Profiler

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1 Profiler Mechanism

1.1 Profile Feature

`mwccarm.exe`, the C compiler from Metrowerks, is set up to support the profile feature. This feature automatically inserts the code for a specific function call in the entry and exit of the function. By taking records and statistics about the call from within the function, you can acquire profile information; which is especially useful for things like debugging.
The profile feature can be enabled by adding the option `-profile` in `mwccarm.exe` and compiling.

The profiler typically created lines of code like the following example.

```
u32 test( u32 a )
  {
     return a + 3;
  }
```

If this function is compiled, usually an object with the following code is output.

```
test:
  add     r0, r0, #3          // Add 3
  bx      lr
```

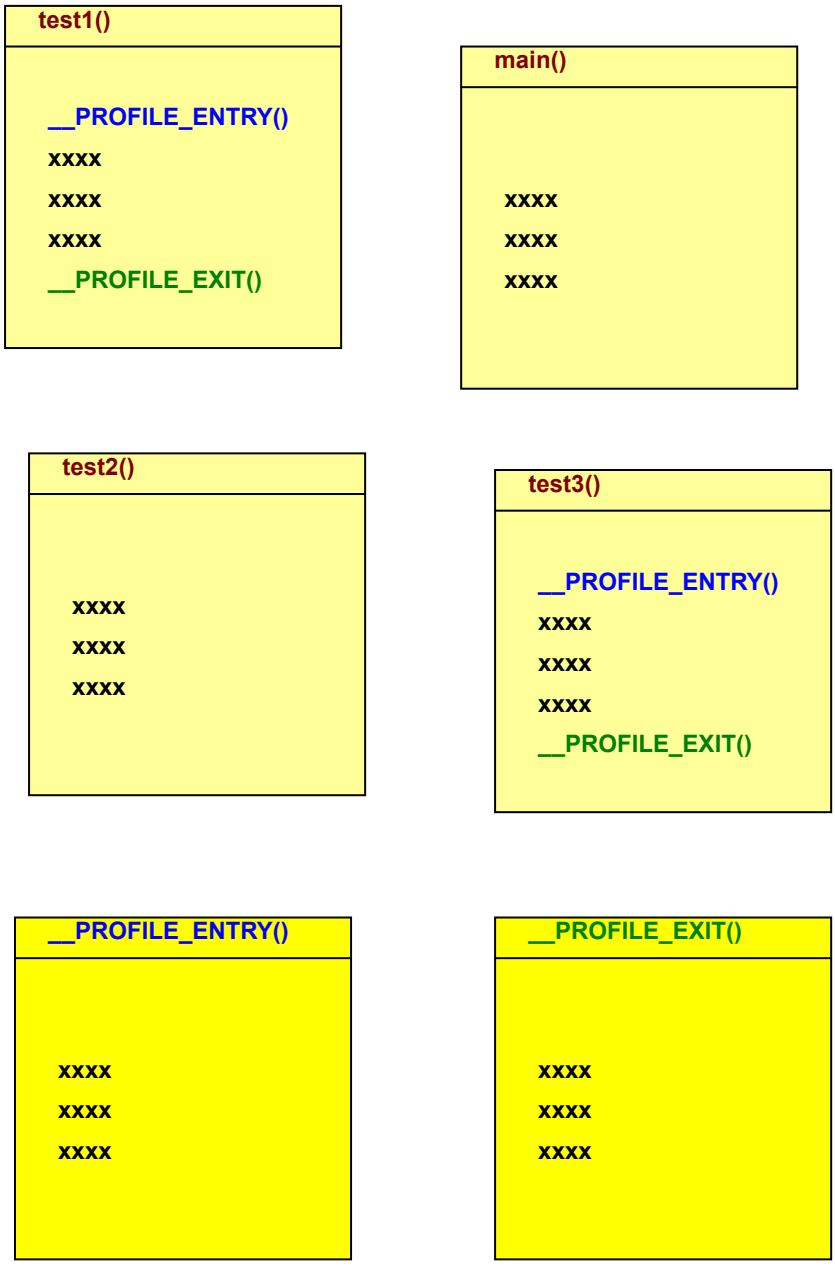
3 is simply added to the argument `r0`. (Return value is also stored in `r0`.)

Next, the case in which compiling with the profile feature ON is shown. `__PROFILE_ENTRY` and `__PROFILE_EXIT` are called during entry and exit respectively. The following is an example of code created by this feature for a stack operation.

```
test:
  stmfd      sp!,{r0,lr}
  ldr        r0,[pc,#32]      // Assign the pointer to the character string
"test" to r0
  bl         __PROFILE_ENTRY   // __PROFILE_ENTRY Call
  ldmfd      sp!,{r0,lr}

  add        r0,r0,#3          // Add 3

  sub        sp,sp,#4
  stmfd      sp!,{lr}
  bl         __PROFILE_EXIT    // __PROFILE_EXIT Call
  ldmfd      sp!,{lr}
  add        sp,sp,#4
  bx         lr
             :
  dcd        xxxx             // pointer to the character string "test"
             :
  xxxx: 74 65 73 74 00       // character string "test"
```

_PROFILE_ENTRY and _PROFILE_EXIT have only the code for calling functions, and the entity of the function must be created in the application. For NITRO-SDK, they are defined in os_callTrace.c and os_functionCost.c so that you can link them into your code if necessary.

Functions that call __PROFILE_ENTRY and __PROFILE_EXIT and functions that do not call __PROFILE_ENTRY and __PROFILE_EXIT can exist in the link object. Since the compiler enters profiling calls function by function, there are no function that calls only __PROFILE_ENTRY or __PROFILE_EXIT unless such function is created deliberately.



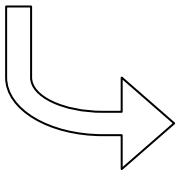
The object that has the _PROFILE function and the object that do not have the _PROFILE function can be mixed. (The _PROFILE function itself does not have the calls to the _PROFILE function.)

1.2 Specifying During a Compile

If NITRO_PROFILE is defined in NitroSDK the -profile option is added during the C source compile.
For the function in the source compiled with -profile added, the calls for __PROFILE_ENTRY and __PROFILE_EXIT are entered at the beginning and the end of the function of the object.

If a simple make is executed

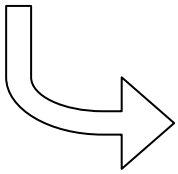
mwccarm ··· test.c



```
function()
xxxx
xxxx
xxxx
```

If make NITRO_PROFILE=TRUE is executed

mwccarm -profile ··· test.c



```
function()
__PROFILE_ENTRY()
xxxx
xxxx
xxxx
__PROFILE_EXIT()
```

It is okay to write this in the Makefile.

