

# Reliable Workflow Execution in Distributed Systems for Cost Efficiency

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- Typical first year for a new cluster

~0.5 **overheating** (power down most machines in <5 mins, ~1-2 days to recover)

~1 **PDU failure** (~500-1000 machines suddenly disappear, ~6 hours to come back)

~1 **rack-move** (plenty of warning, ~500-1000 machines powered down, ~6 hours)

~1 **network rewiring** (rolling ~5% of machines down over 2-day span)

~20 **rack failures** (40-80 machines instantly disappear, 1-6 hours to come back)

~5 **racks go wonky** (40-80 machines see 50% packetloss)

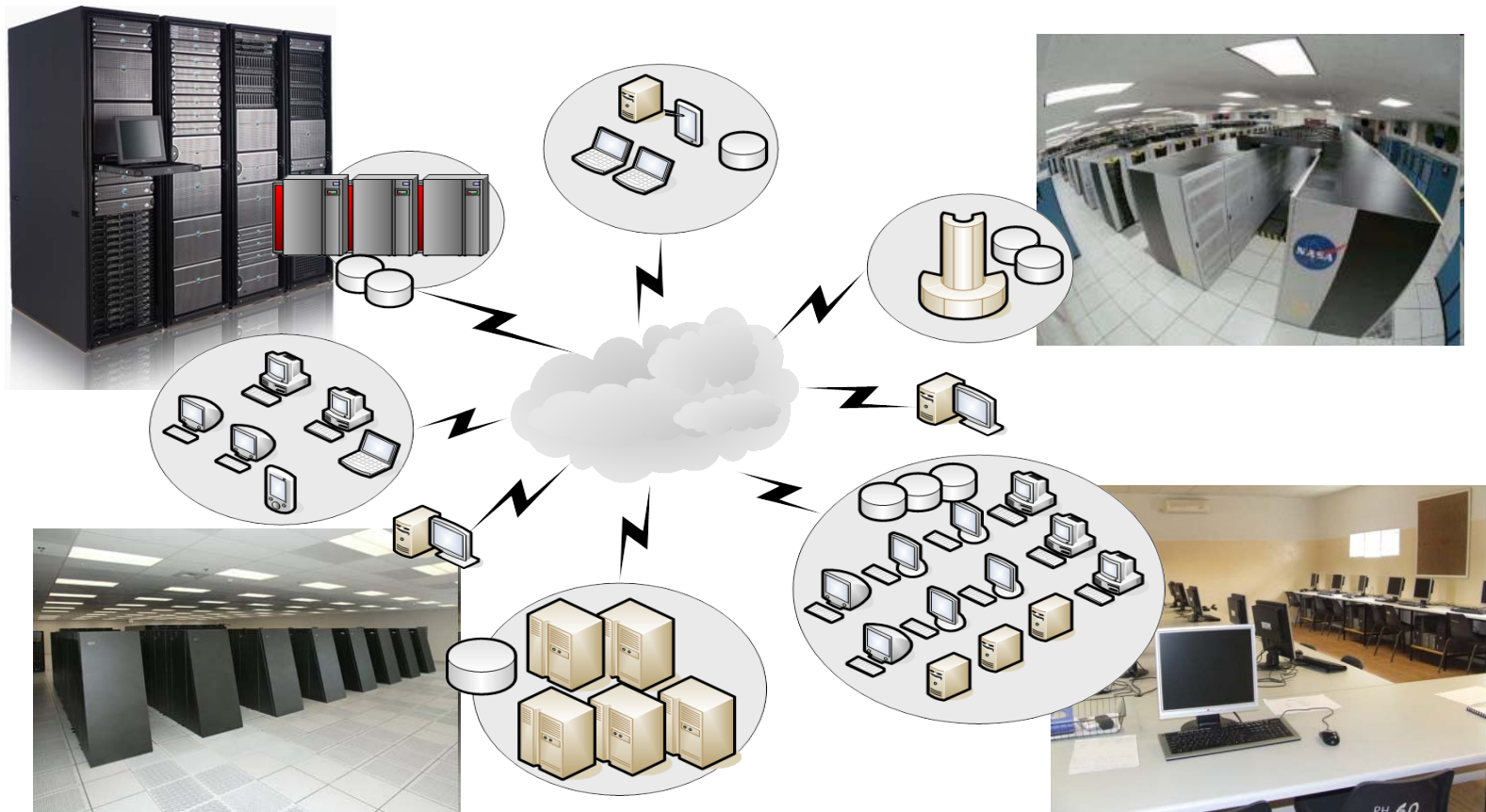
~1000 **individual machine failures**

~thousands of **hard drive failures**

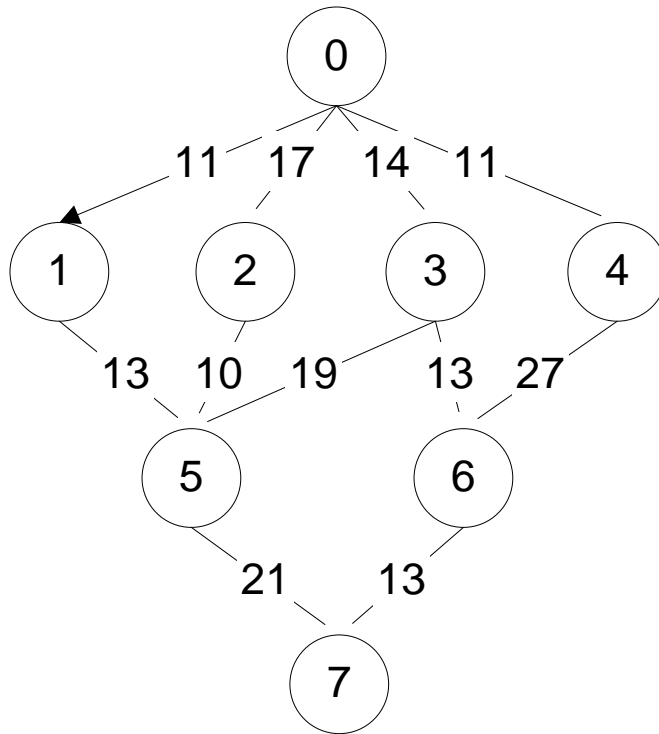
***And much more***

# Large-Scale Distributed Systems (LSDSs)

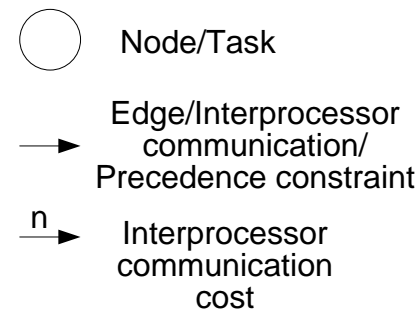
- › Multi-tenant LSDSs like grids and clouds may exhibit various unreliability factors and more complicating effects



