Simulating DAG Scheduling Algorithms with SimDAG

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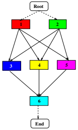
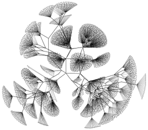
What is a DAG Scheduling Study?

X DAGs



x

Y platforms



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Z Heuristics

```
For each task do
  Select resource
  Schedule task
end do
```

Agenda of this tutorial

1. How to describe DAGs?
2. How to describe resources?
3. How to write scheduling heuristics?

Objective

- Write a (simple) functional simulator step-by-step

Resources

- `http://simgrid.gforge.inria.fr/tutorials/simdag-101/exercises/`
- `http://simgrid.gforge.inria.fr/tutorials/simdag-101/solutions/`

Before Starting to Code Anything

- `#include "simdag/simdag.h"` is mandatory
- Start by initializing the SimDag stuff
- End by cleaning this stuff neatly

```
#include "simdag/simdag.h"

int main(int argc, char **argv){
  SD_init(&argc, argv);

  /* Insert your code here */

  SD_exit();

  return 0;
}
```

- Get this basic skeleton in `exercises/ex1-2_template.c`
- Open it with your favorite editor

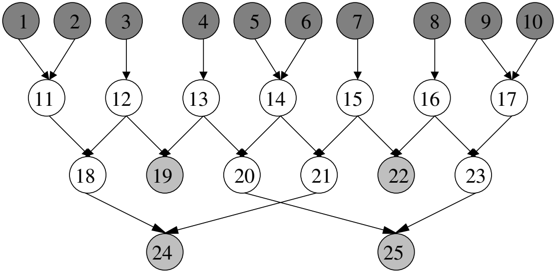
Agenda

- How to describe DAGs?
  - Definition
  - Manual Description
  - External Description and Automatic Load
- How to Describe Resources?
- How to Write Scheduling Heuristics?
- Conclusion

Definition of a DAG

Directed Acyclic Graph $\mathcal{G} = (\mathcal{V}, \mathcal{E})$

- $\mathcal{V} = \{v_i \mid i = 1, \ldots, V\}$
  - A set of vertices representing tasks
- $\mathcal{E} = \{e_{i,j} \mid (i,j) \in \{1, \ldots, V\} \times \{1, \ldots, V\}\}$
  - A set of edges representing precedence constraints and/or data movements between tasks



Representing Vertices/Tasks

Sequential computation

- Use a `SD_task_t` of type `SD_TASK_COMP_SEQ`
- Constructor: `SD_task_create_comp_seq(name, data, amount)`
  - `name`: the name of the task, as given by the user
  - `data`: some user data attached to the task
    - Useful for scheduling attributes
  - `amount`: the number of flops computed by this task
- Destructor: `SD_task_destroy(task)`
- Can be used with any model compound handled by SURF
  - see `--help-models` for details

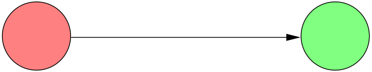
[Advanced] Parallel computation

- No type (`SD_TASK_NOT_TYPED`), default kind of `SD_task_t`
- Constructor: `SD_task_create(name, data, amount)`
  - `amount`: represents the sequential cost of the task
- Restricted to the `ptask_L07` model

Representing Edges/Dependencies

Control flow dependency

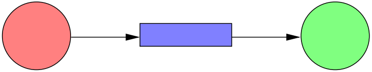
- a.k.a precedence constraint
- Goal: Force SimDAG to wait for the completion of ● to start ●
- Create a `SD_task_dependency`
  - `SD_task_dependency_add (name, data,●, ●)`



Representing Edges/Dependencies

Data flow dependency

- a.k.a passing data from a task to another
- Need to create a transfer ■ task between ● and ●
  - Add `SD_task_dependency` accordingly
  - `SD_task_dependency_add (name, data,●, ■)`
  - `SD_task_dependency_add (name, data,■, ●)`



Question

- How to declare a transfer task?

How to Represent Transfer Tasks

End-to-end communications

- If both source and destination are sequential tasks
- Use a task of type `SD_TASK_COMM_E2E`
- Constructor: `SD_task_create_comm_e2e(name, data, amount)`
  - `name`: the name of the task, as given by the user
  - `data`: some user data attached to the task
  - `amount`: the number of bytes transfered by this task

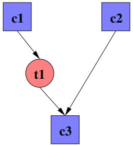
[Advanced] *MxN* data redistributions

- Same as for parallel computations
- No type (`SD_TASK_NOT_TYPED`)
- Constructor: `SD_task_create(name, data, amount)`
  - `amount`: represents the total number of bytes
  - Communication scheme defined at scheduling time
- Restricted to the `ptask_L07` model