Makefile

```
:
NITRO_PROFILE = TRUE
:
```

1.3 Switching with `pragma`

When temporarily switching the profile feature in the C source use `#pragma`.

`#pragma profile on` turns it ON.

`#pragma profile off` turns it OFF.

`#pragma profile reset` returns it to the original status before switching to ON or OFF.

(Example)

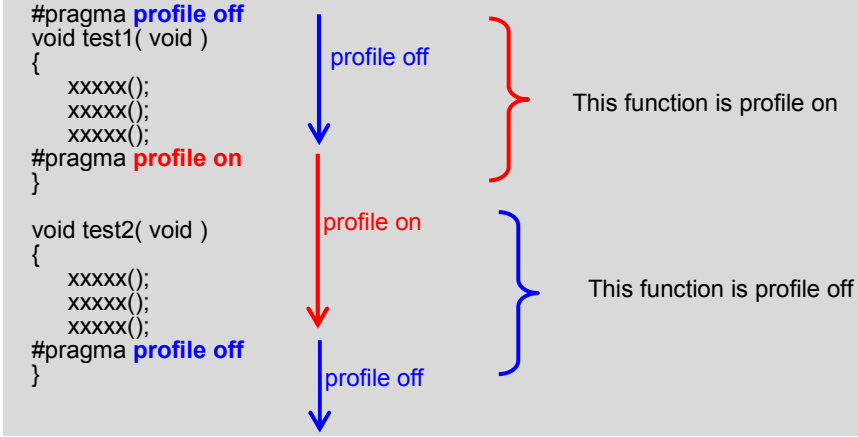
```
  void test1( void )
  {
      :
  }

  void test2( void )
  {
     :
  }

#pragma profile off
void test3( void )
  {
     :
  }
#pragma profile reset

 void test4( void )
 {
    :
 }
```

If this source is compiled with `-profile`, the profile feature for `test1()`, `test2()`, and `test4()` are ON. (without `-profile`, the profile feature will be OFF with all functions.)

1.3.1 Where to Place Pragma

If the function is turned ON before it ends, the profiler feature will be turned ON for that function. If the function is OFF at the moment it ends, the profile feature will be turned OFF. Normally it should be set outside the function so that it is easier to follow.

(Example)



2 Nitro-SDK profiler

By setting up PROFILE functions for objects with calls for __PROFILE_ENTRY() and __PROFILE_EXIT(), the following mechanisms for debugging with Nitro-SDK are available:

- Function Call Trace (OS_CallTrace)
- Function Cost Measurement (OS_FunctionCost)

These features are built separately from the OS library. More specifically, the OS library is libos.a (or libos.thumb.a). The function call trace library is libos.CALLTRACE.a (or libos.CALLTRACE.thumb.a), and the function cost measurement is libos.FUNCTIONCOST.a (or libos.FUNCTIONCOST.thumb.a).

2.1 Function Call Trace

There are two modes for the mechanism that records the results of a PROFILE function to a specified memory location.

One is a stack mode that records the call of the function with __PROFILE_ENTRY() and deletes the record with __PROFILE_EXIT(). By checking the record at a certain point you can find out what function wrote to the record at that point (what type of call was used).

The other is a log mode that records the call of the function with __PROFILE_ENTRY() and does nothing with __PROFILE_EXIT(). The buffer for recording is used repeatedly so the most recent record is always maintained. This allows display of the function that was called (was being called when the record was written).

To enable this profile feature, you must specify NITRO_PROFILE_TYPE=CALLTRACE in the make option. (It can be specified in the Makefile also.)

2.2 Function Cost Measurement

This mechanism measures the time in the ENTRY and EXIT areas of the PROFILE function and checks the duration of the function based on the difference between the two.

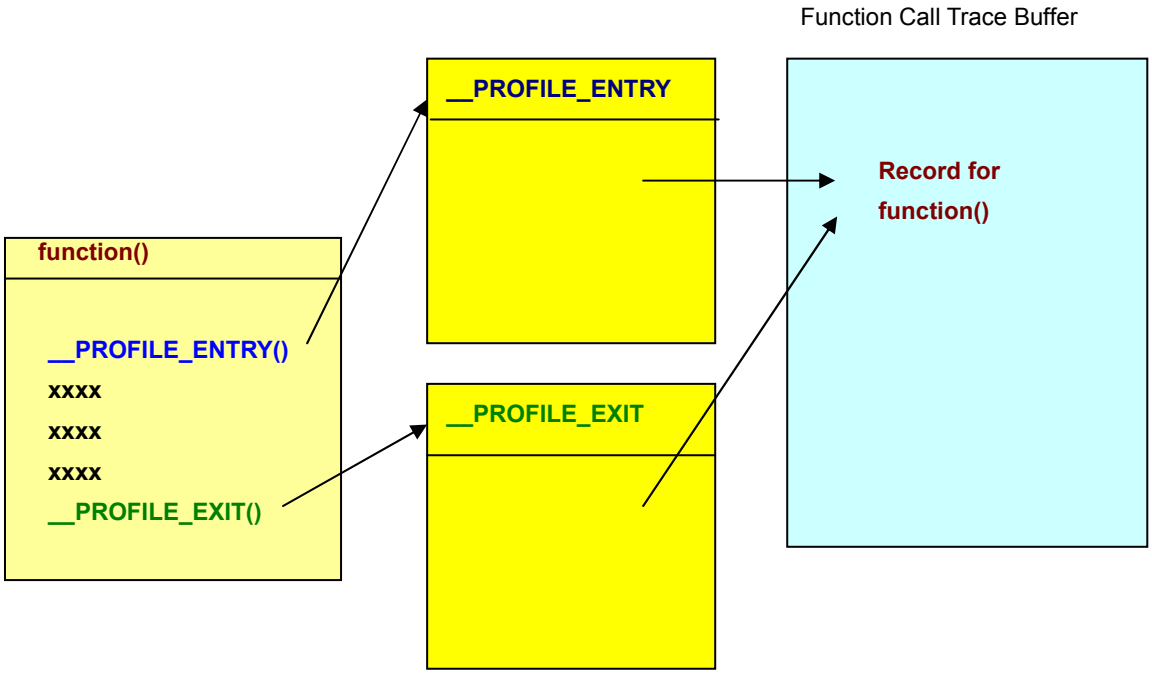
If you are using a thread system, the time while the thread is switched and another thread is running is subtracted from the duration. This allows you to compare the cost of a particular function. In addition, the number of calls is recorded so it is useful for measuring the frequency of calls.

To enable this profile feature, you must specify NITRO_PROFILE_TYPE=FUNCTIONCOST in the make option. (It can be specified in the Makefile also.)

3 Function Call Trace

3.1 Mechanism of Trace Recording

The function call trace works in the following way.



