CS528

End to End Delay Minimization for **Scientific Workflow** in cloud under **Budget Constraints**

Robust Scheduling of **Scientific Workflows** with Deadline and **Budget Constraints** in Clouds

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Reference:

Wu et.al, *End to End Delay Minimization for Scientific Workflow in cloud under Budget Constraints,* IEEE Trans. On Cloud Computing. 2015.

Introduction

- With emergence of cloud computing and rapid deployment of cloud infrastructures
  - Number of **scientific workflows** have been shifted to cloud environments.
- Challenges:
  - Reducing financial cost in addition
  - to meeting the traditional goal : performance
- Quick evaluation of scientific workflow
  - to minimize the workflow end-to-end delay under a user-specified financial constraint

Scientific Workflow : SWF

- Large-scale scientific computing tasks
  - for data generation, processing, and analysis are
  - often assembled and constructed as **Workflows**
  - comprised of many interdependent **modules**
- Workflow (WF) module communicates
  - with others through the sharing of data sets,
  - which are either stored in shared file system or
  - transferred from node to node by WF management system
- Scientific Workflows are
  - typically executed in a distributed manner
  - in heterogeneous network environments

WF in Clouds System

- It is essential construct analytical models
  - to quantify the network performance of scientific workflows
  - in IaaS cloud environments,
  - and formulate a task scheduling problem
- Scheduling Problems: WF on Cloud
  - to minimize the workflow end-to-end delay
  - under a user-specified financial cost constraint,
- Referred to as Minimum End-to-end Delay under Cost Constraint (MED-CC)

Workflow Execution in Cloud

- Workflow is represented as
  - a directed acyclic graph (DAG),
- Submitted to the workflow engine
  - for executing, scheduling, tracking and reporting
- Workflow (WF) have independent tasks (Work/W), and
  - Execution model with inter-module dependencies
  - Identify and quantify the key financial and time cost

a software system that is used to manage and execute complex workflows

Cost Model : time and financial

- **Time Cost or simply Time :** overall time to execute Work W_i on VM_j

$$T_{i,j}=T(I_j)+T(E_{i,j})+T(R_i)$$

  - $T_{i,j}$= overall time to execute Work W_i on VM_j
  - $T(I_j)$ = Startup Time for VM_j
  - $T(E_{i,j})$ = time to execute W_i on VM_j
  - $T(R_i)$ = time of upload/download data from/to VM_j