Exercise 1

Describe the following graph

- Three sequential compute tasks
  - c1 computes 1e9 flops
  - c2 computes 5e9 flops
  - c3 computes 2e9 flops
- One end-to-end transfer task
  - t1 sends 5e8 bytes
- Don't forget the dependencies!
- Use template from `exercises/ex1-2_template.c`



Solution to Exercise 1

```
#include "simdag/simdag.h"

int main(int argc, char **argv) {
  SD_task_t c1, c2, c3, t1;
  SD_init(&argc, argv);

  c1 = SD_task_create_comp_seq("c1", NULL, 1E9);
  c2 = SD_task_create_comp_seq("c2", NULL, 5E9);
  c3 = SD_task_create_comp_seq("c3", NULL, 2E9);

  t1 = SD_task_create_comm_e2e("t1", NULL, 5e8);

  SD_task_dependency_add ("c1-t1", NULL, c1, t1);
  SD_task_dependency_add ("t1-c3", NULL, t1, c3);
  SD_task_dependency_add ("c2-c3", NULL, c2, c3);

  SD_exit();
  return 0;
}
```

- Get solution in `solutions/ex1-2.c`

Manage Your Set of Tasks

Use a Dynamic Array

- One out of the many useful data structures from the eXtended Bundle of Tools (XBT)
  - Requires `#include "xbt.h"`
- Dynars are dynamically sized vectors which may contain any type of variables
  - `xbt_dynar_t`
- Mandatory subset of functions
  - my_dynar = xbt_dynar_new (elm_size, free_method)
  - xbt_dynar_free_container (&my_dynar)
    - Free the dynar but not its content
  - xbt_dynar_push (my_dynar, &element)
  - xbt_dynar_pop(my_dynar, &element)
  - xbt_dynar_foreach(my_dynar, ctr, element)
    - Loop over elements in the array
  - xbt_dynar_length(my_dynar)
  - xbt_dynar_is_empty(my_dynar)
- For more information: `http://simgrid.gforge.inria.fr/simgrid/3.9/doc/group__XBT__dynar.html`

Retrieve Information on Tasks

Parameters of the constructor

- `SD_task_get_name(task)`
  - Can also be modified with `SD_task_set_name(task, "new_name")`
- `SD_task_get_data(task)`
  - Returns a `(void*)`, has to be casted by the user
  - Data can be attached at any time: `SD_task_set_data(task, (void*) data)`
- `SD_task_get_amount(task)` (non modifiable)
- `SD_task_get_kind(task)` (non modifiable)

Dependencies of task `T`

- Tasks on which `T` depends: `SD_task_get_parents(T)`
- Tasks depending on `T`: `SD_task_get_children(T)`
- Both functions return a `xbt_dynar_t`

Get everything

- `SD_task_dump(task)`

Exercise 2

- Get the solution of Exercise 1 in `exercises/ex1-2.c`
- Create a dynar of `SD_task_t`
- Push all the tasks in the dynar
- Browse the dynar
  - Dump information about each task
  - and destroy the task
- Destroy the dynar

Solution to Exercise 2

```
#include "simdag/simdag.h"
#include "xbt.h"

int main(int argc, char **argv) {
  SD_task_t c1, c2, c3, t1, tmp;
  unsigned int ctr;
  xbt_dynar_t tasks = xbt_dynar_new(sizeof(SD_task_t), &xbt_free);
  SD_init(&argc, argv);

  c1 = SD_task_create_comp_seq("c1", NULL, 1E9);
  c2 = SD_task_create_comp_seq("c2", NULL, 5E9);
  c3 = SD_task_create_comp_seq("c3", NULL, 2E9);
  t1 = SD_task_create_comm_e2e("t1", NULL, 5e8);
  SD_task_dependency_add ("c1-t1", NULL, c1, t1);
  SD_task_dependency_add ("t1-c3", NULL, t1, c3);
  SD_task_dependency_add ("c2-c3", NULL, c2, c3);

  xbt_dynar_push(tasks, &c1); xbt_dynar_push(tasks, &c2);
  xbt_dynar_push(tasks, &c3); xbt_dynar_push(tasks, &t1);

  xbt_dynar_foreach(tasks, ctr, tmp){
    SD_task_dump(tmp); SD_task_destroy(tmp);
  }
  xbt_dynar_free_container(&tasks);
  SD_exit();
  return 0;
}
```

- Get solution in solutions/ex1-2.c

SimDag Comes With Two Loaders

Common Features

- Creates all tasks and dependencies automatically
- Adds two special dummy tasks: `root` and `end`
- Returns a `xbt_dynar_t` of typed `SD_task_t`
  - `SD_TASK_COMP_SEQ` and `SD_TASK_COMM_E2E`

DAX format

- Format of workflow used by Pegasus (`http://pegasus.isi.edu/`)
- `SD_daxload(filename)`: loader for DAX files

