Arm® Instruction Emulator

Version 20.1

Developer and Reference Guide

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Arm® Instruction Emulator

Developer and Reference Guide

Release Information

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Preface

This preface introduces the *Arm® Instruction Emulator Developer and Reference Guide*.

It contains the following:

- *About this book* on page 9.

About this book

This guide helps you use Arm Instruction Emulator (ArmIE). Arm Instruction Emulator runs on AArch64 platforms and is a software tool that emulates Scalable Vector Extension (SVE) instructions. Arm Instruction Emulator allows you to run your compiled SVE application binaries on hardware that is not SVE-enabled.

Using this book

This book is organized into the following chapters:

Chapter 1 Get started
This chapter describes how to install and get started with Arm Instruction Emulator.

Chapter 2 Tutorials
Learn how to build instrumentation clients and custom analysis instrumentation for Arm Instruction Emulator, and how to use Arm Instruction Emulator to analyze your Scalable Vector Extension (SVE) applications.

Chapter 3 Reference
View reference guides for `armie` and the emulation functions for Arm Instruction Emulator.

Chapter 4 Further resources
Lists the additional resources available which you can to use to learn more about Arm Instruction Emulator or the Scalable Vector Extension (SVE).

Glossary

The Arm® Glossary is a list of terms used in Arm documentation, together with definitions for those terms. The Arm Glossary does not contain terms that are industry standard unless the Arm meaning differs from the generally accepted meaning.

See the *Arm® Glossary* for more information.

Typographic conventions

italic
Introduces special terminology, denotes cross-references, and citations.

bold
Highlights interface elements, such as menu names. Denotes signal names. Also used for terms in descriptive lists, where appropriate.

`monospace`
Denotes text that you can enter at the keyboard, such as commands, file and program names, and source code.

`monospace`
Denotes a permitted abbreviation for a command or option. You can enter the underlined text instead of the full command or option name.

`monospace italic`
Denotes arguments to monospace text where the argument is to be replaced by a specific value.

`monospace bold`
Denotes language keywords when used outside example code.

`<and>`
Encloses replaceable terms for assembler syntax where they appear in code or code fragments. For example:

```
MRC p15, 0, <Rd>, <CRn>, <CRm>, <Opcode_2>
```

SMALL CAPITALS

Used in body text for a few terms that have specific technical meanings, that are defined in the *Arm® Glossary*. For example, IMPLEMENTATION DEFINED, IMPLEMENTATION SPECIFIC, UNKNOWN, and UNPREDICTABLE.

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Other information

- *Arm® Developer*.
- *Arm® Information Center*.
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- *Technical Support*.
- *Arm® Glossary*.

Chapter 1
Get started

This chapter describes how to install and get started with Arm Instruction Emulator.

Arm Instruction Emulator (`armie`) is an emulator that runs on AArch64 platforms and emulates Scalable Vector Extension (SVE) instructions. Arm Instruction Emulator lets you develop SVE code without needing access to SVE-enabled hardware.

It contains the following sections:

1.1 Install Arm® Instruction Emulator

Follow these steps to download and install Arm Instruction Emulator.

Prerequisites

Ensure that Environment Modules are installed on your machine. Refer to *Environment configuration* for instructions on how to install them.

Procedure

1. Download the appropriate Arm Instruction Emulator package for your Linux host platform. To download Arm Instruction Emulator, see the *Arm Instruction Emulator Downloads page* on the Arm Developer website.
2. Extract the downloaded package:

   ```
   tar -xvf <package_name>
   ```

   replacing `<package_name>` with the full name of the downloaded package.
3. To see the extracted files, change to the extracted package directory:

   ```
   cd <package_name>
   ```

4. Run the installation script as a privileged user:

   ```
   su root Password: ********
   ./<package_name>.sh
   ```

   By default, packages are unpacked to `/opt/arm/<package_name>`. Alternatively, use the `--install-to` option to specify a custom install location, `<install-dir>`:

   ```
   ./<package_name>.sh --install-to <install_dir>
   ```

   Note

   If you use the `--install-to` option, you need to manually make the installation and module files available to other users, if they require them.

5. The installer displays the EULA and prompts you to agree to the terms. To agree, type 'yes' at the prompt. For more information about the release contents, see the release notes, located in the `<install-dir>/<package_name>` directory. If you completed a default installation, this is `/opt/arm/<package_name>`.

Arm Instruction Emulator is installed on your system.

Next Steps

- Configure your Linux environment:
  1. To see which Environment Modules are available on your system, run:

     ```
     module avail
     ```

     Note

     You might need to configure the `MODULEPATH` environment variable to include the Arm Instruction Emulator installation directory:

     ```
     export MODULEPATH=$MODULEPATH:<install-dir>/modulefiles/
     ```

  2. Load the appropriate Arm Instruction Emulator module for the processors in your system, and for the compiler you are using:

     ```
     module load <architecture>/<linux_variant>/<linux_version>/suites/arm-instruction-
     emulator/<version>
     ```

For example:

```
module load Generic-AArch64/SUSE/12/suites/arm-instruction-emulator/20.1
```

Tip: Add the module load command to your `.profile` to run it automatically every time you log in.

3. Check your environment by examining the PATH variable. It should contain the appropriate Arm Instruction Emulator bin directory from `<install-dir>/`.

```
echo $PATH /opt/arm/arm-instruction-emulator-20.1_Generic-AArch64_SUSE-12_aarch64-
linux/bin64:...
```

- To learn how to use Arm Instruction Emulator, refer to *Get started with Arm® Instruction Emulator* on page 1-14.
- For information about environment variables used by the Arm-provided suite of server and High Performance Computing (HPC) tools, see the *Environment variables* reference topic.
- To uninstall Arm Instruction Emulator, run the `uninstall.sh` script located in `<install-dir>/arm-instruction-emulator-<version>_<microarch>_<OS>-<OS_Version>_aarch64-linux/uninstall.sh`

1.2 Get started with Arm® Instruction Emulator

This tutorial uses a couple of simple examples to demonstrate how to compile Scalable Vector Extension (SVE) code and run the resulting binary with Arm Instruction Emulator.

Before you begin

- This task uses Arm Compiler for Linux (part of Arm Allinea Studio). *Download* and *Install* Arm Compiler for Linux for your platform.
- Load the Arm Compiler for Linux module for your platform:

```
module load <architecture>/<linux_variant>/<linux_version>/suites/arm-instruction-
emulator/<version>
```

For example:

```
module load Generic-AArch64/SUSE/12/suites/arm-instruction-emulator/20.1
```

To check that your environment is now configured to run Arm Instruction Emulator, examine the `PATH` variable and confirm that it contains the appropriate Arm Instruction Emulator `bin` directory from your installation location `<install-dir>`:

```
echo $PATH /<install-dir>/arm-instruction-emulator-20.1_Generic-AArch64_SUSE-12_aarch64-
linux/bin64:...
```

Procedure

1. Compile your source code and generate an executable binary.
2. Run the binary with Arm Instruction Emulator. Either:
   a. Invoke Arm Instruction Emulator and specify the vector length to use:

   ```
   armie -msve-vector-bits=<length> ./<binary>
   ```

   b. Invoke Arm Instruction Emulator with an instrumentation (`-i`) or emulation (`-e`) client, and specify the vector length to use:

   ```
   armie -msve-vector-bits=<arg> -e <emulation_client> -i <instrumentation_client> -- ./
   <binary>
   ```

   Instrumentation and emulation clients enable you to extract data on the execution of your binary.

Example: Compile and run a ‘Hello World’ application

In this example you will write a simple Hello World application in C, compile it, and then run it using Arm Instruction Emulator. The example does not contain SVE code.

1. Create a simple “Hello World” C application and save it as a file named `hello.c`.

```
/* Hello World */
#include <stdio.h>
int main()
{
    printf("Hello World\n");
    return 0;
}
```

2. To generate an executable binary, compile your application with Arm C/C++ Compiler.

```
armclang -O3 -march=armv8-a+sve -o hello hello.c
```

The `-O3` flag ensures the highest optimization level with auto-vectorization enabled. The `-march=armv8-a+sve` flag targets hardware with Armv8-A architecture.

Note

In this example, no SVE code is used. However, it is good practice to enable the highest level of auto-vectorization and target an SVE-enabled architecture when compiling any code to be run using Arm Instruction Emulator.

3. Run the generated binary `hello` using Arm Instruction Emulator:

```
armie -msve-vector-bits=256 ./hello
Hello World
```

For this simple Hello World example, Arm Instruction Emulator runs the code on an emulated SVE-enabled architecture without using SVE instructions.

To use Arm Instruction Emulator to its full potential, that is, to emulate SVE instructions, we must look at a more complex application. An example of an application containing SVE code is available in the next section of this tutorial.

Example: Compile, vectorize, and run an application with SVE code

This example demonstrates how to compile and vectorize some C code that targets the SVE-enabled Armv8-A architecture. It also describes how to emulate running the SVE code using Arm Instruction Emulator.

1. Create a file called `example.c`, containing the following code:

```
// example.c
#include <stdio.h>
#include <stdlib.h>
#define ARRAYSIZE 1024
int a[ARRAYSIZE];
int b[ARRAYSIZE];
int c[ARRAYSIZE];
void subtract_arrays(int *restrict a, int *restrict b, int *restrict c)
{
for (int i = 0; i < ARRAYSIZE; i++)
{
    a[i] = b[i] - c[i];
}
}
int main() {
for (int i = 0; i < ARRAYSIZE; i++)
{
  // Generate a random number between 200 and 300
  b[i] = (rand() % 100) + 200;
  // Generate a random number between 0 and 100
  c[i] = rand() % 100;
}
subtract_arrays(a, b, c);
printf("i \ta[i] \tb[i] \tc[i] \n");
printf("=============================\n");
for (int i = 0; i < ARRAYSIZE; i++)
{
    printf("%d \t%d \t%d \t%d\n", i, a[i], b[i], c[i]);
}
}
```

This C code subtracts corresponding elements in two arrays, writing the result to a third array. The three arrays are declared using the restrict keyword, indicating to the compiler that they do not overlap in memory.

2. Compile the C code:

```
armclang -O3 -march=armv8-a+sve -o example example.c
```

3. Run the binary with Arm Instruction Emulator:

```
armie -msve-vector-bits=256 ./example
```

The application returns:

```
i       a[i]    b[i]    c[i]
\=============================
0       197     283     86
1       262     277     15
2       258     293     35
\...
1021    165     234     69
1022    232     295     63
1023    204     235     31
```

The SVE architecture extension specifies an IMPLEMENTATION DEFINED vector length. The `-msve-vector-bits` option lets you specify the vector length used by Arm Instruction Emulator. The vector length is a multiple of 128 bits, with a maximum of 2048 bits. Use the `-mlist-vector-lengths` option to list all valid vector lengths:

```
armie -mlist-vector-lengths
```

Arm Instruction Emulator returns:

```
128 256 384 512 640 768 896 1024 1152 1280 1408 1536 1664 1792 1920 2048
```

Next Steps

To learn how to analyze your application using the emulation and instrumentation clients available for Arm Instruction Emulator, see *Analyze Scalable Vector Extension (SVE) applications with Arm® Instruction Emulator* on page 2-19.

