# Cereon

Procedure Calling Standards

Authors:
Andrei Kapustin

Revision history

| Date | Comment |
|---|---|
| 22 November 2006 | Initial draft. |
| 3 November 2007 | Documented the NPCS, TPCS and BPCS. |

# 1 Contents

# 2 Preface

This document is a definitive guide into the procedure calling standards used by Cereon platforms.

A Procedure Calling Standard (henceforth abbreviated as PCS) is a specification of:

- How arguments are passed to procedures.
- How the said procedures are invoked.
- How results are returned from these procedures.
- What register usage rules must be obeyed.

Note that, although this document describes a number of “standard” procedure calling standards, there is nothing in the world to stop a particular toolchain vendor from inventing and implementing a proprietary PCS of their own – the only drawback of that approach would be in the fact that programs compiled with the said toolchain will not be binary-compatible with those compiled by other toolchains.

Note also that the procedure calling standard described herein have a lot in common, (including register usage rules); therefore, it may be possible, in some cases, for a procedure conforming to one calling standard to call a procedure that conforms to another calling standard (for example, a procedure that conforms to BPCS can be called by a procedure conforming to any other calling standard described); however, this is not recommended.

# 3 Common procedure calling standard

The Common Procedure Calling Standard (abbreviated henceforth as CPCS) is a procedure calling standard that can be used by most of the currently known programming languages. However, the generality of the standard means that, for some languages, a more efficient calling standard is possible; in this case the toolchain vendor has a choice between either using CPCS for maximum interoperability or implementing some other, more efficient, procedure calling standard at the expense of disallowing the toolchain from supporting some of the more elaborate programming languages. Of course, it is also possible to implement a toolchain that allows the user to choose whether CPCS or some other procedure calling standard is used.

The Common Procedure Calling Standard:

- Can be used for writing procedures with both constant and variable number of parameters.
- Allows parameters and return values of certain types to be passed in and out of the procedure in registers, thus frequently eliminating the need for using activation stack.
- Supports languages with static scoping rules (such as Pascal, Ada or SPL).
- Allows for nonlocal jumps and dynamic exception propagation (such as required by Pascal, Ada, SPL or C++).

## 3.1 Register usage conventions

As part of the CPCS, there are conventions about how registers are used across procedure calls. These conventions are outlined in the following sections.

### 3.1.1 Register-passable types

An important concept involved in the CPCS register usage conventions is that of a register-passable type. On an intuitive level, a register-passable type is a type whose values can be passed from caller to callee and/or back in a single Cereon register.

Only following types (and types derived from these types) are register-passable:

- `integer*1`, `integer*2`, `integer*4` and `integer*8`. Values of types `integer*1`, `integer*2`, `integer*4` are sign-extended to 64 bits when passed to/from a procedure in a register.
- `cardinal*1`, `cardinal*2`, `cardinal*4` and `cardinal*8`. Values of types `cardinal*1`, `cardinal*2`, `cardinal*4` are zero-extended to 64 bits when passed to/from a procedure in a register.
- `character*1`, `character*2` and `character*4`. Values of these types are zero-extended to 64 bits when passed to/from a procedure in a register.
- `real*4` and `real*8`. Values of the `real*4` type are converted to `real*8` when passed to/from a procedure in a register.
- `pointer` and `^T`, where `T` can be any type.
- `boolean`. Values of this type are zero-extended to 64 bits when passed to/from a procedure in a register.

- All enumerated types. Values of these types are zero-extended to 64 bits when passed to/from a procedure in a register.

### 3.1.2 Caller-saved registers

The following registers are not expected to keep their values across procedure calls:

- `$rv/$frv`.
- `$a0/$fa0 .. $a3/$fa3`.
- `$t0/$ft0 .. $t7/$ft7`.

These registers are typically used as temporary registers within local code sequences. If the caller needs any of these registers to keep their value after a procedure call, it must save them to memory before the call and reload after the callee has returned.

### 3.1.3 Callee-saved registers

The following registers are expected to keep their values across procedure calls:

- `$s0/$sf0 .. $s12/$fs12`.

These registers are typically used to store long-lived values, such as local variables. If the callee needs to use any of these registers, it must save them to memory before use and reload just before return.

### 3.1.4 Special registers

Several registers have special meaning under CPCS. These registers are:

- `$ra` – upon procedure entry this register contains an address of the instruction to which a jump must be made in order to perform procedure return. Typically a procedure will immediately save this register into its activation frame; however, in a leaf procedure (i.e. procedure that does not call any other procedures) this is optional. Note that the caller does not expect the `$ra` register to retain its value across procedure call.
- `$sp` – at any moment during program execution this register contains the address of the lowest memory byte occupied by the activation stack. Under CPCS stack starts at higher addresses and grows down. Both stack bottom and stack top addresses are always multiples of 8. The caller expects `$sp` to retain its value across calls of procedures with fixed number of parameters but not variadic procedures (see more in "Parameter passing" section below).
- `$fp` – the frame pointer register contains a pointer to a fixed location within the activation stack frame of the currently executing procedure. When a procedure is called, it saves the caller's `$fp` into its own activation frame before establishing an activation frame of its own. The caller expects the `$fp` register to retain its value across procedure calls.
- `$dp` – the display pointer register contains the frame pointer of the current procedure's immediately lexically enclosing parent. If the language in question does not permit nested procedures (which is the case in C or C++), the `$dp` register is always zero. If the language permits nested procedures

(such as SPL or Pascal), the `$dp` register will be zero whenever an outer-level procedure is being executed.