DOT format

- Well-known format of the `graphviz` tool suite
- `SD_dotload(filename)`

DAX Format (1/2)

Header

- Name space and schema declaration (from Pegasus)
- Name of the DAX
- Number of jobs: `jobCount`
- Number of control dependencies: `childCount`

```
<?xml version="1.0" encoding="UTF-8"?>
<adag xmlns="http://pegasus.isi.edu/schema/DAX"
      xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"
      xsi:schemaLocation="http://pegasus.isi.edu/schema/DAX
                          http://pegasus.isi.edu/schema/dax-2.1.xsd"
      version="2.1" count="1" index="0" name="smalldax"
      jobCount="3" fileCount="0" childCount="1">
...
```

DAX format (2/2)

Job description

- Described by: id, name, runtime, input and output files
  - Only computations are described ($\texttt{amount} = \texttt{runtime} \times 4.2e9$)
  - Output of task1 is a input of task2 ⇒ Transfer task + data flow dependency

```
<job id="1" namespace="SG" name="c1" version="1.0" runtime="10">
  <uses file="i1" link="input" register="true" transfer="true"
        optional="false" type="data" size="1000000"/>
  <uses file="o1" link="output" register="true" transfer="true"
        optional="false" type="data" size="1000000"/>
</job>
```

Control flow dependencies

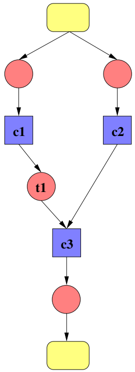
- task3 cannot start before the completion of task2
  - While there is no data flow dependency

```
<child ref="3">
  <parent ref="2"/>
</child>
```

Exercise 3

Describe the following graph in a DAX file

- Three sequential compute tasks
  - c1 runs for 10 seconds
    - Requires an input file of 2e8 bytes
    - Produces an output file of 5e8 bytes
  - c2 runs 50 seconds
    - Requires an input file of 1e8 bytes
  - c3 runs for 20 seconds
    - Requires an input file of 5e8 bytes
    - Produces an output file of 2e8 bytes
- Start from this skeleton:
  `exercises/ex3_template.xml`



Solution to Exercise 3

```
<?xml version="1.0" encoding="UTF-8"?>
<adag xmlns="http://pegasus.isi.edu/schema/DAX"
      xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"
      xsi:schemaLocation="http://pegasus.isi.edu/schema/DAX
                          http://pegasus.isi.edu/schema/dax-2.1.xsd"
      version="2.1" count="1" index="0" name="smalldax"
      jobCount="3" fileCount="0" childCount="1">
  <job id="1" namespace="SG" name="c1" version="1.0" runtime="10">
    <uses file="i1" link="input" register="true" transfer="true"
          optional="false" type="data" size="2e8"/>
    <uses file="o1" link="output" register="true" transfer="true"
          optional="false" type="data" size="5e8"/>
  </job>
  <job id="2" namespace="SG" name="c2" version="1.0" runtime="50">
    <uses file="i2" link="input" register="true" transfer="true"
          optional="false" type="data" size="1e8"/>
  </job>
  <job id="3" namespace="SG" name="c3" version="1.0" runtime="20">
    <uses file="o1" link="input" register="true" transfer="true"
          optional="false" type="data" size="5e8"/>
    <uses file="o3" link="output" register="true" transfer="true"
          optional="false" type="data" size="2e8"/>
  </job>
  <child ref="3">
    <parent ref="2"/>
  </child>
</adag>
```

- Get solution in `solutions/ex3.xml`

DOT Format

Task Description

- Described by an id and a size
  - The size correspond to the `amount` parameter of the task creator
  - Expressed in flops

Dependency Description

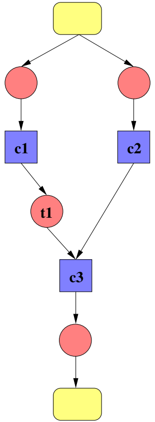
- Described by `src`→`dst` and a size
  - The size also corresponds to `amount`
  - A negative size indicates a control dependency
  - Expressed in bytes
- Dependencies from `root` and to `end` have to be explicit

```
digraph G {
   c1 [size="1e9"];
   root->c1 [size="1e8"];
   c1->end [[size="2e8"];
}
```

Exercise 4

Describe the following graph in a DOT file

- Three sequential compute tasks
  - c1 computes 1e9 flops
    - Requires an input file of 2e8 bytes
    - Produces an output file of 5e8 bytes
  - c2 computes 5e9 flops
    - Requires an input file of 1e8 bytes
  - c3 computes 2e9 flops
    - Requires an input file of 5e8 bytes
    - Produces an output file of 2e8 bytes
- Get Template in `exercises/ex4_template.dot`