Related concepts

1.3 Troubleshoot on page 1-17

Related references

3.1 armie command reference on page 3-44

3.2 Emulation Functions Reference on page 3-46

4.2 Scalable Vector Extension (SVE) resources on page 4-50

Related information

Learn more about Arm Instruction Emulator

DynamoRIO dynamic binary instrumentation tool platform

DynamoRIO API

DynamoRIO API Usage Tutorial

Porting and Optimizing HPC Applications for Arm SVE guide

1.3 Troubleshoot

To show how Arm Instruction Emulator used DynamoRIO's `drrun` command to emulate and instrument the SVE binary, invoke the `-s` (or `--show-drrun-cmd`) option. `libsve_512.so` is the SVE emulation client and `libinscount_emulated.so` is the instrumentation client.

```
armie -s -msve-vector-bits=512 -i libinscount_emulated.so -- ./example_sve
/path/to/armie/bin64/drrun -client /path/to/armie/lib64/release/libsve_512.so 0 "" -client /
path/to/armie/samples/bin64/libinscount_emulated.so 1 "" -max_bb_instrs 32 -max_trace_bbs 4
-- ./example_sve
Client inscount is running
. . .
```

In the event of a program crash, the operating system kernel creates a core dump file. The location and name of this core dump file depends on your system's core dump configuration. If your configuration specifies that core dump filenames include the name of the crashed binary, note that this is the name of the executable being emulated rather than the Arm Instruction Emulator binary name (`armie`).

Core dump files should be sent to Arm support along with the output of `armie --version`. However, if you have confidentiality concerns regarding sensitive data in the core dump file, do not send the core dump to Arm. However, without a core dump file, the Arm Support team might not be able to investigate your issue.

For more information about getting help, see *Contacting Arm Support*.

Chapter 2
Tutorials

Learn how to build instrumentation clients and custom analysis instrumentation for Arm Instruction Emulator, and how to use Arm Instruction Emulator to analyze your Scalable Vector Extension (SVE) applications.

It contains the following sections:

2.1 Analyze Scalable Vector Extension (SVE) applications with Arm® Instruction Emulator

Describes how to run your applications with Arm Instruction Emulator and its instrumentation or emulation clients.

Running an SVE program as described in *Get started with Arm® Instruction Emulator* on page 1-14 verifies that the code you have developed can run on SVE hardware. However, if you are developing high-performance applications, run-time analysis is required to gain insights into their execution behavior. Run-time analysis enables you to identify heavily used loops and instruction sequences so that improvements can be made to execution speed and memory access.

Arm Instruction Emulator uses *DynamoRIO* to emulate and instrument SVE binaries on AArch64 hardware. DynamoRIO is a publicly available dynamic binary instrumentation (DBI) tool platform which supports x86 and Arm binaries. It provides an *API* which enables you to write your own binary level run-time instrumentation, and supply some example instrumentation. Each Arm Instruction Emulator release integrates a stable version of DynamoRIO which you can *download* as one seamless package.

Arm Instruction Emulator provides a set of instrumentation clients which can be used to analyze SVE binaries at runtime. The term ‘instrumentation client’ in this context refers to the way Arm Instruction Emulator uses DynamoRIO to work as an analysis tool and an emulator.

Note

Before looking at an example of an instrumentation client for emulated binaries using Arm Instruction Emulator, Arm recommends that you understand the basic principles of instrumenting binaries using the DynamoRIO API. See the *DynamoRIO API usage tutorial*.

For example, one Arm Instruction Emulator instrumentation feature is called Regions-of-Interest (ROI). Sometimes, when analyzing large, complex, and long running applications, it is necessary to limit the amount of run-time data collected (such as memory traces, instruction, and opcode counts) to specific parts of code. You can use the ROI feature to collect run-time data for regions of the code marked with ROI markers. To add ROI markers and build the application, you must have access to the source code under analysis. To mark a ROI, use start and stop macros in the source.

Note

There are restrictions to the use of ROI markers in source code. ROIs must not be nested and they must not overlap. Violating these restrictions will result in undefined behavior.

To emulate and analyze an SVE binary, invoke Arm Instruction Emulator with an instrumentation client and the SVE binary. The client is a shared object file which uses the DynamoRIO API to capture and process wanted run-time events.

Before you begin

- Ensure you have loaded the Arm Instruction Emulator environment module for your platform.
- Ensure you have already compiled your application binary.

Procedure

1. Invoke Arm Instruction Emulator with an instrumentation (-i) or emulation (-e) client and the binary, use:

   ```
   armie -msve-vector-bits=<arg> -e <emulation_client> -i <instrumentation_client> -- ./
   <binary>
   ```

2. Analyze the results provided by the clients.

Example: Analyze a program with SVE code

The following example demonstrates how to count native AArch64 as well as emulated SVE instructions.

`event_bb_analysis()` is the function which counts instructions in the sample client :file::*<install-dir>/arm-instruction-emulator/samples/inscount_emulated.cpp*.

```
    /* Count instructions */
bb_counts.native_instrs = bb_counts.emulated_instrs = 0;
bool is_emulation = false;
for (instr = instrlist_first(bb); instr != NULL; instr = next_instr) {
    next_instr = instr_get_next(instr);
    if (drmgr_is_emulation_start(instr)) {                 ←[1]
        bb_counts.emulated_instrs++;
        is_emulation = true;
        /* Data about the emulated instruction can be extracted from the
         * start label using drmgr_get_emulated_instr_data().
         */
        emulated_instr_t emulated;
        drmgr_get_emulated_instr_data(instr, &emulated);    ←[2]
        dr_printf("SVE: %p\t", emulated.pc);
        int *sveinstr;
        sveinstr = ((int *)instr_get_raw_bits(emulated.instr));
        dr_printf("0x%08x\n", *sveinstr);
        continue;
    }
    if (drmgr_is_emulation_end(instr)) {                    ←[3]
        is_emulation = false;
        continue;
    }
    if (is_emulation)
        continue;
    if (!instr_is_app(instr))
        continue;
    bb_counts.native_instrs++;
}
 /* Insert clean call */
 dr_insert_clean_call(drcontext, bb, instrlist_first_app(bb),
                      (void *)inscount, false /* save fpstate */, 2,
                      OPND_CREATE_INT64(bb_counts.native_instrs),
                      OPND_CREATE_INT64(bb_counts.emulated_instrs))
```

The count instructions example function is inserted at the end of each basic-block, at transformation time, and iterates over each instruction in a basic-block, at execution time.

Note

The difference between *transformation* and *execution* is described in the **Code Transformation and Code Execution** section of *About instrumentation clients* on page 2-38.

In the count instructions example function:

- `bb_counts.native_instrs` and `bb_counts.emulated_instrs`, increment depending on if the instruction is emulated or not.

  The count instructions example function distinguishes between emulated and native instructions using the `drmgr_is_emulation_start()` ([1]) and `drmgr_is_emulation_end()` ([3]) functions of DynamoRIO.
- Where an instruction is the start of a sequence of instructions that emulate an SVE instruction, `drmgr_is_emulation_start()` returns `true`.

  The `drmgr_is_emulation_start()` instruction also contains data about the instruction being emulated. The instruction data can be extracted using `drmgr_get_emulated_instr_data()` ([2]).
- Where an instruction is the last instruction of a sequence of instructions that emulate an SVE instruction, `drmgr_is_emulation_end()` returns `true`.

Note

The reference documentation for these functions is not yet available on the DynamoRIO web site. For a full description of these functions, see *Emulation Functions Reference* on page 3-46.

You can use the `drmgr_get_emulated_instr_data()` function to extract useful information about the instruction being emulated: the PC address and the instruction encoding.

1. Run Arm Instruction Emulator with the `libinscount_emulated.so` instrumentation client on your example code:

   ```
   armie -msve-vector-bits=512 -i libinscount_emulated.so -- ./example_sve
   ```

   Which returns:

   ```
   Client inscount is running
   SVE: 0x000000000040053c 0x04a0e3ef
   SVE: 0x0000000000400554 0x04a14001
   SVE: 0x000000000040055c 0x25aa1fe0
   SVE: 0x0000000000400560 0x05a039e0
   SVE: 0x0000000000400570 0xe5494101
   SVE: 0x0000000000400574 0x04b0e3e9
   SVE: 0x0000000000400578 0x04a00021
   SVE: 0x000000000040057c 0x25aa1d20
   SVE: 0x0000000000400570 0xe5494101
   SVE: 0x0000000000400574 0x04b0e3e9
   SVE: 0x0000000000400578 0x04a00021
   SVE: 0x000000000040057c 0x25aa1d20
   SVE: 0x00000000004005a8 0x25ac1fe0
   SVE: 0x00000000004005b4 0xa5494100
   SVE: 0x00000000004005b8 0xa54941a1
   SVE: 0x00000000004005bc 0x85604140
   SVE: 0x00000000004005c0 0x04a10000
   SVE: 0x00000000004005c4 0xe5494160
   SVE: 0x00000000004005c8 0x04b0e3e9
   SVE: 0x00000000004005cc 0x25ac1d20
   SVE: 0x00000000004005b4 0xa5494100
   SVE: 0x00000000004005b8 0xa54941a1
   SVE: 0x00000000004005bc 0x85604140
   SVE: 0x00000000004005c0 0x04a10000
   SVE: 0x00000000004005c4 0xe5494160
   SVE: 0x00000000004005c8 0x04b0e3e9
   SVE: 0x00000000004005cc 0x25ac1d20
   120827 instructions executed of which 709 were emulated instructions
   ```

2. To convert the encodings output by `dr_printf("0x%08x\n", *sveinstr)` to instruction mnemonics, use the example helper script `/<install-dir>/arm-instruction-emulator/bin64/enc2instr.py`. `enc2instr.py` shows the use of the `enc2instr()` function and can be copied and modified for your own output transformations.

Example: Analyze the effect of the vector length on the number of AArch64 and emulated SVE instructions

This example uses the same instrumentation client that was used in the preceding example, `libinscount_emulated.so`. However, in this example we show how `libinscount_emulated.so` can be used to investigate the effect that vector length has on the number of SVE instructions, for example to minimize them and help reduce time spent in execution.

