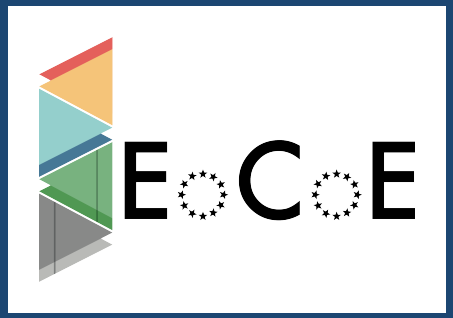

StarPU task-based programming hands-on session

Introduction to task-based programming with StarPU

STORM Team
Inria – LaBRI
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1

Introduction to task-based programming with StarPU

Basic Example: Scaling a Vector

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16 starpu_task_wait_for_all();
17 starpu_data_unregister(vector_handle);
18
19 /* ... display vector ... */
```

Terminology

- Codelet
- Task
- Data handle

Definition: A Codelet

A **Codelet**...

- ... relates an abstract computation kernel to its implementation(s)
- ... can be instantiated into one or more **tasks**
- ... defines characteristics common to a set of **task**s

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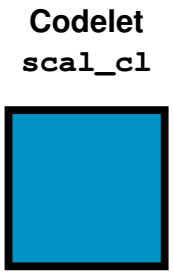

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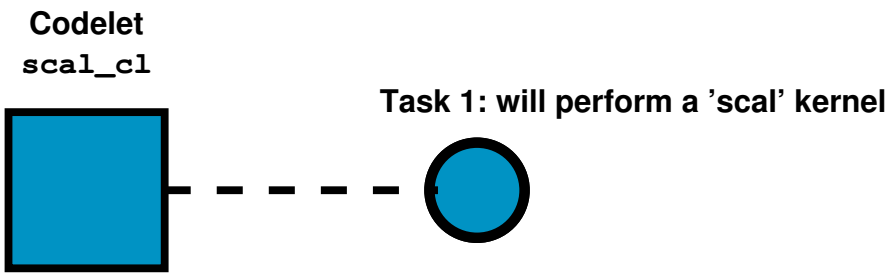

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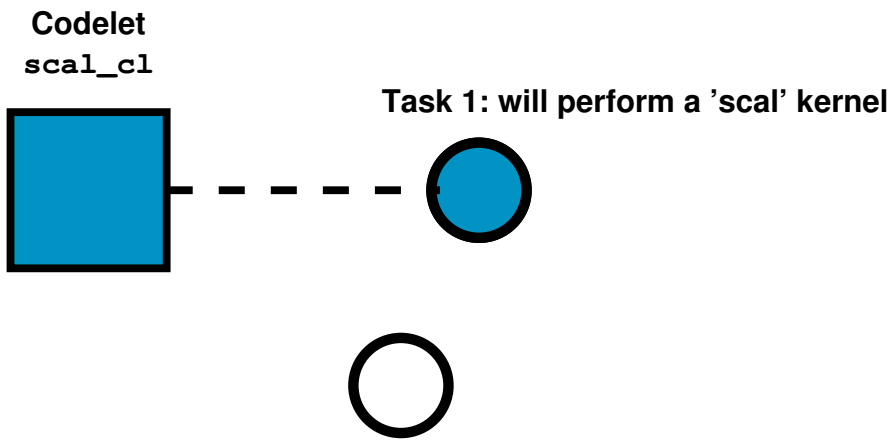

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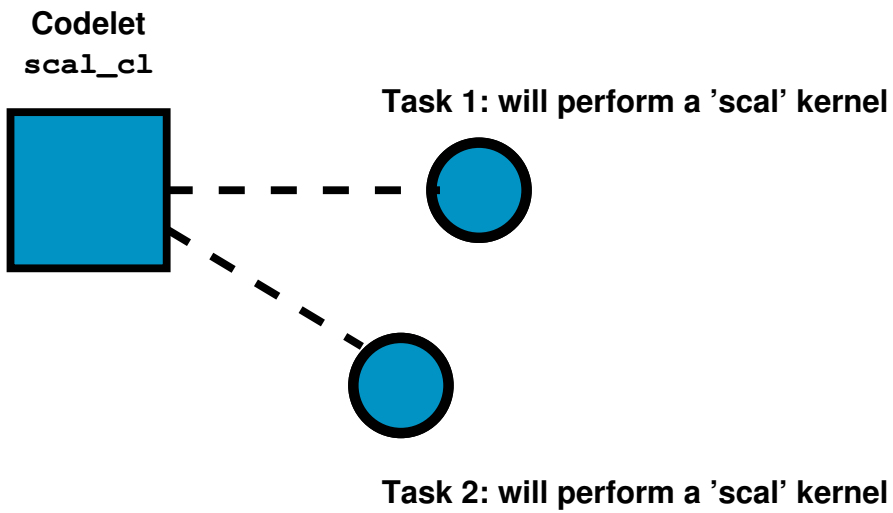

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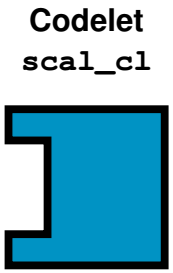

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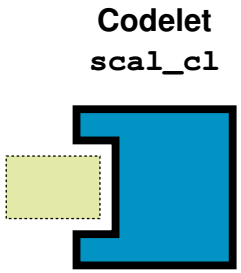

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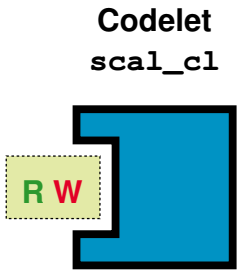

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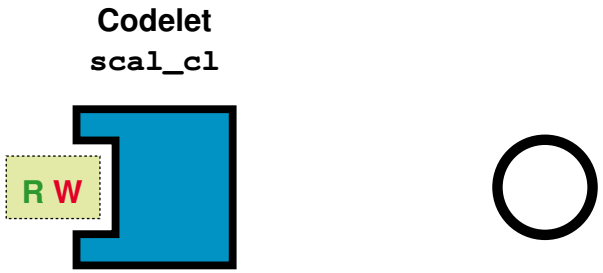

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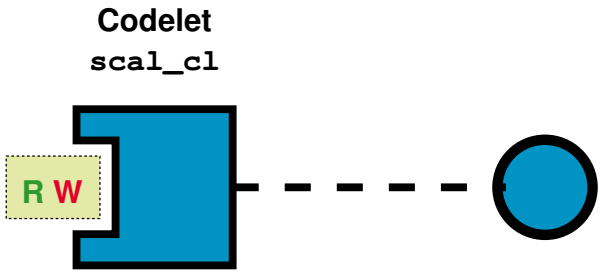

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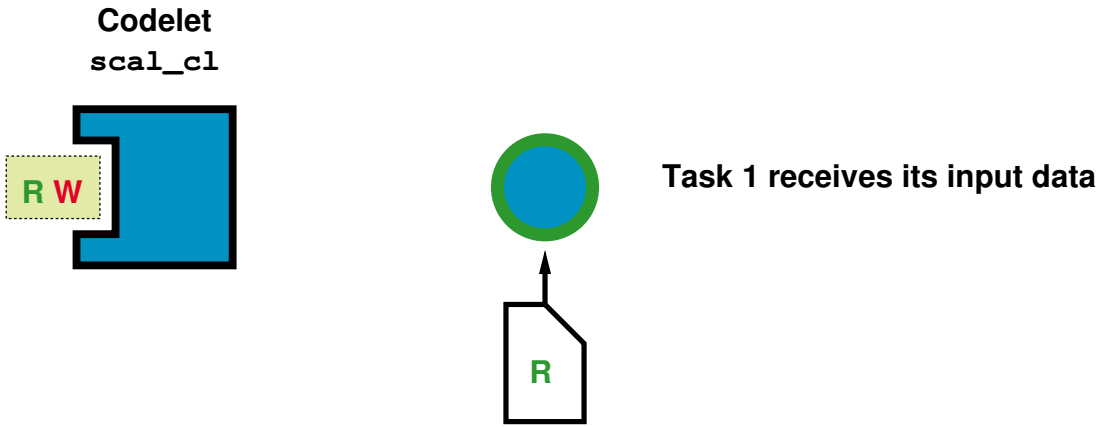

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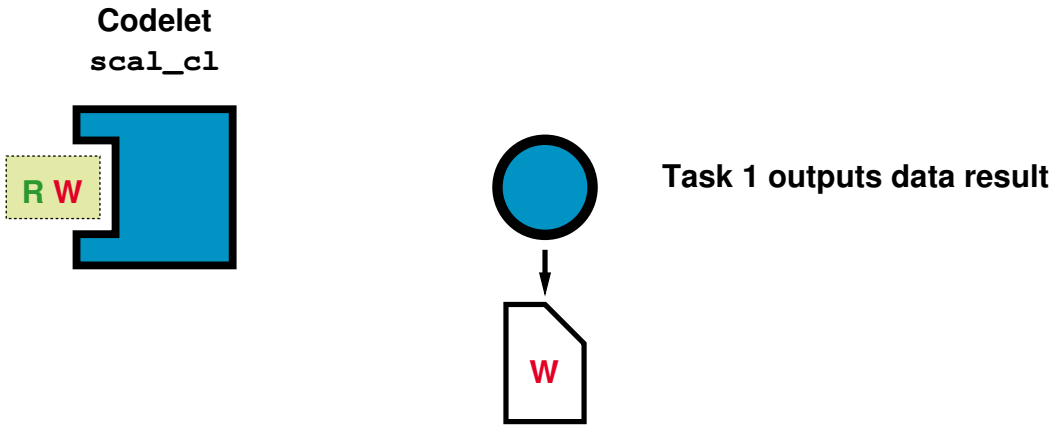

Definition: A Data Handle

A **Data Handle**...

- ... designates a piece of data managed by StarPU
- ... is typed (vector, matrix, etc.)
- ... can be passed as input/output for a **Task**

Elementary API

- Declaring a codelet
- Declaring and Managing Data
- Writing a Kernel Function
- Submitting a task
- Waiting for submitted tasks

Declaring a Codelet

Define a **struct** starpu_codelet