- `$gp` – this register contains an address of an unwind handler of the currently executing procedure. An unwind handler is a fragment of code that must be called if the activation frame of the current procedure is forcibly removed from an activation stack (this happens during C++ exception propagation or SPL nonlocal jumps). If the current procedure does not have an unwind handler, this register will be 0.

## 3.2 Parameter passing

When preparing to call a procedure, parameters are passed using argument registers `$a0/$fa0` .. `$a3/$fa3` and activation stack. The following rules are followed:

- The leftmost 4 parameters of register-passable types are passed in registers `$a0/$fa0` .. `$a3/$fa3` in that order (i.e. the 1st parameter of a register-passable type goes to `$a0/$fa0`, etc.) Note that these parameters are not necessarily consecutive; for example when calling a procedure that has the signature `(* : integer, * : label, * : real)` the 1st parameter will be passed in `$a0` and the 3rd in `$a1`, whereas the 2nd parameter will be passed on the stack. Note that `out` and `in out` parameters are technically pointers, so they are always register-passable.
- All parameters that are not passed in registers are passed on the stack. Parameters are pushed on the stack in right-to-left order, with each parameter being aligned at an 8-byte boundary.
- When a procedure with a fixed number of parameters is called, this procedure is expected to remove parameters from the stack.
- When a procedure with a variable number of parameters is called, this procedure is not expected to remove parameters from the stack, as it does not have sufficient information to do so. In this case, the `$sp` after the call is expected to be the same as `$sp` before the call, the caller will then need to adjust `$sp` before continuing.

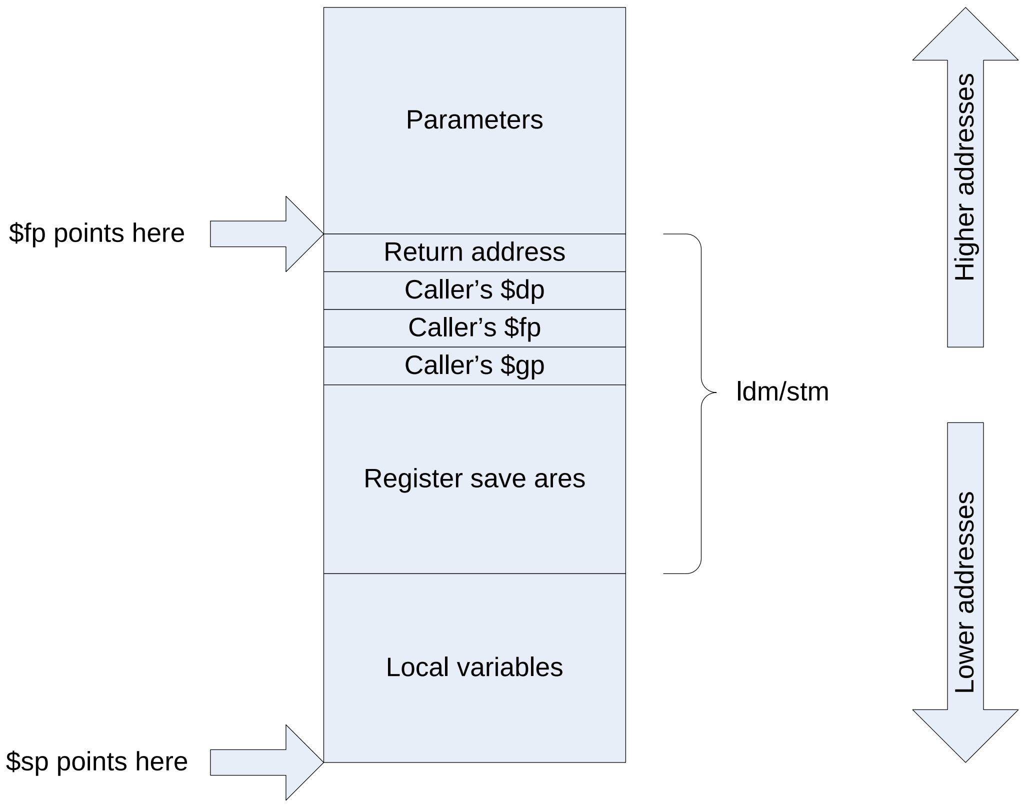
## 3.3 Returning values

If a procedure is a function (i.e. it returns an explicit value), the following rules are used:

- If a procedure returns value of a register-passable type, this value is returned in `$rv/$frv`.
- If a procedure returns value of any other type `T`, an implicit 0th parameter of type `^T` is assumed. Since pointers are register-passable, this implicit parameter will always be passed to the procedure in `$a0` (with the 1st "real" register-passable parameter shifted to `$a1/$fa1`, and so on). This parameter is a pointer to a value of type `T` allocated by the caller, where the return value must be stored.

