StarPU Handbook - StarPU Applications

for StarPU 1.4.9

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This manual documents the usage of StarPU version 1.4.9. Its contents was last updated on 2025-10-24.

Chapter 1

Organization

This part presents how to write a StarPU application from an existing application.
Some of the applications presented in the following chapters and some others are available in the git repository `https://gitlab.inria.fr/starpu/starpu-applications`
A full StarPU tutorial which can be run with Docker is available at `https://starpu.gitlabpages.inria.fr/tutorials/docker/`

Chapter 2

A Vector Scaling Application

2.1 Base version

The non-StarPU version shows a basic example that we will be using to illustrate how to use StarPU. It simply allocates a vector, and calls a scaling function over it.

```
void vector_scal_cpu(float *val, unsigned n, float factor)
{
        unsigned i;
        for (i = 0; i < n; i++)
                val[i] *= factor;
}
#define    NX    2048
int main(void)
{
        float *vector;
        unsigned i;
        vector = malloc(sizeof(vector[0]) * NX);
        for (i = 0; i < NX; i++)
                vector[i] = 1.0f;
        fprintf(stderr, "BEFORE : First element was %f\n", vector[0]);
        float factor = 3.14;
        vector_scal_cpu(vector, NX, factor);
        fprintf(stderr, "AFTER First element is %f\n", vector[0]);
        free(vector);
        return 0;
}
```

2.2 StarPU C version

2.2.1 Computation Kernels

We are going to transform here the computation function `vector_scal_cpu`.

```
void vector_scal_cpu(float *val, unsigned n, float factor)
{
        unsigned i;
        for (i = 0; i < n; i++)
                val[i] *= factor;
}
```

The StarPU corresponding function takes as parameters a list of DSM interfaces and a non-DSM parameter.

```
void vector_scal_cpu(void *buffers[], void *cl_arg)
{
```

The first DSM parameter is the vector and is available through `buffer`[0]. StarPU provides functions to get the vector data, and extract the pointer and size of the vector.

```
        struct starpu_vector_interface *vector = buffers[0];
        float *val = (float *)STARPU_VECTOR_GET_PTR(vector);
        unsigned n = STARPU_VECTOR_GET_NX(vector);
```

The non-DSM parameters are stored in the second argument of the function, and need to be unpacked.

```
        float factor;
        starpu_codelet_unpack_args(cl_arg, &factor);
```

It is then possible to perform the vector scaling as in the original function.

```
        unsigned i;
        for (i = 0; i < n; i++)
                val[i] *= factor;
```

Original code	StarPU code

`void vector_scal_cpu(float *val, unsigned n, float factor)`
`{`
` unsigned i;`
` for (i = 0; i < n; i++)`
` val[i] *= factor;`
`}`
	`void vector_scal_cpu(void *buffers[], void *cl_arg)`
	`{`
	` struct starpu_vector_interface *vector = buffers[0];`
	` float *val = (float *)STARPU_VECTOR_GET_PTR(vector);`
	` unsigned n = STARPU_VECTOR_GET_NX(vector);`
	` float factor;`
	` starpu_codelet_unpack_args(cl_arg, &factor);`
	` unsigned i;`
	` for (i = 0; i < n; i++)`
	` val[i] *= factor;`
	`}`

The GPU and OpenCL implementations can be seen in FullSourceCodeVectorScal.

2.2.2 Main Code

Let's look now at the main code.

- The `cl` codelet structure simply gathers pointers on the functions mentioned above, and notes that the functions takes only one DSM parameter.

```
static struct starpu_codelet cl =
{
        .cpu_funcs = {vector_scal_cpu},
        .cuda_funcs = {vector_scal_cuda},
        .opencl_funcs = {vector_scal_opencl},
        .nbuffers = 1,
        .modes = {STARPU_RW}
};
```

- The `main` function starts with initializing StarPU with the default parameters.

```
        int ret = starpu_init(NULL);
        STARPU_CHECK_RETURN_VALUE(ret, "starpu_init");
```

- It then allocates the vector and fills it like the original code.

```
        vector = malloc(sizeof(vector[0]) * NX);
        for (i = 0; i < NX; i++)
                vector[i] = 1.0f;
        fprintf(stderr, "BEFORE : First element was %f\n", vector[0]);
```