1. Invoke Arm Instruction Emulator with an instrumentation client named `libinscount_emulated.so` and run the `example` binary:

   ```
   armie -msve-vector-bits=128 -i libinscount_emulated.so -- ./example_sve
   ```

   Which returns:

   ```
   Client inscount is running
   SVE: 0x00000000004006c8 0x25a91fe0
   SVE: 0x00000000004006d0 0xa54842a0
   SVE: 0x00000000004006d4 0xa54842c1
   SVE: 0x00000000004006d8 0x04a10400
   SVE: 0x00000000004006dc 0xe54842e0
   SVE: 0x00000000004006e0 0x04b0e3e8
   SVE: 0x00000000004006e4 0x25a91d00
   SVE: 0x00000000004006d0 0xa54842a0
   SVE: 0x00000000004006d4 0xa54842c1
   ```

```
SVE: 0x00000000004006d8 0x04a10400
SVE: 0x00000000004006dc 0xe54842e0
SVE: 0x00000000004006e0 0x04b0e3e8
SVE: 0x00000000004006e4 0x25a91d00
i       a[i]    b[i]    c[i]
=============================
0       197     283     86
1       262     277     15
2       258     293     35
3       194     286     92
. . .
1019    243     290     47
1020    185     261     76
1021    165     234     69
1022    232     295     63
1023    204     235     31
2134094 instructions executed of which 1537 were emulated instructions
```

Notice the difference in output from the preceding example shown in *Get started with Arm® Instruction Emulator* on page 1-14 (see section *Compile, vectorize, and run a program with SVE code*) which did not use `-i libinscount_emulated.so`. The additional information is what the instrumentation client `libinscount_emulated.so` outputs as part of its analysis of the example binary as it runs:

```
Client inscount is running
SVE: 0x00000000004006c8 0x25a91fe0
...
2134094 instructions executed of which 1537 were emulated instructions
```

2. Run the example binary with each vector length and tabulate the results:

Vector Length	**128**	**256**	**384**	**512**	**640**	**768**	**896**	**1024**	**1152**	**1280**	**1408**	**1536**	**1664**	**1792**	**1920**	**2048**
SVE Instructions	1537	769	517	385	313	259	223	193	175	157	145	133	121	115	109	97

3. Plot the results on a line graph:

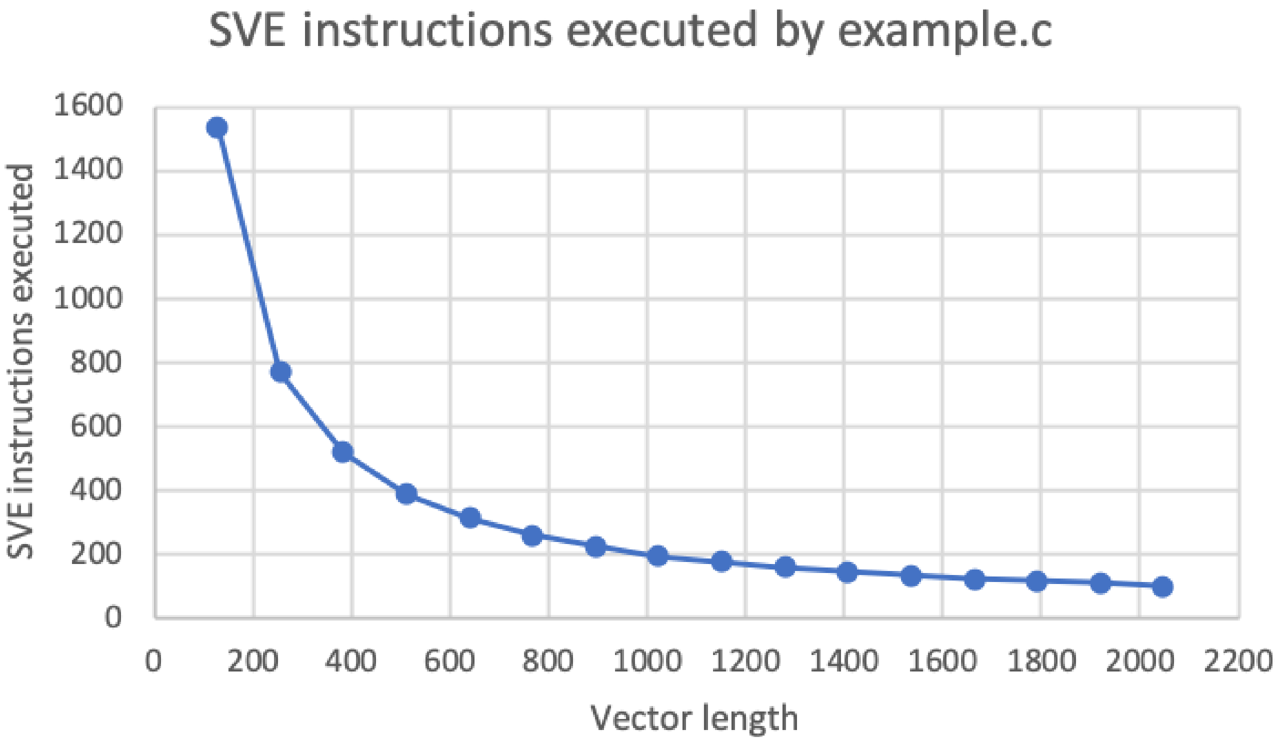


Figure 2-1 Plot of SVE Instructions

The graph shows us that the largest reduction in SVE instructions executed occurs between 128 and about 512 bits. This type of analysis of the run-time behavior of an application can be used with other types of analysis. For example, to study the impact of vector length on performance.

Example: Analyze Regions-of-Interest (ROI)

This example illustrates the use of the `libinscount_emulated.so` client, an instrumentation client that allows you to limit the amount of run-time data collected to specific parts of code. Limiting the amount of run-time data is particularly useful when analyzing large, complex, or long-running applications.

This program used in this example, `loops`, contains two loops. This example uses the ROI feature to limit instruction counting to a single loop. First, the first loop is investigated, then the second is investigated and compared. The initial source code for `loops` is:

```
#define N 42
int a[N], b[N], c[N];
int main(void) {
  a[0] = 0;
  b[0] = 1;
  c[0] = a[0] + b[0];
for(int i=0; i<N; ++1)
  c[i] = i;
for(int i=0; i<N; ++i)
  a[i] = b[i] + b[c[i]];
}
```

1. Build and run the example `loops` program with the `libinscount_emulated.so` client:

   ```
   armie -msve-vector-bits=512 -i libinscount_emulated.so ./loops
   Client inscount is running
   89539 instructions executed of which 36 were emulated instructions
   $
   ```

   All instructions executed are counted.
2. To limit instruction counting to a specific area of code, or the region of interest (ROI), add ROI markers to the `loops` source. To indicate where to start counting, add the `__START_TRACE()` marker. To indicate where to stop counting, add `__STOP_TRACE`. For example, to wrap the first loop of the `loops` code in ROI markers, use:

   ```
   #define N 42
   int a[N], b[N], c[N];
   #define __START_TRACE() { asm volatile (".inst 0x2520e020"); }
   #define __STOP_TRACE() { asm volatile (".inst 0x2520e040"); }
   int main(void) {
     __START_TRACE();
     a[0] = 0;
     b[0] = 1;
     c[0] = a[0] + b[0];
   for(int i=0; i<N; ++i)
       c[i] = i;
     __STOP_TRACE();
     for(int i=0; i<N; ++i)
       a[i] = b[i] + b[c[i]];
   }
   ```
3. Build the new binary, call it `first_loop.`
4. Run `first_loop` with the `libinscount_emulated.so` client:

   ```
   armie -msve-vector-bits=512 -i libinscount_emulated.so -a -roi ./first_loop
   Client inscount is running
   31 instructions executed of which 16 were emulated instructions
   ```

   Notice the difference from the `loops` run:
   - Only the first loop has been instrumented and as a result fewer executed instructions have been counted at runtime.
   - The `armie` command includes the `-a -roi` option to inform the `libinscount_emulated.so` client. `a roi` informs the client to enable and disable instruction counting, based on the `__START_TRACE()` and `__STOP_TRACE()` macros. Without the `-a -roi` option, the client will ignore the macros and count all instructions producing the same output as for the `loops` run above:

     ```
     armie -msve-vector-bits=512 -i libinscount_emulated.so ./first_loop
     Client inscount is running
     89539 instructions executed of which 36 were emulated instructions
     ```

The -a option is a new feature introduced in Arm Instruction Emulator 20.0 to enable you to pass command line arguments to instrumentation clients. In this case, the argument is -roi but it can be any string which the client can use to adjust its behavior at execution time. For a description of the -a option, run armie --help or, see the *armie command reference* on page 3-44 section.

5. Next, the second loop is analyzed. Move the __START_TRACE() and __STOP_TRACE markers to surround the second for loop:

```
#define N 42
int a[N], b[N], c[N];
#define __START_TRACE() { asm volatile (".inst 0x2520e020"); }
#define __STOP_TRACE() { asm volatile (".inst 0x2520e040"); }
int main(void) {
  a[0] = 0;
  b[0] = 1;
  c[0] = a[0] + b[0];
 for(int i=0; i<N; ++i)
    c[i] = i;
  __START_TRACE();
  for(int i=0; i<N; ++i)
    a[i] = b[i] + b[c[i]];
  __STOP_TRACE();
}
```

6. Build the new binary, call it second_loop.
7. Run and analyze the second_loop binary:

```
armie -msve-vector-bits=512 -i libinscount_emulated.so -a -roi ./second_loop
Client inscount is running
31 instructions executed of which 20 were emulated instructions
```

In this run, more SVE instructions are executed than for the first_loop run. More instructions are run because of the extra vector load and arithmetic instructions in the second loop.

The source code is in the Arm Instruction Emulator installation's samples directory. You can modify these clients for your own custom analysis requirements.

Example: Count the dynamic instruction counts

Dynamic instruction counts, in other words, counting instructions executed by a binary at run-time, is a useful way of assessing the performance-related behavior of an application. An instruction count client, libinscount.so, is supplied as an example of how to use the DynamoRIO API with SVE emulation. The client source code is available as a DynamoRIO example in api/samples/inscount.cpp. Use the -i or --iclient option to run the client with armie, for example:

```
armie -msve-vector-bits=512 -i libinscount.so -- ./example_sve
Client inscount is running
Instrumentation results: 106384 instructions executed
```

To compare the number of SVE instructions to the number of native AArch64 instructions executed, use the libinscount_emulated.so client, for example:

```
armie -msve-vector-bits=512 -i libinscount_emulated.so -- ./example_sve
Client inscount is running
106384 instructions executed of which 22 were emulated instructions
```

The source code is available in samples/inscount_emulated.cpp

Another useful way of assessing the performance-related behavior of an application is to count instructions executed by opcode type. Such a count can give users more detailed insights into execution behavior than a total instruction count. For an example, see the *Emulating SVE on Armv8 using DynamoRIO and ArmIE* blog.