Solution to Exercise 4

```
digraph G {
   c1 [size="1e9"];
   c2 [size="5e9"];
   c3 [size="2e9"];

   root->c1 [size="2e8"];
   root->c2 [size="1e8"];
   c1->c3   [size="5e8"];
   c2->c3   [size="-1."];
   c3->end  [size="2e8"];
}
```

- Get solution in `solutions/ex4.dot`

Exercise 5

Use the DAX (or DOT) loader (use a new source file)

- Call the loader
- Dump information of all tasks
- Destroy each task

Solution to Exercise 5

Exercise 5

Use the DAX (or DOT) loader (use a new source file)

- Call the loader
- Dump information of all tasks
- Destroy each task

Solution to Exercise 5

```
#include "simdag/simdag.h"
#include "xbt.h"

int main(int argc, char **argv) {
  unsigned int cpt;
  SD_task_t task;
  xbt_dynar_t dag;
  SD_init(&argc, argv);

  dag = SD_daxload(argv[1]);

  xbt_dynar_foreach(dag, cpt, task){
    SD_task_dump(task);
    SD_task_destroy(task);
  }
  SD_exit();
  return 0;
}
```

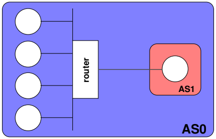
Agenda

- How to describe DAGs?
- How to Describe Resources?
  - Available Types of Resources
  - Creating an Experimental Environment
  - Attach User Data
- How to Write Scheduling Heuristics?
- Conclusion

Available Types of Resources

Types of resources

- Single Hosts: id and power
- Links: id, latency and bandwidth
- Clusters
  - id and name (prefix radical suffix)
  - power
  - private link latency (lat) and bandwidth (bw)
  - backbone latency (bb_lat) and bandwidth (bb_bw)
  - router

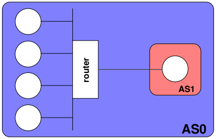


- routes: src and dst
- Resources grouped in Autonomous Systems (AS)
- Description in an XML platform file
- From a SimDag point of view:
  - A Host and (some) link(s) are grouped to form a workstation
  - SD_workstation_t data structure

Exercise 6

Describe the following platform

- One cluster
  - Named `my_cluster`
  - Four homogeneous hosts running at 4.2e9 flop/s
    - Named `c-x.me`, with x $\in [1-4]$
  - Four private links
    - Latency: 5e-5 seconds
    - Bandwidth: 1.25e8 bytes/s
  - One backbone
    - Latency: 5e-4 seconds
    - Bandwidth: 2.25e9 bytes/s
- One host in its own AS
  - Named `host1` and running at 4.2e9 flop/s
- One link connecting both ASes
  - Latency: 0.01 seconds
  - Bandwidth: 1e5 bytes/s
- Start from skeleton in `exercices/ex6_template.xml`



Solution to Exercise 6

cluster_and_one_host.xml

```
<?xml version='1.0'?>
<!DOCTYPE platform SYSTEM "http://simgrid.gforge.inria.fr/simgrid.dtd">
<platform version="3">
  <AS id="AS0" routing="Full">
    <cluster id="my_cluster" prefix="c-" suffix=".me" radical="1-4"
             power="4.2e9" bw="125000000" lat="5E-5"
             bb_bw="2250000000" bb_lat="5E-4"
             router_id="router1"/>

    <AS id="AS1" routing="Full">
      <host id="host1" power="1000000000"/>
    </AS>

    <link id="link1" bandwidth="100000" latency="0.01"/>

    <ASroute src="my_cluster" dst="AS1" gw_src="router1" gw_dst="host1">
      <link_ctn id="link1"/>
    </ASroute>
  </AS>
</platform>
```

- Get the platform file in solutions/ex6.xml

Creating the Environment

Loading the Platform File

- Use the `SD_create_environment` function
  - Takes a filename as input
  - Creates an array of `SD_workstation_t`
  - No need for deployment file in SimDag

Getting all the workstations

- Number of workstations: `SD_workstation_get_number()`
- Array of workstations: `SD_workstation_get_list()`

Workstation specific information

- `SD_workstation_get_name(workstation)` (non modifiable)
- `SD_workstation_get_power(workstation)` (non modifiable)
- `SD_workstation_get_data(workstation)`
  - Returns a `(void*)`, has to be casted by the user
  - Data can be attached at any time
    `SD_task_set_data(workstation, (void*) data)`
- Get everything: `SD_workstation_dump(workstation)`

Retrieving Information About Network

Getting all the links

- `SD_link_get_number()` returns the number of links
- `SD_link_get_list()` returns the list of links

Link specific information

- `SD_link_get_name(link)` (non modifiable)
- `SD_link_get_data(workstation)`
  - Returns a `(void*)`, has to be casted by the user
  - Data can be attached at any time: `SD_link_set_data(link, (void*) data)`
- `SD_link_get_sharing_policy (link)`
  - May this link cause contention or not