- It then registers the data to StarPU, and gets back a DSM handle. From now on, the application is not supposed to access `vector` directly, since its content may be copied and modified by a task on a GPU, the main-memory copy then being outdated.

```
        starpu_data_handle_t vector_handle;
        starpu_vector_data_register(&vector_handle, STARPU_MAIN_RAM, (uintptr_t)vector, NX,
sizeof(vector[0]));
```

- It then submits a (asynchronous) task to StarPU.

```
        float factor = 3.14;
        ret = starpu_task_insert(&cl,
                                 STARPU_RW, vector_handle,
                                 STARPU_VALUE, &factor, sizeof(factor),
                                 0);
        STARPU_CHECK_RETURN_VALUE(ret, "starpu_task_insert");
```

- It waits for task completion, and unregisters the vector from StarPU, which brings back the modified version to main memory, so the result can be read.

```
        starpu_task_wait_for_all();
        starpu_data_unregister(vector_handle);
```

- Eventually, it shuts down StarPU:

```
        starpu_shutdown();
```

Original code	StarPU code

<pre>#define NX 2048
int main(void)
{
 float *vector;
 unsigned i;
 vector = malloc(sizeof(vector[0]) * NX);
 for (i = 0; i < NX; i++)
 vector[i] = 1.0f;
 fprintf(stderr, "BEFORE : First element was %f\n",
      vector[0]);
 float factor = 3.14;
 vector_scal_cpu(vector, NX, factor);
 fprintf(stderr, "AFTER First element is %f\n",
      vector[0]);
 free(vector);
 return 0;
}</pre>
	<pre>#include <starpu.h>
	extern void vector_scal_cpu(void *buffers[], void
	      *_args);
	extern void vector_scal_cuda(void *buffers[], void
	      *_args);
	extern void vector_scal_opencl(void *buffers[],
	      void *_args);
	static struct starpu_codelet cl =
	{
	 .cpu_funcs = {vector_scal_cpu},
	 .cuda_funcs = {vector_scal_cuda},
	 .opencl_funcs = {vector_scal_opencl},
	 .nbuffers = 1,
	 .modes = {STARPU_RW}
	};
	#ifdef STARPU_USE_OPENCL
	struct starpu_opencl_program programs;
	#endif
	#define NX 2048
	int main(void)
	{
	 float *vector;
	 unsigned i;
	 int ret = starpu_init(NULL);
	 STARPU_CHECK_RETURN_VALUE(ret, "starpu_init");
	#ifdef STARPU_USE_OPENCL
	 starpu_opencl_load_opencl_from_file("vector_scal_opencl_kernel.cl",
	      &programs, NULL);
	#endif
	 vector = malloc(sizeof(vector[0]) * NX);
	 for (i = 0; i < NX; i++)
	 vector[i] = 1.0f;
	 fprintf(stderr, "BEFORE : First element was %f\n",
	      vector[0]);
	 starpu_data_handle_t vector_handle;
	 starpu_vector_data_register(&vector_handle,
	      STARPU_MAIN_RAM, (uintptr_t)vector, NX,
	      sizeof(vector[0]));
	 float factor = 3.14;
	 ret = starpu_task_insert(&cl,
	 STARPU_RW, vector_handle,
	 STARPU_VALUE, &factor, sizeof(factor),
	 0);
	 STARPU_CHECK_RETURN_VALUE(ret,
	      "starpu_task_insert");
	 starpu_task_wait_for_all();
	 starpu_data_unregister(vector_handle);
	 fprintf(stderr, "AFTER First element is %f\n",
	      vector[0]);
	 free(vector);
	#ifdef STARPU_USE_OPENCL
	 starpu_opencl_unload_opencl(&programs);
	#endif
	 starpu_shutdown();
	 return 0;
	}</pre>

2.3 Building and Running

We will use the StarPU docker image.

```
$ docker run -it registry.gitlab.inria.fr/starpu/starpu-docker/starpu:latest
```

If your machine has GPU devices, you can use the following command to enable the GPU devices within the docker image.

```
$ docker run -it --gpus all registry.gitlab.inria.fr/starpu/starpu-docker/starpu:latest
```

From your docker image, you can then call the following commands.

```
$ cd tutorial/files
$ make vector_scal_task_insert
$ ./vector_scal_task_insert
```