__PROFILE_ENTRY()

Records that “function was called” in the function call trace buffer. Specifically, the pointer to the function name character string, return address from the function, and argument (options) are recorded together.

__PROFILE_EXIT()

`(Stack Mode)` — Deletes the record that states the “function was called” most recently written to the function call trace buffer.

`(Log Mode)` — Performs no processes.

3.2 Saved Information

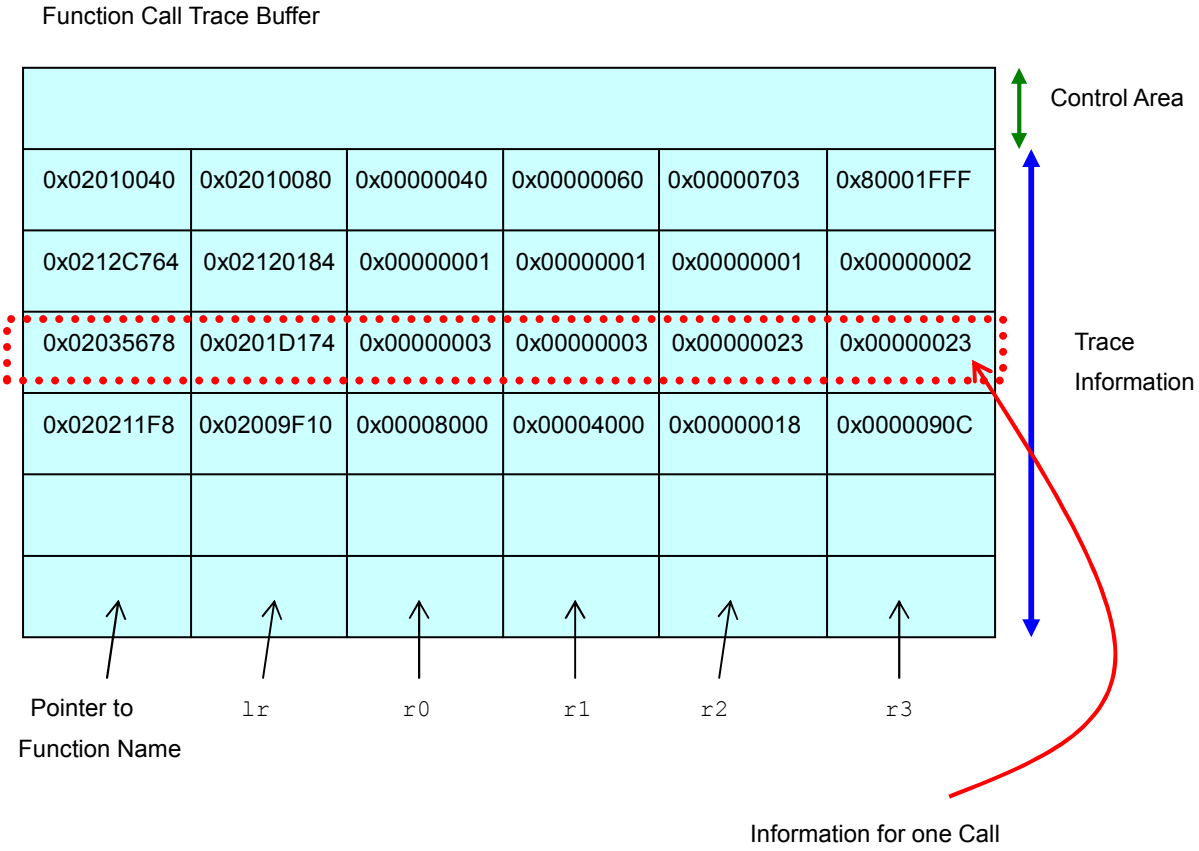
The following information is saved with the function call trace:

- Pointer to the function name character string
- Value of `lr` Register at the point from which the function was called
- Value of `r0` Register at the point from which the function was called (optional)
- Value of `r1` Register at the point from which the function was called (optional)
- Value of `r2` Register at the point from which the function was called (optional)
- Value of `r3` Register at the point from which the function was called (optional)

The memory address from which the function was called is stored in the `lr` register. In other words, if the value of the `lr` register is known, you can use that value to determine the address from which the function was called.

The `r0` – `r3` registers are used for the passing of the values of argument for the function that has arguments. This allows you to see what type of argument was specified when the function is called. However, the values of registers not used in passing arguments do not have much meaning. Saving the values of `r0` – `r3` is optional. These require a dedicated 4-byte area for each register. Keep these memory requirements in mind when allocating your buffer.

The buffer is used in the following manner.



In the preceding diagram, `r0` – `r3` are saved so a 24-byte information region is required for one call. If `r0` – `r3` do not need to be saved, the buffer size required for one call is 8 bytes.

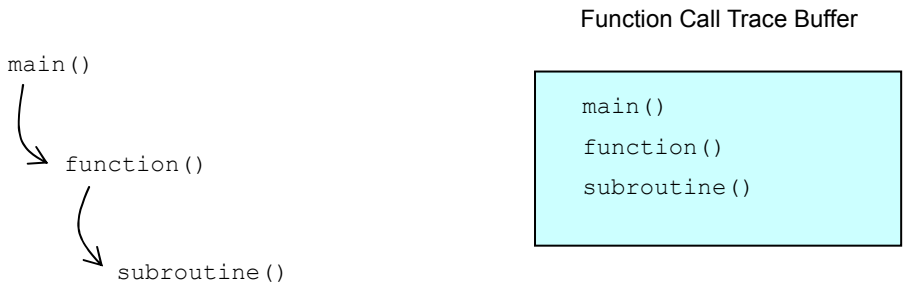
Information such as the area of the buffer currently in use and the location of the upper limit is stored in the Control Area.

3.3 Two Modes of Function Call Trace

There are two modes for the function call trace, stack mode and log mode. In stack mode, information is saved by `__PROFILE_ENTRY()` and deleted by `__PROFILE_EXIT()`. In log mode, `__PROFILE()` does not delete the information. Also, the same region is used for saving information and the old information is deleted.

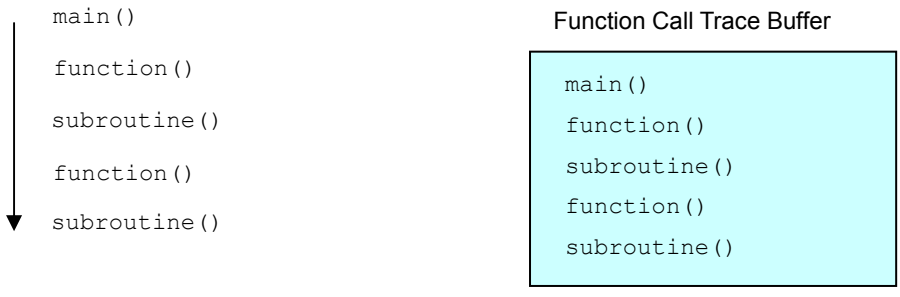
The buffer stores the following information:

Stack Mode



If you check the function call trace buffer, you can view the information about a function call at a particular point. In the diagram above, you can see that `main()` called `function()`, and `function()` called `subroutine()`.