Route specific information

- `SD_route_get_size (src_workstation, dst_workstation)`
  - Returns the number of links on the route between two workstations
- `SD_route_get_list (src_workstation, dst_workstation)`
  - Returns the list of links on the route between two workstations

Exercise 7

- Use the source code of Exercise 5
- Load the platform file from Exercise 6
- Get the number of workstations
- Get the list of workstations
- Dump information about each workstation

Solution to Exercise 7

```
#include "simdag/simdag.h"
#include "xbt.h"

int main(int argc, char **argv) {
  unsigned int cpt;
  int nworkstations;
  const SD_workstation_t * workstations;
  SD_task_t task;
  xbt_dynar_t dag;
  SD_init(&argc, argv);

  dag = SD_daxload(argv[1]);

  xbt_dynar_foreach(dag, cpt, task)
    SD_task_dump(task);
  xbt_dynar_foreach(dag, cpt, task)
    SD_task_destroy(task);


  SD_create_environment(argv[2]);
  nworkstations = SD_workstation_get_number();
  workstations = SD_workstation_get_list();
  for (cpt = 0; cpt < nworkstations; cpt++)
    SD_workstation_dump(workstations[cpt]);

  SD_exit();
  return 0;
}
```

▶ Get solution in `solutions/ex5-7.c`

Attach User Data to Workstations

- This can be useful for scheduling
- Examples
  - When is a workstation available to execute a new task?
    - `double available_at /* a time */`
  - What is the last task scheduled on a workstation?
    - `SD_task_t last_scheduled_task`
- Principle:
  - Create a data structure comprising all needed information
    - Allocation and destruction functions
  - Write access functions (set/get)
    - Use the `data` field of a workstation (same is true for `SD_task_t`)

```
typedef struct _WorkstationAttribute {
  double available_at;
  SD_task_t last_scheduled_task;
} *WorkstationAttribute;

static double SD_workstation_get_available_at(SD_workstation_t ws) {
  WorkstationAttribute attr = (WorkstationAttribute) SD_workstation_get_data(ws);
  return attr->available_at;
}
static void SD_workstation_set_available_at(SD_workstation_t ws, double time) {
  WorkstationAttribute attr = (WorkstationAttribute) SD_workstation_get_data(ws);
  attr->available_at = time;
  SD_workstation_set_data(ws, attr);
}
```

Exercise 8

- Write a `SD_workstation_allocate_attribute` function
  - Allocate the data structure
  - Attach it the workstation given as input
- Write a `SD_workstation_free_attribute` function
  - Free the data structure
  - Reset the `data` field
- Write the access functions for the `last_scheduled_task` attribute
  - Use the functions for the `available_at` attribute

Solution to Exercise 8

```
static void SD_workstation_allocate_attribute(SD_workstation_t ws){
  void *data = calloc(1, sizeof(struct _WorkstationAttribute));
  SD_workstation_set_data(ws, data);
}

static void SD_workstation_free_attribute(SD_workstation_t ws) {
  free(SD_workstation_get_data(ws));
  SD_workstation_set_data(ws, NULL);
}

static SD_task_t SD_workstation_get_last_scheduled_task(SD_workstation_t ws){
  WorkstationAttribute attr = (WorkstationAttribute) SD_workstation_get_data(ws);
  return attr->last_scheduled_task;
}

static void SD_workstation_set_last_scheduled_task(SD_workstation_t ws, SD_task_t task){
  WorkstationAttribute attr = (WorkstationAttribute) SD_workstation_get_data(ws);
  attr->last_scheduled_task=task;
  SD_workstation_set_data(ws, attr);
}
```

- Get solution in `solutions/ex8.c`
- ...and copy the contents in `solutions/ex5-7.c`

Agenda

- How to describe DAGs?
- How to Describe Resources?
- How to Write Scheduling Heuristics?
  - General Information
  - A Simple Static Round-Robin Scheduler
  - The Min-Min List Scheduling Algorithm
- Conclusion

Definition of DAG Scheduling

Basic principle

- For each task
  - Assign a (set of) resource(s) for execution
  - Define an execution order
- Respect the precedence constraints
  - A task cannot start before all its predecessors have completed

Types of scheduling

- Offline
  - Take all decisions beforehand and then simulate
- Online
  - Take the decisions as the simulation goes

Running the Simulation

Static Schedules

- Build the complete schedule before running the simulation
  - Call a `SD_task_schedule*` function for each task
- Then call `SD_simulate(-1.)`
  - It will stop when all the work has been done
  - Or if no more tasks are reachable