You can set the environment variable STARPU_WORKER_STATS to `1` when running your application to see the number of tasks executed by each device.

```
$ STARPU_WORKER_STATS=1 ./vector_scal_task_insert
```

If your machine has GPU devices, you can force the execution on the GPU devices by setting the number of CPU workers to 0.

```
# to force the implementation on a GPU device, by default, it will enable CUDA
$ STARPU_WORKER_STATS=1 STARPU_NCPU=0 ./vector_scal_task_insert

# to force the implementation on a OpenCL device
$ STARPU_WORKER_STATS=1 STARPU_NCPU=0 STARPU_NCUDA=0 ./vector_scal_task_insert
```

Chapter 3

A Stencil Application

3.1 The Original Application

```
#define _(row,col,ld) ((row)+(col)*(ld))
void stencil5_cpu(double *xy, double *xm1y, double *xp1y, double *xym1, double *xyp1)
{
  *xy = (*xy + *xm1y + *xp1y + *xym1 + *xyp1) / 5;
}
int main(int argc, char **argv)
{
  int niter, n;
  int x, y, loop;
  read_params(argc, argv, &n, &niter);
  double *A = calloc(n*n, sizeof(*A));
  fill(A, n, n);
  for(loop=0 ; loop<niter; loop++)
  {
    for (x = 0; x < n; x++)
    {
      for (y = 0; y < n; y++)
      {
        int xm1 = (x==0) ?  n-1 :  x-1;
        int xp1 = (x==n-1) ?  0 :  x+1;
        int ym1 = (y==0) ?  n-1 :  y-1;
        int yp1 = (y==n-1) ?  0 :  y+1;
        stencil5_cpu(&A[_(x,y,n)],
                     &A[_(xm1,y,n)], &A[_(xp1,y,n)],
                     &A[_(x,ym1,n)], &A[_(x,yp1,n)]);
      }
    }
  }
  return 0;
}
```

3.2 The StarPU Application

The computation function must be defined through a codelet.

```
#define _(row,col,ld) ((row)+(col)*(ld))
void stencil5_cpu(void *descr[], void *_args)
{
  (void)_args;
  double *xy = (double *)STARPU_VARIABLE_GET_PTR(descr[0]);
  double *xm1y = (double *)STARPU_VARIABLE_GET_PTR(descr[1]);
  double *xp1y = (double *)STARPU_VARIABLE_GET_PTR(descr[2]);
  double *xym1 = (double *)STARPU_VARIABLE_GET_PTR(descr[3]);
  double *xyp1 = (double *)STARPU_VARIABLE_GET_PTR(descr[4]);
  *xy = (*xy + *xm1y + *xp1y + *xym1 + *xyp1) / 5;
}
struct starpu_codelet stencil5_cl =
{
  .cpu_funcs = {stencil5_cpu},
  .nbuffers = 5,
  .modes = {STARPU_RW, STARPU_R, STARPU_R, STARPU_R, STARPU_R},
  .model = &starpu_perfmodel_nop,
};
```

Data must be registered to StarPU.

```
  data_handles = malloc(n*n*sizeof(*data_handles));
  for(x = 0; x < n; x++)
  {
    for (y = 0; y < n; y++)
    {
```

```
      starpu_variable_data_register(&data_handles[_(x,y,n)],
                                    STARPU_MAIN_RAM,
                                    (uintptr_t)&(A[_(x,y,n)]), sizeof(double));
    }
  }
```

Instead of directly calling the function, a StarPU task must be created.

```
        int xm1 = (x==0) ?  n-1 :  x-1;
        int xp1 = (x==n-1) ?  0 :  x+1;
        int ym1 = (y==0) ?  n-1 :  y-1;
        int yp1 = (y==n-1) ?  0 :  y+1;
        starpu_task_insert(&stencil5_cl,
                           STARPU_RW, data_handles[_(x,y,n)],
                           STARPU_R, data_handles[_(xm1,y,n)],
                           STARPU_R, data_handles[_(xp1,y,n)],
                           STARPU_R, data_handles[_(x,ym1,n)],
                           STARPU_R, data_handles[_(x,yp1,n)],
                           0);
```