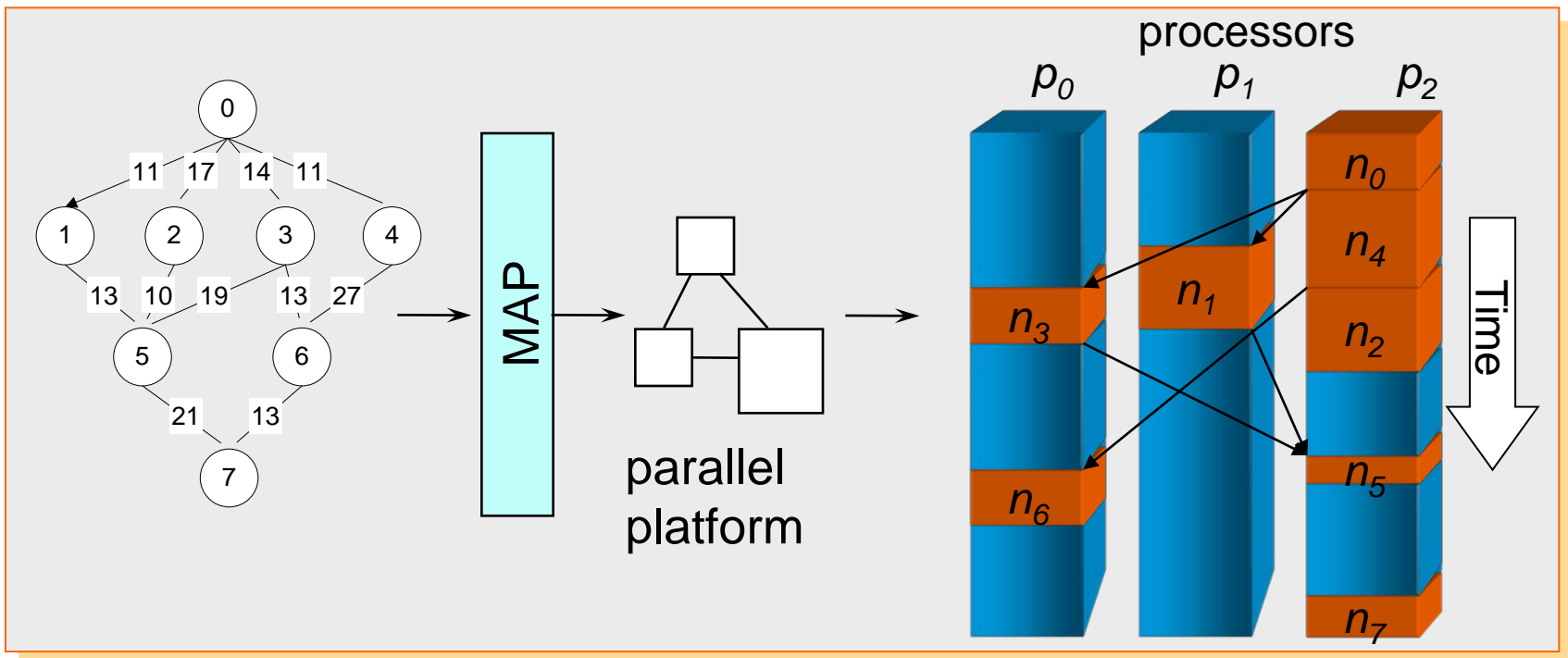
› A DAG,  $G = (N, E)$ , consists of a set  $N$  of  $n$  nodes, and a set  $E$  of  $e$  edges



- *Task 0: Entry task*
- *Task 7: Exit task*

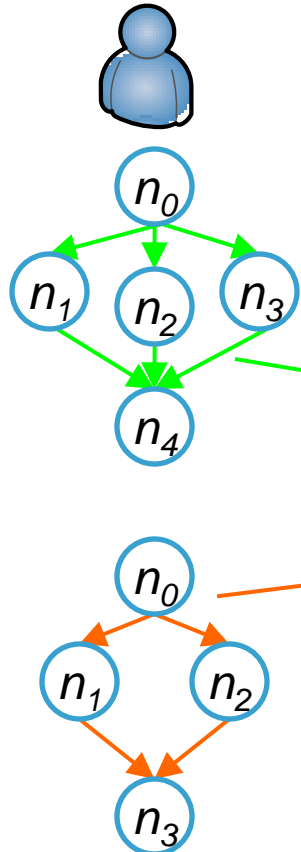


- How to assign interdependent tasks to computing resources (processors) aiming to minimize makespan without violating precedence constraints



# Workflow Scheduling in Market-based LSDSs

## Consumer 0



## Consumer 1



## Resource provider



SLA contains

- $V_{MAX}$ : max value for an application
- $\alpha$ : decay rate (penalty)
- $T_{MAX}$ : deadline

# Market-based Distributed Computing Systems

- › Advertised cost ( $ac$ ) per unit time per resource occupancy is charged to the resource consumer:

$$ac = oc \cdot (1 + pr^{net})$$

where  $oc$  is the net operating cost and  $pr^{net}$  is the net profit rate set by a provider.

