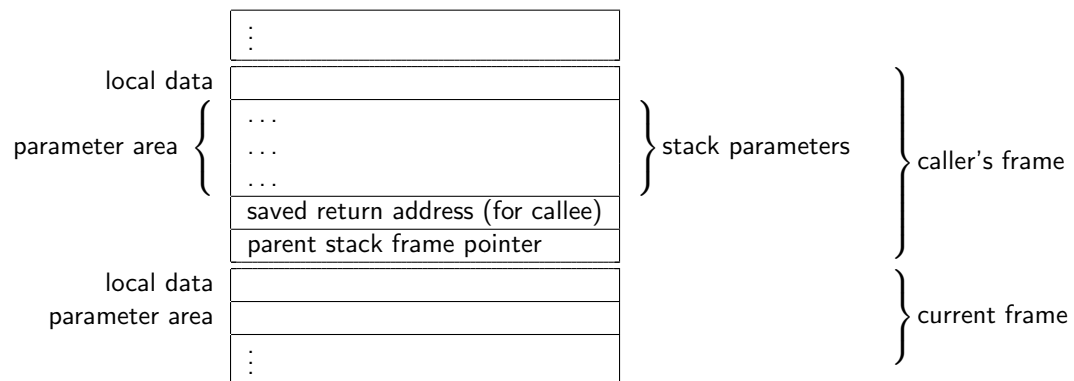


Figure 14: Stack layout on System V ABI for PowerPC 32-bit calling convention

## D.4 ARM32 Calling Convention

### Overview

The ARM32 family of processors is based on the Advanced RISC Machines (ARM) processor architecture (32 bit RISC). The word size is 32 bits (and the programming model is LLP64). Basically, this family of microprocessors can be run in 2 major modes:

Mode	Description
<b>ARM</b>	32bit instruction set
<b>THUMB</b>	compressed instruction set using 16bit wide instruction encoding

For more details, take a look at the ARM-THUMB Procedure Call Standard (ATPCS) [?], the Procedure Call Standard for the ARM Architecture (AAPCS) [?], as well as the Debian ARM EABI port wiki [?].

### dyncall support

Currently, the *dyncall* library supports the ARM and THUMB mode of the ARM32 family (ATPCS [?] and EABI [?]), excluding manually triggered ARM-THUMB interworking calls. Although it's quite possible that the current implementation runs on other ARM processor families as well, please note that only the ARMv4t family has been thoroughly tested at the time of writing. Please report if the code runs on other ARM families, too.

It is important to note, that dyncall supports the ARM architecture calling convention variant **with floating point hardware disabled** (meaning that the FPA and the VFP (scalar mode) procedure call standards are not supported). This processor family features some instruction sets accelerating DSP and multimedia application like the ARM Jazelle Technology (direct Java bytecode execution, providing acceleration for some bytecodes while calling software code for others), etc. that are not supported by the dyncall library.

#### D.4.1 ATPCS ARM mode

##### Registers and register usage

In ARM mode, the ARM32 processor has sixteen 32 bit general purpose registers, namely r0-15:

Name	Brief description
<b>r0</b>	parameter 0, scratch, return value
<b>r1</b>	parameter 1, scratch, return value
<b>r2-r3</b>	parameters 2 and 3, scratch
<b>r4-r10</b>	permanent
<b>r11</b>	frame pointer, permanent
<b>r12</b>	scratch
<b>r13</b>	stack pointer, permanent
<b>r14</b>	link register, permanent
<b>r15</b>	program counter (note: due to pipeline, r15 points to 2 instructions ahead)

Table 25: Register usage on arm32

### Parameter passing

- stack parameter order: right-to-left
- caller cleans up the stack
- first four words are passed using r0-r3
- subsequent parameters are pushed onto the stack (in right to left order, such that the stack pointer points to the first of the remaining parameters)
- if the callee takes the address of one of the parameters and uses it to address other parameters (e.g. varargs) it has to copy - in its prolog - the first four words to a reserved stack area adjacent to the other parameters on the stack
- parameters  $\leq 32$  bits are passed as 32 bit words
- 64 bit parameters are passed as two 32 bit parts (even partly via the register and partly via the stack), although this doesn't seem to be specified in the ATPCS), with the loword coming first
- structures and unions are passed by value, with the first four words of the parameters in r0-r3
- if return value is a structure, a pointer pointing to the return value's space is passed in r0, the first parameter in r1, etc... (see **return values**)
- keeping the stack eight-byte aligned can improve memory access performance and is required by LDRD and STRD on ARMv5TE processors which are part of the ARM32 family, so, in order to avoid problems one should always align the stack (tests have shown, that GCC does care about the alignment when using the ellipsis)