Example: Examine memory access behavior

The memory access behavior of an executable is another useful aspect of performance. Memory trace emulation clients for all vector lengths, libmemtrace_sve_<vector length>.so are supplied to work with the DynamoRIO instrumentation client, `libmemtrace_emulated.so`. To trace memory accesses, use the `-e` and `-i` options of `armie`. For example:

```
armie -e libmemtrace_sve_512.so -i libmemtrace_emulated.so -- ./example_sve
```

This creates two trace files in the current directory: a non-SVE AArch64 trace from `libmemtrace_emulated.so` and a SVE trace from `libmemtrace_sve_512.so`. For example:

```
head memtrace.example_sve.10120.0000.log
0: 0, 0,  0,  8, 0xffffe31ea730, 0x40043c
1: 0, 0,  0,  8, 0x400460, 0x400448
2: 0, 0,  0,  8, 0x400468, 0x40044c
3: 0, 0,  0,  8, 0x400470, 0x400450
4: 0, 0,  0,  8, 0x420000, 0x400404
5: 0, 0,  1, 16, 0xffffe31ea720, 0x4003e0
6: 0, 0,  0,  8, 0x41fff8, 0x4003e8
7: 0, 0,  1, 16, 0xffffe31ea5c0, 0x400610
8: 0, 0,  1, 16, 0xffffe31ea5d8, 0x400618
```

```
head sve-memtrace.example_sve.10120.log
27, -1, 0, 1, 0, (nil), (nil)
40, 0, 0, 0, 64, 0x4200d8, 0x4005e4
41, 0, 0, 0, 64, 0x420030, 0x4005e8
42, 0, 3, 0, 4, 0x420030, 0x4005ec
43, 0, 2, 0, 4, 0x420034, 0x4005ec
44, 0, 2, 0, 4, 0x420038, 0x4005ec
45, 0, 2, 0, 4, 0x42003c, 0x4005ec
46, 0, 2, 0, 4, 0x420040, 0x4005ec
47, 0, 2, 0, 4, 0x420044, 0x4005ec
48, 0, 2, 0, 4, 0x420048, 0x4005ec
. . .
86, 0, 2, 0, 4, 0x4200c8, 0x4005ec
87, 0, 2, 0, 4, 0x4200cc, 0x4005ec
88, 0, 6, 0, 4, 0x4200d0, 0x4005ec
89, 0, 0, 0, 36, 0x420200, 0x4005f4
90, -2, 0, 1, 0, (nil), (nil)
```

The SVE trace includes start and stop trace entries to delimit the chosen Region-of-Interest (RoI):

```
start -> xx, -1, 0, 1, 0, (nil), (nil)
stop  -> xx, -2, 0, 1, 0, (nil), (nil)
```

For an explanation on RoI, see the previous example

The sequence number of the SVE trace is delimited by a comma to distinguish from the non-SVE trace, which uses a colon.

To enable you to analyze memory trace files, utilities are provided. For example, the merge utility produces one file with each trace, in chronological order, from a non-SVE AArch64 trace file and an SVE trace file:

```
merge memtrace.example_sve.10120.0000.log sve-memtrace.example_sve.10120.log > merged-
memtrace.log
```

Next steps

- Further instrumentation clients are available, that provide different insights, including:
  - `inscount_emulated.cpp`
  - `instrace_emulated.c`
  - `meminstrace_emulated.c`
  - `memtrace_emulated.c`
  - `opcodes_emulated.cpp`

  These are ROI-capable and their source code is in the Arm Instruction Emulator installation `samples` directory:

  ```
  /path/to/your/arm-instruction-emulator-<xx.y>_Generic-AArch64_<OS>_aarch64-linux/samples/
  ```

You can modify and enhance these clients for your specific analysis requirements. For examples and guidance on how to modify and enhance clients, see *Building Custom Analysis Instrumentation* on page 2-32.

- For more advanced analysis examples of a real-world application, see *Emulating SVE on existing Armv8-A hardware using DynamoRIO and ArmIE*. This includes use-case examples of `libopcodes_emulated.so` and `libmemtrace_simple.so`.

Related references

2.3 Building Custom Analysis Instrumentation on page 2-32

Related information

Porting and Optimizing HPC Applications for Arm SVE

Arm Instruction Emulator

2.2 Building an emulation-aware instrumentation client

The ability to instrument emulated applications is a recent addition to the DynamoRIO API. Therefore, most of the samples which come with DynamoRIO (and Arm Instruction Emulator) are not capable of interpreting emulated instructions. This tutorial demonstrates how to modify existing native-only clients to also handle emulated instructions, and how to write your own emulation aware clients.

Before you begin

- This tutorial assumes that you have a good working knowledge about the DynamoRIO API. Documentation is available at:

  http://dynamorio.org/docs/

  and includes the *event driven usage model of DynamoRIO* and *example clients* from which `inscount_emulated.cpp`, `opcodes_emulated.cpp` and `memtrace_simple.c` are derived.
- Work through *Analyze Scalable Vector Extension (SVE) applications with Arm® Instruction Emulator* on page 2-19 to learn how to run a pre-built instrumentation client.
- Understand the *About instrumentation clients* on page 2-38.

Procedure

1. Run the pre-built `libbbcount.so` client with Arm Instruction Emulator, which counts the number of basic blocks executed by an application:

   ```
   armie -msve-vector-bits=128 -i libbbcount.so -- ./example
   ```

   Which returns:

   ```
   Client bbcount is running
   i       a[i]    b[i]    c[i]
   =============================
   0       197     283     86
   1       262     277     15
   . . .
   1021    165     234     69
   1022    232     295     63
   1023    204     235     31
   Instrumentation results:
   449561 basic block executions
     1971 basic blocks needed flag saving
        0 basic blocks did not
   ```

   We will change this to write both native and emulated basic block execution counts to `stdout`.
2. Add the emulated instruction counter variable. Copy the `bbcount.cpp` file to `bbcount_tut2.cpp` in: `/path/to/your/arm-instruction-emulator-<xx.y>_Generic-AArch64_<OS>_aarch64-linux/samples`.

   Where `bbcount.cpp`, is:

   ```
   /* we only have a global count */
   static int global_count;
   #ifdef SHOW_RESULTS
   /* some meta-stats: static (not per-execution) */
   static int bbs_eflags_saved;
   static int bbs_no_eflags_saved;
   #endif
   static void
   event_exit(void)
   {
   #ifdef SHOW_RESULTS
       char msg[512];
       int len;
       len = dr_snprintf(msg, sizeof(msg) / sizeof(msg[0]),
                         "Instrumentation results:\n"
                         "%10d basic block executions\n"
                         "%10d basic blocks needed flag saving\n"
                         "%10d basic blocks did not\n",
                         global_count, bbs_eflags_saved, bbs_no_eflags_saved);
       DR_ASSERT(len > 0);
       NULL_TERMINATE(msg);
       DISPLAY_STRING(msg);
   ```

```
#endif /* SHOW_RESULTS */
    drx_exit();
    drreg_exit();
    drmgr_exit();
}
```

Edit `bbcount_tut2.cpp` to add a global emulation counter variable:

```
/* we have global native and emulated counts */
static int native_count;
static int emulated_count;
#ifdef SHOW_RESULTS
/* some meta-stats: static (not per-execution) */
static int bbs_eflags_saved;
static int bbs_no_eflags_saved;
#endif
static void
event_exit(void)
{
#ifdef SHOW_RESULTS
    char msg[512];
    int len;
    len = dr_snprintf(msg, sizeof(msg) / sizeof(msg[0]),
                        "Instrumentation results:\n"
                        "%10d native basic block executions\n
                        "%10d emulated basic block executions
                        "%10d basic blocks needed flag saving
                        "%10d basic blocks did not\n",
                        native_count, emulated_count,
                        bbs_eflags_saved, bbs_no_eflags_saved
    DR_ASSERT(len > 0);
    NULL_TERMINATE(msg);
    DISPLAY_STRING(msg);
#endif /* SHOW_RESULTS */
    drx_exit();
    drreg_exit();
    drmgr_exit();
}
```

3. Add the basic block emulation counting function. Modify the instrumentation callback function `event_app_instruction()` to look for at least one emulated instruction in a block, and if found, increment `emulated_count` when the block is executed.

   `bbcount.c`:

```
static dr_emit_flags_t
event_app_instruction(void *drcontext, void *tag, instrlist_t *bb, instr_t *inst,
                      bool for_trace, bool translating, void *user_data)
{
#ifdef SHOW_RESULTS
    bool aflags_dead;
#endif
   /* By default drmgr enables auto-predication, which predicates all instructions with
    * the predicate of the current instruction on ARM.
    * We disable it here because we want to unconditionally execute the following
    * instrumentation.
    */
    drmgr_disable_auto_predication(drcontext, bb);
    if (!drmgr_is_first_instr(drcontext, inst))
        return DR_EMIT_DEFAULT;
#ifdef VERBOSE
    dr_printf("in dynamorio_basic_block(tag=" PFX ")\n", tag);
#    ifdef VERBOSE_VERBOSE
    instrlist_disassemble(drcontext, tag, bb, STDOUT);
#    endif
#endif
#ifdef SHOW_RESULTS
    if (drreg_are_aflags_dead(drcontext, inst, &aflags_dead) == DRREG_SUCCESS &&
        !aflags_dead)
        bbs_eflags_saved++;
    else
        bbs_no_eflags_saved++;
#endif
    /* racy update on the counter for better performance */
    drx_insert_counter_update(drcontext, bb, inst,
                              /* We're using drmgr, so these slots
                              * here won't be used: drreg's slots will be.
                              */
                              SPILL_SLOT_MAX + 1,
                              IF_AARCHXX_(SPILL_SLOT_MAX + 1) & global_count, 1, 0);
#if defined(VERBOSE) && defined(VERBOSE_VERBOSE)
    dr_printf("Finished instrumenting dynamorio_basic_block(tag=" PFX ")\n", tag);
    instrlist_disassemble(drcontext, tag, bb, STDOUT);
#endif
    return DR_EMIT_DEFAULT;
}
```