## 3.4 Activation frame layout

The following diagram illustrates the layout of a single procedure activation frame:




Individual areas within the activation frame have the following functions:

- Parameters – this is the area used by those parameters which did not make it into registers. If all parameters are passed in registers, this area will be empty/
- Return address – the $ra register is saved here upon procedure entry. It will be restored just before returning to the caller in order to determine where to return.
- Caller's `$dp`, `$fp` and `$gp` – these 3 registers are saved here upon entry to the procedure. They will be restored just before returning to the caller, as the latter expects all three registers to retain their values across procedure calls.
- Register save area – if the procedure wishes to use any of the callee-saved registers for its own needs, these registers must be saved upon procedure entry and restored before returning to the caller. This is the area where these registers are saved.
- Local variables – if a procedure needs some in-memory local variables for its own needs, they are allocated here.

Note that the entire memory area marked as "`ldm`/`stm`" can be saved (upon procedure entry) or reloaded (upon procedure exit) by a single `ldm`/`stm` instruction. This ensures that procedure entry/exit code is but a few instructions long.

## 3.5 Accessing nonlocal variables

While in-memory local variables allow for straightforward access (via `$fp`-based relative addresses), accessing nonlocal variables from enclosing procedures is only slightly more complicated.

The central point of nonlocal variable accesses is in that it is always known at compile-time which level of nesting each procedure is declared at. Accessing a variable from an immediately enclosing procedure requires a `$dp`-based relative address instead of an `$fp`-based one. If the difference in the level of nesting is greater than 1, `$dp` points to an activation frame of an immediately enclosing procedure, and the static chain of long words at offset -8 within each activation frame gives an address of the next lexically enclosing activation frame.

## 3.6 Forced stack unwinding

In a language that permits exception propagation (such as C++) or nonlocal jumps (such as SPL) a situation may arise when a number of activation frames must be forcefully removed.

To unwind a single activation frame, the following steps must be performed:

1. An `ldm` from a register save area makes sure callee-saved registers have the same values they did before the call.
2. The unwind handler of the current procedure must be called, provided one exists. The address of an unwind handler of the procedure associated with the topmost activation frame is always in `$gp`; an absence of an unwind handler is represented by `$gp` = 0.
3. `$sp` is adjusted to `$fp` (for variadic procedures) or `$fp` + <parameter area size> (for procedures with fixed number of parameters).

After the steps above have been completed, the program state is restored to exactly what it was just before the call. Any number of stack frames can be unwound by repeating the same sequence of actions once per activation stack frame.

# 4 Nested procedure calling standard

The Nested Procedure Calling Standard (abbreviated henceforth as NPCS) is a procedure calling standard that can be used by programming languages that allow nonlocal nonstatic scopes and nested procedures but *not* the forced stack unwinding (such as Modula-2). It will typically be used by Modula-2 – only toolchains that do not care much about interoperability with other languages.

The Nested Procedure Calling Standard:

- Can be used for writing procedures with both constant and variable number of parameters.
- Allows parameters and return values of certain types to be passed in and out of the procedure in registers, thus frequently eliminating the need for using activation stack.
- Supports languages with static scoping rules (such as Pascal, Ada or SPL).
- Does not allow for nonlocal jumps and dynamic exception propagation.

## 4.1 Register usage conventions

As part of the NPCS, there are conventions about how registers are used across procedure calls. These conventions are outlined in the following sections.

### 4.1.1 Register-passable types

An important concept involved in the NPCS register usage conventions is that of a register-passable type. On an intuitive level, a register-passable type is a type whose values can be passed from caller to callee and/or back in a single Cereon register.

Only following types (and types derived from these types) are register-passable:

- `integer*1`, `integer*2`, `integer*4` and `integer*8`. Values of types `integer*1`, `integer*2`, `integer*4` are sign-extended to 64 bits when passed to/from a procedure in a register.
- `cardinal*1`, `cardinal*2`, `cardinal*4` and `cardinal*8`. Values of types `cardinal*1`, `cardinal*2`, `cardinal*4` are zero-extended to 64 bits when passed to/from a procedure in a register.
- `character*1`, `character*2` and `character*4`. Values of these types are zero-extended to 64 bits when passed to/from a procedure in a register.
- `real*4` and `real*8`. Values of the `real*4` type are converted to `real*8` when passed to/from a procedure in a register.
- `pointer` and `^T`, where `T` can be any type.
- `boolean`. Values of this type are zero-extended to 64 bits when passed to/from a procedure in a register.
- All enumerated types. Values of these types are zero-extended to 64 bits when passed to/from a procedure in a register.

### 4.1.2 Caller-saved registers

The following registers are not expected to keep their values across procedure calls:

- `$rv/$frv`.
- `$a0/$fa0 .. $a3/$fa3`.
- `$t0/$ft0 .. $t7/$ft7`.

These registers are typically used as temporary registers within local code sequences. If the caller needs any of these registers to keep their value after a procedure call, it must save them to memory before the call and reload after the callee has returned.