```
1 struct starpu_codelet scal_cl = {
2       ...
3 };
```

Declaring a Codelet

Define a **struct** **starpu_codelet**

- Plug the kernel function
  - Here: scal_cpu_func

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1 struct starpu_codelet scal_cl = {
2       .cpu_func  = { scal_cpu_func },
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Declaring a Codelet

Define a **struct** **starpu_codelet**

- Plug the kernel function
  - Here: scal_cpu_func
- Declare the number of data pieces used by the kernel
  - Here: A single vector

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1 struct starpu_codelet scal_cl = {
2       .cpu_func  = { scal_cpu_func },
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4       ...
5 };
```

Declaring a Codelet

Define a **struct** **starpu_codelet**

- Plug the kernel function
  - Here: scal_cpu_func
- Declare the number of data pieces used by the kernel
  - Here: A single vector
- Declare how the kernel accesses the piece of data
  - Here: The vector is scaled in-place, thus R/W

```
1 struct starpu_codelet scal_cl = {
2       .cpu_func  = { scal_cpu_func },
3       .nbuffers = 1,
4       .modes = { STARPU_RW },
5 };
```

Declaring and Managing Data

Put data under StarPU control

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- Initialize a piece of data

```
1 float vector[NX];
2 /* ... fill data ... */
```

Declaring and Managing Data

Put data under StarPU control

- Initialize a piece of data
- Register the piece of data and get a handle
  - The vector is now under StarPU control

```
1 float vector[NX];
2 /* ... fill data ... */
3
4 starpu_data_handle_t vector_handle;
5 starpu_vector_data_register(&vector_handle, 0,
6                             (uintptr_t)vector, NX, sizeof(vector[0]));
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Declaring and Managing Data

Put data under StarPU control

- Initialize a piece of data
- Register the piece of data and get a handle
  - The vector is now under StarPU control
- Use data through the handle
- Unregister the piece of data
  - The handle is destroyed
  - The vector is now back under user control

```
1  float vector[NX];
2  /* ... fill data ... */
3
4  starpu_data_handle_t vector_handle;
5  starpu_vector_data_register(&vector_handle, 0,
6                              (uintptr_t)vector, NX, sizeof(vector[0]));
7
8  /* ... use the vector through the handle ... */
9
10 starpu_data_unregister(vector_handle);
```

Writing a Kernel Function

- Every kernel function has the same C prototype

```
1 void scal_cpu_func(void *buffers[], void *cl_arg) {
2     ...
3 }
```

Writing a Kernel Function

- Every kernel function has the same C prototype
- Retrieve the vector's handle

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- Retrieve the vector's handle
- Get vector's number of elements and base pointer

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Writing a Kernel Function

- Every kernel function has the same C prototype
- Retrieve the vector's handle
- Get vector's number of elements and base pointer
- Get the scaling factor as inline argument
- Compute the vector scaling

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4    unsigned n    = STARPU_VECTOR_GET_NX(vector_handle);
5    float *vector = STARPU_VECTOR_GET_PTR(vector_handle);
6
7    float *ptr_factor = cl_arg;
8
9    unsigned i;
10   for (i = 0; i < n; i++)
11     vector[i] *= *ptr_factor;
12 }
```

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The **starpu_task_insert** call

- **Inserts** a task in the StarPU DAG

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Arguments

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1 starpu_task_insert(&scal_cl
2                    ...);
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Submitting a task

The starpu_task_insert call

- **Inserts** a task in the StarPU DAG

Arguments

- The codelet structure
- The StarPU-managed data

```
1 starpu_task_insert(&scal_cl,
2                     STARPU_RW, vector_handle,
3                     ...);
```

Submitting a task

The **starpu_task_insert** call

- **Inserts** a task in the StarPU DAG

Arguments

- The codelet structure
- The StarPU-managed data
- The small-size inline data

```
1 starpu_task_insert(&scal_cl,
2                     STARPU_RW, vector_handle,
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- 0 to mark the end of arguments

Notes

- The task is submitted non-blockingly
- Dependencies are enforced with previously submitted tasks' data...
- ... following the natural order of the program
- This is the **Sequential Task Flow Paradigm**

Waiting for Submitted Task Completion

- Tasks are submitted non-blockingly

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1 /* non-blocking task submits */
2 starpu_task_insert(...);
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4 starpu_task_insert(...);
5 ...
```

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- Tasks are submitted non-blockingly
- Wait for all submitted tasks to complete their work

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1 /* non-blocking task submits */
2 starpu_task_insert(...);
3 starpu_task_insert(...);
4 starpu_task_insert(...);
5 ...
6
7 /* wait for all task submitted so far */
8 starpu_task_wait_for_all();
```

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3  starpu_data_handle_t vector_handle;
4
5  /* ... fill vector ... */
6
7  starpu_vector_data_register(&vector_handle, 0,
8                              (uintptr_t)vector, NX, sizeof(vector[0]))
                                   ;
9
10 starpu_task_insert(
11                   &scal_cl,
12                   STARPU_RW, vector_handle,
13                   STARPU_VALUE, &factor, sizeof(factor),
14                   0);
15
16 starpu_task_wait_for_all();
17 starpu_data_unregister(vector_handle);
18
19 /* ... display vector ... */
```

Heterogeneity: Device Kernels

Extending a codelet to handle heterogeneous platforms

Heterogeneity: Device Kernels

Extending a codelet to handle heterogeneous platforms

- Multiple kernel implementations for a CPU
  - SSE, AVX, ... optimized kernels

```
1 struct starpu_codelet scal_cl = {
2       .cpu_func  = { scal_cpu_func,
3                      scal_sse_cpu_func, scal_avx_cpu_func },
4       .nbuffers = 1,
5       .modes = { STARPU_RW },
6 };
```

Heterogeneity: Device Kernels

Extending a codelet to handle heterogeneous platforms

- Multiple kernel implementations for a CPU
  - SSE, AVX, ... optimized kernels
- Kernels implementations for accelerator devices
  - OpenCL, NVidia Cuda kernels

```
1 struct starpu_codelet scal_cl = {
2       .cpu_func  = { scal_cpu_func,
3                      scal_sse_cpu_func, scal_avx_cpu_func },
4       .opencl_func  = { scal_cpu_opencl },
5       .cuda_func  = { scal_cpu_cuda },
6       .nbuffers = 1,
7       .modes = { STARPU_RW },
8 };
```

Writing a Kernel Function for CUDA

Writing a Kernel Function for CUDA

```
1
2
3
4
5
6
7
8  extern "C" void scal_cuda_func(void *buffers[], void *cl_arg)
       {
9    struct starpu_vector_interface *vector_handle = buffers[0];
10   unsigned n    = STARPU_VECTOR_GET_NX(vector_handle);
11   float *vector = STARPU_VECTOR_GET_PTR(vector_handle);
12   float *ptr_factor = cl_arg;
13
14   ...
15
16
17
18
19
20 }
```