bbcount_tut2.c:

```
static dr_emit_flags_t
event_app_instruction(void *drcontext, void *tag, instrlist_t *bb, instr_t *inst,
                      bool for_trace, bool translating, void *user_data)
{
    instr_t *instr, *next_instr;
#ifdef SHOW_RESULTS
    bool aflags_dead;
#endif
    /* By default drmgr enables auto-predication, which predicates all instructions wi
    * the predicate of the current instruction on ARM.
    * We disable it here because we want to unconditionally execute the following
    * instrumentation.
    */
    drmgr_disable_auto_predication(drcontext, bb);
    if (!drmgr_is_first_instr(drcontext, inst))
        return DR_EMIT_DEFAULT;
#ifdef VERBOSE
    dr_printf("in dynamorio_basic_block(tag=" PFX ")\n", tag);
#    ifdef VERBOSE_VERBOSE
    instrlist_disassemble(drcontext, tag, bb, STDOUT);
#    endif
#endif
#ifdef SHOW_RESULTS
    if (drreg_are_aflags_dead(drcontext, inst, &aflags_dead) == DRREG_SUCCESS &&
        !aflags_dead)
        bbs_eflags_saved++;
    else
        bbs_no_eflags_saved++;
#endif
    for (instr = instrlist_first(bb); instr != NULL; instr = next_instr) {
        next_instr = instr_get_next(instr);
        if (drmgr_is_emulation_start(instr)) {
            drx_insert_counter_update(drcontext, bb, inst,
                        SPILL_SLOT_MAX + 1,
                        IF_AARCHXX_(SPILL_SLOT_MAX + 1) & emulated_count, 1, 0);
            return DR_EMIT_DEFAULT;
        }
    }
    /* racy update on the counter for better performance */
    drx_insert_counter_update(drcontext, bb, inst,
                              /* We're using drmgr, so these slots
                              * here won't be used: drreg's slots will be.
                              */
                              SPILL_SLOT_MAX + 1,
                              IF_AARCHXX_(SPILL_SLOT_MAX + 1) & native_count, 1, 0);
#if defined(VERBOSE) && defined(VERBOSE_VERBOSE)
    dr_printf("Finished instrumenting dynamorio_basic_block(tag=" PFX ")\n", tag);
    instrlist_disassemble(drcontext, tag, bb, STDOUT);
#endif
    return DR_EMIT_DEFAULT;
}
```

There are three things to note about this change:

a. The `for()` loop uses `instrlist_first()` and `instr_get_next()` to look at each instruction in a block. This is a standard DynamoRIO method used in many clients.

b. The `drmgr_is_emulation_start()` function is used to detect if an instruction is the start of a sequence of instructions which are emulating a non-native instruction. There is also a `drmgr_is_emulation_end()` function which detects the end of the sequence but it is not required in this client as we only want to know if there is at least one emulated instruction in the block. See `opcodes_emulated.cpp` as an example of how `drmgr_is_emulation_start()`and `drmgr_is_emulation_end()` are used together.

   Note

   The reference documentation for these functions is not yet available at the DynamoRIO web site. See *Emulation Functions Reference* on page 3-46 for a full description of these functions.

c. Instead of using `dr_insert_clean_call()` as in `opcodes_emulated.cpp`, the client uses `drx_insert_counter_update()` to increment `native_count` and `emulated_count`. The difference is that `dr_insert_clean_call()`inserts a user-defined function, which is run when the block is executed. Whereas, `drx_insert_counter_update()`inserts its own code to increment a variable, which is run when the block is executed. See the *DynamoRIO API reference documentation* for more details.

4. Download the files *bbcount.c* and *bbcount_tut2.c* and compare them with a diff viewer to look at the modifications in full.
5. To build the modified client, add `bbcount_tut2.c` to `/path/to/your/arm-instruction-emulator-<xx.y>_Generic-AArch64_<OS>_aarch64-linux/samples/CMakeLists.txt`:

```
. . .
add_sample_client(bbcount      "bbcount.c"       "drmgr;drreg;drx")
add_sample_client(bbcount_tut2 "bbcount_tut2.c" "drmgr;drreg;drx")
add_sample_client(bbsize       "bbsize.c"        "drmgr")
. . .
```

6. Run `cmake`. Note that the current version of Arm Instruction Emulator (20.1) requires that clients are built with GCC version 7.1.0 or higher:

```
cmake .
```

This returns:

```
-- The C compiler identification is GNU 7.1.0
-- The CXX compiler identification is GNU 7.1.0
-- Check for working C compiler: /opt/arm/gcc-7.1.0_Generic-AArch64_SUSE-12_aarch64-
linux/bin/cc
-- Check for working C compiler: /opt/arm/gcc-7.1.0_Generic-AArch64_SUSE-12_aarch64-
linux/bin/cc -- works
-- Detecting C compiler ABI info
-- Detecting C compiler ABI info - done
-- Detecting C compile features
-- Detecting C compile features - done
-- Check for working CXX compiler: /opt/arm/gcc-7.1.0_Generic-AArch64_SUSE-12_aarch64-
linux/bin/c++
-- Check for working CXX compiler: /opt/arm/gcc-7.1.0_Generic-AArch64_SUSE-12_aarch64-
linux/bin/c++ -- works
-- Detecting CXX compiler ABI info -- Detecting CXX compiler ABI info - done
-- Detecting CXX compile features -- Detecting CXX compile features - done
-- Configuring done
-- Generating done
-- Build files have been written to: /path/to/your/arm-instruction-emulator-
<xx.y>_Generic-AArch64_<OS>_aarch64-linux/samples
```

7. Run make:

```
make
```

Which returns:

```
. . .
Scanning dependencies of target bbcount_tut2
[ 46%] Building C object CMakeFiles/bbcount_tut2.dir/bbcount_tut2.c.o
[ 48%] Linking C shared library bin/libbbcount_tut2.so
Usage: pass to drconfig or drrun: -c /path/to/your/arm-instruction-emulator-
<xx.y>_Generic-AArch64_<OS>_aarch64-linux/samples/bin/libbbcount_tut2.so
[ 48%] Built target bbcount_tut2
. . .
```

8. Copy the built client from `/path/to/your/arm-instruction-emulator-<xx.y>_Generic-AArch64_<OS>_aarch64-linux/samples/bin` to `/path/to/your/arm-instruction-emulator-<xx.y>_Generic-AArch64_<OS>_aarch64-linux/samples/bin64`:

```
cp bin/libbbcount_tut2.so ./bin64/
file bin64/libbbcount_tut2.so bin64/libbbcount_tut2.so: ELF 64-bit LSB shared object, ARM
aarch64, version 1 (SYSV), dynamically linked, not stripped
```

9. Run the modified client:

```
armie -msve-vector-bits=128 -i libbbcount_tut2.so -- ./example
```

The output now includes a count for blocks which contain at least one emulated instruction:

```
Client bbcount is running
i       a[i]    b[i]    c[i]
=============================
0       197     283     86
```

```
1       262     277     15
2       258     293     35
. . .
1021    165     234     69
1022    232     295     63
1023    204     235     31
Instrumentation results:
449306 native basic block executions
   256 emulated basic block executions
  1971 basic blocks needed flag saving
     0 basic blocks did not
```

Results

The output now includes a count for blocks which contain at least one emulated instruction.

Related references

2.3 Building Custom Analysis Instrumentation on page 2-32

3.2 Emulation Functions Reference on page 3-46

2.4 About instrumentation clients on page 2-38

Related information

Arm Instruction Emulator

2.3 Building Custom Analysis Instrumentation

Using the DynamoRIO API, you can change existing instrumentation clients or write your own from scratch. This tutorial describes how to modify the instrumentation of an existing client for your own purposes and build and execute the modified client with Arm Instruction Emulator.

Before you begin

- This tutorial assumes that you have a good working knowledge about the DynamoRIO API. *DynamoRIO Documentation* is available at and includes DynamoRIO's event driven usage model example clients from which `inscount_emulated.cpp`, `opcodes_emulated.cpp`, and `memtrace_simple.c` are derived.
- Work through *Analyze Scalable Vector Extension (SVE) applications with Arm® Instruction Emulator* on page 2-19 to learn how to run a pre-built instrumentation client.
- Understand the *About instrumentation clients* on page 2-38, `libopcodes_emulated.so` and its implementation in the file `opcodes_emulated.cpp`.

Procedure

1. Use the following command to run Arm Instruction Emulator, with the pre-built instrumentation client, `libopcodes_emulated.so`. This client writes native AArch64 opcode counts to stdout and emulated counts to a file:

   ```
   $ armie -msve-vector-bits=128 -i libopcodes_emulated.so -- ./example
   ```

   Which returns:

   ```
   Client opcodes_emulated is running
   i       a[i]    b[i]    c[i]
   =============================
   0       197     283     86
   1       262     277     15
   . . .
   1022    232     295     63
   1023    204     235     31
   Opcode execution counts in AArch64 mode:
         34900 : bl
         39725 : and
         41232 : csel
         44149 : ret
         54344 : ldrb
         68104 : cbnz
         73037 : ldp
         77676 : cbz
         79184 : stp
        100349 : sub
        110960 : movz
        126343 : str
        144182 : bcond
        171068 : subs
        171899 : orr
        183813 : add
        234517 : ldr
   7 unique emulated instructions written to undecoded.txt
   ```

   The file `undecoded.txt` contains:

   ```
       256 : 0xe54842e0
   256 : 0xa54842c1
   256 : 0xa54842a0
   256 : 0x25a91d00
   256 : 0x04b0e3e8
   256 : 0x04a10400
     1 : 0x25a91fe0
   ```

We are going to modify this instrumentation client, so that it writes both native and emulated counts to stdout in a format which makes it easier to be parsed by scripts when running and collating output from many applications, typically in an automated test environment.

Note

To correctly modify the `libopcodes_emulated.so` client, you must understand its existing implementation, `opcodes_emulated.cpp`. Refer to *About instrumentation clients* on page 2-38 for a detailed description of instrumentation client structure.