### 4.1.3 Callee-saved registers

The following registers are expected to keep their values across procedure calls:

- `$s0/$sf0 .. $s12/$fs12`.

These registers are typically used to store long-lived values, such as local variables. If the callee needs to use any of these registers, it must save them to memory before use and reload just before return.

### 4.1.4 Special registers

Several registers have special meaning under NPCS. These registers are:

- `$ra` – upon procedure entry this register contains an address of the instruction to which a jump must be made in order to perform procedure return. Typically a procedure will immediately save this register into its activation frame; however, in a leaf procedure (i.e. procedure that does not call any other procedures) this is optional. Note that the caller does not expect the `$ra` register to retain its value across procedure call.
- `$sp` – at any moment during program execution this register contains the address of the lowest memory byte occupied by the activation stack. Under NPCS stack starts at higher addresses and grows down. Both stack bottom and stack top addresses are always multiples of 8. The caller expects `$sp` to retain its value across calls of procedures with fixed number of parameters but not variadic procedures (see more in "Parameter passing" section below).
- `$fp` – the frame pointer register contains a pointer to a fixed location within the activation stack frame of the currently executing procedure. When a procedure is called, it saves the caller's `$fp` into its own activation frame before establishing an activation frame of its own. The caller expects the `$fp` register to retain its value across procedure calls.
- `$dp` – the display pointer register contains the frame pointer of the current procedure's immediately lexically enclosing parent. If the language in question does not permit nested procedures (which is the case in C or C++), the `$dp` register is always zero. If the language permits nested procedures (such as SPL or Pascal), the `$dp` register will be zero whenever an outer-level procedure is being executed.

## 4.2 Parameter passing

When preparing to call a procedure, parameters are passed using argument registers `$a0/$fa0` .. `$a3/$fa3` and activation stack. The following rules are followed:

- The leftmost 4 parameters of register-passable types are passed in registers `$a0/$fa0` .. `$a3/$fa3` in that order (i.e. the 1st parameter of a register-passable type goes to `$a0/$fa0`, etc.) Note that these parameters are not necessarily consecutive; for example when calling a procedure that has the signature `(* : integer, * : label, * : real)` the 1st parameter will be passed in `$a0` and the 3rd in `$a1`, whereas the 2nd parameter will be passed on the stack. Note that `out` and `in out` parameters are technically pointers, so they are always register-passable.
- All parameters that are not passed in registers are passed on the stack. Parameters are pushed on the stack in right-to-left order, with each parameter being aligned at an 8-byte boundary.
- When a procedure with a fixed number of parameters is called, this procedure is expected to remove parameters from the stack.
- When a procedure with a variable number of parameters is called, this procedure is not expected to remove parameters from the stack, as it does not have sufficient information to do so. In this case, the `$sp` after the call is expected to be the same as `$sp` before the call, the caller will then need to adjust `$sp` before continuing.

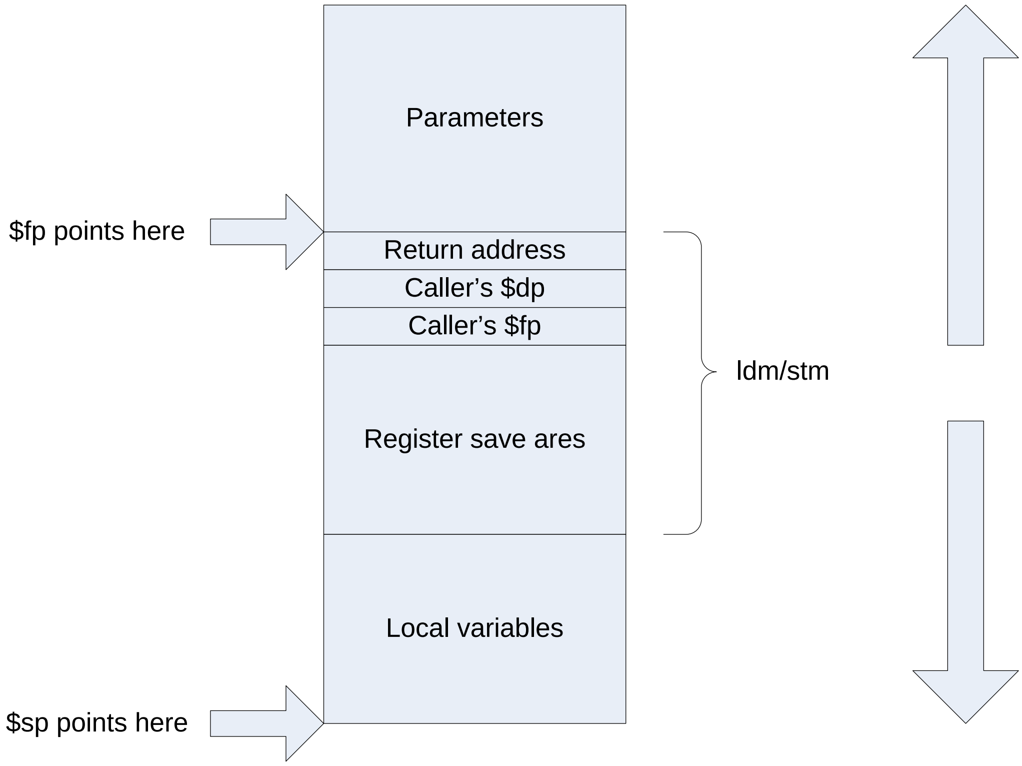
## 4.3 Returning values

If a procedure is a function (i.e. it returns an explicit value), the following rules are used:

- If a procedure returns value of a register-passable type, this value is returned in `$rv/$frv`.
- If a procedure returns value of any other type `T`, an implicit 0th parameter of type `^T` is assumed. Since pointers are register-passable, this implicit parameter will always be passed to the procedure in `$a0` (with the 1st "real" register-passable parameter shifted to `$a1/$fa1`, and so on). This parameter is a pointer to a value of type `T` allocated by the caller, where the return value must be stored.

## 4.4 Activation frame layout

The following diagram illustrates the layout of a single procedure activation frame:




Individual areas within the activation frame have the following functions:

- Parameters – this is the area used by those parameters which did not make it into registers. If all parameters are passed in registers, this area will be empty/
- Return address – the $ra register is saved here upon procedure entry. It will be restored just before returning to the caller in order to determine where to return.
- Caller’s `$dp` and `$fp` – these 2 registers are saved here upon entry to the procedure. They will be restored just before returning to the caller, as the latter expects both registers to retain their values across procedure calls.
- Register save area – if the procedure wishes to use any of the callee-saved registers for its own needs, these registers must be saved upon procedure entry and restored before returning to the caller. This is the area where these registers are saved.
- Local variables – if a procedure needs some in-memory local variables for its own needs, they are allocated here.

Note that the entire memory area marked as “`ldm`/`stm`” can be saved (upon procedure entry) or reloaded (upon procedure exit) by a single `ldm`/`stm` instruction. This ensures that procedure entry/exit code is but a few instructions long.

## 4.5 Accessing nonlocal variables

While in-memory local variables allow for straightforward access (via `$fp`-based relative addresses), accessing nonlocal variables from enclosing procedures is only slightly more complicated.

The central point of nonlocal variable accesses is in that it is always known at compile-time which level of nesting each procedure is declared at. Accessing a variable from an immediately enclosing procedure requires a `$dp`-based relative address instead of an `$fp`-based one. If the difference in the level of nesting is greater than 1, `$dp` points to an activation frame of an immediately enclosing procedure, and the static chain of long words at offset -8 within each activation frame gives an address of the next lexically enclosing activation frame.

# 5 Throwing procedure calling standard

The Throwing  Procedure Calling Standard (abbreviated henceforth as TPCS) is a procedure calling standard that can be used by programming languages that allow forced stack unwinding and exception propagation but do not allow nested procedures (such as C and C++). It will typically be used by C/C++ – only toolchains that do not care much about interoperability with other languages.

The Throwing Procedure Calling Standard:

- Can be used for writing procedures with both constant and variable number of parameters.
- Allows parameters and return values of certain types to be passed in and out of the procedure in registers, thus frequently eliminating the need for using activation stack.
- Does not supports languages with nonlocal static scoping rules.
- Allows for nonlocal jumps and dynamic exception propagation (such as required by C or C++).

## 5.1 Register usage conventions

As part of the TPCS, there are conventions about how registers are used across procedure calls. These conventions are outlined in the following sections.

### 5.1.1 Register-passable types

An important concept involved in the TPCS register usage conventions is that of a register-passable type. On an intuitive level, a register-passable type is a type whose values can be passed from caller to callee and/or back in a single Cereon register.

Only following types (and types derived from these types) are register-passable:

- `integer*1`, `integer*2`, `integer*4` and `integer*8`. Values of types `integer*1`, `integer*2`, `integer*4` are sign-extended to 64 bits when passed to/from a procedure in a register.
- `cardinal*1`, `cardinal*2`, `cardinal*4` and `cardinal*8`. Values of types `cardinal*1`, `cardinal*2`, `cardinal*4` are zero-extended to 64 bits when passed to/from a procedure in a register.
- `character*1`, `character*2` and `character*4`. Values of these types are zero-extended to 64 bits when passed to/from a procedure in a register.
- `real*4` and `real*8`. Values of the `real*4` type are converted to `real*8` when passed to/from a procedure in a register.
- `pointer` and `^T`, where `T` can be any type.
- `boolean`. Values of this type are zero-extended to 64 bits when passed to/from a procedure in a register.
- All enumerated types. Values of these types are zero-extended to 64 bits when passed to/from a procedure in a register.

### 5.1.2 Caller-saved registers

The following registers are not expected to keep their values across procedure calls:

- `$rv/$frv`.
- `$a0/$fa0 .. $a3/$fa3`.
- `$t0/$ft0 .. $t7/$ft7`.

These registers are typically used as temporary registers within local code sequences. If the caller needs any of these registers to keep their value after a procedure call, it must save them to memory before the call and reload after the callee has returned.