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11   float *vector = STARPU_VECTOR_GET_PTR(vector_handle);
12   float *ptr_factor = cl_arg;
13
14   unsigned threads_per_block = 64;
15   unsigned nblocks = (n+threads_per_block-1)
16                      /threads_per_block;
17
18   ...
19
20 }
```

Writing a Kernel Function for CUDA

```
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2
3
4
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8  extern "C" void scal_cuda_func(void *buffers[], void *cl_arg)
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12   float *ptr_factor = cl_arg;
13
14   unsigned threads_per_block = 64;
15   unsigned nblocks = (n+threads_per_block-1)
16                      /threads_per_block;
17
18   vector_mult_cuda<<<nblocks,threads_per_block,0,
19       starpu_cuda_get_local_stream()>>>(n,vector,*ptr_factor);
20 }
```

Writing a Kernel Function for CUDA

```
1  static __global__ void vector_mult_cuda(unsigned n,
2                                          float *vector, float factor){
3    unsigned i = blockIdx.x*blockDim.x + threadIdx.x;
4
5    ...
6  }
7
8  extern "C" void scal_cuda_func(void *buffers[], void *cl_arg)
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9    struct starpu_vector_interface *vector_handle = buffers[0];
10   unsigned n    = STARPU_VECTOR_GET_NX(vector_handle);
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4    if (i < n)
5        vector[i] *= factor;
6  }
7
8  extern "C" void scal_cuda_func(void *buffers[], void *cl_arg)
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19       starpu_cuda_get_local_stream()>>>(n,vector,*ptr_factor);
20 }
```

Writing a Kernel Function for OpenCL

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

extern "C" void scal_opencl_func(void *buffers[], void *cl_arg
    ){
  struct starpu_vector_interface *vector_handle = buffers[0];
  unsigned n    = STARPU_VECTOR_GET_NX(vector_handle);
  float *vector = STARPU_VECTOR_GET_PTR(vector_handle);
  float *ptr_factor = cl_arg;

  cl_kernel kernel;
  cl_command_queue queue;
  starpu_opencl_load_kernel(&kernel, &queue, &opencl_program,
      name, "vector_mult_opencl", devid);
  clSetKernelArg(kernel, 0, sizeof(val), &val);
  ...
  clEnqueueNDRangeKernel(queue, kernel, 1, NULL, ...);
}
```

Declaring a codelet in Fortran

- Defined as a C_PTR allocated by StarPU

```
1 TYPE(C_PTR) :: scal_cl = C_NULL_PTR
2
3 scal_cl = fstarpu_codelet_allocate()
```

Declaring a codelet in Fortran

- Defined as a C_PTR allocated by StarPU
- Plug the kernel function

```
1 TYPE(C_PTR) :: scal_cl = C_NULL_PTR
2
3 scal_cl = fstarpu_codelet_allocate()
4
5 CALL fstarpu_codelet_add_cpu_func(scal_cl,
6   C_FUNLOC(scal_cpu_func))
```

Declaring a codelet in Fortran

- Defined as a C_PTR allocated by StarPU
- Plug the kernel function
- Declare data

```
1 TYPE(C_PTR) :: scal_cl = C_NULL_PTR
2
3 scal_cl = fstarpu_codelet_allocate()
4
5 CALL fstarpu_codelet_add_cpu_func(scal_cl,
6   C_FUNLOC(scal_cpu_func))
7
8 CALL fstarpu_codelet_add_buff(scal_cl, FSTARPU_RW)
```

Writing a Kernel Function in Fortran

- Every kernel function has the same Fortran prototype

```
1 recursive subroutine scal_cpu_func(buffers, cl_args) bind(c)
2   type(c_ptr), value, intent(in) :: buffers, cl_args
3
4   ...
```

Writing a Kernel Function in Fortran

- Every kernel function has the same Fortran prototype
- Get vector's number of elements and base pointer

```
1  recursive subroutine scal_cpu_func(buffers, cl_args) bind(c)
2    type(c_ptr), value, intent(in) :: buffers, cl_args
3
4    integer :: n
5    real(8), dimension(:), pointer :: val
6
7
8    n = fstarpu_vector_get_nx(buffers, 0)
9    call c_f_pointer(fstarpu_vector_get_ptr(buffers, 0), &
10     val, shape=[n])
11
12   ...
```

Writing a Kernel Function in Fortran

- Every kernel function has the same Fortran prototype
- Get vector's number of elements and base pointer
- Get the scaling factor as inline argument

```
1  recursive subroutine scal_cpu_func(buffers, cl_args) bind(c)
2    type(c_ptr), value, intent(in) :: buffers, cl_args
3
4    integer :: n
5    real(8), dimension(:), pointer :: val
6    real(8), target :: factor
7
8    n = fstarpu_vector_get_nx(buffers, 0)
9    call c_f_pointer(fstarpu_vector_get_ptr(buffers, 0), &
10     val, shape=[n])
11   call fstarpu_unpack_arg(cl_args, (/ c_loc(factor) /)))
12
13   ...
```

Writing a Kernel Function in Fortran

- Every kernel function has the same Fortran prototype
- Get vector's number of elements and base pointer
- Get the scaling factor as inline argument
- Compute the vector scaling

```
1  recursive subroutine scal_cpu_func(buffers, cl_args) bind(c)
2    type(c_ptr), value, intent(in) :: buffers, cl_args
3
4    integer :: n
5    real(8), dimension(:), pointer :: val
6    real(8), target :: factor
7
8    n = fstarpu_vector_get_nx(buffers, 0)
9    call c_f_pointer(fstarpu_vector_get_ptr(buffers, 0), &
10     val, shape=[n])
11   call fstarpu_unpack_arg(cl_args, (/ c_loc(factor) /)))
12
13   do i = 1, n
14     val(i) = val(i)*factor
15   end do
```

Registering an array to StarPU from Fortran

```
1   real(8), dimension(:), allocatable, target :: array
2   allocate(array(NX))
3   array = (/ (1.0, i=1, NX) /)
4
5   type(c_ptr) :: vector_handle
6   call fstarpu_vector_data_register(vector_handle, &
7     0, c_loc(array), NX, c_sizeof(array(0)))
```

Submitting a task from Fortran

```
1  real(kind=c_double), target :: factor
2
3  call fstarpu_task_insert((/     &
4    scal_cl,                      &
5    FSTARPU_RW                    &
6    FSTARPU_VALUE, c_loc(factor) &
7      FSTARPU_SZ_C_DOUBLE,        &
8    C_NULL_PTR /))
```

Data Interfaces

Multiple data types supported

- Vector
- Matrix
- BCSR sparse matrix

```
1 int vector[NX];
2 starpu_data_handle_t handle;
3
4 starpu_vector_data_register(&handle, 0, (uintptr_t)vector,
5                             NX, sizeof(vector[0]));
```

Data Interfaces

Multiple data types supported

- Vector
- Matrix
- BCSR sparse matrix

```
1 float matrix[NX*NY];
2 starpu_data_handle_t handle;
3
4 starpu_matrix_data_register(&handle, 0, (uintptr_t)matrix,
5                             NX, NX, NY, sizeof(matrix[0]));
```

Data Interfaces

Multiple data types supported

- Vector
- Matrix
- BCSR sparse matrix

```
1 ...
2 starpu_data_handle_t handle;
3
4 starpu_bcsr_data_register(&handle, 0, NNZ, NROW,
5             (uintptr_t)bcsr_matrix_data,
6             bcsr_matrix_indices, bcsr_matrix_rowptr,
                  first_entry,
7             BLOCK_NROW, BLOCK_NCOL, sizeof(double));
```

Data Interfaces

Multiple data types supported

- Vector
- Matrix
- BCSR sparse matrix
- Extensible data type set
  - You can write your own, specifically tailored data type

Data Interfaces

Multiple data types supported

- Vector
- Matrix
- BCSR sparse matrix
- Extensible data type set
  - You can write your own, specifically tailored data type
- Only the byte size and the shape of data matter, not the actual element type (integer, float, double precision float, . . .)