### Return values

- return values  $\leq 32$  bits use r0
- 64 bit return values use r0 and r1
- if return value is a structure, the caller allocates space for the return value on the stack in its frame and passes a pointer to it in r0

### Stack layout

Stack directly after function prolog:

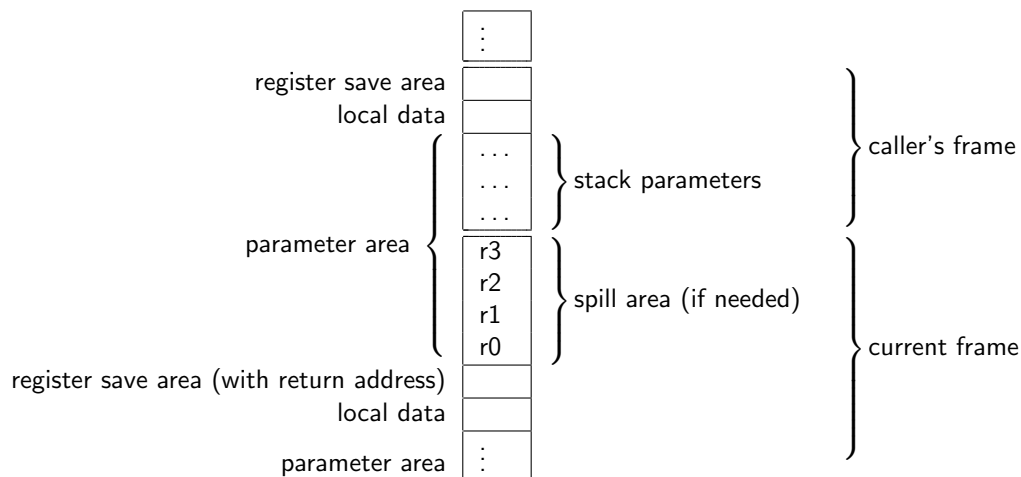


Figure 15: Stack layout on arm32

#### D.4.2 ATPCS THUMB mode

##### Status

- The ATPCS THUMB mode is untested.
- Ellipse calls may not work.
- C++ this calls do not work.

##### Registers and register usage

In THUMB mode, the ARM32 processor family supports eight 32 bit general purpose registers r0-r7 and access to high order registers r8-r15:

Name	Brief description
<b>r0</b>	parameter 0, scratch, return value
<b>r1</b>	parameter 1, scratch, return value
<b>r2-r3</b>	parameters 2 and 3, scratch
<b>r4-r6</b>	permanent
<b>r7</b>	frame pointer, permanent
<b>r8-r11</b>	permanent
<b>r12</b>	scratch
<b>r13</b>	stack pointer, permanent
<b>r14</b>	link register, permanent
<b>r15</b>	program counter (note: due to pipeline, r15 points to 2 instructions ahead)

Table 26: Register usage on arm32 thumb mode

##### Parameter passing

- stack parameter order: right-to-left

- caller cleans up the stack
- first four words are passed using r0-r3
- subsequent parameters are pushed onto the stack (in right to left order, such that the stack pointer points to the first of the remaining parameters)
- if the callee takes the address of one of the parameters and uses it to address other parameters (e.g. varargs) it has to copy - in its prolog - the first four words to a reserved stack area adjacent to the other parameters on the stack
- parameters  $\leq 32$  bits are passed as 32 bit words
- 64 bit parameters are passed as two 32 bit parts (even partly via the register and partly via the stack), although this doesn't seem to be specified in the ATPCS), with the loword coming first
- structures and unions are passed by value, with the first four words of the parameters in r0-r3
- if return value is a structure, a pointer pointing to the return value's space is passed in r0, the first parameter in r1, etc. (see **return values**)
- keeping the stack eight-byte aligned can improve memory access performance and is required by LDRD and STRD on ARMv5TE processors which are part of the ARM32 family, so, in order to avoid problems one should always align the stack (tests have shown, that GCC does care about the alignment when using the ellipsis)

### Return values

- return values  $\leq 32$  bits use r0
- 64 bit return values use r0 and r1
- if return value is a structure, the caller allocates space for the return value on the stack in its frame and passes a pointer to it in r0