Dynamic Schedules

- Build the schedule during the simulation
- Two options
  - Hold the simulation every X seconds to take more decisions: `SD_simulate(X)`
  - Add watchpoints on the state of tasks
    - `SD_task_watch (task, state)`
    - The simulation will be hold each time a watch point is reached
    - For in time when a task goes from `SD_TASK_RUNNING` to `SD_TASK_DONE`
- This requires to add an outer loop
- Dynamic rescheduling is possible with `SD_task_unschedule`

What You Can Get After the Simulation

- When the task did actually start
  - `SD_task_get_start_time (task)`
- When the task did actually finish
  - `SD_task_get_finish_time (task)`
- How many workstation were used to execute a task
  - `SD_task_get_workstation_count (task)`
- And which ones
  - `SD_task_get_workstation_list (task)`
- Plot a Gantt chart and analyze performance metrics
  - Using either Jedule or Pajé built-in instrumentation

A Simple Static Round-Robin Scheduler

- When scheduling DAGs
  - Compute tasks run on one host only
  - Data transfers are point-to-point communications
- Typed tasks ⇒ Get rid off all the complexity of parallel tasks
  -
- Creation
  - `compute_task = SD_task_create_comp_seq(name, data, amount)`
  - `transfer_task = SD_task_create_comm_e2e(name, data, amount)`
- Scheduling
  - `SD_task_schedulev(task, workstation_nb, workstation_list)`
  - `SD_task_schedulel(task, workstation_nb, ...)`
  - `amount` will be directly used
- Transfers are auto-scheduled

Exercise 9

- Start from the solution of exercise 8 in `solutions/ex8.c`
  - Important: Remove the line that destroy all the tasks
- Allocate attributes for each workstation
- Code the following (dummy) heuristic
  - For each compute task, i.e., whose kind is `SD_TASK_COMP_SEQ`
    - Schedule it on a workstation in a round robin fashion
    - Update the `last_scheduled_task` attribute
- Call the main simulation function
- Print value of the `last_scheduled_task` attribute, dump information and destroy attributes for each workstation
- Dump information for and destroy each task
- Print simulation time
  - Use the `SD_get_clock()` function

Solution to Exercise 9 (1/2)

```
int main(int argc, char **argv){
  unsigned int cpt, cpt2;
  int nworkstations;
  const SD_workstation_t * workstations;
  SD_task_t task;
  xbt_dynar_t dag;

  SD_init(&argc, argv);

  dag = SD_daxload(argv[1]);

  xbt_dynar_foreach(dag, cpt, task)
    SD_task_dump(task);

  SD_create_environment(argv[2]);

  nworkstations = SD_workstation_get_number();
  workstations = SD_workstation_get_list();

  for (cpt = 0; cpt < nworkstations; cpt++){
    SD_workstation_dump(workstations[cpt]);
    SD_workstation_allocate_attribute(workstations[cpt]);
  }

  ...
```

Solution to Exercise 9 (2/2)

```
  ...
  cpt=0;
  xbt_dynar_foreach(dag, cpt2, task)
    if (SD_task_get_kind(task) == SD_TASK_COMP_SEQ){
      SD_task_schedulel(task, 1, workstations[cpt]);
      SD_workstation_set_last_scheduled_task(workstations[cpt++], task);
    }
  SD_simulate(-1);

  for (cpt = 0; cpt < nworkstations; cpt++){
    printf("Last scheduled task on %s is %s\n",
           SD_workstation_get_name(workstations[cpt]),
           SD_task_get_name(SD_workstation_get_last_scheduled_task(workstations[cpt])));
    SD_workstation_dump(workstations[cpt]);
    SD_workstation_free_attribute(workstations[cpt]);
  }

  xbt_dynar_foreach(dag, cpt, task){
    SD_task_dump(task);
    SD_task_destroy(task);
  }
  printf("Simulation time: %f seconds\n", SD_get_clock());
  SD_exit();
  return 0;
}
```

- Get solution in `solutions/ex9.c`

A Complete Scheduling Simulator Example

The Min-Min List Scheduling Algorithm

- For each ready task
  - get the workstation that minimizes the completion time
- select the task that has the minimum completion time on its best workstation
  - And schedule it there
- Full code available at `$SIMGRID_HOME/examples/simdag/scheduling/minmin_test.c`

What is needed ?

- Functions to
  - Estimate the Earliest Finish Time of a task on a workstation
  - Find the workstation that minimizes this EFT
  - Get the list of ready tasks
- The main scheduling function
  - That dynamically take decisions each time a task completes
    - Thanks to watchpoints
    - Call `SD_simulate` several times

Some Useful Prediction Functions

Sequential Computation and End-to-End Communications

- `SD_workstation_get_computation_time (workstation, amount)`
- `SD_route_get_communication_time (src, dst, amount)`
- These functions do not take concurrent executions into account

Routes and workstations

- `SD_route_get_current_bandwidth (src, dest)`
- `SD_route_get_current_latency (src, dest)`
- `SD_workstation_get_available_power(workstation)`

[Advanced] Default Parallel Tasks

- `SD_task_get_execution_time`
  - Workstation list
  - Array of computation amounts
  - Communication matrix
- `SD_task_get_remaining_amount`
  - The simulation is hold, how much computation remains for this task?