Partitioning

Splitting a piece of managed data into several handles

- Granularity adjustment
- Notion of **filter**

Partitioning

Splitting a piece of managed data into several handles

- Granularity adjustment
- Notion of **filter**

Partition

```
1  int vector[NX];
2  starpu_data_handle_t handle;
3  starpu_vector_data_register(&handle, 0, (uintptr_t)vector,
4                              NX, sizeof(vector[0]));
5
6  /* Partition the vector in NB_PARTS sub-vectors */
7  struct starpu_data_filter filter = {
8      .filter_func = starpu_vector_filter_block,
9      .nchildren = NB_PARTS
10 };
11 starpu_data_partition(handle, &filter);
12
13 /* Data can only be accessed through sub-handles now */
```

Partitioning

Splitting a piece of managed data into several handles

- Granularity adjustment
- Notion of **filter**

Partition → Use

```
for (i=0; i<starpu_data_get_nb_children(handle); i++) {
    /* Get subdata number i */
    starpu_data_handle_t sub_handle =
        starpu_data_get_sub_data(handle, 1, i);

    starpu_task_insert(
        &scal_cl,
        STARPU_RW, sub_handle,
        STARPU_VALUE, &factor, sizeof(factor),
        0);
}
```

Partitioning

Splitting a piece of managed data into several handles

- Granularity adjustment
- Notion of **filter**

Partition → Use → Unpartition

```
1 /* Wait for submitted tasks to complete */
2 starpu_task_wait_for_all();
3
4 /* Unpartition data */
5 starpu_data_unpartition(handle, 0);
6
7 /* Data can now be accessed through 'handle' only */
```

2

Hands-on session 1

3

Advanced principles of StarPU

Asynchronous Partitioning

Inserting a partitioning request in the submission flow

Two steps

Asynchronous Partitioning

Inserting a partitioning request in the submission flow

Two steps

- Partition planning

```
1  int vector[NX];
2  starpu_data_handle_t handle;
3  starpu_vector_data_register(&handle, 0, (uintptr_t)vector,
4                              NX, sizeof(vector[0]));
5
6  /* Partition the vector in NB_PARTS sub-vectors */
7  struct starpu_data_filter filter = {
8      .filter_func = starpu_vector_filter_block,
9      .nchildren = NB_PARTS
10 };
11 starpu_data_handle_t children[NB_PARTS];
12 starpu_data_partition_plan(handle, &filter, children);
13
14 /* Data can only be accessed through sub-handles now */
```

Asynchronous Partitioning

Inserting a partitioning request in the submission flow

Two steps

- Partition planning
- Asynchronous partition inforcement

```
1  starpu_task_insert(&scal_cl,
2        STARPU_RW, handle,
3        STARPU_VALUE, &factor1, sizeof(factor1), 0);
4  starpu_data_partition_submit(handle, NB_PARTS, children);
5  for (i=0; i<NB_PARTS; i++) {
6       starpu_task_insert(&scal_cl,
7             STARPU_RW, children[i],
8             STARPU_VALUE, &factor2, sizeof(factor2),
9             0);
10 }
11 starpu_data_unpartition_submit(handle, NB_PARTS, children,
       node);
12 starpu_task_insert(&scal_cl,
13       STARPU_RW, handle,
14       STARPU_VALUE, &factor3, sizeof(factor3), 0);
```

Asynchronous Partitioning

Inserting a partitioning request in the submission flow

Two steps

- Partition planning
- Asynchronous partition inforcement, or automatic!

```
starpu_task_insert(&scal_cl,
        STARPU_RW, handle,
        STARPU_VALUE, &factor1, sizeof(factor1), 0);
//starpu_data_partition_submit(handle, NB_PARTS, children);
for (i=0; i<NB_PARTS; i++) {
    starpu_task_insert(&scal_cl,
            STARPU_RW, children[i],
            STARPU_VALUE, &factor2, sizeof(factor2),
            0);
}
//starpu_data_unpartition_submit(handle, NB_PARTS, children,
    node);
starpu_task_insert(&scal_cl,
        STARPU_RW, handle,
        STARPU_VALUE, &factor3, sizeof(factor3), 0);
```

Reduction

Merge contributions from a set of tasks into a single buffer

- Define neutral element initializer
- Define reduction operator

Reduction

Merge contributions from a set of tasks into a single buffer

- Define neutral element initializer
- Define reduction operator

Define zero

```
1 void bzero_cpu(void *descr[], void *cl_arg) {
2     double *v_zero = (double *)STARPU_VARIABLE_GET_PTR(descr
          [0]);
3     *v_zero = 0.0;
4 }
5
6 struct starpu_codelet bzero_cl = {
7     .cpu_funcs = { bzero_cpu, NULL },
8     .nbuffers = 1
9 };
```

Reduction

Merge contributions from a set of tasks into a single buffer

- Define neutral element initializer
- Define reduction operator

Define zero → Define op

```
1  void accumulate_cpu(void *descr[], void *cl_arg) {
2      double *v_dst = (double *)STARPU_VARIABLE_GET_PTR(descr
           [0]);
3      double *v_src = (double *)STARPU_VARIABLE_GET_PTR(descr
           [1]);
4      *v_dst = *v_dst + *v_src;
5  }
6
7  struct starpu_codelet accumulate_cl = {
8      .cpu_funcs = { accumulate_cpu, NULL },
9      .nbuffers = 1
10 };
```

Reduction

Merge contributions from a set of tasks into a single buffer

- Define neutral element initializer
- Define reduction operator

Define zero → Define op → Reduce task contributions

```
starpu_variable_data_register(&accum_handle, -1,
                              NULL, sizeof(type));
starpu_data_set_reduction_methods(accum_handle,
                                  &accumulate_cl, &bzero_cl);

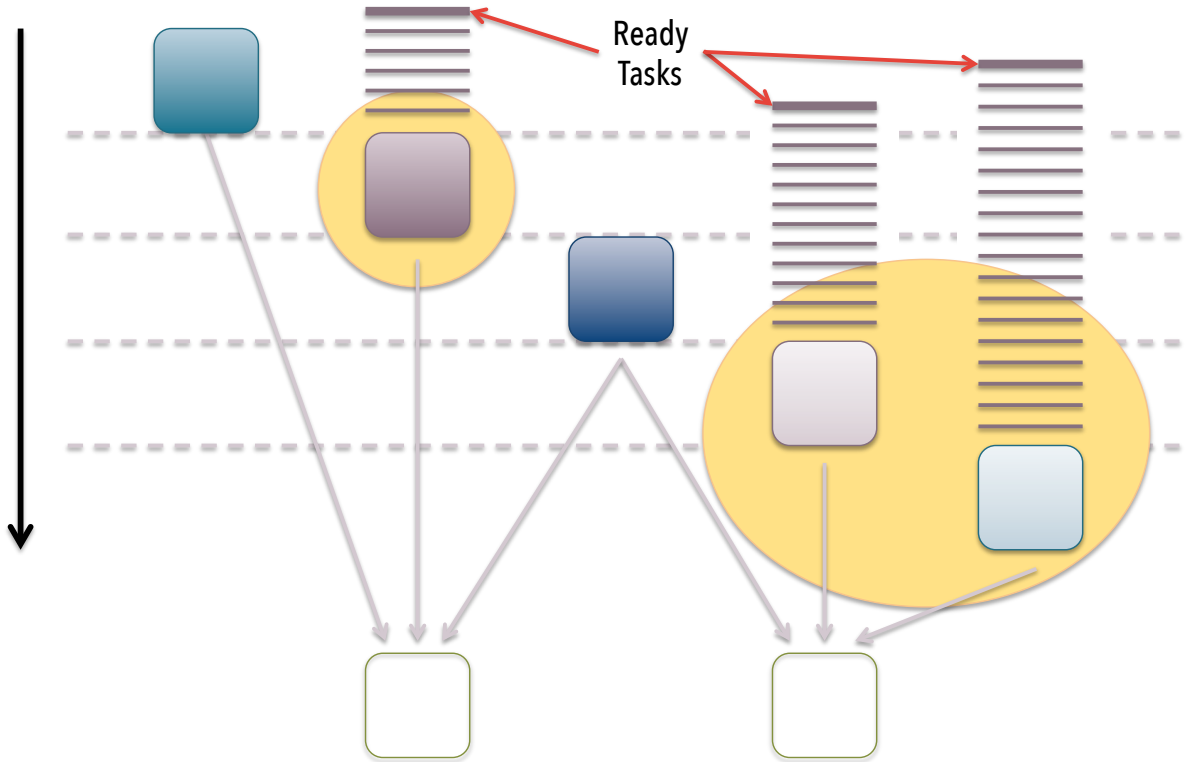
for (b = 0; b < nblocks; b++)
    starpu_task_insert(&dot_kernel_cl,
        STARPU_REDUX, accum_handle,
        STARPU_R, starpu_data_get_sub_data(v1, 1, b),
        STARPU_R, starpu_data_get_sub_data(v2, 1, b),
        0);
```

