StarPU task-based programming hands-on session

Introduction to task-based programming with StarPU

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Basic Example: Scaling a Vector

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starpu_task_wait_for_all();
starpu_data_unregister(vector_handle);

/* ... 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**
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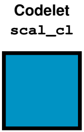

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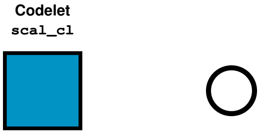

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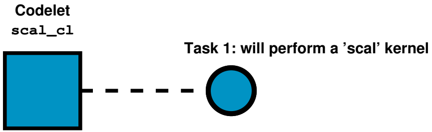

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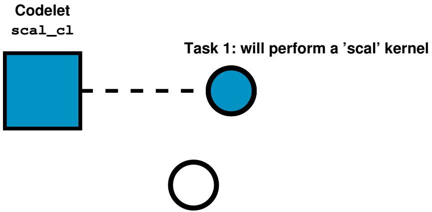

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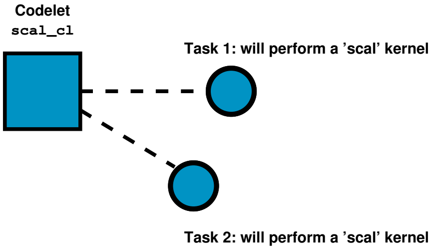

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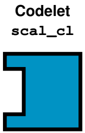

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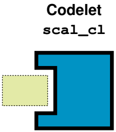

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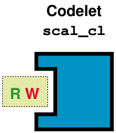

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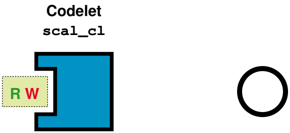

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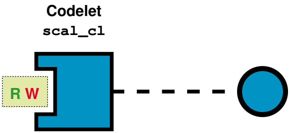

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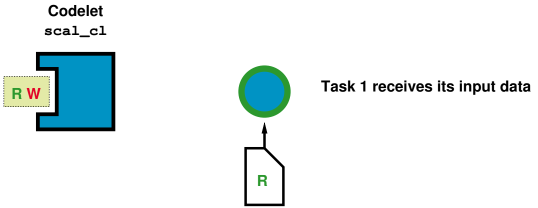

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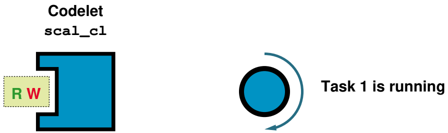

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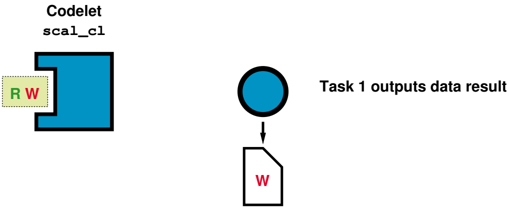

Definition: A Data Handle

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**

```
struct starpu_codelet scal_cl = {
    ...
};
```

Declaring a Codelet

Define a **struct** starpu_codelet

- Plug the kernel function
  - Here: scal_cpu_func

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struct starpu_codelet scal_cl = {
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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

```
struct starpu_codelet scal_cl = {
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    .nbuffers = 1,
    ...
};
```

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

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

Declaring and Managing Data

Put data under StarPU control

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- Initialize a piece of data

```
float vector[NX];
/* ... 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

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

starpu_data_handle_t vector_handle;
starpu_vector_data_register(&vector_handle, 0,
                            (uintptr_t)vector, NX, sizeof(vector[0]));
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- Use data through the handle

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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

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

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

/* ... use the vector through the handle ... */

starpu_data_unregister(vector_handle);
```

Writing a Kernel Function

- Every kernel function has the same C prototype

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

Writing a Kernel Function

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- Retrieve the vector's handle

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void scal_cpu_func(void *buffers[], void *cl_arg) {
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  ...
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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

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void scal_cpu_func(void *buffers[], void *cl_arg) {
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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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void scal_cpu_func(void *buffers[], void *cl_arg) {
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  unsigned i;
  for (i = 0; i < n; i++)
    vector[i] *= factor;
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The **starpu_task_insert** call

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Arguments

- The codelet structure
- The StarPU-managed data

```
starpu_task_insert(&scal_cl,
                   STARPU_RW, vector_handle,
                   ...);
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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
- The small-size inline data