Cost Model : time and financial

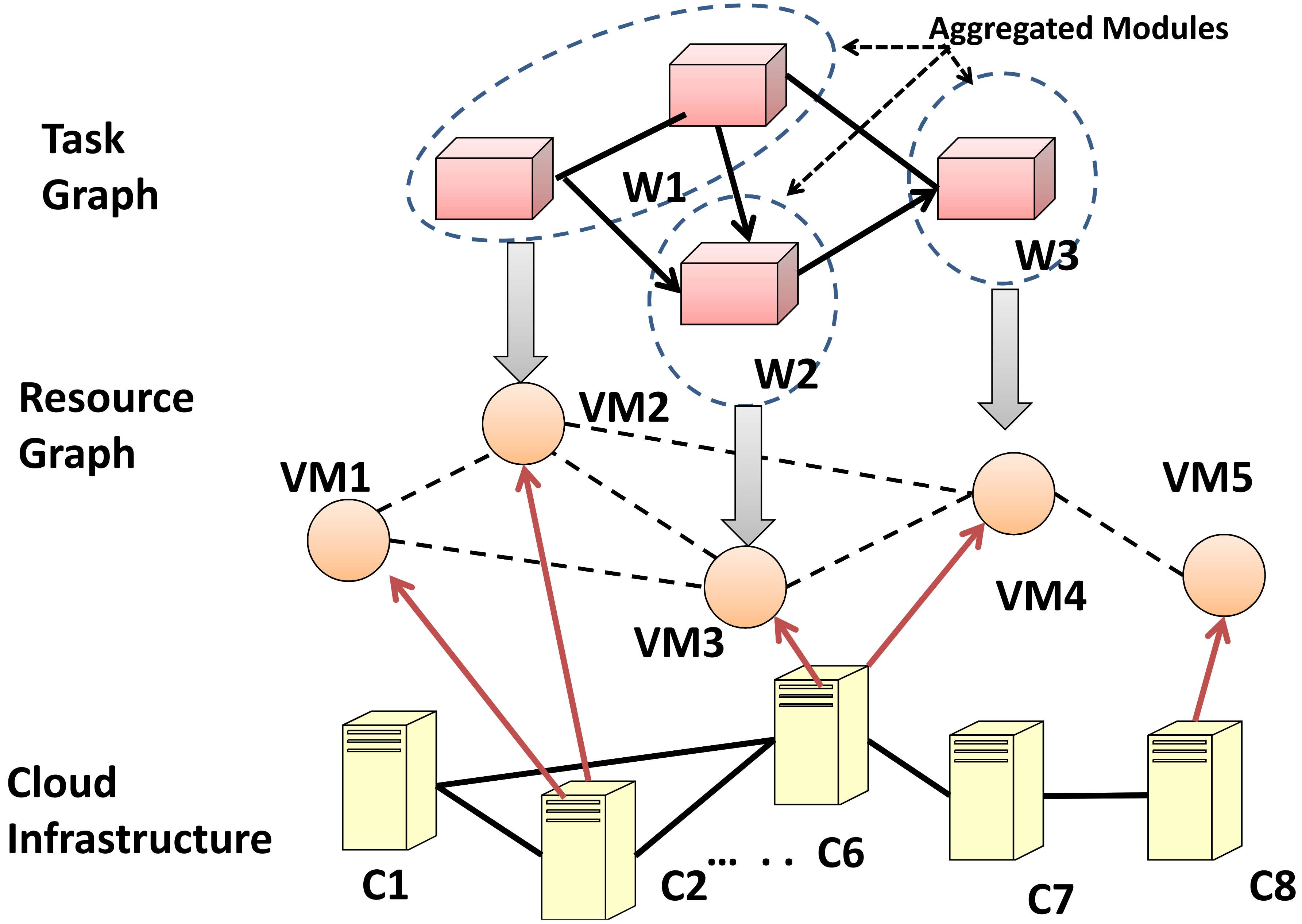
- **Financial Cost (or simply Cost): Overall time to** execute Work W_i on **VM_j**

$$C_{i,j}=C(I_j)+C(E_{i,j})+C(R_i)+C(S_i)$$

  - $C(S_i)$ = data storage cost of W_i
  - **$C(I_j)$, $C(E_{i,j})$, $C(R_i)$** cost of Init VMj, execution of Wi on VMj and download/upload data to/from VM_j for W_i
- Set of Available VM type $VT=\{vt_0,vt_1,..vt_{n-1}\}$
  - **vt_j have processing power p_j and cost c_j**
- Cost of executing W_i on VM_j

$$C(E_{i,j})=T(E_{i,j})*c_j$$

Modeling Workflow Exe in Cloud



3 Layer Models of WF Exe^{n} in Cloud

- Three layers in the work-flow scheduling problem in cloud environments
  - **Task graph layer** comprised of interdependent workflow modules,
  - **Resource graph layer** representing a network of VMs,
  - **Cloud infrastructure layer** consisting of physical computer nodes connected by network links

Work mapping to VM

- **Task graph layer** : scientific work- flows
  - preprocessed by an appropriate clustering technique
  - based on the inter-module dependencies
  - and the volumes of inter-module data transfer
- A group of modules in the original workflow are
  - bundled together as one aggregate module in the resulted task graph
- Simple mapping: one-to-one mapping scheme
  - **Each aggregate module** in the task graph is
  - **Assigned to a different VM** for execution.

Layer1 : Workflow Model

- Task graph/workflow modeled as DAG

$$G_w(V_w, \; E_w)$$

  - Consisting of V_w modules
  - with E_w directed edges $l_{i,j}$ representing the data dependency between module w_i and w_j
  - Each module $w_i \epsilon V_w$ carries a certain amount of workload WL_i
  - Each edge $l_{i,j}$ transfers a certain data size $DS_{i,j}$.