Log Mode



If you check the function call trace buffer, you can view the information for functions called up to that point. In the diagram above, you can see that `main()`, `function()`, `subroutine()`, `function()`, and `subroutine()` were called.

3.4 Implementing in the Program

The call trace begins with the initialization of the call trace buffer at the beginning of the program. In stack mode, the functions carrying out initialization must be at the highest level (not called from within other functions). This consideration is not particularly necessary in log mode.

```
// Function call trace initialization
void OS_InitCallTrace( void* buf, u32 size, OSCallTraceMode mode );
```

`buf`	Function call trace buffer
`size`	Buffer size
`mode`	stack mode or log mode

As described previously, the function call trace buffer stores the information necessary for controlling the buffer and the actual trace information. The mode is specified by `OSCallTraceMode` with a value of either `OS_CALLTRACE_STACK` (stack mode) or `OS_CALLTRACE_LOG` (log mode).
If you know the size of a `CallTrace` buffer and want to know how many lines it can store, use the following function.

```
// Calculate the number of trace information sets based on the size of the buffer.
int OS_CalcCallTraceLines( u32 size )
```

`size`	Buffer size
Return Value	Number of lines that can be secured (number of trace information sets)

Use the following function to determine the minimum size required for your buffer based on the number of lines you want it to contain.

```
// Calculate the buffer size based on the number of
// trace information sets that can be stored.
u32 OS CalcCallTraceBufferSize( int lines );
```

`lines`	Number lines in the buffer (number of trace information sets)
Return Value	required size of your buffer

The following function is used for displaying the contents of a trace buffer. The displayed content is described later in this document.

```
// Function call trace display
u32 OS_DumpCallTraceBufferSize( void );
```

You can temporarily stop recording information or restore the setting by using the following functions. Recording of information remains disabled even if __PROFILE_ENTRY() or __PROFILE_EXIT() are called. If you are using stack mode, the information inside the buffer may be invalid or corrupt depending on when the __PROFILE function is stopped.

```
// Function call trace enable/disable/restore
BOOL OS_EnableCallTrace( void );
BOOL OS_DisableCallTrace( void );
BOOL OS_RestoreCallTrace( BOOL enable );
```

enable	Enable (TRUE) or Disable (FALSE)
Return Value	Status prior to this function call. Enable (TRUE)/ Disable (FALSE)

To clear the contents of the buffer in log mode, use the following function. (You can also use this function in stack mode. However, it is strongly recommended that you develop a full understanding of the way in which this function operates before using it in stack mode.)

```
// Function call trace buffer clear
void OS_ClearCallTraceBuffer ( void );
```

The following are actual in-program examples.
In stack mode:

```
#define TRACEBUFSIZE 0x300
u32  traceBuffer[ TRACEBUFSIZE / sizeof(u32) ];

void NitroMain( void )
{
  OS_Init();

  //---- init callTrace (STACK mode)
  OS_InitCallTrace( &traceBuffer, TRACEBUFSIZE, OS_CALLTRACE_STACK );
     :
}

void function()
{
  //---- display callTrace
  OS_DumpCallTrace();  // Displays status of function call at this point
}
```

In log mode:

```
#define TRACEBUFSIZE 0x300
u32  traceBuffer[ TRACEBUFSIZE / sizeof(u32) ];

void NitroMain( void )
{
  OS_Init();

  //---- init callTrace (LOG mode)
  OS_InitCallTrace( &traceBuffer, TRACEBUFSIZE, OS_CALLTRACE_LOG );

     : // Location to be logged

  //---- display callTrace
  OS_DumpCallTrace();
}
```

3.5 Display Example with Dump

3.5.1 In Stack Mode

The following is an example of the output from a `OS_DumpCallTrace()` function call.

```
OS_DumpCallTrace: lr=0200434c
  test3: lr=02004390, r0=00000103, r1=00000080, r2=00000080, r3=2000001f
 test2: lr=020043c4, r0=00000101, r1=00000080, r2=00000080, r3=2000001f
test1: lr=02004254, r0=00000100, r1=00000080, r2=00000080, r3=2000001f
```

In this example, the `lr=` value shows that `OS_DumpCallTrace()` was called immediately before `0x0200434c`. You can also see that `test1()` calls `test2()` and `test2()` calls `test3()`. The position returning from `test3()` is before `0x2004390`.
The example also shows that when `test3()` is called, `r0` is `0x103`, `r1` is `0x80`, `r2` is `0x80`, and `r3` is `0x2000001f`. Therefore, if `test3()` is a function that uses an argument, you can apply these values and figure out the arguments when the functions are called. The same analysis is possible with other functions.

(Note) In the example above, descriptions like "`test1()` called `test2()`" are based on the premise that this executable file has the profile feature enabled for all the objects and is compiled. So, if `test1()` calls `test4()` when `test4()` does not have an enabled profile feature. Then, `test4()` calls `test2()` which does have an enabled profile feature. The result will be what you see in the example—`test2()` above `test1()` with no `test4()` displayed at all.

The display above was output from the program below.

```
int test1( int a ){  return test2( a + 1 );  }
int test2( int a ){  return test3( a + 2 );  }
int test3( int a ){  OS_DumpCallTrace(); return a + 4;  }

void NitroMain( void )
{
  OS_Init();
      :
  OS_InitCallTrace( &buffer, BUFFERSIZE, OS_CALLTRACE_STACK );
  (void) test1( 0x100 );
      :
}
```

3.5.2 In Log Mode

The following is an example of the output from a `OS_DumpCallTrace()` function call.

```
   test3: lr=020043a0, r0=00000103, r1=00000080, r2=00000080, r3=2000001f
  test2: lr=020043d4, r0=00000101, r1=00000080, r2=00000080, r3=2000001f
test1: lr=0200423c, r0=00000100, r1=00000080, r2=00000080, r3=2000001f
   test3: lr=020043a0, r0=00000203, r1=00000080, r2=00000080, r3=2000001f
  test2: lr=020043d4, r0=00000201, r1=00000080, r2=00000080, r3=2000001f
test1: lr=02004244, r0=00000200, r1=00000080, r2=00000080, r3=2000001f
```

Since the newest information is displayed first, you can see that for the functions that have an active profile feature, the calling order is `test1`, `test2`, `test3`, `test1`, `test2`, and `test3`. Return address, argument and other information can be determined from the `lr` register or `r0` – `r3` registers at that point.