Commutative Write Accesses

- Write accesses enforce sequential consistency by default
  - Too strong for some kind of workloads
  - N-body, unstructured meshes

Commutative Write Accesses

- Write accesses enforce sequential consistency by default
  - Too strong for some kind of workloads
  - N-body, unstructured meshes



Commutative Write Accesses

- Write accesses enforce sequential consistency by default
  - Too strong for some kind of workloads
  - N-body, unstructured meshes
- **Commute**: allows a set of tasks to modify a buffer in any order

```
starpu_task_insert(&cl1,
        STARPU_R, handle0,
        STARPU_RW, handle,
        0);
starpu_task_insert(&cl2,
        STARPU_R, handle1,
        STARPU_RW|STARPU_COMMUTE, handle,
        0);
starpu_task_insert(&cl2,
        STARPU_R, handle2,
        STARPU_RW|STARPU_COMMUTE, handle,
        0);
starpu_task_insert(&cl3,
        STARPU_R, handle3,
        STARPU_RW, handle,
        0);
```

Performance models

- Provide estimated task duration
- For advanced task scheduling: tells about the future!
- For task performance feedback

Performance models

- Provide estimated task duration
- For advanced task scheduling: tells about the future!
- For task performance feedback

```
1 struct starpu_perfmodel scal_cl_model = {
2    .type = STARPU_HISTORY_BASED,
3    .symbol = "scal",
4 };
5 struct starpu_codelet scal_cl = {
6    .cpu_funcs = { scal_cpu_func },
7 ...
8    .model = &scal_cl_model;
9 }
```

Performance models

- Provide estimated task duration
- For advanced task scheduling: tells about the future!
- For task performance feedback

```
1 struct starpu_perfmodel scal_cl_model = {
2    .type = STARPU_REGRESSION_BASED,
3    .symbol = "scal",
4 };
5 struct starpu_codelet scal_cl = {
6    .cpu_funcs = { scal_cpu_func },
7 ...
8    .model = &scal_cl_model;
9 }
```

Performance models

- Provide estimated task duration
- For advanced task scheduling: tells about the future!
- For task performance feedback

```
1 struct starpu_perfmodel scal_cl_model = {
2    .type = STARPU_NL_REGRESSION_BASED,
3    .symbol = "scal",
4 };
5 struct starpu_codelet scal_cl = {
6    .cpu_funcs = { scal_cpu_func },
7 ...
8    .model = &scal_cl_model;
9 }
```

Performance models

- Provide estimated task duration
- For advanced task scheduling: tells about the future!
- For task performance feedback

```
1 struct starpu_perfmodel scal_cl_model = {
2    .type = STARPU_MULTIPLE_REGRESSION_BASED,
3    .symbol = "scal",
4 };
5 struct starpu_codelet scal_cl = {
6    .cpu_funcs = { scal_cpu_func },
7 ...
8    .model = &scal_cl_model;
9 }
```

Feedback mechanisms

Online Tools

- Statistics
- Visual debugging

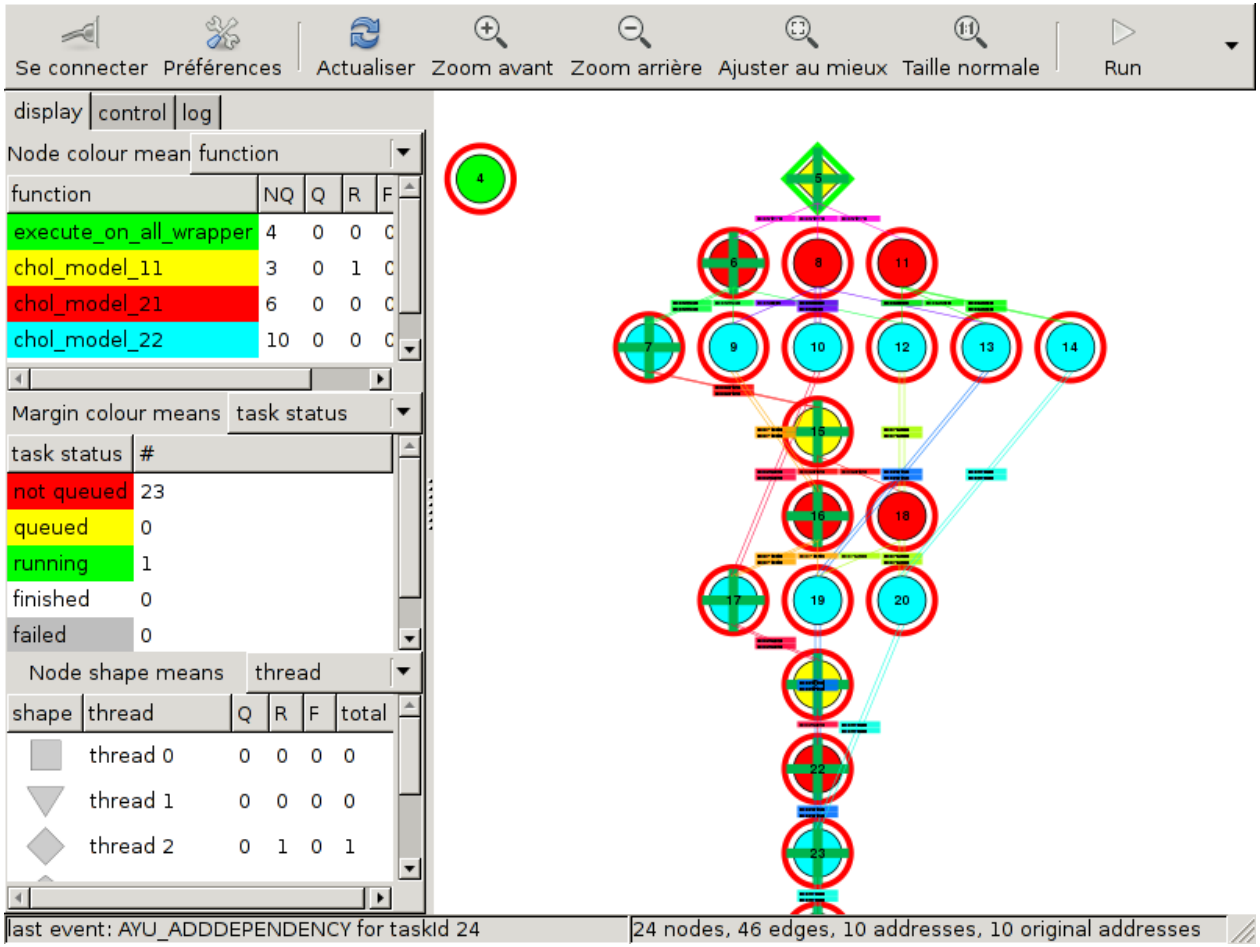
Offline Tools

- Performance models
- Trace-based analysis

Visual debugging: Temanejo

A debugger at the task level

- Visualize task graph
- Add breakpoints
- Execute task-by-task
- ...