VM Cost and Perf. Model

- A set of available VM types

$$VT = \{ vt_0, vt_1, \ . \ . \ . \ vt_{n}\}$$

  - where each type vt_j is associated with both cost- and performance-related attributes vt_j as : $vt_j\ (vp_j, Cv_j)$
- vp_j : Processing power of VM type vt_j
  - including its processor, speed, disk volume and memory space
- $Cv_{j\,:}$ Financial cost for using this VM
  - Per time unit including all cost components such as
  - VM initialization, module execution, and data transfer

Layer3: Cloud Infrastructure Model

- cloud infrastructure is model as arbitrary weighted graph $\mathbf{G_c=\{V_c, E_c\}}$
  - consisting of a set of physical computer nodes.
  - Each computer node $c_i \in V_c$ has a processing power PP_i
- Cost of a data transfer R_{ij} of size DS_{ij} from module $\mathbf{w_i}$ to w_j is calculated as:

$$C(R_{i,j}) = C_R\,.DS_{i,j}$$

Layer 2 :Virtual Resource Model

- Virtual Resource : Modeled as fully connected weighted graph $G'_c(V'_c, E'_c)$
  - consisting of $|V'_c|$ VMs connected by $|E'_c|$ virtual links.
  - Each virtual link $l'_{p,q}$ has a bandwidth $BW'_{p,q}$,
  - which is a function of physical bandwidth between two physical machines provisioning VMs c'_p and c'_q.
  - Each VM $c' \in V'_c$ is an instance of a certain VM type.
- Time of data transfer R_{ij} of size DS_{ij} from module w_i to w_j is calculated as

$$T(R_{i,j}) = DS_{i,j}/BW'_{pq} + d'_{pq}$$

  - where d'_{pq} is delay of the virtual link

Time and Cost Execution W_i on VM_J

- Time of Execution E_{ij} of module w_i on a VM of type vt_j

$$T\,(\,E_{ij}\,) \;=\; Wl_i\,/\,vp_j$$

  - Wl_i is workload of w_i and
  - vp_j is performance of vt_j of VM_j
- Module execution cost is calculated as:

$$C(E_{ij}) = T(E_{ij})\, C_{Vj}$$

Min End2End Exe Cost Constraints

- MED-CC Problem : Given DAG ***$G_w(V_w, E_w)$***, VT set ***$VT = \{ vt_0, vt_1, \ldots vt_{n-1}\}$*** and budget **B**
- Find a Schedule S, such that
  - minimum end-to-end delay of the one-to-one mapped workflow is achieved

MED= $\min_{all\ possible\ S}(T_{total}) = \min_{all\ possible\ S}\left(\sum_{all\ w_i \in CP} T_{i,j}\right)$

- Subjected Cost Constraints $C_{total} = \sum_{i=0}^{m-1} C_{i,j} \leq B$
- Proved to be NPC
  - Using Multiple Choice Knapsack Problem (MCKP)

Critical Greedy Heuristics

```
CriticalGreedy(G, VT, B){
1. For all $w_i$, for all $vt_j$ calculate $C_{ij}$ and $T_{ij}$
2. Find Minimal Cost $C_{min}$
3.      if ($B < C_{min}$ )  No Solution, return;
4. Find Maximal Cost $C_{max}$,
5. if ($B>C_{max}$ ) Map  all $w_i$ to best $vt_{max}$ return;
6. AllcateVM using global budget level();
7. Do local adjustment ();
}
```

Allocate VM using Global Budget Level

Try to allocate good VT based on Budget

$$GBL = (B-C_{min})/(C_{max}-C_{min})$$

For all $\mathbf{w}_i$ map to $\mathbf{vt}_j$ with GBL

Target cost for $\mathbf{w}_i$, $\mathbf{tc}_i = C_{i,min}+(C_{i,max}-C_{i,min})*GBL$