Looking at the display of `test1`, `test2`, and `test3` you can see that `test2` and `test3` are indented. This happens because `test2` was called before the `__PROFILE_EXIT()` of `test1`, and `test3` was called before the `__PROFILE_EXIT()` of `test2`.

The display above was output from the program below.

```
int test1( int a ){  return test2( a + 1 );  }
int test2( int a ){  return test3( a + 2 );  }
int test3( int a ){  return a + 4;  }

void NitroMain( void )
{
  OS_Init();
      :
  OS_InitCallTrace( &buffer, BUFFERSIZE, OS_CALLTRACE_LOG );
  (void) test1( 100 );
  (void) test1( 100 );
  OS_DumpCallTrace();
}
```

3.6 Specification When Linking

To enable the function call trace feature, `NITRO_PROFILE_TYPE=CALLTRACE` must be specified for the make option. Due to this requirement, `libos.CALLTRACE.a` (or `libos.CALLTRACE.thumb.a`) is included when linking. This can also be described in the Makefile.

3.7 Operation on Thread

If a thread system is being used, the function call trace information runs independently for each thread. Therefore, initialization of a particular buffer declared with OS_InitCallTrace() only records information from the thread in which it was generated. Status settings for functions like `OS_EnableCallTrace()` are also independent for each thread.

Avoid declaring the same buffer with a different thread using `OS_InitCallTrace()`.

3.8 Cost

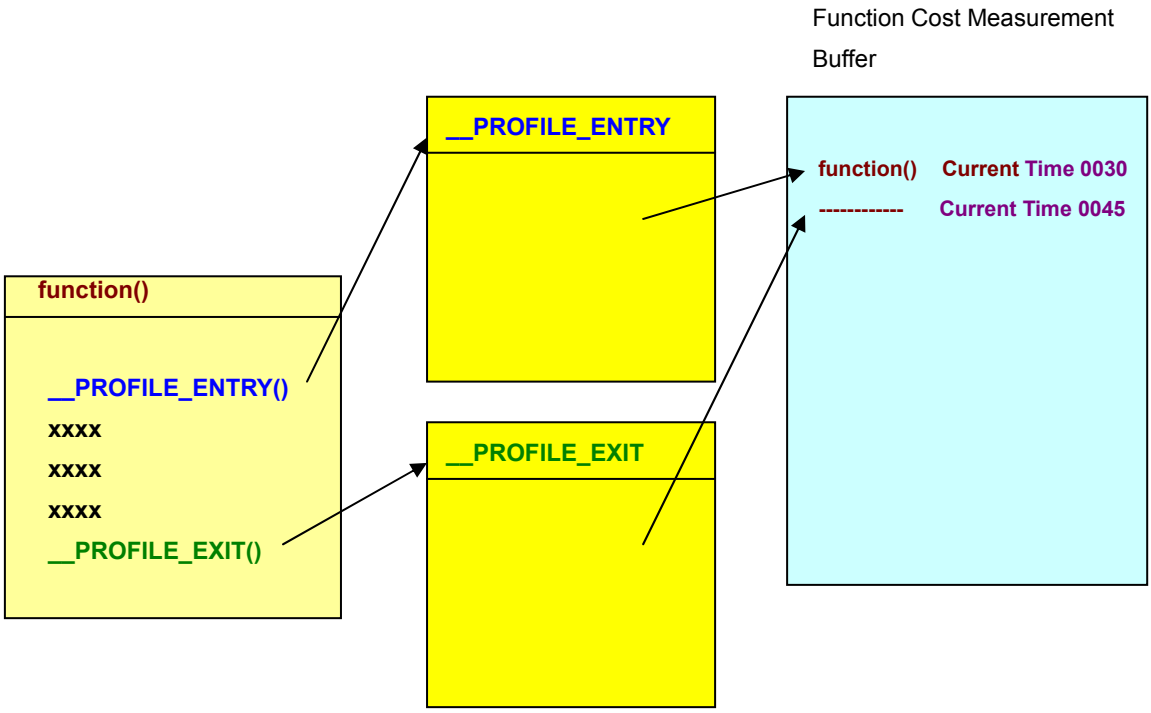
Because the function calls are saved in the buffer, function calls cost more than the normal operation. Since every function must include the `__PROFILE_ENTRY/EXIT` calls, the optimization during compile is not as much as expected, compared to a situation where there is no restrictions. Further, to save the pointer to the function name in the buffer, the function name string is placed on the memory, which causes additional memory usage.

The operational cost varies based on factors such as: whether there is a thread or not, the information saved, and the mode. With `__PROFILE_ENTRY()` extra 60 – 70 instructions are passed, and with `__PROFILE_EXIT()` an extra 20 – 40 instructions.

4 Function Cost Measurement

4.1 Cost Measurement Mechanism

Two buffers are used with function cost measurement. As shown below, they are the “Function Cost Measurement Buffer” and “Function Cost Statistics Buffer”.

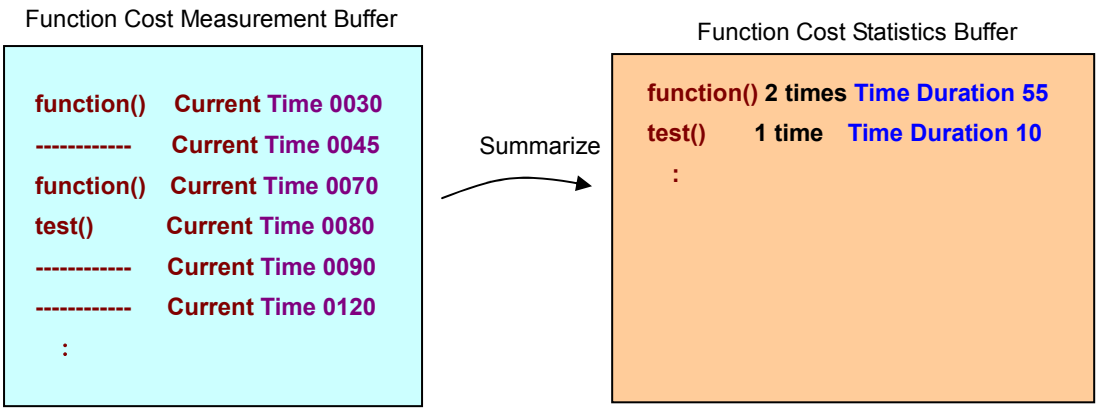


__PROFILE_ENTRY()

This records the pointer to the function name character string and the current time to the cost measurement buffer the user specified.

__PROFILE_EXIT()

This records the tag written by `__PROFILE_EXIT()` and the current time.



4.2 Saved Information

The following information is recorded with the function cost measurement.