Exercise 10

- Start again from the solution of exercise 8 in `solutions/ex8.c`
  - Important: Remove the line that destroy all the tasks
  - Allocate attributes for each workstation
- Write a function `double finish_on_at(SD_task_t task, SD_workstation_t workstation)` that
  - Estimate when the last incoming data (if any) may arrive on `workstation`
    - Got to know the *grand parent* of the task to know the transfer source
    - Got to know the *parent* of the task to know the transfer size
  - Estimate when `task` can actually start
    - Maximum of arrival of last data and availability time of `workstation`
  - Estimate the execution time of `task` on `workstation`
  - Add both values and return the result

Solution to Exercise 10 (1/2)

```
double finish_on_at(SD_task_t task, SD_workstation_t workstation){
  double result, data_available = 0., last_data_available, redist_time = 0;
  unsigned int i;
  SD_task_t parent, grand_parent;
  xbt_dynar_t parents, grand_parents;
  SD_workstation_t *grand_parent_workstation_list;

  parents = SD_task_get_parents(task);

  if (!xbt_dynar_is_empty(parents)) {
    last_data_available = -1.0;
    xbt_dynar_foreach(parents, i, parent) {
      if (SD_task_get_kind(parent) == SD_TASK_COMM_E2E) {      /* normal case */
        grand_parents = SD_task_get_parents(parent);

        xbt_dynar_get_cpy(grand_parents, 0, &grand_parent);
        grand_parent_workstation_list = SD_task_get_workstation_list(grand_parent);

        /* Estimate the redistribution time from this parent */
        redist_time = SD_route_get_communication_time(grand_parent_workstation_list[0],
                                                      workstation, SD_task_get_amount(parent));
        data_available = SD_task_get_finish_time(grand_parent) + redist_time;

        xbt_dynar_free_container(&grand_parents);
      }
  ...
```

Solution to Exercise 10 (2/2)

```
  ...

      if (SD_task_get_kind(parent) == SD_TASK_COMP_SEQ) { /* no transfer: control dep. */
        data_available = SD_task_get_finish_time(parent);
      }

      if (last_data_available < data_available)
        last_data_available = data_available;
    }

    xbt_dynar_free_container(&parents);

    result = MAX(SD_workstation_get_available_at(workstation), last_data_available) +
        SD_workstation_get_computation_time(workstation, SD_task_get_amount(task));
  } else {
    xbt_dynar_free_container(&parents);

    result = SD_workstation_get_available_at(workstation) +
             SD_workstation_get_computation_time(workstation, SD_task_get_amount(task));
  }
  return result;
}
```

- Get source of code of this function in `solutions/ex10.c`

Exercise 11

- Write a function `SD_workstation_t SD_task_get_best_workstation(SD_task_t task)` that
  - For each workstation, estimate the time at which `task` would finish
  - Keep the workstation that leads to the minimum value
  - Return this workstation
- Write a function `xbt_dynar_t get_ready_tasks(xbt_dynar_t dag)` that
  - Create a dynamic array of tasks
  - Browse the dag and push in the array all the tasks that are
    - A computation
    - And in the `SD_SCHEDULABLE` state (all compute ancestors are SD_DONE)
  - Return the built array

Solution to Exercise 11

```
SD_workstation_t SD_task_get_best_workstation(SD_task_t task) {
  int i, nworkstations = SD_workstation_get_number();
  double EFT, min_EFT = -1.0;
  const SD_workstation_t *workstations = SD_workstation_get_list();
  SD_workstation_t best_workstation;

  best_workstation = workstations[0];
  min_EFT = finish_on_at(task, workstations[0]);

  for (i = 1; i < nworkstations; i++) {
    EFT = finish_on_at(task, workstations[i]);
    if (EFT < min_EFT){
      min_EFT = EFT;  best_workstation = workstations[i];
    }
  }
  return best_workstation;
}
xbt_dynar_t get_ready_tasks(xbt_dynar_t dag) {
  unsigned int i;
  xbt_dynar_t ready_tasks = xbt_dynar_new(sizeof(SD_task_t), NULL);
  SD_task_t task;

  xbt_dynar_foreach(dag, i, task)
    if (SD_task_get_kind(task)==SD_TASK_COMP_SEQ && SD_task_get_state(task)==SD_SCHEDULABLE)
      xbt_dynar_push(ready_tasks, &task);

  return ready_tasks;
}
```