### 5.1.3 Callee-saved registers

The following registers are expected to keep their values across procedure calls:

- `$s0/$sf0 .. $s12/$fs12`.

These registers are typically used to store long-lived values, such as local variables. If the callee needs to use any of these registers, it must save them to memory before use and reload just before return.

### 5.1.4 Special registers

Several registers have special meaning under TPCS. These registers are:

- `$ra` – upon procedure entry this register contains an address of the instruction to which a jump must be made in order to perform procedure return. Typically a procedure will immediately save this register into its activation frame; however, in a leaf procedure (i.e. procedure that does not call any other procedures) this is optional. Note that the caller does not expect the `$ra` register to retain its value across procedure call.
- `$sp` – at any moment during program execution this register contains the address of the lowest memory byte occupied by the activation stack. Under TPCS stack starts at higher addresses and grows down. Both stack bottom and stack top addresses are always multiples of 8. The caller expects `$sp` to retain its value across calls of procedures with fixed number of parameters but not variadic procedures (see more in “Parameter passing” section below).
- `$fp` – the frame pointer register contains a pointer to a fixed location within the activation stack frame of the currently executing procedure. When a procedure is called, it saves the caller’s `$fp` into its own activation frame before establishing an activation frame of its own. The caller expects the `$fp` register to retain its value across procedure calls.
- `$gp` – this register contains an address of an unwind handler of the currently executing procedure. An unwind handler is a fragment of code that must be called if the activation frame of the current procedure is forcibly removed from an activation stack (this happens during C++ exception propagation or SPL nonlocal jumps). If the current procedure does not have an unwind handler, this register will be 0.

## 5.2 Parameter passing

When preparing to call a procedure, parameters are passed using argument registers `$a0/$fa0` .. `$a3/$fa3` and activation stack. The following rules are followed:

- The leftmost 4 parameters of register-passable types are passed in registers `$a0/$fa0` .. `$a3/$fa3` in that order (i.e. the 1st parameter of a register-passable type goes to `$a0/$fa0`, etc.) Note that these parameters are not necessarily consecutive; for example when calling a procedure that has the signature `(* : integer, * : label, * : real)` the 1st parameter will be passed in `$a0` and the 3rd in `$a1`, whereas the 2nd parameter will be passed on the stack. Note that `out` and `in out` parameters are technically pointers, so they are always register-passable.
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- When a procedure with a fixed number of parameters is called, this procedure is expected to remove parameters from the stack.
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## 5.3 Returning values

If a procedure is a function (i.e. it returns an explicit value), the following rules are used:

- If a procedure returns value of a register-passable type, this value is returned in `$rv/$frv`.
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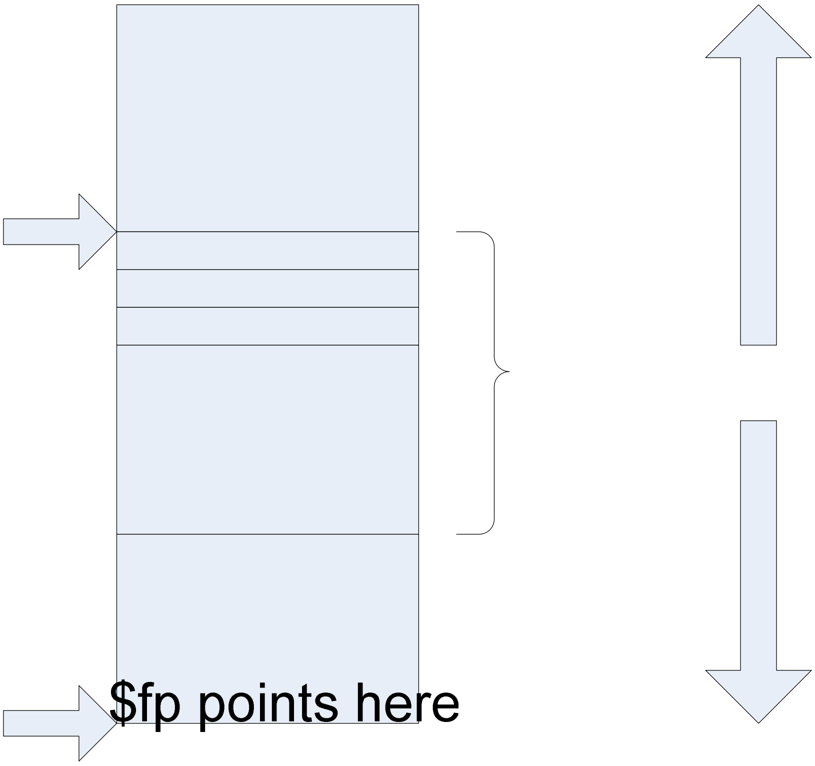
## 5.4 Activation frame layout

The following diagram illustrates the layout of a single procedure activation frame:

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- Parameters – this is the area used by those parameters which did not make it into registers. If all parameters are passed in registers, this area will be empty/
- Return address – the $ra register is saved here upon procedure entry. It will be restored just before returning to the caller in order to determine where to return.
- Caller's `$dp`, `$fp` and `$gp` – these 3 registers are saved here upon entry to the procedure. They will be restored just before returning to the caller, as the latter expects all three registers to retain their values across procedure calls.
- Register save area – if the procedure wishes to use any of the callee-saved registers for its own needs, these registers must be saved upon procedure entry and restored before returning to the caller. This is the area where these registers are saved.
- Local variables – if a procedure needs some in-memory local variables for its own needs, they are allocated here.