With `__PROFILE_ENTRY`:

- Pointer to function name character string
- Current time, value of `OS_GetTickLo()`

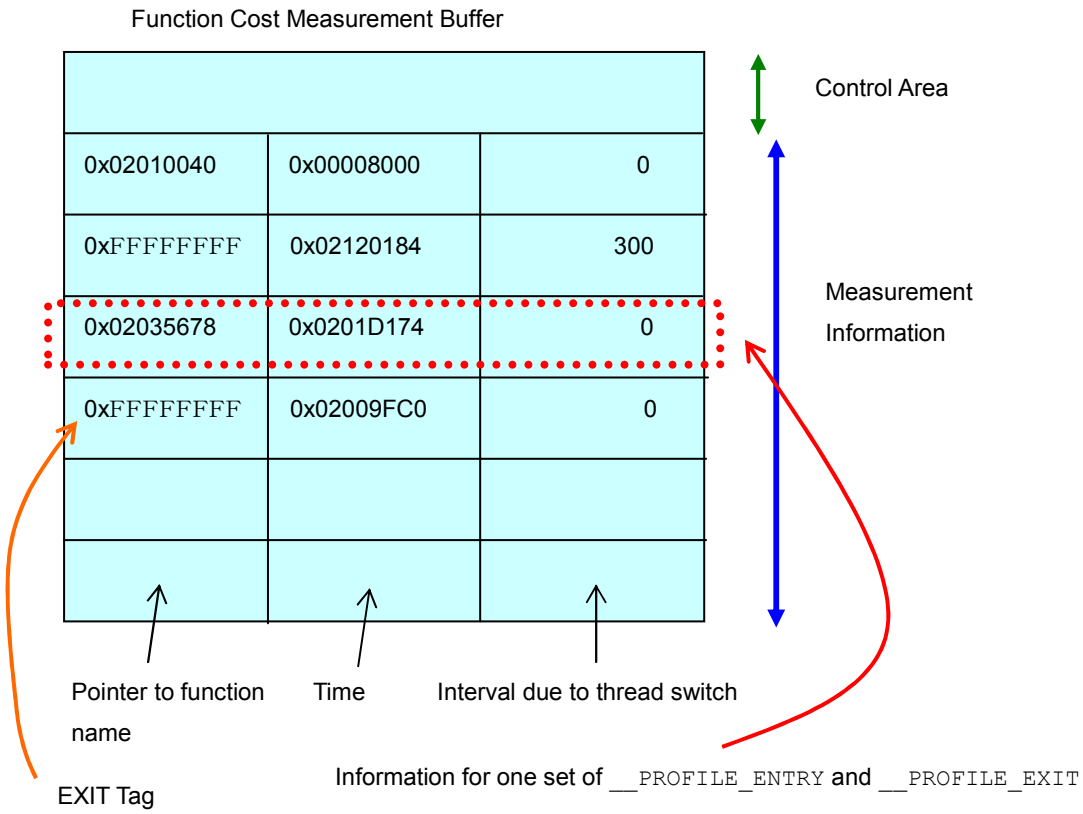
With `__PROFILE_EXIT`:

- Special value for area where pointer was saved with `__PROFILE_ENTRY` (called the EXIT tag value.).
- Current time, value of `OS_GetTickLo()`
- Interval due to thread switch if required (optional)

The current time is a value that can be obtained with `OS_GetTickLo()`. The Tick feature of the OS has a 64-bit value, but it is sufficient to only check the lower half when calling a function so it is managed as a 32-bit value.

The special value (called the EXIT tag) for distinguishing the pointer to the character string of `__PROFILE_ENTRY` with `__PROFILE_EXIT` is secured in the pointer to the function name character string.

The amount of time it takes to change threads (including the time spent in any other thread) is deducted from the total time elapsed from `__PROFILE_ENTRY` to `__PROFILE_EXIT`.



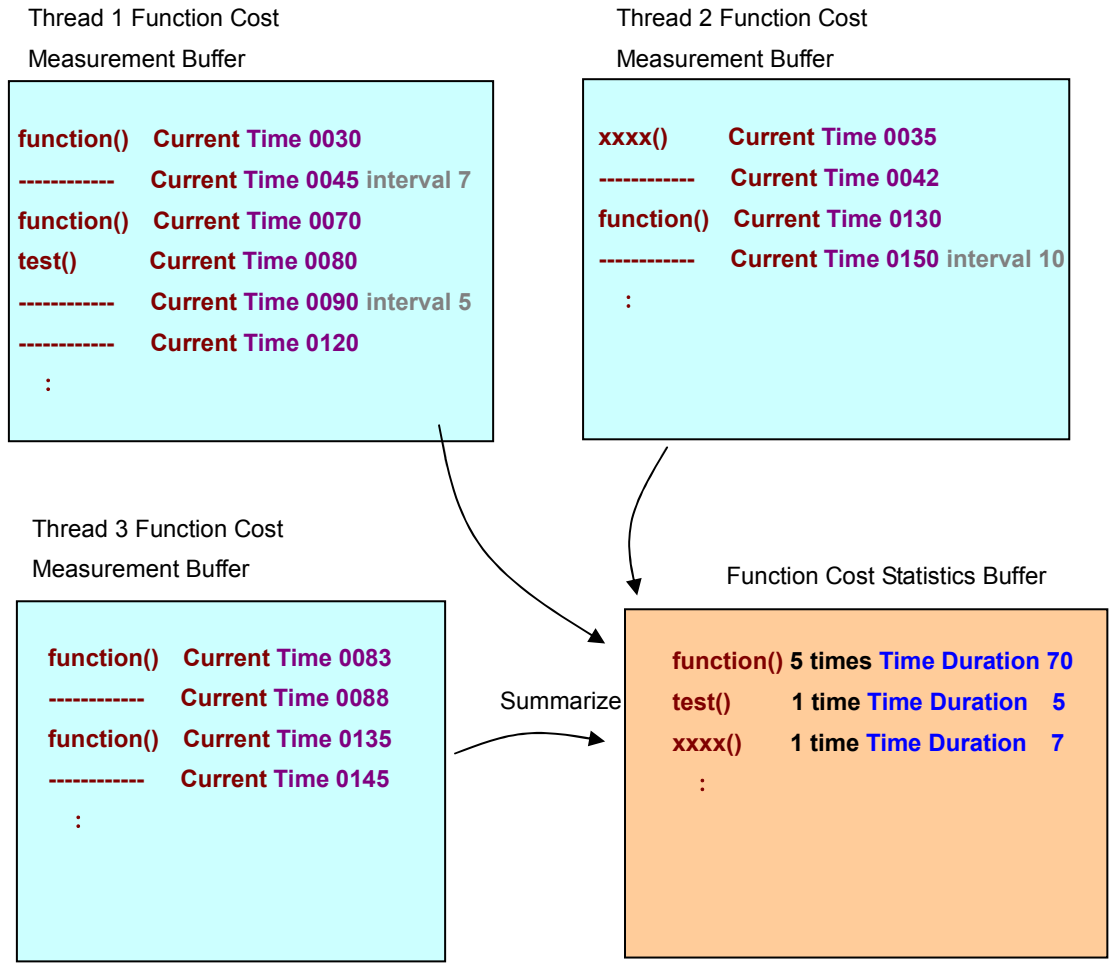
Types of information stored in the “Control Area” include: the part of the buffer currently being used, location of the upper limit of the buffer, the counter value for the duration of a thread switch, etc.