Offline Feedback – Kernel Model

Display the codelet performance models recorded by StarPU

- Command-line tool starpu_perfmodel_display
- History-based models
- Regression-based models

Offline Feedback – Kernel Model

Display the codelet performance models recorded by StarPU

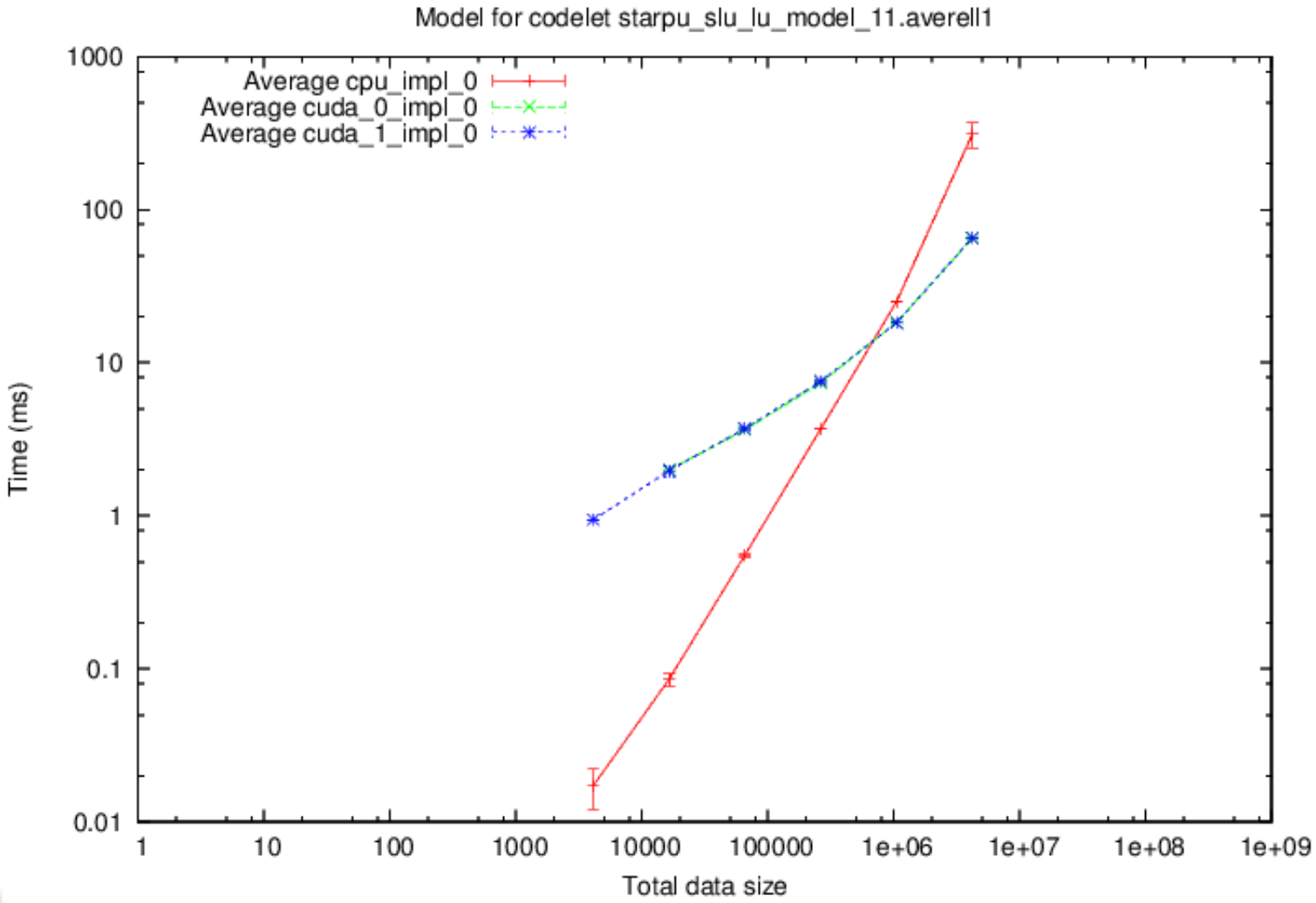
- Command-line tool starpu_perfmodel_display
- History-based models
- Regression-based models

```
$ starpu_perfmodel_display -s starpu_slu_lu_model_11

performance model for cpu0_parallel1_impl0
# hash         size         mean (us)         stddev (us)       n
aa6d4ef7       4194304      3.055501e+05      5.804822e+04      48
```

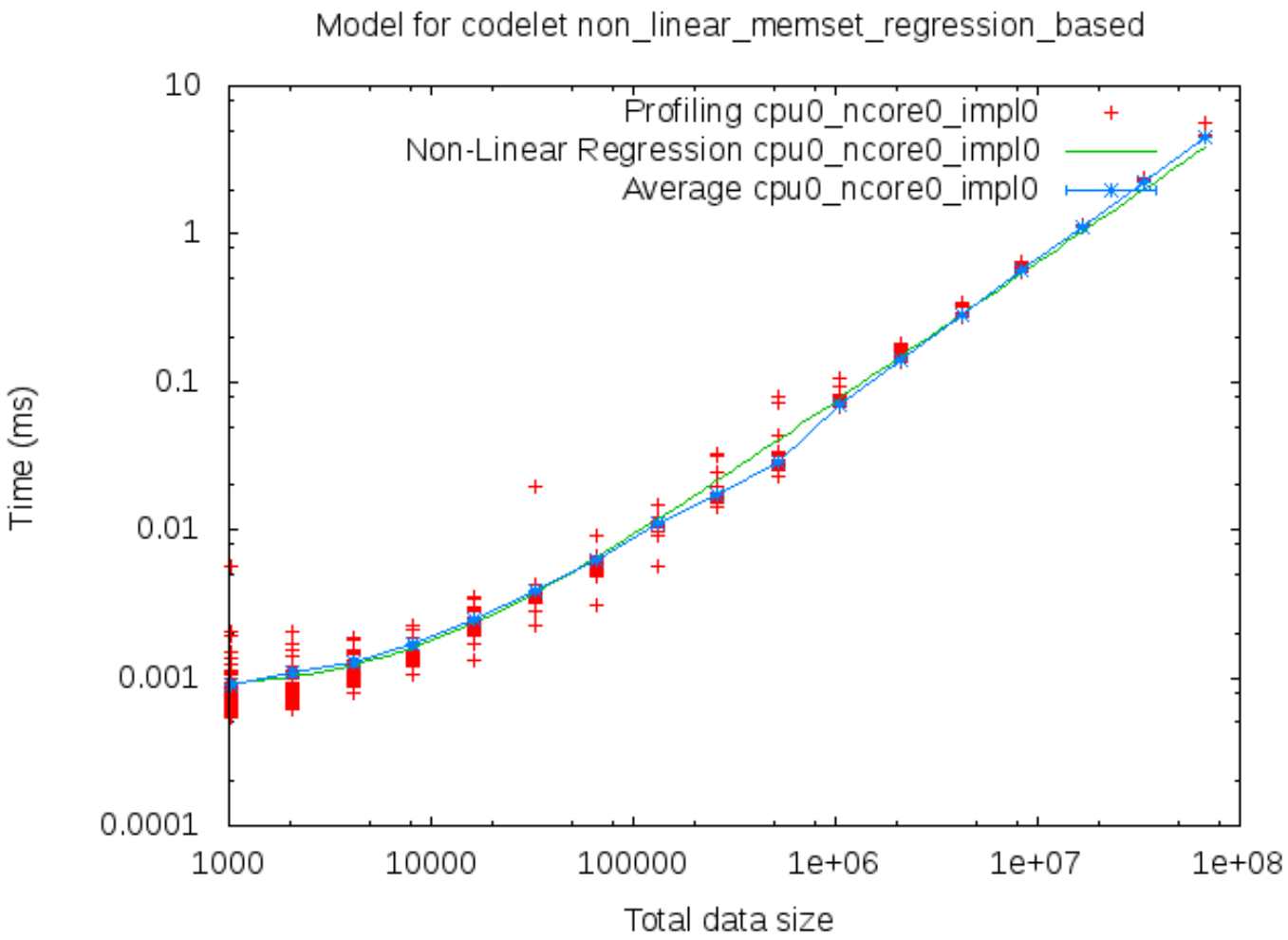
Offline Feedback – Kernel Model Characteristics

```
$ starpu_perfmodel_plot -s starpu_slu_lu_model_11
```