```
starpu_task_insert(&scal_cl ,
                   STARPU_RW , vector_handle ,
                   STARPU_VALUE , &factor , sizeof(factor) ,
                   ...) ;
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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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/* non-blocking task submits */
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- Wait for all submitted tasks to complete their work

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```
/* non-blocking task submits */
starpu_task_insert(...);
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/* wait for all task submitted so far */
starpu_task_wait_for_all();
```

Basic Example: Scaling a Vector

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float factor = 3.14;
float vector[NX];
starpu_data_handle_t vector_handle;

/* ... fill vector ... */

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

starpu_task_insert(
                   &scal_cl,
                   STARPU_RW, vector_handle,
                   STARPU_VALUE, &factor, sizeof(factor),
                   0);

starpu_task_wait_for_all();
starpu_data_unregister(vector_handle);

/* ... display vector ... */
```

Heterogeneity: Device Kernels

Extending a codelet to handle heterogeneous platforms

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Extending a codelet to handle heterogeneous platforms

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

```
struct starpu_codelet scal_cl = {
    .cpu_func  = { scal_cpu_func,
            scal_sse_cpu_func, scal_avx_cpu_func },
    .nbuffers = 1,
    .modes = { STARPU_RW },
};
```

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

```
struct starpu_codelet scal_cl = {
    .cpu_func  = { scal_cpu_func,
                   scal_sse_cpu_func, scal_avx_cpu_func },
    .opencl_func  = { scal_cpu_opencl },
    .cuda_func  = { scal_cpu_cuda },
    .nbuffers = 1,
    .modes = { STARPU_RW },
};
```

Writing a Kernel Function for CUDA

Writing a Kernel Function for CUDA

```
extern "C" void scal_cuda_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);
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  unsigned threads_per_block = 64;
  unsigned nblocks = (n+threads_per_block-1)
                     /threads_per_block;

  ...


}
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  unsigned threads_per_block = 64;
  unsigned nblocks = (n+threads_per_block-1)
                     /threads_per_block;

  vector_mult_cuda<<<nblocks,threads_per_block,0,
      starpu_cuda_get_local_stream()>>>(n,vector,factor);
  cudaStreamSynchronize(starpu_cuda_get_local_stream());
}
```

Writing a Kernel Function for CUDA

```
static __global__ void vector_mult_cuda(unsigned n,
                                         float *vector, float factor){
  unsigned i = blockIdx.x*blockDim.x + threadIdx.x;

  ...
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Writing a Kernel Function for CUDA

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  if (i < n)
      vector[i] *= factor;
}

extern "C" void scal_cuda_func(void *buffers[], void *cl_arg)
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  cudaStreamSynchronize(starpu_cuda_get_local_stream());
}
```

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 factor;
  starpu_codelet_unpack_args(cl_arg, &factor)

  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

```fortran
TYPE(C_PTR) :: scal_cl = C_NULL_PTR

scal_cl = fstarpu_codelet_allocate()
```

Declaring a codelet in Fortran

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

```fortran
TYPE(C_PTR) :: scal_cl = C_NULL_PTR

scal_cl = fstarpu_codelet_allocate()

CALL fstarpu_codelet_add_cpu_func(scal_cl,
  C_FUNLOC(scal_cpu_func))
```

Declaring a codelet in Fortran

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

```
TYPE(C_PTR) :: scal_cl = C_NULL_PTR

scal_cl = fstarpu_codelet_allocate()

CALL fstarpu_codelet_add_cpu_func(scal_cl,
  C_FUNLOC(scal_cpu_func))

CALL fstarpu_codelet_add_buff(scal_cl, FSTARPU_RW)
```

Writing a Kernel Function in Fortran

- Every kernel function has the same Fortran prototype

```
recursive subroutine scal_cpu_func(buffers, cl_args) bind(c)
  type(c_ptr), value, intent(in) :: buffers, cl_args

  ...
```

Writing a Kernel Function in Fortran

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

```fortran
recursive subroutine scal_cpu_func(buffers, cl_args) bind(c)
  type(c_ptr), value, intent(in) :: buffers, cl_args

  integer :: n
  real(8), dimension(:), pointer :: val


  n = fstarpu_vector_get_nx(buffers, 0)
  call c_f_pointer(fstarpu_vector_get_ptr(buffers, 0), &
    val, shape=[n])

  ...
```