4.3 Conversion to Statistics Buffer

It is difficult to obtain cost information only with the function cost measurement data since the measurement data needs to be summarized as statistics buffer data.

The summary relates the call information of the function and the EXIT tag, then totals the number of calls and the time spent in the function. When the control is transferred to a separate thread due to a switch in threads, the amount of time until it returns to the original thread is recorded as an interval line of the EXIT tag. Calculations are carried out to take this into consideration.

Summarizations must be carried out explicitly. When summarized, the contents of the function cost measurement buffer are cleared. Repeatedly storing these results in the summarization buffer (before the function cost measurement buffer overflows) helps to ensure accurate measurement for long processes. Since the same summarization buffer can be shared with multiple threads, avoid summarizing a separate thread while summarizing on another thread.



The results of multiple measurements can be written to the statistics buffer

4.4 Implementing in the Program

Cost measurement begins recording to the buffer as soon as a function is initialized.
The Tick system of the OS is used for cost measurement so you must call `OS_InitTick()` before initializing any cost measurement buffers.

```
// Function cost measurement initialization
void OS_InitFunctionCost( void* buf, u32 size );

     buf     Function cost measurement buffer
     size    Buffer size (byte)
```

As described previously, the information for controlling the buffer and the actual time information are stored.

If you know the size of a buffer and want to know how many lines it can store, use the following function.

```
// Calculate the number of information sets based on the size of the buffer.
int OS_CalcFunctionCostLines( u32 size )

     size          Buffer size (bytes)
     Return Value  Number of lines that can be secured (number of information sets for cost measurement)
```

Use the following function to determine the minimum size required for your buffer based on the number of lines you want it to contain.

```
// Calculate the buffer size based on the number of
// measurement information that can be stored.

u32 OS_CalcFunctionCostBufferSize( int lines );

     lines         Number of lines in the buffer
     Return Value  required size of you buffer (in bytes)
```

Initialize the cost statistics buffer with the following function.

```
// Function cost statistics buffer initialization
void OS InitStatistics( void* statBuf, u32 size );

     statBuf  Buffer
     size     Buffer size (bytes)
```

The following function stores the value of the cost statistics buffer.

```
// Summarize function cost
OS_CalcStatistics( void* statBuf );

     statBuf   Statistics buffer
```

The current contents of the function cost measurement buffer are cleared when `OS_CalcStatistics()` is called.

The following function displays the summarization results. The output of this function is described later in this document.

```
// Function cost summarization display
OS_DispStatistics( void* statBuf );

     statBuf    Statistics buffer
```

You can temporarily stop recording profiling data or restore the setting by using the following functions. Recording of information remains disabled even if __PROFILE_ENTRY() or __PROFILE_EXIT() are called. If a thread switch takes place so that only the information recorded with __PROFILE_ENTRY() or the information recorded with __PROFILE_EXIT() is written to the buffer, the cost measurement data may be invalid. It is strongly suggested that you pay particular attention when using these functions.

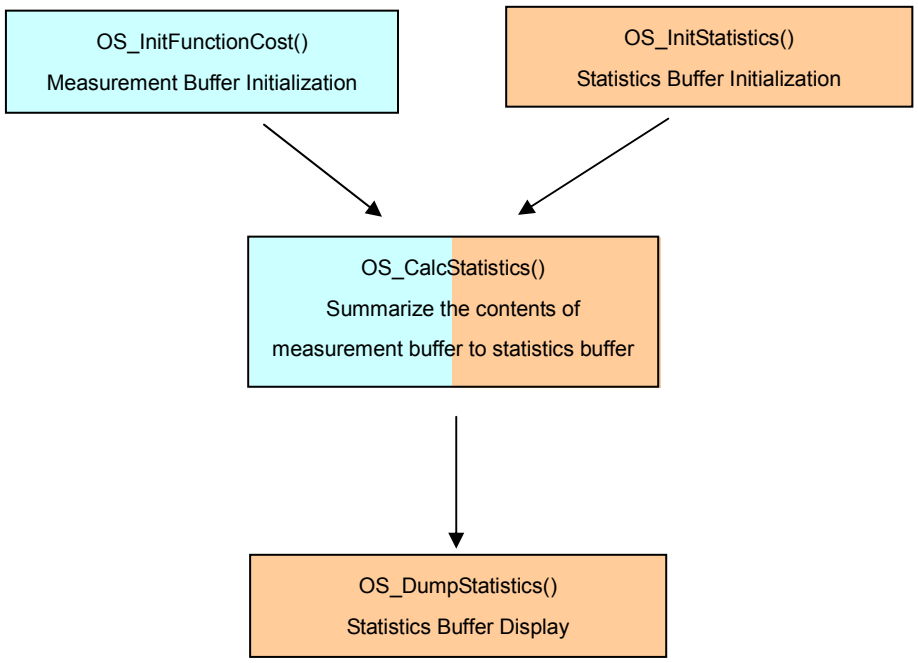
```
// Function cost measurement enable/disable/restore
BOOL OS_EnableFunctionCost( void );
BOOL OS_DisableFunctionCost( void );
BOOL OS_RestoreFunctionCost( BOOL enable );

       enable          Enable (TRUE), Disable (FALSE)
       Return Value    Status prior to function call. Enable (TRUE)/disable (FALSE)
```

If you want to explicitly clear the contents of the function cost measurement buffer, call the following function.

```
// Function cost measurement buffer clear
void OS_ClearFunctionCostBuffer ( void );
```

The following is an in-program example.

```
   #define COSTSIZE 0x3000
   #define STATSIZE 0x300

   u32  CostBuffer[ COSTSIZE / sizeof(u32) ]
   u32  StatBuffer[ STATSIZE / sizeof(u32) ];

   void NitroMain( void )
   {
     OS_Init();
     OS_InitTick();

     //---- init functionCost
     OS_InitFunctionCost( &CostBuffer, COSTSIZE );
     OS_InitStatistics( &StatBuffer, STATSIZE );  // This initialization can be
done after measurement

        : // This is the location to be measured

     //---- calculate cost
     OS_CalcStatistics( &StatBuffer );

     //---- display functionCost
     OS_DumpStatistics( &StatBuffer );

         :
   }
```



4.5 Display Example with Dump

A following is an example of the output of an `OS_DumpStatistics()` function call.

```
test1: count 1, cost 25
test2: count 3, cost 185
test3: count 4, cost 130
```

In the example, there was one call for `test1()` with an elapsed time (duration) of 25. (The units of this value are the same as those used in the Tick system of the OS.)