▶ Get source of code of these functions in `solutions/ex11.c`

Exercise 12

- Start from solutions of `ex8.c`, `ex10.c`, and `ex11.c`
- Write the `main` function that
  - Load the environment
    - Allocate attributes for all workstations
  - Load the DAG
    - Add watchpoints on the `SD_DONE` state for all tasks
  - Schedule the `root` on the first workstation
  - While `SD_simulate` return tasks whose state changed
    - Get the ready tasks, if none exists, just continue
    - Get their best workstation
    - Compute their EFT on that workstation
    - Select the one finishing the earliest
    - Schedule it
  - Manage resource dependencies
  - Do some cleaning

Solution to Exercise 12 (1/3)

```
int main(int argc, char **argv) {
  unsigned int cursor;
  double finish_time, min_finish_time = -1.0;
  SD_task_t task, selected_task = NULL, last_scheduled_task;
  xbt_dynar_t ready_tasks;
  SD_workstation_t workstation, selected_workstation = NULL;
  int total_nworkstations = 0;
  const SD_workstation_t *workstations = NULL;
  xbt_dynar_t dag, changed;

  SD_init(&argc, argv); /* initialization of SD */

  dag = SD_daxload(argv[1]);   /* load the DAX file */

  xbt_dynar_foreach(dag, cursor, task) /* add watchpoint on task completion */
    SD_task_watch(task, SD_DONE);

  SD_create_environment(argv[2]);  /* creation of the environment */

  /*  Allocating the workstation attribute */
  total_nworkstations = SD_workstation_get_number();
  workstations = SD_workstation_get_list();

  for (cursor = 0; cursor < total_nworkstations; cursor++)
    SD_workstation_allocate_attribute(workstations[cursor]);

  ...
```

Solution to Exercise 12 (2/3)

```
...
/* Schedule the DAX root first */
xbt_dynar_get_cpy(dag, 0, &task);
workstation = SD_task_get_best_workstation(task);
SD_task_schedulel(task, 1, workstation);

while (!xbt_dynar_is_empty((changed = SD_simulate(-1.0)))) {
  /* Get the set of ready tasks */
  ready_tasks = get_ready_tasks(dag);
  if (xbt_dynar_is_empty(ready_tasks)) {
    xbt_dynar_free_container(&ready_tasks);
    xbt_dynar_free_container(&changed);
    continue;  /* there is no ready task, let advance the simulation */
  }
  xbt_dynar_foreach(ready_tasks, cursor, task) {
    workstation = SD_task_get_best_workstation(task);
    finish_time = finish_on_at(task, workstation);
    if (min_finish_time == -1. || finish_time < min_finish_time) {
      min_finish_time = finish_time;
      selected_task = task;
      selected_workstation = workstation;
    }
  }

  SD_task_schedulel(selected_task, 1, selected_workstation);
  ...
```

Solution to Exercise 12 (3/3)

```
    ...
    /* Manage resource dependencies */
    last_scheduled_task =  SD_workstation_get_last_scheduled_task(selected_workstation);
    if (last_scheduled_task && (SD_task_get_state(last_scheduled_task) != SD_DONE) &&
        (SD_task_get_state(last_scheduled_task) != SD_FAILED) &&
        !SD_task_dependency_exists(SD_workstation_get_last_scheduled_task(
                                   selected_workstation), selected_task))
      SD_task_dependency_add("resource", NULL, last_scheduled_task, selected_task);

    SD_workstation_set_last_scheduled_task(selected_workstation, selected_task);
    SD_workstation_set_available_at(selected_workstation, min_finish_time);

    xbt_dynar_free_container(&ready_tasks);
    xbt_dynar_free_container(&changed);
    min_finish_time = -1.;     /* reset the min_finish_time for the next round */
  }
  xbt_dynar_foreach(dag, cursor, task)
    SD_task_destroy(task);
  xbt_dynar_free_container(&dag);
  xbt_dynar_free_container(&changed);

  for (cursor = 0; cursor < total_nworkstations; cursor++)
    SD_workstation_free_attribute(workstations[cursor]);

  SD_exit();
  return 0;
}
```

- Get source of code in `solutions/ex12.c`

Conclusion

- This tutorial gives examples of the basic usage of most SimDag function
  - You should be able to code your own simulator now!
- Where to find more information on SimDag
  - in `$SIMGRID_HOME/examples/simdag`
  - in the contrib section of SimGrid
    - A set of implementations of classical DAG scheduling algorithms
    - `svn co svn://scm.gforge.inria.fr/svn/simgrid/contrib/trunk/DAGSched`
- Feel free to contribute to SimDag and the contrib section
  - And to ask questions on `simgrid-user@lists.gforge.inria.fr`