And finally data must be released from StarPU.

```
  for(x = 0; x < n; x++)
  {
    for (y = 0; y < n; y++)
    {
      starpu_data_unregister(data_handles[_(x,y,n)]);
    }
  }
```

The whole StarPU application looks as follows.

```
#define _(row,col,ld) ((row)+(col)*(ld))
void stencil5_cpu(void *descr[], void *_args)
{
  (void)_args;
  double *xy = (double *)STARPU_VARIABLE_GET_PTR(descr[0]);
  double *xm1y = (double *)STARPU_VARIABLE_GET_PTR(descr[1]);
  double *xp1y = (double *)STARPU_VARIABLE_GET_PTR(descr[2]);
  double *xym1 = (double *)STARPU_VARIABLE_GET_PTR(descr[3]);
  double *xyp1 = (double *)STARPU_VARIABLE_GET_PTR(descr[4]);
  *xy = (*xy + *xm1y + *xp1y + *xym1 + *xyp1) / 5;
}
struct starpu_codelet stencil5_cl =
{
  .cpu_funcs = {stencil5_cpu},
  .nbuffers = 5,
  .modes = {STARPU_RW, STARPU_R, STARPU_R, STARPU_R, STARPU_R},
  .model = &starpu_perfmodel_nop,
};
int main(int argc, char **argv)
{
  starpu_data_handle_t *data_handles;
  int ret;
  int niter, n;
  int x, y, loop;
  ret = starpu_init(NULL);
  STARPU_CHECK_RETURN_VALUE(ret, "starpu_init");
  read_params(argc, argv, &verbose, &n, &niter);
  double *A = calloc(n*n, sizeof(*A));
  fill(A, n, n);
  data_handles = malloc(n*n*sizeof(*data_handles));
  for(x = 0; x < n; x++)
  {
    for (y = 0; y < n; y++)
    {
      starpu_variable_data_register(&data_handles[_(x,y,n)],
                                    STARPU_MAIN_RAM,
                                    (uintptr_t)&(A[_(x,y,n)]), sizeof(double));
    }
  }
  for(loop=0 ; loop<niter; loop++)
  {
    for (x = 0; x < n; x++)
    {
      for (y = 0; y < n; y++)
      {
        int xm1 = (x==0) ?  n-1 :  x-1;
        int xp1 = (x==n-1) ?  0 :  x+1;
        int ym1 = (y==0) ?  n-1 :  y-1;
        int yp1 = (y==n-1) ?  0 :  y+1;
        starpu_task_insert(&stencil5_cl,
                           STARPU_RW, data_handles[_(x,y,n)],
                           STARPU_R, data_handles[_(xm1,y,n)],
                           STARPU_R, data_handles[_(xp1,y,n)],
                           STARPU_R, data_handles[_(x,ym1,n)],
                           STARPU_R, data_handles[_(x,yp1,n)],
                           0);
      }
    }
  }
  starpu_task_wait_for_all();
```

```
  for(x = 0; x < n; x++)
  {
    for (y = 0; y < n; y++)
    {
      starpu_data_unregister(data_handles[_(x,y,n)]);
    }
  }
  starpu_shutdown();
  return 0;
}
```

3.3 The StarPU MPI Application

The initialisation for StarPU-MPI is as follows.

```
  int ret = starpu_mpi_init_conf(&argc, &argv, 1, MPI_COMM_WORLD, NULL);
  STARPU_CHECK_RETURN_VALUE(ret, "starpu_mpi_init_conf");
  starpu_mpi_comm_rank(MPI_COMM_WORLD, &my_rank);
  starpu_mpi_comm_size(MPI_COMM_WORLD, &size);
```

An additional call to starpu_mpi_data_register() is necessary.

```
      starpu_variable_data_register(&data_handles[_(x,y,n)],
                                    STARPU_MAIN_RAM,
                                    (uintptr_t)&(A[_(x,y,n)]), sizeof(double));
      int mpi_rank = my_distrib(x, y, size);
      starpu_mpi_data_register(data_handles[_(x,y,n)], (y*n)+x, mpi_rank);
```

And to insert a task, the function starpu_mpi_task_insert() must be used.

```
        starpu_mpi_task_insert(MPI_COMM_WORLD, &stencil5_cl,
                               STARPU_RW, data_handles[_(x,y,n)],
                               STARPU_R, data_handles[_(xm1,y,n)],
                               STARPU_R, data_handles[_(xp1,y,n)],
                               STARPU_R, data_handles[_(x,ym1,n)],
                               STARPU_R, data_handles[_(x,yp1,n)],
                               0);
```