There were three calls for `test2()` with a total duration of 185. For `test3()`, there were four calls with a total duration 130.

4.6 Specification When Linking

To enable the function cost measurement feature, `NITRO_PROFILE_TYPE=FUNCTIONCOST` must be specified for the make option. Due to this setting, `libos.FUNCTIONCOST.a` (or `libos.FUNCTIONCOST.thumb.a`) is included when linking. This can also be described in the makefile.

4.7 Operation on Thread

If a thread system is being used, the function cost measurement information runs independently for each thread. Therefore, initialization of a particular buffer declared with `OS_InitFunctionCost()` only records information from the thread in which it was generated. Status settings for functions like `OS_EnableFunctionCost()` are also independent for each thread.

Avoid declaring the same measurement buffer with a different thread using `OS_InitFunctionCost()`.

4.8 Cost

Because time information is saved in the buffer every time the function is called, function calls cost more than the normal operation. Since every function must include the `__PROFILE_ENTRY/EXIT` calls, the optimization during compile is not as much as expected, compared to a situation where there is no restrictions. Further, to save the pointer to the function name in the buffer, the function name string is placed on the memory, which causes additional memory usage.

The operational cost changes based on factors such as if there is a thread or not. With `__PROFILE_ENTRY()` an extra 25 – 35 instructions, and with `__PROFILE_EXIT()` an extra 20 – 30 instructions are passed. Also, interval calculation is done when the thread is switched so an extra 30 – 40 instructions are required. The time is obtained by reading the 32-bit timer value from the IO register so the cost of obtaining the time is not significant.

5 Other Profilers (non-Nitro-SDK)

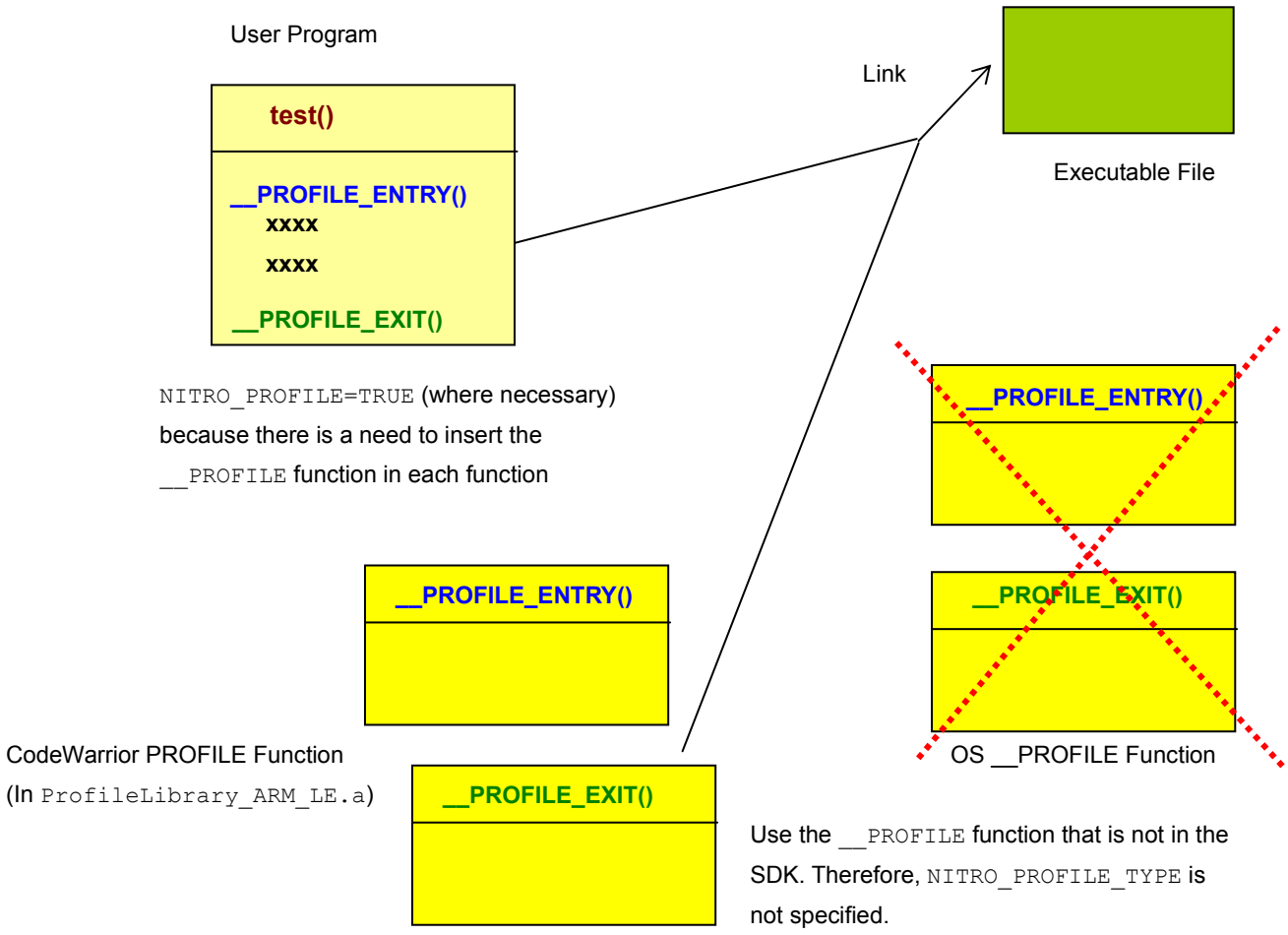
Preparing __PROFILE_ENTRY() and __PROFILE_EXIT() allows you to use a Profiler other than the one provided in the Nitro-SDK OS.

For example, if you use the Profiler offered as the CodeWarrior Example, __PROFILE_ENTRY() and __PROFILE_EXIT() are defined within it so the ones provided in the OS should not be defined..

5.1 Specification When Linking

NITRO_PROFILE_TYPE must be specified for elements other than CALLTRACE or FUNCTIONCOST during an OS compile (In other words, nothing needs to be specified). Due to this, the profile library such as libos.XXXX.a (XXXX = either CALLTRACE or FUNCTIONCOST) will not be linked.

Be aware that in order to insert the __PROFILE function at the beginning and end of each function NITRO_PROFILE=TRUE must be specified.



Revision History

08/11/2004 Revised the error in 3.4 where “stack mode” was “trace mode”