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

```
recursive subroutine scal_cpu_func(buffers, cl_args) bind(c)
  type(c_ptr), value, intent(in) :: buffers, cl_args

  integer :: n
  real(8), dimension(:), pointer :: val
  real(8), target :: factor

  n = fstarpu_vector_get_nx(buffers, 0)
  call c_f_pointer(fstarpu_vector_get_ptr(buffers, 0), &
    val, shape=[n])
  call fstarpu_unpack_arg(cl_args, (/ c_loc(factor) /)))

  ...
```

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

```fortran
recursive subroutine scal_cpu_func(buffers, cl_args) bind(c)
  type(c_ptr), value, intent(in) :: buffers, cl_args

  integer :: n
  real(8), dimension(:), pointer :: val
  real(8), target :: factor

  n = fstarpu_vector_get_nx(buffers, 0)
  call c_f_pointer(fstarpu_vector_get_ptr(buffers, 0), &
    val, shape=[n])
  call fstarpu_unpack_arg(cl_args, (/ c_loc(factor) /))

  do i = 1, n
    val(i) = val(i)*factor
  end do
```

Registering an array to StarPU from Fortran

```fortran
real(8), dimension(:), allocatable, target :: array
allocate(array(NX))
array = (/ (1.0, i=1, NX) /)

type(c_ptr) :: vector_handle
call fstarpu_vector_data_register(vector_handle, &
  0, c_loc(array), NX, c_sizeof(array(0)))
```

Submitting a task from Fortran

```fortran
real(kind=c_double), target :: factor

call fstarpu_task_insert((/     &
  scal_cl,                       &
  FSTARPU_RW                     &
  FSTARPU_VALUE, c_loc(factor)   &
    FSTARPU_SZ_C_DOUBLE,         &
  C_NULL_PTR /))
```

Data Interfaces

Multiple data types supported

- Vector
- Matrix
- BCSR sparse matrix

```
int vector[NX];
starpu_data_handle_t handle;

starpu_vector_data_register(&handle, 0, (uintptr_t)vector,
                            NX, sizeof(vector[0]));
```

Data Interfaces

Multiple data types supported

- Vector
- Matrix
- BCSR sparse matrix

```
float matrix[NX*NY];
starpu_data_handle_t handle;

starpu_matrix_data_register(&handle, 0, (uintptr_t)matrix,
                            NX, NX/10, NY/10, sizeof(matrix
                                [0]));
```

Data Interfaces

Multiple data types supported

- Vector
- Matrix
- BCSR sparse matrix

```
...
starpu_data_handle_t handle;

starpu_bcsr_data_register(&handle, 0, NNZ, NROW,
            (uintptr_t)bcsr_matrix_data,
            bcsr_matrix_indices, bcsr_matrix_rowptr,
                 first_entry,
            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

```c
int vector[NX];
starpu_data_handle_t handle;
starpu_vector_data_register(&handle, 0, (uintptr_t)vector,
                            NX, sizeof(vector[0]));

/* Partition the vector in NB_PARTS sub-vectors */
struct starpu_data_filter filter = {
    .filter_func = starpu_vector_filter_block,
    .nchildren = NB_PARTS
};
starpu_data_partition(handle, &filter);

/* 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

```
/* Wait for submitted tasks to complete */
starpu_task_wait_for_all();

/* Unpartition data */
starpu_data_unpartition(handle, 0);

/* 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

```c
int vector[NX];
starpu_data_handle_t handle;
starpu_vector_data_register(&handle, 0, (uintptr_t)vector,
                            NX, sizeof(vector[0]));

/* Partition the vector in NB_PARTS sub-vectors */
struct starpu_data_filter filter = {
    .filter_func = starpu_vector_filter_block,
    .nchildren = NB_PARTS
};
starpu_data_handle_t children[NB_PARTS];
starpu_data_partition_plan(handle, &filter, children);

/* 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

```
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);
```

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

```
void bzero_cpu(void *descr[], void *cl_arg) {
    double *v_zero = (double *)STARPU_VARIABLE_GET_PTR(descr
        [0]);
    *v_zero = 0.0;
}

struct starpu_codelet bzero_cl = {
    .cpu_funcs = { bzero_cpu },
    .nbuffers = 1
};
```