Note that the entire memory area marked as "`ldm`/`stm`" can be saved (upon procedure entry) or reloaded (upon procedure exit) by a single `ldm`/`stm` instruction. This ensures that procedure entry/exit code is but a few instructions long.

## 5.5 Forced stack unwinding

In a language that permits exception propagation (such as C++) or nonlocal jumps (such as SPL) a situation may arise when a number of activation frames must be forcefully removed.

To unwind a single activation frame, the following steps must be performed:

4. An `ldm` from a register save area makes sure callee-saved registers have the same values they did before the call.
5. The unwind handler of the current procedure must be called, provided one exists. The address of an unwind handler of the procedure associated with the topmost activation frame is always in `$gp`; an absence of an unwind handler is represented by `$gp` = 0.
6. `$sp` is adjusted to `$fp` (for variadic procedures) or `$fp` + <parameter area size> (for procedures with fixed number of parameters).

After the steps above have been completed, the program state is restored to exactly what it was just before the call. Any number of stack frames can be unwound by repeating the same sequence of actions once per activation stack frame.

# 6 Basic procedure calling standard

The Basic Procedure Calling Standard (abbreviated henceforth as BPCS) is a procedure calling standard that can be used by programming languages that do not allow nested procedures or forced stack unwinding (such as COBOL or XPL) and is also useful in Assembler-only programs. Although the least general standard, the BPCS allows the most efficient procedure call/return sequences to be implemented. It will typically be used by low-level toolchains that do not care much about interoperability with other languages, preferring to address the maximum operation efficiency instead.

The Basic Procedure Calling Standard:

- Can be used for writing procedures with both constant and variable number of parameters.
- Allows parameters and return values of certain types to be passed in and out of the procedure in registers, thus frequently eliminating the need for using activation stack.
- Does not support languages with nonlocal static scoping rules.
- Does not allow for nonlocal jumps and dynamic exception propagation.

## 6.1 Register usage conventions

As part of the BPCS, there are conventions about how registers are used across procedure calls. These conventions are outlined in the following sections.

### 6.1.1 Register-passable types

An important concept involved in the BPCS register usage conventions is that of a register-passable type. On an intuitive level, a register-passable type is a type whose values can be passed from caller to callee and/or back in a single Cereon register.

Only following types (and types derived from these types) are register-passable:

- `integer*1`, `integer*2`, `integer*4` and `integer*8`. Values of types `integer*1`, `integer*2`, `integer*4` are sign-extended to 64 bits when passed to/from a procedure in a register.
- `cardinal*1`, `cardinal*2`, `cardinal*4` and `cardinal*8`. Values of types `cardinal*1`, `cardinal*2`, `cardinal*4` are zero-extended to 64 bits when passed to/from a procedure in a register.
- `character*1`, `character*2` and `character*4`. Values of these types are zero-extended to 64 bits when passed to/from a procedure in a register.
- `real*4` and `real*8`. Values of the `real*4` type are converted to `real*8` when passed to/from a procedure in a register.
- `pointer` and `^T`, where `T` can be any type.
- `boolean`. Values of this type are zero-extended to 64 bits when passed to/from a procedure in a register.
- All enumerated types. Values of these types are zero-extended to 64 bits when passed to/from a procedure in a register.

### 6.1.2 Caller-saved registers

The following registers are not expected to keep their values across procedure calls:

- `$rv/$frv`.
- `$a0/$fa0 .. $a3/$fa3`.
- `$t0/$ft0 .. $t7/$ft7`.

These registers are typically used as temporary registers within local code sequences. If the caller needs any of these registers to keep their value after a procedure call, it must save them to memory before the call and reload after the callee has returned.

### 6.1.3 Callee-saved registers

The following registers are expected to keep their values across procedure calls:

- `$s0/$sf0 .. $s12/$fs12`.

These registers are typically used to store long-lived values, such as local variables. If the callee needs to use any of these registers, it must save them to memory before use and reload just before return.

### 6.1.4 Special registers

Several registers have special meaning under BPCS. These registers are:

- `$ra` – upon procedure entry this register contains an address of the instruction to which a jump must be made in order to perform procedure return. Typically a procedure will immediately save this register into its activation frame; however, in a leaf procedure (i.e. procedure that does not call any other procedures) this is optional. Note that the caller does not expect the `$ra` register to retain its value across procedure call.
- `$sp` – at any moment during program execution this register contains the address of the lowest memory byte occupied by the activation stack. Under BPCS stack starts at higher addresses and grows down. Both stack bottom and stack top addresses are always multiples of 8. The caller expects `$sp` to retain its value across calls of procedures with fixed number of parameters but not variadic procedures (see more in "Parameter passing" section below).
- `$fp` – the frame pointer register contains a pointer to a fixed location within the activation stack frame of the currently executing procedure. When a procedure is called, it saves the caller's `$fp` into its own activation frame before establishing an activation frame of its own. The caller expects the `$fp` register to retain its value across procedure calls.