- › Resource occupancy: the resource is exclusively allocated for a particular request.
- › The amount of a resource occupancy includes:
  - actual task execution time
  - idle time occurring due to inaccurate execution time estimate, and
  - waiting time caused by delays (from resource failures) in the completion of predecessor tasks

› Key SLA parameters of an application are:

- $V_{MAX}$ : maximum value

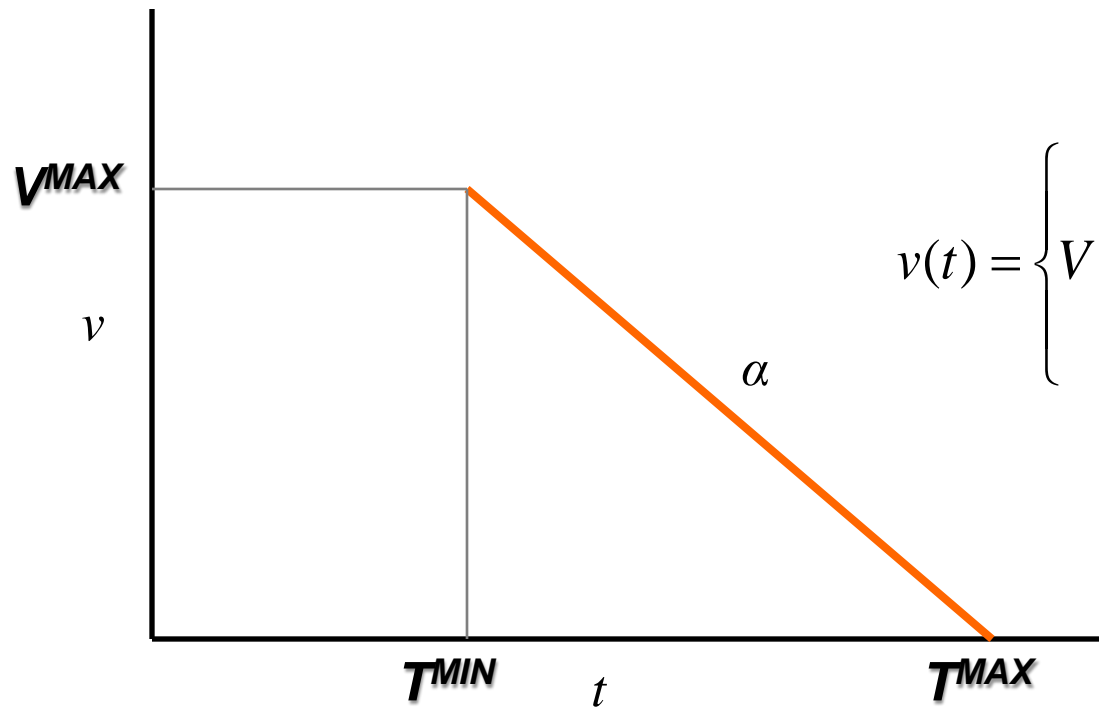
$$V_{MIN} = \sum_{i=1}^n w_i \cdot ac$$

$$V_{MAX} = V_{MIN} + \Delta v$$

- $\alpha$ : value decay rate

$$\alpha = \frac{V_{MAX}}{(T_{MAX} - T_{MIN})}$$

- › Value (profit)  $v$  is inversely related to processing time  $t$



$$v(t) = \begin{cases} V & , \quad t \leq T_{MIN} \\ V - \alpha t & , \quad T_{MIN} \leq t \leq T_{MAX} \\ 0 & , \quad t > T_{MAX} \end{cases}$$

- › A resource provider attempts to guarantee the quality of service to a certain degree in the way its profit is maximized.
- › In this scenario, resource failures should be explicitly and proactively addressed, or QoS is much compromised and profit is reduced accordingly.
- › Those reserved resources can be seen as a result of resource co-allocation using advance reservation at the arrival of the workflow in grids, or that of resource provisioning for the next time frame (epoch) at the finalization of a given bidding event in clouds.
- › We investigate the reliability of workflow execution in the context of scheduling and its effect on operating costs in LSDSs
- › The main objective is the maximization of profitability reducing costs incurred specifically by resource failures.