Reduction

Merge contributions from a set of tasks into a single buffer

- Define neutral element initializer
- Define reduction operator

Define zero → Define op

```c
void accumulate_cpu(void *descr[], void *cl_arg) {
    double *v_dst = (double *)STARPU_VARIABLE_GET_PTR(descr
        [0]);
    double *v_src = (double *)STARPU_VARIABLE_GET_PTR(descr
        [1]);
    *v_dst = *v_dst + *v_src;
}

struct starpu_codelet accumulate_cl = {
    .cpu_funcs = { accumulate_cpu },
    .nbuffers = 1
};
```

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

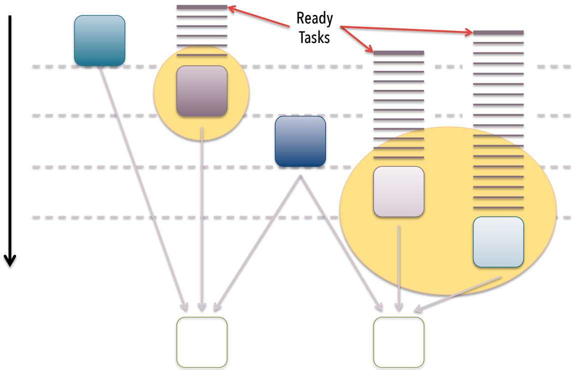
```
starpu_variable_data_register(&accum_handle, -1,
                              NULL, sizeof(type));
starpu_data_set_reduction_methods(accum_handle,
                                  &accumulate_cl, &bzero_cl);

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

```
struct starpu_perfmodel scal_cl_model = {
  .type = STARPU_HISTORY_BASED,
  .symbol = "scal",
};
struct starpu_codelet scal_cl = {
  .cpu_funcs = { scal_cpu_func },
...
  .model = &scal_cl_model;
}
```

Performance models

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

```
struct starpu_perfmodel scal_cl_model = {
  .type = STARPU_REGRESSION_BASED,
  .symbol = "scal",
};
struct starpu_codelet scal_cl = {
  .cpu_funcs = { scal_cpu_func },
...
  .model = &scal_cl_model;
}
```

Performance models

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

```
struct starpu_perfmodel scal_cl_model = {
   .type = STARPU_NL_REGRESSION_BASED,
   .symbol = "scal",
};
struct starpu_codelet scal_cl = {
   .cpu_funcs = { scal_cpu_func },
...
   .model = &scal_cl_model;
}
```

Performance models

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

```c
struct starpu_perfmodel scal_cl_model = {
  .type = STARPU_MULTIPLE_REGRESSION_BASED,
  .symbol = "scal",
};
struct starpu_codelet scal_cl = {
  .cpu_funcs = { scal_cpu_func },
...
  .model = &scal_cl_model;
}
```

Feedback mechanisms

Online Tools

- Statistics
- Visual debugging

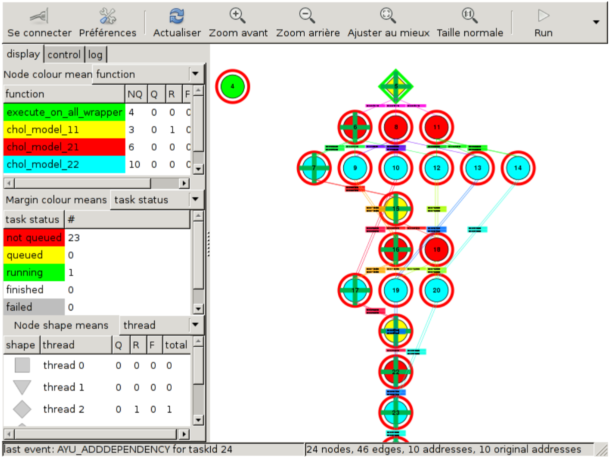
Offline Tools

- 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

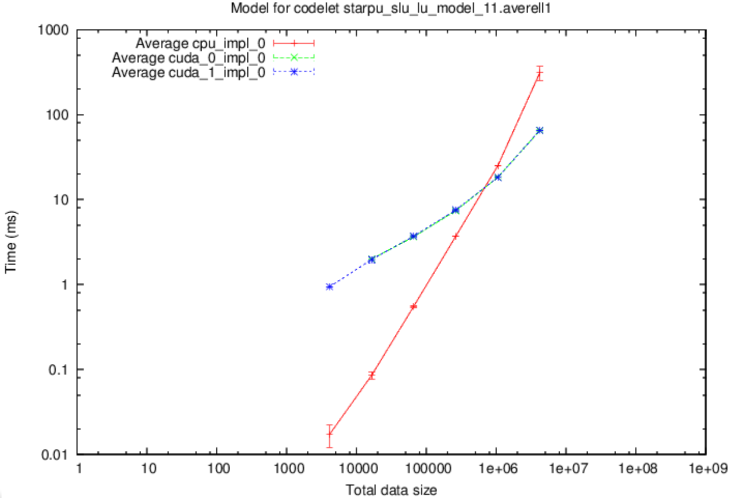
Display the codelet performance models recorded by StarPU

- 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
```

