Hands-on Lab
Programming and Understanding a Real Processing-in-Memory Architecture

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1. Introduction
In this lab, you will work hands-on with a real processing-in-memory (PIM) architecture. You will program the UPMEM PIM architecture [1,2,3,4] for several workloads and will experiment with them. Your main goals are (1) to become familiar with the UPMEM PIM system organization (as an example of real-world memory-centric computing system), (2) to understand the UPMEM programming model and write your own code, and (3) to understand the microarchitecture and instruction set architecture (ISA) of UPMEM’s PIM core (called DRAM Processing Unit, DPU).

As we introduced in this tutorial, the UPMEM PIM architecture is composed of multiple DPUs (up to 2,560), each of which has access to its own DRAM bank (called Main RAM, MRAAM) and its own scratchpad memory (called Working RAM, WRAAM). You can find a full description of the UPMEM PIM system in [3,4].

2. Your Task 04: Accessing the UPMEM PIM Server
UPMEM has granted us with remote access to servers with UPMEM DIMMs in a datacenter.

Our username is: ethaspl023 and we are part of the group upmem0063 (ETH ASPLOS 2023 team). You can download the SSH private key used to connect the machines from here: https://events.safari.ethz.ch/asplos-pim-tutorial/lib/exe/fetch.php/media=upmemcloud_ethaspl023.zip (download and unzip)

Put the following base configuration in your .ssh/config file:

```
Host upmemcloud
  User ethaspl023
  Hostname 5h.cloud.upmem.com
  IdentityFile ~/.ssh/upmemcloud_ethaspl023
  StrictHostKeyChecking no
  UserKnownHostsFile=/dev/null
```

You can connect to the booked machine anytime until 6am (Vancouver time) on Monday, March 27, 2023.

The booked machine for this period is upmemcloud05 with ‘20 UPMEM-P2I’. You can connect to it by doing: ssh upmemcloud05, if you have the private SSH key and the .ssh/config file provided above.

The machine is installed with the latest and greatest UPMEM SDK version (also available on https://sdk.upmem.com). As an introduction, the public demonstration program doing a trivial checksum in parallel on one DPU can be run by doing:

git clone https://github.com/upmem/dpu.demo.git
cd /dpu.demo/checksum
NR_DPUS=1 make test

Please read the entire Section 2.1 before you access the server.

In summary, the steps are:

1. Paste the configuration into .ssh/config.
2. Copy the private key upmemcloud_ethaspl023 to your .ssh folder. You may need to change permissions, as indicated in Section 2.1.
3. ssh upmemcloud05 from the terminal. Note that the server is already reserved for us. No booking is needed.
How to Access the UPMEM PIM Server?

1. Paste the configuration into `.ssh/config`
   Host upmemcloud*
   User ethasplos23
   Hostname %h.cloud.upmem.com
   IdentityFile ~/.ssh/upmemcloud_ethasplos23
   StrictHostKeyChecking no
   UserKnownHostsFile=/dev/null

2. Copy the private key `upmemcloud_ethasplos23` to your `.ssh` folder. You may need to change permissions

3. `ssh upmemcloud5` from the terminal
Template Files

• Contain templates for task 1 and task 2
• Task 2’s template can be used for the remaining tasks
Task 1: CPU-DPU and DPU-CPU Transfers

• Use serial, parallel, and broadcast transfers

Your tasks are as follows:

1. Write a host program that exercises all types of data transfers between the host main memory and one or multiple MRAM banks. Concretely, there are three types of data transfers [2]: (1) serial, (2) parallel, and (3) broadcast. Serial and parallel transfers move data from main memory to the MRAM banks or vice versa. Broadcast transfers can only happen from the main memory to the MRAM banks.

2. Evaluate all different types of data transfers for data transfers of size (1) 1MB, (2) 24MB, (3) 48MB per DPU. Use different numbers of DPUs between 1 and 64.
Task 2: AXPY

Your tasks are as follows:

1. Write a DPU kernel that executes the AXPY operation \( y = y + \alpha x \) [5] on every element of a vector. You have to (1) transfer two input vectors, \( Y \) and \( X \), to the MRAM bank/s, (2) perform the AXPY operation with a variable number of tasklets, (3) write the results to the output vector, \( Y \), and (4) transfer the output vector back to the host main memory.

• VA is a good reference code for this task
Task 3: Operations and Datatypes

Your tasks are as follows:

1. Modify your AXPY DPU kernel to make it a vector addition \( y = y + x \) and to support other operations besides addition (i.e., subtraction, multiplication, division).

2. Evaluate the performance of your new kernel for different operations (addition, subtraction, multiplication, division) and data types (char, short, int, long long int, float, double).

• You will observe significant variations in arithmetic throughput for different operations and datatypes.
Task 4: Vector Reduction

Your tasks are as follows:

1. Your vector reduction DPU kernel should have four different versions: (1) final reduction with a single tasklet, (2) final tree-based reduction with barriers, (3) final tree-based reduction with handshakes, (4) final reduction with mutexes.

• Performance differences due to the final reduction step
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