2. Copy the `opcodes_emulated.cpp` file to a new file, `opcodes_emulated_tut1.cpp` and save it in the following location:

   `/path/to/your/arm-instruction-emulator-<xx.y>_Generic-AArch64_<OS>_aarch64-linux/samples`
3. Edit `opcodes_emulated_tut1.cpp` to merge `opcount()` and `record_emulated_inst()` into one function:

   `opcodes_emulated.cpp`:

```
  static void
  record_emulated_inst(uint code)
  {
    emulated[code]++;
  }
  static void
  opcount(uint opcode)
  {
    count[opcode]++;
  }
:file:`opcodes_emulated_tut1.cpp`:
```

```
static void
opcount(uint opcode, int is_emulated)
{
    if (is_emulated == 0)
        count[opcode]++;
    else
        emulated[opcode]++;
}
```

4. Update the `dr_insert_clean_call()` calls which insert `opcount()`:

   `opcodes_emulated.cpp`

```
static dr_emit_flags_t
event_basic_block(void *drcontext, void *tag, instrlist_t *bb,
                  bool for_trace, bool translating)
{
    instr_t *instr;
    for (instr = instrlist_first(bb);
        instr != NULL;
        instr = instr_get_next(instr)) {
        if (drmgr_is_emulation_start(instr)) {
            is_emulation = true;
            emulated_instr_t emulated;
            drmgr_get_emulated_instr_data(instr, &emulated);
            dr_insert_clean_call(drcontext, bb, instr,
                                 (void *)record_emulated_inst, false, 1,
                                 OPND_CREATE_INT32(
                                     instr_get_raw_word(emulated.instr, 0)));
        }
        if (drmgr_is_emulation_end(instr))
            is_emulation = false;
        if (is_emulation)
            continue;
        if (!instr_is_app(instr))
            continue;
        dr_insert_clean_call(drcontext, bb, instr,
                             (void *)opcount, false, 1,
                             OPND_CREATE_INT32(instr_get_opcode(instr)));
    }
    return DR_EMIT_DEFAULT;
}
```

opcodes_emulated_tut1.cpp

```
static dr_emit_flags_t
event_basic_block(void *drcontext, void *tag, instrlist_t *bb,
                  bool for_trace, bool translating)
{
    instr_t *instr;
    for (instr = instrlist_first(bb);
        instr != NULL;
        instr = instr_get_next(instr)) {
        if (drmgr_is_emulation_start(instr)) {
            is_emulation = true;
            emulated_instr_t emulated;
            drmgr_get_emulated_instr_data(instr, &emulated);
            dr_insert_clean_call(drcontext, bb, instr,
                (void *)opcount, false, 2,
                OPND_CREATE_INT32(instr_get_raw_word(emulated.instr, 0)),
                OPND_CREATE_INT(1));
        }
        if (drmgr_is_emulation_end(instr))
            is_emulation = false;
        if (is_emulation)
            continue;
        if (!instr_is_app(instr))
            continue;
        dr_insert_clean_call(drcontext, bb, instr,
                            (void *)opcount, false, 2,
                            OPND_CREATE_INT32(instr_get_opcode(instr)),
                            OPND_CREATE_INT(0));
    }
    return DR_EMIT_DEFAULT;
}
```

Notice that by merging `opcount()` and `record_emulated_inst()` into one callback function, `opcount()`, the `dr_insert_clean_call()` functions, which insert `opcount()`, must now define 2 input parameters rather than one. The `dr_insert_clean_call()` functions must also pass 1 for emulated instructions and 0 for native instructions.

5. Update `event_exit()` to write the emulated instruction data to stdout rather than a file:

opcodes_emulated.cpp:

```
static void
event_exit(void)
{
#ifdef SHOW_RESULTS
    char msg[(NUM_COUNT_SHOW + 2) * 80];
    int len, i;
    size_t sofar = 0;
    /* First, sort the counts */
    uint indices[NUM_COUNT];
    /* Initialise indices */
    for (i = 0; i < NUM_COUNT; i++)
        indices[i] = i;
    qsort(indices, NUM_COUNT, sizeof(indices[0]), compare_counts);
    len = dr_snprintf(msg, sizeof(msg) / sizeof(msg[0]),
                      "Opcode execution counts in AArch64 mode:\n");
    DR_ASSERT(len > 0);
    sofar += len;
    for (i = OP_LAST - 1 - NUM_COUNT_SHOW; i <= OP_LAST; i++) {
        if(count[indices[i]] != 0) {
            len = dr_snprintf(msg + sofar, sizeof(msg) / sizeof(msg[0]) - sofar,
                              "  %9lu : %-15s\n", count[indices[i]],
                              decode_opcode_name(indices[i]));
            DR_ASSERT(len > 0);
            sofar += len;
        }
    }
    len = dr_snprintf(msg + sofar, sizeof(msg) / sizeof(msg[0]) - sofar,
          "%u unique emulated instructions written to undecoded.txt\n",
          emulated.size());
    DR_ASSERT(len > 0);
    sofar += len;
    NULL_TERMINATE(msg);
    DISPLAY_STRING(msg);
#endif /* SHOW_RESULTS */
    map<uint,long>::iterator iter;
    multimap<long,uint>::reverse_iterator iter2;
    for(iter=emulated.begin(); iter!=emulated.end();++iter) {
        ranks.insert(make_pair(iter->second,iter->first));
    }
    for(iter2=ranks.rbegin(); iter2!=ranks.rend(); ++iter2) {
        fprintf(file, "%9lu : 0x%08x\n", iter2->first, iter2->second);
    }
    fclose(file);
    emulated.clear();
    if (!drmgr_unregister_bb_app2app_event(event_basic_block))
      DR_ASSERT(false);
    drmgr_exit();
}
```

`opcodes_emulated_tut1.cpp`:

```
static void
event_exit(void)
{
#ifdef SHOW_RESULTS
    char msg[(NUM_COUNT_SHOW + 2) * 80];
    int len, i;
    size_t sofar = 0;
    /* First, sort the counts */
    uint indices[NUM_COUNT];
    /* Initialise indices */
    for (i = 0; i < NUM_COUNT; i++)
        indices[i] = i;
    qsort(indices, NUM_COUNT, sizeof(indices[0]), compare_counts);
    len = dr_snprintf(msg, sizeof(msg) / sizeof(msg[0]),
                      "Opcode execution counts for AArch64 instructions:\n");
    DR_ASSERT(len > 0);
    sofar += len;
    for (i = OP_LAST - 1 - NUM_COUNT_SHOW; i <= OP_LAST; i++) {
        if(count[indices[i]] != 0) {
            len = dr_snprintf(msg + sofar, sizeof(msg) / sizeof(msg[0]) - sofar,
                              "  %9lu : %-15s\n", count[indices[i]],
                              decode_opcode_name(indices[i]));
            DR_ASSERT(len > 0);
            sofar += len;
        }
    }
    len = dr_snprintf(msg + sofar, sizeof(msg) / sizeof(msg[0]) - sofar,
          "Instruction execution counts for %u emulated instructions:",
          emulated.size());
    DR_ASSERT(len > 0);
    sofar += len;
    NULL_TERMINATE(msg);
    DISPLAY_STRING(msg);
#endif /* SHOW_RESULTS */
    map<uint,long>::iterator iter;
    multimap<long,uint>::reverse_iterator iter2;
    for(iter=emulated.begin(); iter!=emulated.end();++iter) {
        ranks.insert(make_pair(iter->second,iter->first));
    }
    for(iter2=ranks.rbegin(); iter2!=ranks.rend(); ++iter2) {
        dr_printf("  %9lu : 0x%08x\n", iter2->first, iter2->second);
    }
    fclose(file);
    emulated.clear();
    if (!drmgr_unregister_bb_app2app_event(event_basic_block))
      DR_ASSERT(false);
    drmgr_exit();
}
```

Download the files for `opcodes_emulated.cpp` and `opcodes_emulated_tut1.cpp` and compare them with a diff viewer to view the modifications in full.

6. To build the modified client, add `opcodes_emulated_tut1.cpp` to `/path/to/your/arm-instruction-emulator-<xx.y>_Generic-AArch64_<OS>_aarch64-linux/samples/CMakeLists.txt`:

```
. . .
add_sample_client(opcodes "opcodes.c" "drmgr;drreg;drx")
add_sample_client(opcodes_emulated "opcodes_emulated.cpp" "drmgr;drreg")
add_sample_client(opcodes_emulated_tut1 "opcodes_emulated_tut1.cpp" "drmgr;drreg")
add_sample_client(stl_test "stl_test.cpp" "")
. . .
```

7. Run `cmake`. Note that the current version of Arm Instruction Emulator (20.1) requires that clients are built with GCC version 7.1.0 or higher:

```
cmake .
```

Which returns:

```
-- The C compiler identification is GNU 7.1.0
-- The CXX compiler identification is GNU 7.1.0
-- Check for working C compiler: /opt/arm/gcc-7.1.0_Generic-AArch64_SUSE-12_aarch64-
linux/bin/cc
-- Check for working C compiler: /opt/arm/gcc-7.1.0_Generic-AArch64_SUSE-12_aarch64-
linux/bin/cc -- works
-- Detecting C compiler ABI info -- Detecting C compiler ABI info - done -- Detecting C
compile features
-- Detecting C compile features - done
-- Check for working CXX compiler: /opt/arm/gcc-7.1.0_Generic-AArch64_SUSE-12_aarch64-
linux/bin/c++
-- Check for working CXX compiler: /opt/arm/gcc-7.1.0_Generic-AArch64_SUSE-12_aarch64-
linux/bin/c++ -- works
-- Detecting CXX compiler ABI info
-- Detecting CXX compiler ABI info - done
-- Detecting CXX compile features -- Detecting CXX compile features - done
-- Configuring done
-- Generating done
-- Build files have been written to: /path/to/your/arm-instruction-emulator-
<xx.y>_Generic-AArch64_<OS>_aarch64-linux/samples
```

8. Run `make`:

   ```
   make
   ```

   Which returns:

   ```
   . . .
   Scanning dependencies of target opcodes_emulated_tut1
   [ 7%] Building CXX object CMakeFiles/opcodes_emulated_tut1.dir/opcodes_emulated_tut1.cpp.o
   [ 9%] Linking CXX shared library bin/libopcodes_emulated_tut1.so
   Usage: pass to drconfig or drrun: -c /path/to/your/arm-instruction-emulator-
   <xx.y>_Generic-AArch64_<OS>_aarch64-linux/samples/bin/libopcodes_emulated_tut1.so
   [ 9%] Built target opcodes_emulated_tut1
   . . .
   ```

9. Copy the built client from: /path/to/your/arm-instruction-emulator-<xx.y>_Generic-AArch64_<OS>_aarch64-linux/samples/bin `` to ``/path/to/your/arm-instruction-emulator-<xx.y>_Generic-AArch64_<OS>_aarch64-linux/samples/bin64

   For example:

   ```
   cp bin/libopcodes_emulated_tut1.so ./bin64/
   file ./libopcodes_emulated_tut1.so ./libopcodes_emulated_tut1.so: ELF 64-bit LSB shared
   object, ARM aarch64, version 1 (SYSV), dynamically linked, not stripped
   ```

10. Run the modified client. Now, the emulated instruction output is written to stdout and the `undecoded.txt` file is not created:

    ```
    armie -msve-vector-bits=128 -i libopcodes_emulated_tut1.so -- ./example
    ```

    Which returns:

    ```
    . . .
    1022 232 295 63
    1023 204 235 31
    Opcode execution counts for AArch64 instructions:
     34900 : bl
     39725 : and
     41232 : csel
     44149 : ret
     54344 : ldrb
     68104 : cbnz
     73037 : ldp
     77676 : cbz
     79184 : stp
     100349 : sub
     110960 : movz
     126343 : str
     144182 : bcond
     171068 : subs
     171899 : orr
     183813 : add
     234517 : ldr
    Instruction execution counts for 7 emulated instructions:
     256 : 0xe54842e0
     256 : 0xa54842c1
     256 : 0xa54842a0
    ```

```
256 : 0x25a91d00
256 : 0x04b0e3e8
256 : 0x04a10400
1 : 0x25a91fe0
```

Results

Notice that the emulated instructions appear as raw encodings rather than mnemonics. This is a reflection of the current state of emulation support in the Public DynamoRIO API. Arm is working to improve such emulated instrumentation features and more comprehensive features will be available in the public API for future Arm Instruction Emulator releases.