The whole StarPU-MPI application looks as follows.

```
#define _(row,col,ld) ((row)+(col)*(ld))
void stencil5_cpu(void *descr[], void *_args); // Same as in sequential StarPU
struct starpu_codelet stencil5_cl;  // Same as in sequential StarPU
/* Returns the MPI node number where data indexes index is */
int my_distrib(int x, int y, int nb_nodes)
{
  return ((int)(x / sqrt(nb_nodes) + (y / sqrt(nb_nodes)) * sqrt(nb_nodes))) % nb_nodes;
}
int main(int argc, char **argv)
{
  starpu_data_handle_t *data_handles;
  int niter, n;
  int my_rank, size, x, y, loop;
  int ret = starpu_mpi_init_conf(&argc, &argv, 1, MPI_COMM_WORLD, NULL);
  STARPU_CHECK_RETURN_VALUE(ret, "starpu_mpi_init_conf");
  starpu_mpi_comm_rank(MPI_COMM_WORLD, &my_rank);
  starpu_mpi_comm_size(MPI_COMM_WORLD, &size);
  read_params(argc, argv, &n, &niter);
  double *A = calloc(n*n, sizeof(*A));
  fill(A, n, n);
  data_handles = malloc(n*n*sizeof(*data_handles));
  for(x = 0; x < n; x++)
  {
    for (y = 0; y < n; y++)
    {
      starpu_variable_data_register(&data_handles[_(x,y,n)],
                                    STARPU_MAIN_RAM,
                                    (uintptr_t)&(A[_(x,y,n)]), sizeof(double));
      int mpi_rank = my_distrib(x, y, size);
      starpu_mpi_data_register(data_handles[_(x,y,n)], (y*n)+x, mpi_rank);
    }
  }
  for(loop=0 ; loop<niter; loop++)
  {
    for (x = 0; x < n; x++)
    {
      for (y = 0; y < n; y++)
      {
        int xm1 = (x==0) ?  n-1 :  x-1;
        int xp1 = (x==n-1) ?  0 :  x+1;
        int ym1 = (y==0) ?  n-1 :  y-1;
        int yp1 = (y==n-1) ?  0 :  y+1;
        starpu_mpi_task_insert(MPI_COMM_WORLD, &stencil5_cl,
                               STARPU_RW, data_handles[_(x,y,n)],
                               STARPU_R, data_handles[_(xm1,y,n)],
                               STARPU_R, data_handles[_(xp1,y,n)],
                               STARPU_R, data_handles[_(x,ym1,n)],
                               STARPU_R, data_handles[_(x,yp1,n)],
                               0);
      }
```

```
    }
  }
  starpu_task_wait_for_all();
  /* bring data back to node 0 and unregister it */
  for(x = 0; x < n; x++)
  {
    for (y = 0; y < n; y++)
    {
        starpu_mpi_data_migrate(MPI_COMM_WORLD, data_handles[_(x,y,n)], 0);
        starpu_data_unregister(data_handles[_(x,y,n)]);
    }
  }
  starpu_mpi_shutdown();
  return 0;
}
```

3.4 Running the application

```
$ docker run -it registry.gitlab.inria.fr/starpu/starpu-docker/starpu:latest
```

If your machine has GPU devices, you can use the following command to enable the GPU devices within the docker image.

```
$ docker run -it --gpus all registry.gitlab.inria.fr/starpu/starpu-docker/starpu:latest
```

From your docker image, you can then call the following commands.

```
$ git clone https://gitlab.inria.fr/starpu/starpu-applications.git
$ cd starpu-applications/stencil5
$ make
```

To run the non-StarPU application

```
$ ./stencil5 -v
```

To run the sequential StarPU application

```
$ ./stencil5_starpu -v
```

To run the StarPU MPI application. Setting the variable STARPU_COMM_STATS to 1 will display the amount of communication between the different MPI processes.

```
$ STARPU_COMM_STATS=1 mpirun -np 4 ./stencil5_starpu_mpi -v 4 3
```

Part I

Appendix

Chapter 4

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