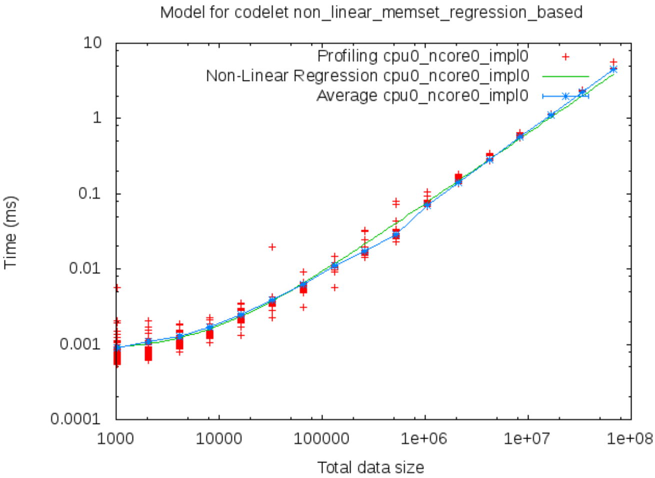
Offline Feedback – Kernel Model Characteristics

```
$ starpu_perfmodel_plot -s starpu_slu_lu_model_11
```



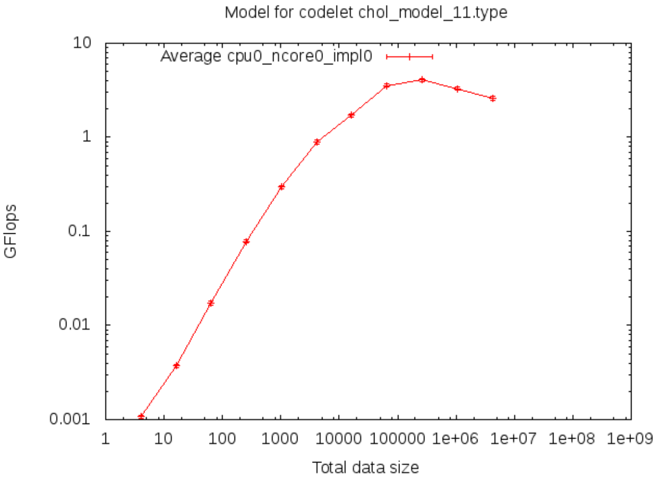
Offline Feedback – Kernel Model Regression Fitness

```
$ starpu_perfmodel_plot -s non_linear_memset_regression_based
```



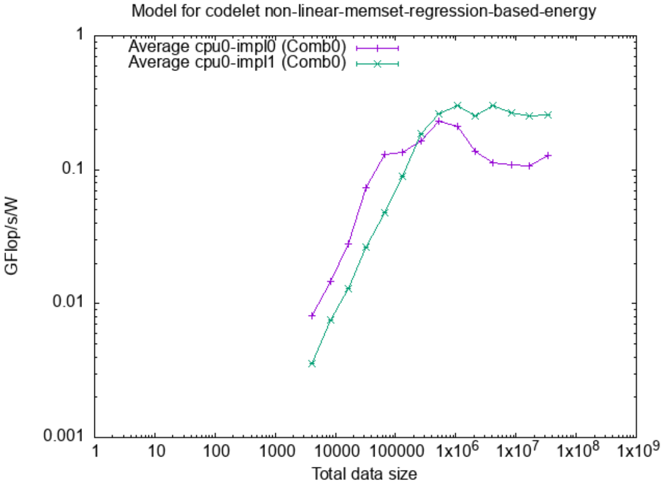
Offline Feedback – Kernel Model Efficiency