Until then, as a workaround, a helper script is provided with Arm Instruction Emulator, enc2instr.py, which can be used to disassemble the encodings in your own post-processing scripts:

```
export LLVM_MC=/<install-dir>/arm-linux-compiler-<xx.y>_Generic-AArch64_<OS>-<OS-
version>_aarch64-linux/llvm-bin/llvm-mc
echo 0xe54842e0 | /<install-dir>/arm-instruction-emulator-<xx.y>_Generic-
AArch64_<OS>_aarch64-linux//bin64/enc2instr.py 0xe54842e0 : st1w {z0.s}, p0, [x23, x8, lsl
#2]
```

Next steps

- *Building an emulation-aware instrumentation client* on page 2-27

Related references

2.1 Analyze Scalable Vector Extension (SVE) applications with Arm® Instruction Emulator on page 2-19

Related information

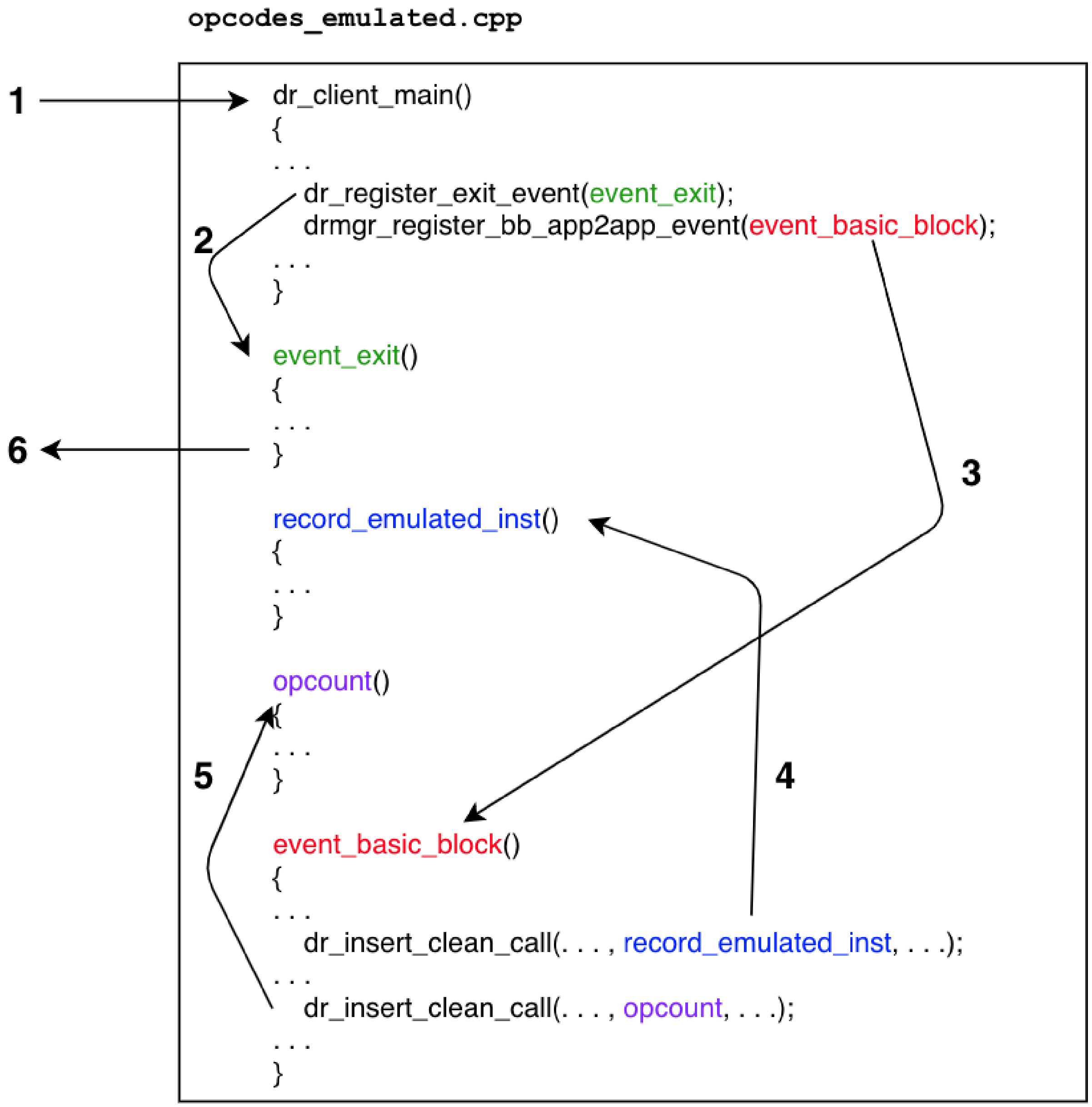
Arm Instruction Emulator

2.4 About instrumentation clients

This topic describes the basic structure of an instrumentation client, including the main events which occur during execution and what is typically done in each event.

Arm Instruction Emulator provides a set of instrumentation clients which can be used to analyze SVE binaries at runtime. The term ‘instrumentation client’ in this context refers to how Arm Instruction Emulator uses *DynamoRIO* to work as an analysis tool as well as an emulator. Arm Instruction Emulator is invoked with an instrumentation client and the SVE binary to be emulated and analyzed. The client is simply a shared object file which uses the DynamoRIO API to capture and process wanted run-time events.

To correctly modify the `libopcodes_emulated.so` client, you must understand its existing implementation, `opcodes_emulated.cpp` (*download this file*). The diagram below shows the key functions in `opcodes_emulated.cpp` and how they relate to each other.



opcodes_emulated.cpp

```
dr_client_main()
{
. . .
   dr_register_exit_event(event_exit);
   drmgr_register_bb_app2app_event(event_basic_block);
. . .
}

event_exit()
{
. . .
}

record_emulated_inst()
{
. . .
}

opcount()
{
. . .
}

event_basic_block()
{
. . .
   dr_insert_clean_call(. . . , record_emulated_inst, . . .);
. . .
   dr_insert_clean_call(. . . , opcount, . . .);
. . .
}
```

Figure 2-2 Diagram showing the key functions in opcodes_emulated.cpp

The easiest way to understand the client is to think of it as event-driven. Each function is called as a result of events which occur as the application is running:

1. DynamoRIO loads and runs the client, calling `dr_client_main()`, before beginning to execute the application.
2. In `dr_client_main()`, the client registers a function which is called just before the client stops running, `event_exit()`. Registering such a function for an event is usually referred to as a ‘callback function’.
3. In `dr_client_main()`, the client registers a callback function as each block of code in the application is prepared before being executed.
4. In `event_basic_block()`, the client registers a callback function which is executed for each emulated instruction which appears in the code of the application, `record_emulated_inst()`. The `record_emulated_inst()` function is the instrumentation which is the purpose of the client.

5. In `event_basic_block()`, the client registers a callback function which is executed for each native instruction which appears in the code of the application, `opcount()`. The `opcount()` function is the instrumentation which is the purpose of the client.
6. The application stops running and DynamoRIO calls `event_exit()`.

The preceding information is a simplified explanation of how a client operates. For a more detailed information, read the `opcodes_emulated.cpp` file, which can be *downloaded* from the Arm Developer website, and refer to details of key functions in the *DynamoRIO functions reference manual*, especially:

- **`dr_insert_clean_call()` which implements the instrumentation you**

  want.
- **`drmgr_register_bb_app2app_event()` which defines where the**

  instrumentation must be inserted.

Code Transformation and Code Execution

If you are new to the *DynamoRIO dynamic binary instrumentation tool platform* (DBI) in general and DynamoRIO in particular, ensure you understand the method by which instrumentation is added to application code.

Remember that instrumentation occurs in two phases, transformation and execution:

- Transformation - Instrumentation code is inserted into the application code.
- Execution - The application code runs, including the instrumentation code which was inserted during transformation.

DynamoRIO performs transformation and execution transparently, provided that you conform to the rules of its API.

In the preceding example, `event_basic_block()` is the transformation phase. Calls to `opcount()` or `record_emulated_inst()` are inserted for each instruction but are not called at transformation time. If or when a particular block of code is run at execution time, those functions are called, to increment and store the instruction and count.

This is a subtle distinction for new users. The best way to think of the difference is to recognize that `dr_insert_clean_call()` ```` will be called once when a block of application code is transformed but the function it registered may be called many times when the block is executed.

Related references

2.3 Building Custom Analysis Instrumentation on page 2-32

2.1 Analyze Scalable Vector Extension (SVE) applications with Arm® Instruction Emulator on page 2-19

3.2 Emulation Functions Reference on page 3-46

Related information

Arm Instruction Emulator

2.5 View the drrun command

This topic describes how to use the `-s` or `--show-drrun-cmd` option when running Arm Instruction Emulator on a binary, to output the full DynamoRIO `drrun` command that Arm Instruction Emulator uses. The `-s` option is provided to enable the full range of options for `drrun`, and to pass command-line arguments to clients. Without this feature, options and arguments are required to be passed through the `-a` or `-arg-iclient` options to the `armie` command.

Before you begin

- Work through *Get started with Arm® Instruction Emulator* on page 1-14 and *Analyze Scalable Vector Extension (SVE) applications with Arm® Instruction Emulator* on page 2-19 to gain an understanding of how Arm Instruction Emulator is used.