### Stack layout

Stack directly after function prolog:

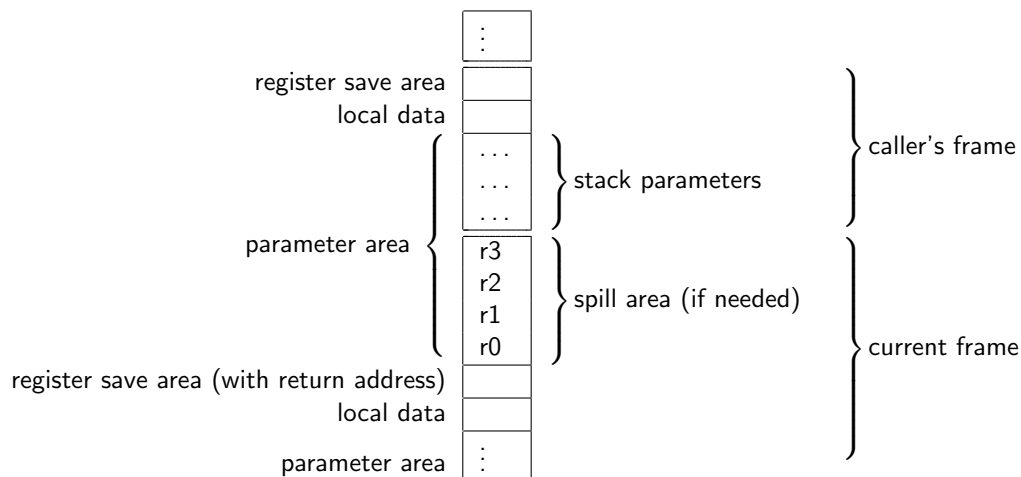


Figure 16: Stack layout on arm32 thumb mode

### D.4.3 EABI (ARM and THUMB mode)

The ARM EABI is very similar to the ABI outlined in ARM-THUMB procedure call standard (ATPCS) [?] - however, the EABI requires the stack to be 8-byte aligned at function entries, as well as 64 bit parameters. The latter are aligned on 8-byte boundaries on the stack and 2-registers for parameters passed via register. In order to achieve such an alignment, a register might have to be skipped for parameters passed via registers, or 4-bytes on the stack for parameters passed via the stack. Refer to the Debian ARM EABI port wiki for more information [?].

#### Status

- The EABI THUMB mode is tested and works fine (contrary to the ATPCS).
- Ellipse calls do not work.
- C++ this calls do not work.

#### D.4.4 ARM on Apple's iOS (Darwin) Platform

The iOS runs on ARMv6 (iOS 2.0) and ARMv7 (iOS 3.0) architectures. Typically code is compiled in Thumb mode.

##### Register usage

Name	Brief description
<b>R0</b>	parameter 0, scratch, return value
<b>R1</b>	parameter 1, scratch, return value
<b>R2-R3</b>	parameters 2 and 3, scratch
<b>R4-R6</b>	permanent
<b>R7</b>	frame pointer, permanent
<b>R8</b>	permanent
<b>R9</b>	permanent(iOS 2.0) and scratch (since iOS 3.0)
<b>R10-R11</b>	permanent
<b>R12</b>	scratch, intra-procedure scratch register (IP) used by dynamic linker
<b>R13</b>	stack pointer, permanent
<b>R14</b>	link register, permanent
<b>R15</b>	program counter (note: due to pipeline, r15 points to 2 instructions ahead)
<b>CPSR</b>	Program status register
<b>D0-D7</b>	scratch. aliases S0-S15, on ARMv7 also as Q0-Q3. Not accessible from Thumb mode on ARMv6.
<b>D8-D15</b>	permanent, aliases S16-S31, on ARMv7 also as Q4-A7. Not accesible from Thumb mode on ARMv6.
<b>D16-D31</b>	Only available in ARMv7, aliases Q8-Q15.
<b>FPSCR</b>	VFP status register.

Table 27: Register usage on ARM Apple iOS

The ABI is based on the AAPCS but with some important differences listed below:

- R7 instead of R11 is used as frame pointer
- R9 is scratch since iOS 3.0, was preserved before.

#### D.4.5 Architectures

The ARM architecture family contains several revisions with capabilities and extensions (such as thumb-interworking and more vector registers) The following table summaries important properties of the various architecture standards.