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



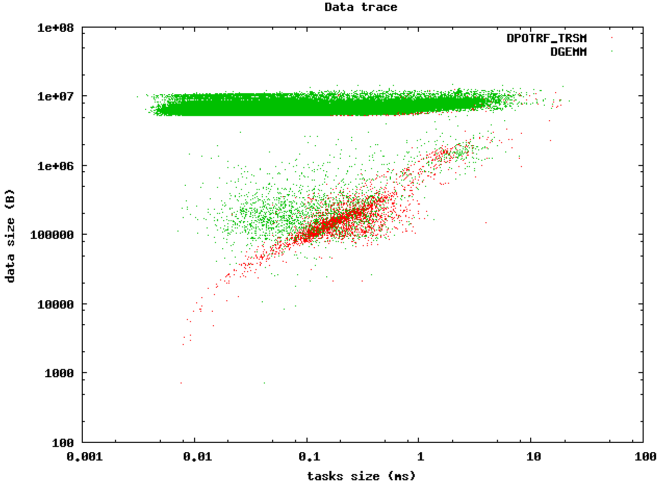
Offline Feedback – Kernel Model Power Efficiency

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



Offline Feedback – Synthetic Kernels' Behaviour

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



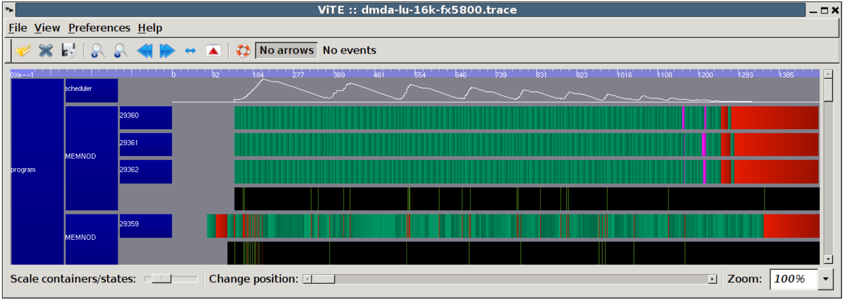
Offline Trace-Based Feedback

- FxT trace collection
- Trace analysis and display
  - ViTE Gantt
  - Graphviz DAG
  - StarVZ Gantt / 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

```
for (loop = 0; loop < NLOOPS; loop++) {






  for (i = 0; i < n; i++)
    update(&blocks[i-1],    /* R  */
           &blocks[i],      /* RW */
           &blocks[i+1]);   /* R  */


}
```

Distributed task graph

1D blocked stencil example, MPI version

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

```
for (loop = 0; loop < NLOOPS; loop++) {
  int first = me * num_blocks_per_rank;
  int last = (me+1) * num_blocks_per_rank - 1;

  MPI_Recv(&blocks[first -1], me-1);
  MPI_Recv(&blocks[last+1], me+1);

  for (i = first; i <= last; i++)
    update(&blocks[i-1],    /* R  */
           &blocks[i],      /* RW */
           &blocks[i+1]);   /* R  */

  MPI_Send(&blocks[first], me-1);
  MPI_Send(&blocks[last], me+1);
}
```

Distributed task graph

1D blocked stencil example, task version, explicit

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

```
for (loop = 0; loop < NLOOPS; loop++) {
  int first = me * num_blocks_per_rank;
  int last = (me+1) * num_blocks_per_rank - 1;

  starpu_mpi_irecv_submit(handles[first -1], me-1);
  starpu_mpi_irecv_submit(handles[last +1], me+1);

  for (i = first; i <= last; i++)
    starpu_task_insert(&cl_update, STARPU_R,  handles[i -1],
                                   STARPU_RW, handles[i],
                                   STARPU_R,  handles[i +1],0);

  starpu_mpi_isend_submit(handles[first], me-1);
  starpu_mpi_isend_submit(handles[last], me+1);
}
starpu_task_wait_for_all();
```

Distributed task graph

1D blocked stencil example, task version, implicit

- Let communication tasks get inferred from data mapping

```
for (loop = 0; loop < NLOOPS; loop++) {







  for (i = 0; i < n; i++)
    starpu_mpi_task_insert(&cl_update,
                           STARPU_R,  handles[i-1],
                           STARPU_RW, handles[i],
                           STARPU_R,  handles[i+1],0);


}
starpu_task_wait_for_all();
```

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Hands-on session 2