Target VT for $\mathbf{w}_i$, for $\min(tc_i-C_{i,k})$ and $C_{i,k}<tc_i$

Do local adjustment ();

```
While cost2Spend > 0 {
Calculate Current Critical path CP;
For all $w_i$ in CP for all $vt_j$
    find max benefit with $\Delta T_{i,j} > 0$ and max $\frac{\Delta T_{i,j}}{\Delta C_{i,j}}$
    //Putting small money but max time reduction
    if such $w_i$ found change mapping of $w_i$ to new $vt_j$
    cost2Spend -= ExtraCostSpendonThis;
}
```

Reference:

Poola et.al, ***Robust Scheduling of Scientific Workflows with Deadline and Budget Constraints in Clouds,*** IEEE Int. Conf. on Adv. Info. Networking & Applications,. 2014.

Introduction

- **Scientific workflows** Scheduling in Cloud
  - Cost and Deadline common criteria
- Reliability and Robustness is also Important
- Robust scheduling
  - that handles performance variations of Cloud resources and
  - failures in the environment is essential in the context of Clouds
- Robust and fault-tolerant schedule
  - while minimizing makespan.

Failure in Cloud

- Failures also affect the overall workflow execution and increase the makespan.
- Failures in a workflow application are types
  - Task failures, VM failures, WF level failures
- Task failures may occur due to
  - dynamic execution environment configurations,
  - missing input data, or
  - system errors.
- VM failures are caused by
  - hardware failures and load in the datacenter

Failure in Cloud

- Workflow level failures can occur due to
  - server failures, Cloud outages,
- Prominent fault tolerant techniques that handle such failures are
  - retry, alternate resource, check-pointing, and replication
- Workflow management systems
  - should handle performance variations and
  - failures while scheduling workflows

Robust Scheduler

- A schedule is said to be robust if
  - it is able to absorb some degree of uncertainty
  - in the task execution time
- Robust schedules are much needed in
  - mission-critical applications and
  - time-critical applications
- Robust and fault-tolerant scheduling algorithms
  - identify these aspects and provide a schedule
  - that is insensitive to these uncertainties
  - by tolerating variations and failures
  - in the environment up to a certain degree.

Robust Scheduler

- Robustness of a schedule is always
  - measured with respect to another parameter such as makespan, schedule length
- Robustness is usually achieved
  - with redundancy in **time or space**
  - Adding **slack time** or **replication of nodes**.
- Robust Scheduling Approach
  - efficiently maps tasks on resources
  - judiciously adds slack time based on the deadline and budget constraints

System Model

- **Cloud environment** in system model has a single datacenter
  - that provides heterogeneous VM/resource types

$$VT = \{vt_1, vt_2, \ldots, vt_m\}$$

- Each VM type has : config. and price
- Configuration of VM type differs
  - with respect to memory, CPU measured in (MIPS) and OS.
- Each vt_i has a $Price(vt_i)$ associated with it
  - charged on an unit time basis
  - (e.g. 1 hour, 10 minutes, etc.)

Kind of Failure/Uncertainty

- Two kinds of uncertainties
  - task failures and performance variations of VMs.
- Performance variations in the system arise due to
  - factors like load, network delays, VM consolidation, etc.
- Due to the performance variation of a VM
  - Execution time of task increase/decrease by ***y***
- ***y*** is a random variable with a mean value of zero.
- Actual execution time (AET) of a task is

$$AET(t_j) = e_j\,(1 + y),$$

  - where e_j is the expected execution time of task t_j .

Workflow representation

- **Workflow** as DAG , ***G* = (*T, E*)**,
  - where ***T*** is a set of nodes, ***T* = {t_1, t_2, …, t_n}**, each node represents a task
  - ***E*** represents a set of edges between tasks, which can be control and/or data dependencies.
- Each workflow : bounded by user defined
  - deadline ***D***, money budget ***B*** constraints.
- Each task t_j has a task length (Payload/work) of
  - len_j given in Million Instructions.
- Task length and MIPS value of VM are used
  - Estimate the execution time on a particular VM type