Procedure

1. Run Arm Instruction Emulator with the `-s` option, using the example described in *Get started with Arm® Instruction Emulator* on page 1-14:

   ```
   armie -msve-vector-bits=128 -s -- ./example
   ```

   Which returns:

   ```
   /path/to/your/arm-instruction-emulator-<xx.y>_Generic-AArch64_<OS>_aarch64-linux/bin64/
   drrun -max_bb_instrs 32 -max_trace_bbs 4 -c /path/to/your/arm-instruction-emulator-
   <xx.y>_Generic-AArch64_<OS>_aarch64-linux/lib64/release/libsve_128.so -- ./example
    i       a[i]    b[i]    c[i]
   =============================
   0       197     283     86
   1       262     277     15
   . . .
   1021    165     234     69
   1022    232     295     63
   1023    204     235     31
   ```

   Notice that `drrun` uses the emulation client `libsve_128.so` to run the example binary.
2. If an instrumentation client is specified:

   ```
   armie -msve-vector-bits=128 -s -i libinscount_emulated.so -- ./example
   ```

   Which returns:

   ```
   /path/to/your/arm-instruction-emulator-<xx.y>_Generic-AArch64_<OS>_aarch64-linux/bin64/
   drrun -client /path/to/your/arm-instruction-emulator-<xx.y>_Generic-AArch64_<OS>_aarch64-
   linux/lib64/release/libsve_128.so 0 "" -client /path/to/your/arm-instruction-emulator-
   <xx.y>_Generic-AArch64_<OS>_aarch64-linux/samples/bin64/libinscount_emulated.so 1 "" -
   max_bb_instrs 32 -max_trace_bbs 4 -- ./example
   Client inscount is running
   . . .
   1022    232     295     63
   1023    204     235     31
       2134094 instructions executed of which 1537 were emulated instructions
   ```

   Notice that `drrun` now uses two clients: the emulation client `libsve_128.so` and `libinscount_emulated.so` to run and count instructions executed by example.
3. The `-only_from_app` option for the `libinscount_emulated.so` client only counts instructions executed by the application, rather than also including linked libraries. You can copy and paste the above command and add `-only_from_app`:

   ```
   /path/to/your/arm-instruction-emulator-<xx.y>_Generic-AArch64_<OS>_aarch64-linux/bin64/
   drrun -client /path/to/your/arm-instruction-emulator-<xx.y>_Generic-AArch64_<OS>_aarch64-
   linux/lib64/release/libsve_128.so 0 "" -client /path/to/your/arm-instruction-emulator-
   <xx.y>_Generic-AArch64_<OS>_aarch64-linux/samples/bin64/libinscount_emulated.so 1 "-
   only_from_app" -max_bb_instrs 32 -max_trace_bbs 4 -- ./example
   Client inscount is running
       . . .
       1021    165     234     69
       1022    232     295     63
       1023    204     235     31
       42902 instructions executed of which 1537 were emulated instructions
   ```

Notice that the native AArch64 instruction count has dropped to 42902 from 2134094 due to the exclusion of library instructions.

Related references

2.3 Building Custom Analysis Instrumentation on page 2-32

1.2 Get started with Arm® Instruction Emulator on page 1-14

2.1 Analyze Scalable Vector Extension (SVE) applications with Arm® Instruction Emulator on page 2-19

Related information

Arm Instruction Emulator

Chapter 3
Reference

View reference guides for `armie` and the emulation functions for Arm Instruction Emulator.

It contains the following sections:

3.1 armie command reference

The `armie` command runs a compiled binary using Arm Instruction Emulator. Arm Instruction Emulator is an emulator that can execute AArch64 and Scalable Vector Extension (SVE) instructions on Armv8-A hardware.

Note

The following content is relevant for Arm Instruction Emulator versions 18.2 and later. If you are using a previous version of Arm Instruction Emulator, please *download the Arm Instruction Emulator v1.2.1 user guide* instead.

Usage

To execute and provide operational instructions to the Arm Instruction Emulator, use:

```
armie  [options] -- <command to execute>
```

Options

Table 3-1 armie command options

Option	Description

`-m<string>`
`-msve-vector-bits=<uint>`
`-mlist-vector-lengths`
	Architecture-specific options.
	`-msve-vector-bits=<uint>` is the vector length to use. `<uint>` must be a multiple of 128 bits up to 2048 bits.
	`-mlist-vector-lengths` lists all the valid vector lengths.

`-e <client>`, `--eclient <client>`	Use an emulation client based on the DynamoRIO API. The `libmemtrace_sve_<width>.so` SVE emulation clients (in lib64/release) can be used with the memory tracing instrumentation clients, where `<width>` is the vector width between 128 bits and 2048 bits (in increments of 128 bits). **Note** If an SVE emulation client is not specified, the default SVE client is used by `armie`.
`-i <client>`, `--iclient <client>`	Use an instrumentation client based on the DynamoRIO API. The following instrumentation clients are provided with Arm Instruction Emulator (in samples/bin64): • `libinscount_emulated.so` • `libinstrace_emulated.so` • `libmeminstrace_emulated.so` • `libmemtrace_emulated.so` • `libopcodes_emulated.so` • `libemulated_regs.so` To learn how to create your own custom instrumentation client, see *Building Custom Analysis Instrumentation* on page 2-32 and *Building an emulation-aware instrumentation client* on page 2-27
`-a, --arg-iclient <string>`	Pass an (optional) `<string>` argument to the instrumentation client.

Table 3-1 armie command options (continued)

Option	Description
`-x`, `--unsafe-ldstex`	**This options is DEPRECATED** Enables a workaround which avoids an exclusive load/store bug on certain AArch64 hardware. `-x` is always enabled and no longer must be set from the command line. For more information, see the ‘Known Issues’ in `RELEASE_NOTES.txt`.
`-y`, `--safe-ldstex`	Use `-y` in the unlikely event that `-x` or `--unsafe-ldstex` must be disabled. For more information, see the ‘Known Issues’ in `RELEASE_NOTES.txt`.
`-s`, `--show-drrun-cmd`	Write the full DynamoRIO `drrun` command used to execute `armie` to `stderr`. `-s` can be useful when debugging or developing clients.
`-h`, `--help`	Show the command help.
`-V`, `--version`	Print the version.

Example: Use -mlist-vector-lengths to list the valid vector lengths

To list all valid vector lengths, use:

```
armie -mlist-vector-lengths
```

Which returns:

```
128 256 384 512 640 768 896 1024 1152 1280 1408 1536 1664 1792 1920 2048
```

Example: Use ‘-msve-vector-bits’ to specify the number of vector bits

To run the compiled binary ‘sve_program’ with 256-bit vectors, use:

```
armie -msve-vector-bits=256 -- ./sve_program
```

Related references

1.2 Get started with Arm® Instruction Emulator on page 1-14

2.1 Analyze Scalable Vector Extension (SVE) applications with Arm® Instruction Emulator on page 2-19

3.2 Emulation Functions Reference

This topic describes the emulation functions applicable to Arm Instruction Emulator.

Arm Instruction Emulator (ArmIE) is based on the *DynamoRIO dynamic binary instrumentation tool platform* (DBI) and allows developers to use *DynamoRIO’ sAPI* to write instrumentation clients which run alongside the SVE emulation client to analyze SVE binaries at runtime.

- `drmgr_is_emulation_start()`
- `drmgr_is_emulation_end()`
- `drmgr_get_emulated_instr_data()`
- `emulated_instr_t`

drmgr_is_emulation_start()

Checks the instruction `instr` to see if it is an emulation start label created by `drmgr_insert_emulation_start()`. Typically used in an instrumentation client running with an emulation client.

Syntax

```
bool drmgr_is_emulation_start ( instr_t* instr )
```

Returns

Returns true if `instr` is an emulation start label, false if it is not an emulation start label.

drmgr_is_emulation_end()

Checks the instruction `instr` to see if it is an emulation end label created by `drmgr_insert_emulation_end()`. Typically used in an instrumentation client running with an emulation client.

Syntax

```
bool drmgr_is_emulation_end ( instr_t* instr )
```

Returns

Returns true if `instr` is an emulation end label, false if it is not an emulation end label.

drmgr_get_emulated_instr_data()

Loads `emulated` with the emulated instruction data from `instr` set by `drmgr_insert_emulation_start()`. When calling this function, the `size` field of `emulated` should be set using sizeof(). This enables the API to check for compatibility.

Syntax

```
bool drmgr_get_emulated_instr_data ( instr_t* instr, emulated_instr_t* emulated )
```

Parameters

`instr`

Input parameter. The label instruction that specifies the start of emulation.

`emulated`

Output parameter. The emulated instruction data.

Returns

Returns false if the caller’s `emulated_instr_t` is not compatible, true if it is compatible.

emulated_instr_t

Holds data about an emulated instruction, typically populated by an emulation client and read by an observational client.

Data fields:

Table 3-2 data fields for emulated_instr_t

size_t	size
app_pc	pc
instr_t*	instr

The emulated instruction `instr` is part of the label represented by `emulated_instr_t` and as such it will be freed when the label created by `drmgr_insert_emulation_start()` is freed.

Syntax

```
typedef struct _emulated_instr_t emulated_instr_t
```

Fields

`instr`

The emulated instruction.

```
instr_t* _emulated_instr_t::instr
```

`pc`

The PC address of the emulated instruction.

```
app_pc _emulated_instr_t::pc
```

`size`

The size of this struct, used for API compatibility checks.

```
size_t _emulated_instr_t::size
```

Related references

1.2 Get started with Arm® Instruction Emulator on page 1-14

Related information

Arm Instruction Emulator

API Usage Tutorial

Learn about SVE

Chapter 4
Further resources

Lists the additional resources available which you can to use to learn more about Arm Instruction Emulator or the Scalable Vector Extension (SVE).

It contains the following sections:

4.1 Arm® Instruction Emulator resources

This topic lists some useful resources where you can read more about Arm Instruction Emulator.

- *Arm Instruction Emulator*
- *Download Arm Instruction Emulator*
- *Release History*
- *Get help*
- *Blog: DynamoRIO and ArmIE*
- *Blog: Optimizing HPCG for Arm SVE*

4.2 Scalable Vector Extension (SVE) resources

This topic lists some useful resources you can use to learn more about the Scalable Vector Extension (SVE).

- *Porting and Tuning HPC Applications for Arm SVE*

  A guide to the tools and methodologies to porting your applications to SVE-enabled hardware, or to emulate with Arm Instruction Emulator.
- *Past presentations and Hackathon materials*

  Past presentations at Arm events, including downloadable SVE Hackathon materials.
- *White Paper: A sneak peek into SVE and VLA programming*

  An overview of SVE with information on the new registers, the new instructions, and the Vector Length Agnostic (VLA) programming technique, with some examples.
- *White Paper: Arm Scalable Vector Extension and application to Machine Learning*

  In this white paper, code examples are presented that show how to vectorize some of the core computational kernels that are part of a machine learning system. Thee examples are written using the Vector Length Agnostic (VLA) approach introduced by the Scalable Vector Extension (SVE).
- *Arm C Language Extensions (ACLE) for SVE*

  The SVE ACLE defines a set of C and C++ types and accessors for SVE vectors and predicates.
- *DWARF for the ARM® 64-bit Architecture (AArch64) with SVE support*

  This document describes the use of the DWARF debug table format in the Application Binary Interface (ABI) for the Arm 64-bit architecture.
- *Procedure Call Standard for the ARM 64-bit Architecture (AArch64) with SVE support*

  This document describes the Procedure Call Standard use by the Application Binary Interface (ABI) for the Arm 64-bit architecture.
- *Arm Architecture Reference Manual Supplement - The Scalable Vector Extension (SVE), for ARMv8-A*

  This supplement describes the Scalable Vector Extension to the Armv8-A architecture profile.