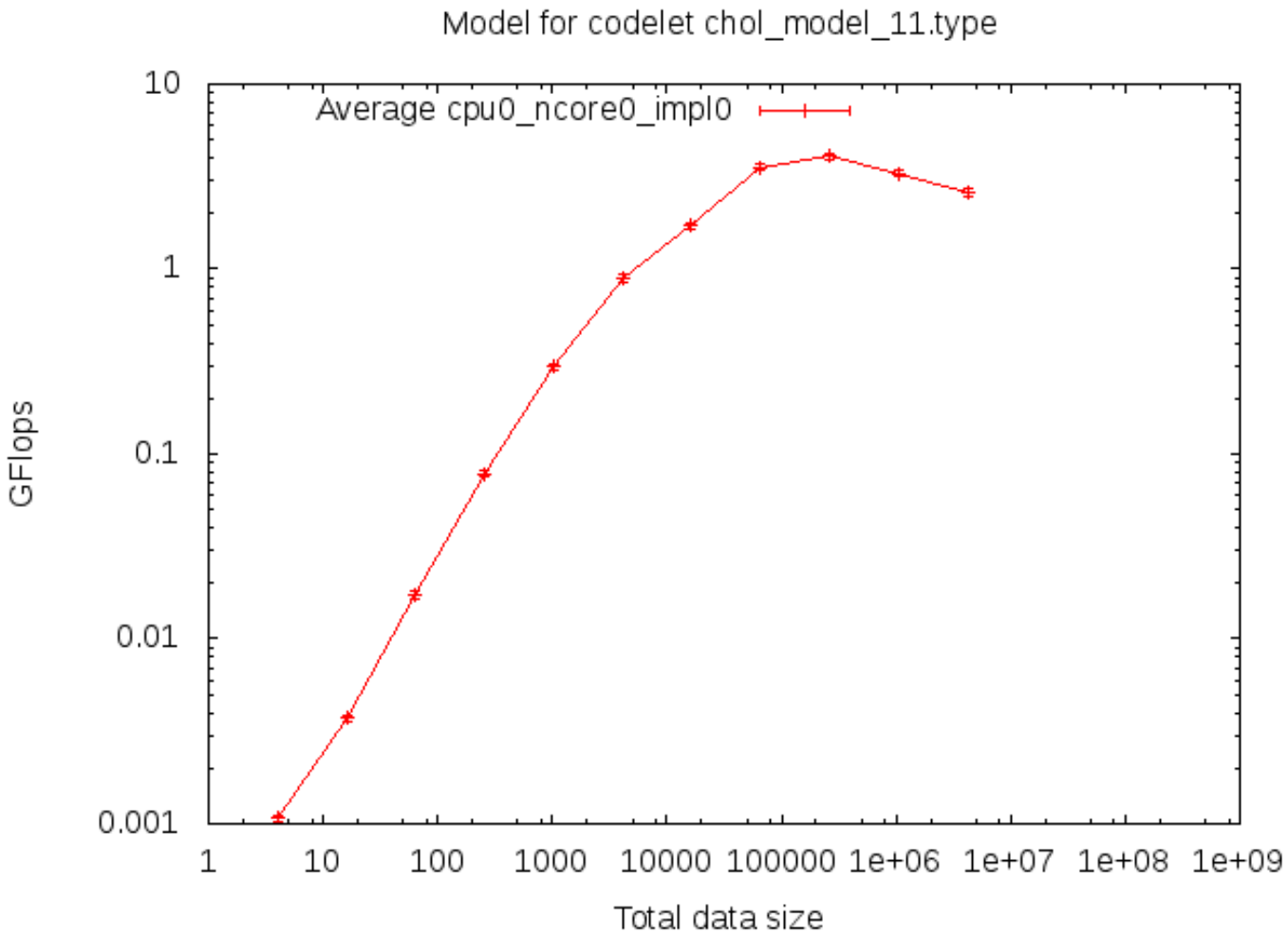
Offline Feedback – Kernel Model Regression Fitness

```
$ starpu_perfmodel_plot -s non_linear_memset_regression_based
```



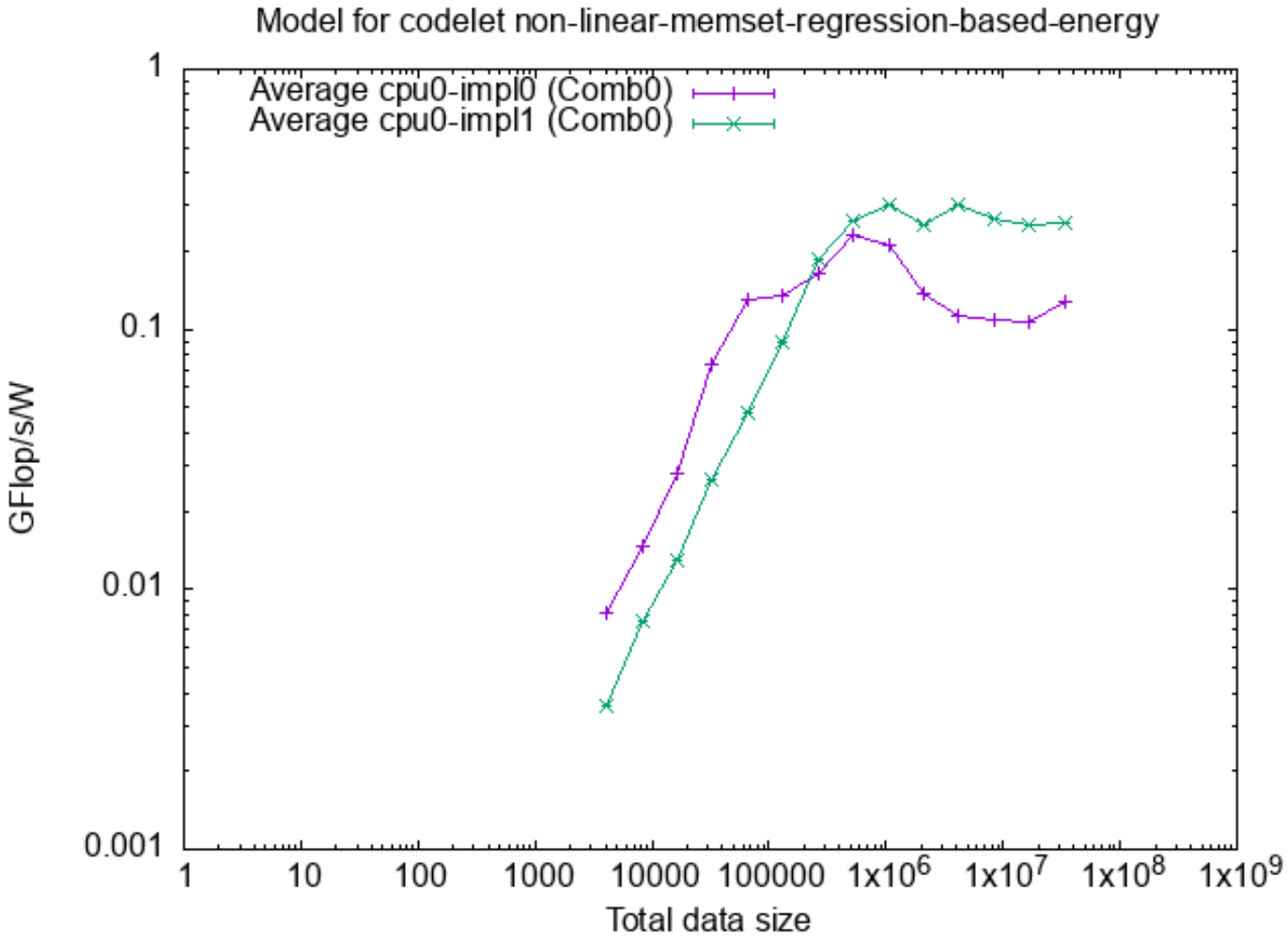
Offline Feedback – Kernel Model Efficiency

```
$ starpu_perfmodel_plot -f -s chol_model_11
```