Arch	Platforms	Details
ARMv4		
ARMv4T	ARM 7, ARM 9, Neo FreeRunner (OpenMoko)	
ARMv5		BLX instruction available
ARMv6		No vector registers available in thumb
ARMv7	iPod touch, iPhone 3GS/4	

Table 28: Overview of ARM Architecture, Platforms and Details



## D.5 MIPS Calling Convention

### Overview

The MIPS family of processors is based on the MIPS processor architecture. Multiple revisions of the MIPS Instruction set exist, namely MIPS I, MIPS II, MIPS III, MIPS IV, MIPS32 and MIPS64. Today, MIPS32 and MIPS64 for 32-bit and 64-bit respectively. Several add-on extensions exist for the MIPS family:

**MIPS-3D** simple floating-point SIMD instructions dedicated to common 3D tasks.

**MDMX** (MaDMaX) more extensive integer SIMD instruction set using 64 bit floating-point registers.

**MIPS16e** adds compression to the instruction stream to make programs take up less room (allegedly a response to the THUMB instruction set of the ARM architecture).

**MIPS MT** multithreading additions to the system similar to HyperThreading.

Unfortunately, there is actually no such thing as "The MIPS Calling Convention". Many possible conventions are used by many different environments such as *32*, *O64*, *N32*, *64* and *EABI*.

### dyncall support

Currently, dyncall supports the EABI calling convention which is used on the Homebrew SDK for the Playstation Portable. As documentation for this EABI is unofficial, this port is currently experimental.

#### D.5.1 MIPS EABI 32-bit Calling Convention

##### Register usage

Name	Alias	Brief description
<b>\$0</b>	<b>\$zero</b>	Hardware zero
<b>\$1</b>	<b>\$at</b>	Assembler temporary
<b>\$2-\$3</b>	<b>\$v0-\$v1</b>	Integer results
<b>\$4-\$11</b>	<b>\$a0-\$a7</b>	Integer arguments
<b>\$12-\$15,\$24,\$25</b>	<b>\$t4-\$t7,\$8,\$9</b>	Integer temporaries
<b>\$16-\$23</b>	<b>\$s0-\$s7</b>	Preserved
<b>\$26-\$27</b>	<b>\$kt0-\$kt1</b>	Reserved for kernel
<b>\$28</b>	<b>\$gp</b>	Global pointer
<b>\$29</b>	<b>\$sp</b>	Stack pointer
<b>\$30</b>	<b>\$s8</b>	Frame pointer
<b>\$31</b>	<b>\$ra</b>	Return address
<b>hi, lo</b>		Multiply/divide special registers
<b>\$f0,\$f2</b>		Float results
<b>\$f1,\$f3,\$f4-\$f11,\$f20-\$f23</b>		Float temporaries
<b>\$f12-\$f19</b>		Float arguments

Table 29: Register usage on mips32 eabi calling convention

##### Parameter passing

- Stack parameter order: right-to-left
- Caller cleans up the stack

- Stack always aligned to 8 bytes.
- first 8 integers and floats are passed independently in registers using \$a0-\$a7 and \$f12-\$f19, respectively.
- if either integer or float registers are consumed up, the stack is used.
- 64-bit floats and integers are passed on two integer registers starting at an even register number, probably skipping one odd register.
- \$a0-\$a7 and \$f12-\$f19 are not required to be preserved.
- results are returned in \$v0 (32-bit integer), \$v0 and \$v1 (64-bit integer/float), \$f0 (32 bit float) and \$f0 and \$f2 ( $2 \times 32$  bit float e.g. complex).

### Stack layout

Stack directly after function prolog:

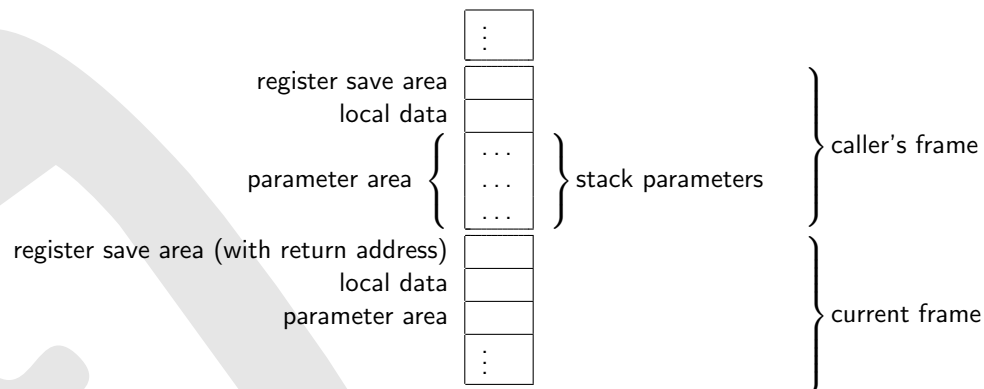


Figure 17: Stack layout on mips32 eabi calling convention

## D.6 SPARC Calling Convention

### Overview

The SPARC family of processors is based on the SPARC instruction set architecture, which comes in basically three revisions, V7, V8 and V9. The former two are 32-bit whereas the latter refers to the 64-bit SPARC architecture (see next chapter). SPARC is big endian.

### dyncall support

*dyncall* fully supports the SPARC 32-bit instruction set (V7 and V8), *dyncallback* support is missing, though.

### D.6.1 SPARC (32-bit) Calling Convention

#### Register usage

- 32 32-bit integer/pointer registers
- 32 floating point registers (usable as 8 quad precision, 16 double precision or 32 single precision registers)
- 32 registers are accessible at a time (8 are global ones ( $g^*$ ), whereas the rest forms a register window with 8 input ( $i^*$ ), 8 output ( $o^*$ ) and 8 local ( $l^*$ ) ones)
- invoking a function shifts the register window, the old output registers become the new input registers (old local and input ones are not accessible anymore)

Name	Alias	Brief description
<b>%g0</b>		Read-only, hardwired to 0
<b>%g1-%g7</b>		Global
<b>%o0 and %i0</b>		Output and input argument 0, return value
<b>%o1-%o5 and %i1-%i5</b>		Output and input argument registers
<b>%o6 and %i6</b>		Stack and frame pointer
<b>%o7 and %i7</b>		Return address (caller writes to o7, callee uses i7)

Table 30: Register usage on sparc calling convention

#### Parameter passing

- Stack parameter order: right-to-left @@@ really?
- Caller cleans up the stack @@@ really?
- Stack always aligned to 8 bytes.
- first 6 integers and floats are passed independently in registers using %o0-%o5
- for every other argument the stack is used
- @@@ what about floats, 64bit integers, etc.?
- results are returned in %i0, and structs/unions pass a pointer to them as a hidden stack parameter (see below)

## Stack layout

Stack directly after function prolog:

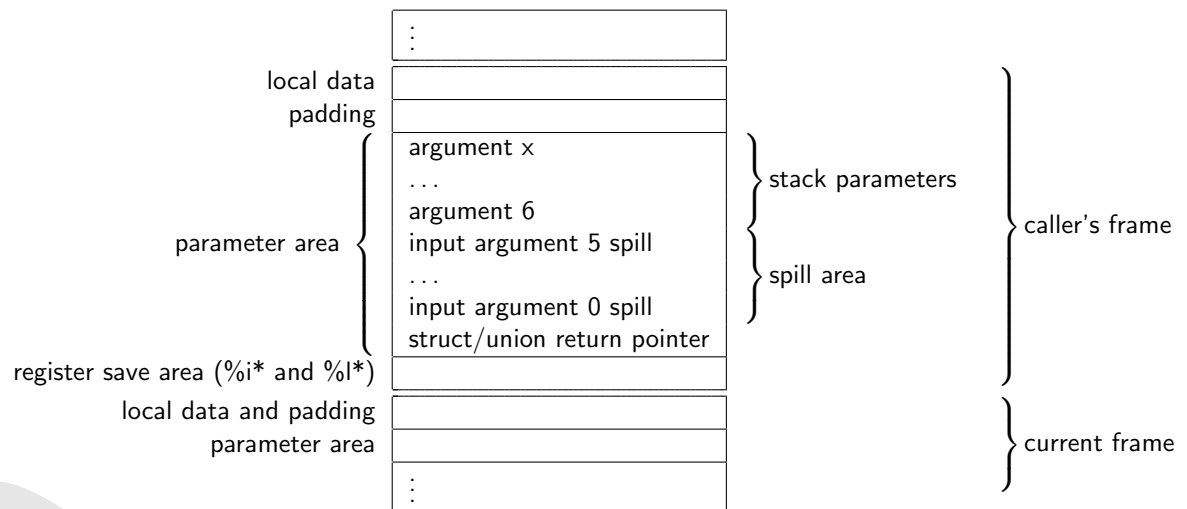


Figure 18: Stack layout on sparc calling convention

## D.7 SPARC64 Calling Convention

### Overview

The SPARC family of processors is based on the SPARC instruction set architecture, which comes in basically three revisions, V7, V8 and V9. The former two are 32-bit (see previous chapter) whereas the latter refers to the 64-bit SPARC architecture. SPARC is big endian.