## 6.2 Parameter passing

When preparing to call a procedure, parameters are passed using argument registers `$a0/$fa0` .. `$a3/$fa3` and activation stack. The following rules are followed:

- The leftmost 4 parameters of register-passable types are passed in registers `$a0/$fa0` .. `$a3/$fa3` in that order (i.e. the 1st parameter of a register-passable type goes to `$a0/$fa0`, etc.) Note that these parameters are not necessarily consecutive; for example when calling a procedure that has the signature `(* : integer, * : label, * : real)` the 1st parameter will be passed in `$a0` and the 3rd in `$a1`, whereas the 2nd parameter will be passed on the stack. Note that `out` and `in out` parameters are technically pointers, so they are always register-passable.

- All parameters that are not passed in registers are passed on the stack. Parameters are pushed on the stack in right-to-left order, with each parameter being aligned at an 8-byte boundary.
- When a procedure with a fixed number of parameters is called, this procedure is expected to remove parameters from the stack.
- When a procedure with a variable number of parameters is called, this procedure is not expected to remove parameters from the stack, as it does not have sufficient information to do so. In this case, the `$sp` after the call is expected to be the same as `$sp` before the call, the caller will then need to adjust `$sp` before continuing.

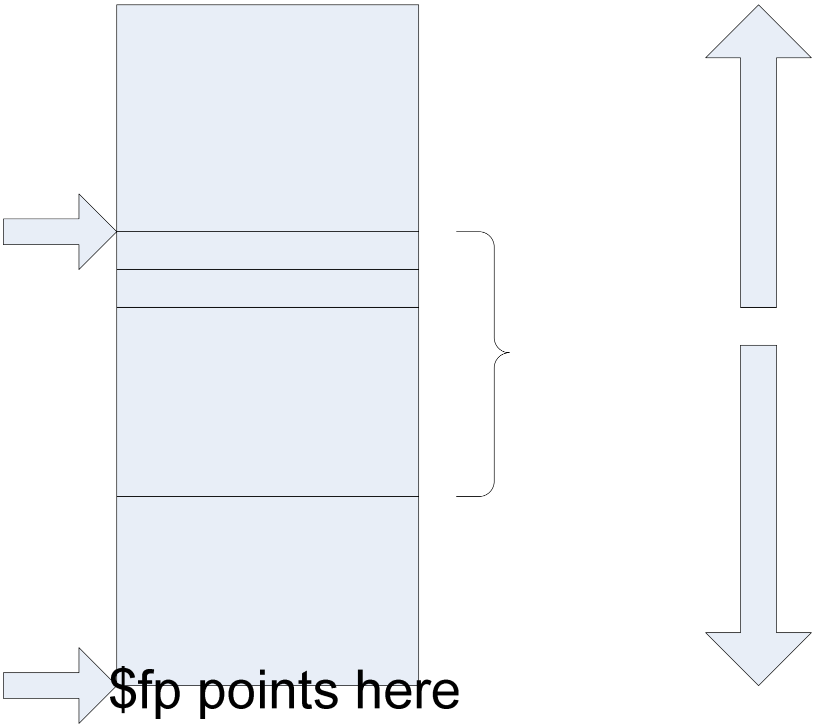
## 6.3 Returning values

If a procedure is a function (i.e. it returns an explicit value), the following rules are used:

- If a procedure returns value of a register-passable type, this value is returned in `$rv/$frv`.
- If a procedure returns value of any other type `T`, an implicit 0th parameter of type `^T` is assumed. Since pointers are register-passable, this implicit parameter will always be passed to the procedure in `$a0` (with the 1st "real" register-passable parameter shifted to `$a1/$fa1`, and so on). This parameter is a pointer to a value of type `T` allocated by the caller, where the return value must be stored.

## 6.4 Activation frame layout

The following diagram illustrates the layout of a single procedure activation frame:




Individual areas within the activation frame have the following functions:

- Parameters – this is the area used by those parameters which did not make it into registers. If all parameters are passed in registers, this area will be empty/
- Return address – the $ra register is saved here upon procedure entry. It will be restored just before returning to the caller in order to determine where to return.
- Caller's `$fp` – this register is saved here upon entry to the procedure. It will be restored just before returning to the caller, as the latter expects the register to retain its values across procedure calls.
- Register save area – if the procedure wishes to use any of the callee-saved registers for its own needs, these registers must be saved upon procedure entry and restored before returning to the caller. This is the area where these registers are saved.
- Local variables – if a procedure needs some in-memory local variables for its own needs, they are allocated here.

Note that the entire memory area marked as "`ldm/stm`" can be saved (upon procedure entry) or reloaded (upon procedure exit) by a single `ldm/stm` instruction. This ensures that procedure entry/exit code is but a few instructions long.

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Version 1.2, November 2002



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