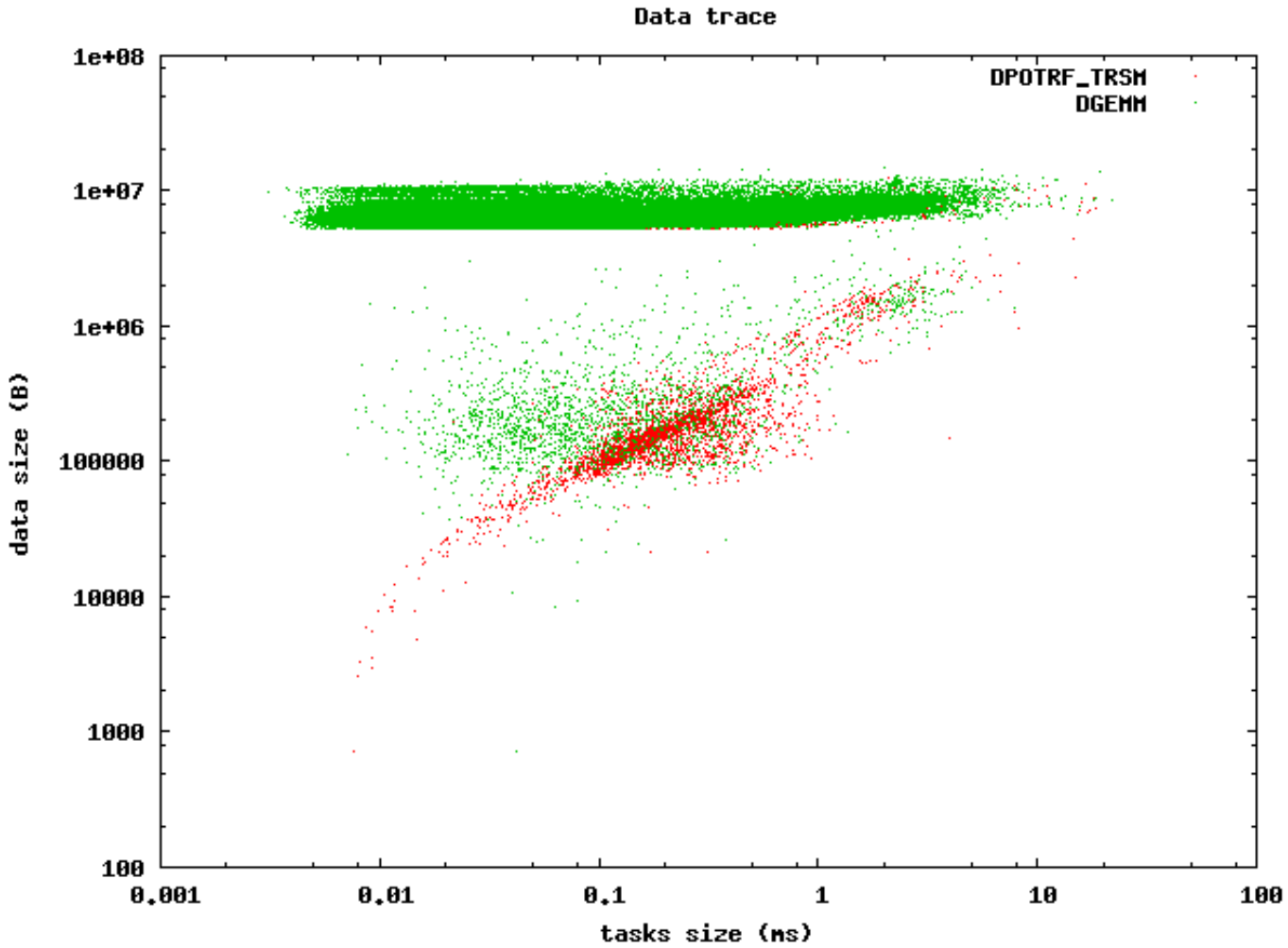
Offline Feedback – Kernel Model Power Efficiency

```
$ starpu_perfmodel_plot -f -se memset memset_energy
```



Offline Feedback – Synthetic Kernels' Behaviour

```
$ starpu_fxt_data_trace /tmp/prof_file_user_0
```



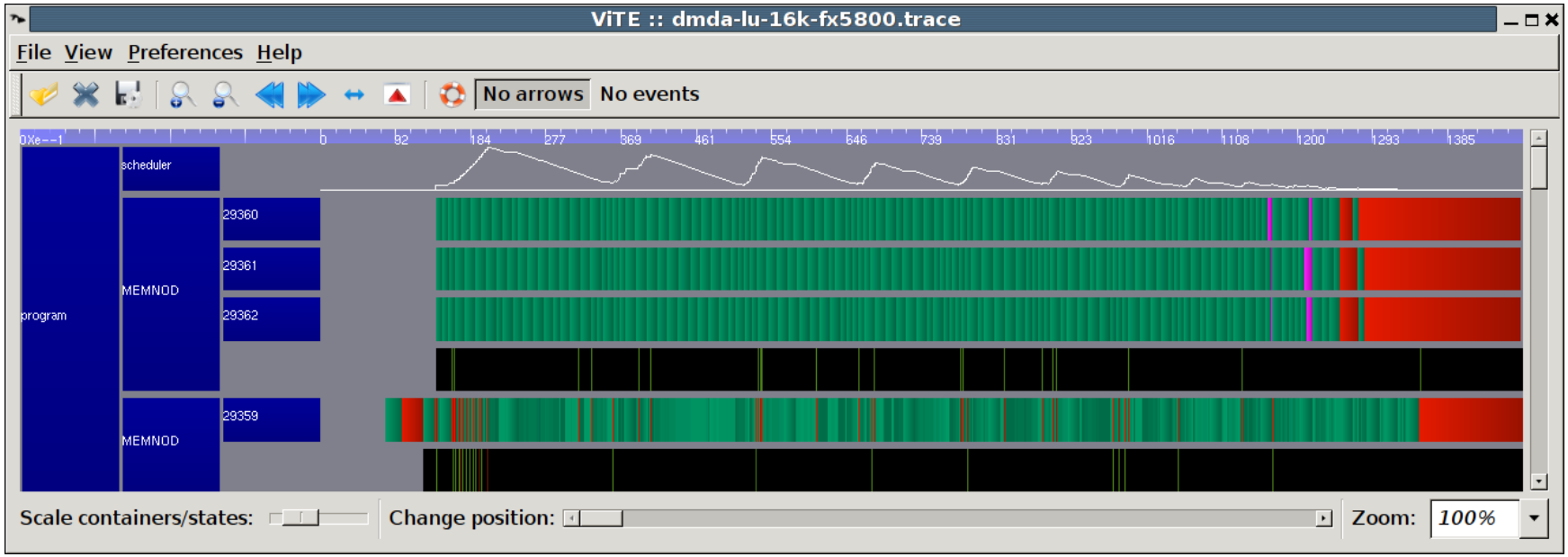
Offline Trace-Based Feedback

- FxT trace collection
- Trace analysis and display
  - ViTE Gantt
  - Graphviz DAG
  - R plots

Offline Feedback – Trace Analysis

Automatically generated

- Dependency graph (DAG)
- Activity diagramm (GANTT)
  - Visualize with ViTE



Offline Feedback – Trace Analysis

StarVZ

Distributed task graph

1D blocked stencil example, sequential version

```
1  for (loop = 0; loop < NLOOPS; loop++) {
2
3
4
5
6
7
8    for (i = 0; i < n; i++)
9      update(&blocks[i-1],    /* R  */
10            &blocks[i],      /* RW */
11            &blocks[i+1]);   /* R  */
12
13
14 }
```

Distributed task graph

1D blocked stencil example, MPI version

- Distribute `for i` iterations, receive/send contributions

```
1  for (loop = 0; loop < NLOOPS; loop++) {
2    int first = me * num_blocks_per_rank;
3    int last = (me+1) * num_blocks_per_rank - 1;
4
5    MPI_Recv(&blocks[first-1], me-1);
6    MPI_Recv(&blocks[last+1], me+1);
7
8    for (i = first; i <= last; i++)
9      update(&blocks[i-1],    /* R  */
10            &blocks[i],      /* RW */
11            &blocks[i+1]);   /* R  */
12
13   MPI_Send(&blocks[first], me-1);
14   MPI_Send(&blocks[last], me+1);
15 }
```

Distributed task graph

1D blocked stencil example, task version, explicit

- Submit send/recv and update tasks → tasks+communications graph

```
1  for (loop = 0; loop < NLOOPS; loop++) {
2    int first = me * num_blocks_per_rank;
3    int last = (me+1) * num_blocks_per_rank - 1;
4
5    starpu_mpi_irecv_submit(handles[first -1], me-1);
6    starpu_mpi_irecv_submit(handles[last+1], me+1);
7
8    for (i = first; i <= last; i++)
9      starpu_task_insert(&cl_update,STARPU_R,  handles[i-1],
10                                   STARPU_RW, handles[i],
11                                   STARPU_R,  handles[i+1],0);
12
13   starpu_mpi_isend_submit(handles[first], me-1);
14   starpu_mpi_isend_submit(handles[last], me+1);
15 }
16 starpu_task_wait_for_all();
```

Distributed task graph

1D blocked stencil example, task version, implicit

- Let communication tasks get inferred from data mapping

```
1  for (loop = 0; loop < NLOOPS; loop++) {
2    int first = me * num_blocks_per_rank;
3    int last = (me+1) * num_blocks_per_rank - 1;
4
5
6
7
8    for (i = 0; i < n; i++)
9      starpu_task_insert(&cl_update,STARPU_R,  handles[i-1],
10                                    STARPU_RW, handles[i],
11                                    STARPU_R,  handles[i+1],0);
12
13
14
15 }
16 starpu_task_wait_for_all();
```

4

Hands-on session 2