### dyncall support

*dyncall* fully supports the SPARC 64-bit instruction set (V9), *dyncallback* support is missing, though.

#### D.7.1 SPARC (64-bit) Calling Convention

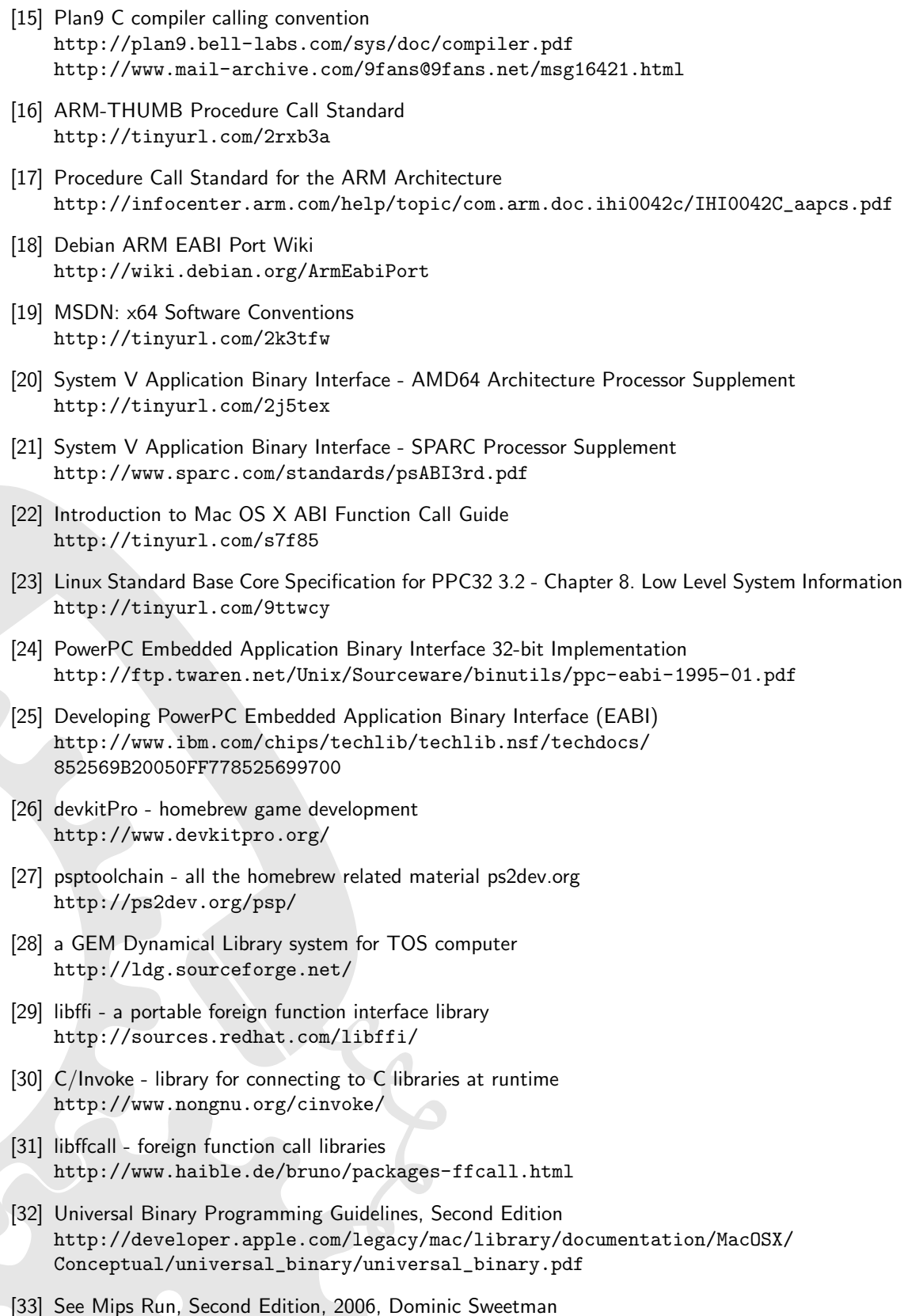
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