## Reliability for Profit Assurance (RPA)

- › The rationale behind our *RPA* algorithm is that the cost efficiency in workflow scheduling is heavily dependent on the reliable execution of high impact tasks (normally, small in number) who have a large number of successor tasks.
- › Task replication is adopted to deal with resource failures.
- › However, replicas created in response for increasing reliability are clearly a major source of resource wastage.
- › Replication is guided by “replicability parameters”: loss, actual loss and replication cost.

## Algorithm 1: RPA

```
1: Let  $Q = \emptyset$ 
2: while  $\exists n_i \in N \mid n_i$  is not scheduled do
3:   Let  $n^*$  = the first ready task in  $N$  to be scheduled
4:   Let  $p^*$  = processor in  $P$  on which  $n^*$ 's  $EFT$  is the smallest
5:   Reserve  $p^*$  for  $n^*$ 
6:   Enqueue  $n^*$  to  $Q$ 
7: end while
8: Let  $ms$  = makespan based on the current schedule
9: while  $Q \neq \emptyset$  do
10:  Let  $n_i$  = the first task in  $Q$ 
11:  Dequeue  $Q$ 
12:  Let  $cd_i$  = compute_cumulative_delay( $n_i, w_i/2$ )
13:  Compute  $mi_i$  based on  $ms$  // makespan increase
14:  Let  $loss = VMAX - (mi_i \cdot \alpha + cd_i \cdot oc)$ 
15:  Let  $actLoss = loss \cdot ur(w_i, *)$ 
16:  Let  $p_j$  = processor in  $P$  on which  $n_i$ 's  $EFT$  is the smallest
17:  Let  $repCost = w_{i,j} \cdot oc$ 
18:  if  $actLoss > repCost$  then
19:    Let  $n_i'$  = a replica of  $n_i$ 
20:    Assign  $n_i'$  to  $p_j$ 
21:  end if
22: end while
```

Initial scheduling

Task replication

## Function: `compute_cumulative_delay`

**Input:** a task  $n_i \in N$  and the estimated delay  $ed_i$

- 1: **for**  $\forall n_{i,j} \in succ(n_i)$  **do**
- 2:   Let  $w_{i,j} = EFT(n_{i,j}) - EST(n_{i,j})$
- 3:   Update  $EFT(n_{i,j})$  considering  $pd_i$
- 4:   **if** ( $EFT(n_i) > EST(n_{i,j})$ ) **then**
- 5:     Let  $EST(n_{i,j}) = EFT(n_i)$
- 6:   **end if**
- 7:   Let  $d_{i,j} = EFT(n_{i,j}) - EST(n_{i,j}) - w_{i,j}$
- 8:   Let  $cd_i = cd_i + d_{i,j}$      *// recursive function call*
- 9:   Let  $cd_i = cd_i + \mathbf{compute\_cumulative\_delay}(n_{i,j}, ed_i)$
- 10: **end for**
- 11: Return  $cd_i$

- › The total number of experiments conducted is 1,012,500 (337,500 for each *algorithm*—*Dynamic*, *Reactive* and **RPA**)

	Parameter	Value
Global	# different workflow applications	500
	mean for workflow inter-arrival times	U(10, 100)
	simulation duration	{2,000, 4,000, 8,000, 16,000, 32,000}
	operating cost ( <i>oc</i> )	10
	net profit rate ( $pr^{net}$ )	{20%, 40%, 60%, 80%, 100%}
	reservation delay ( <i>rd</i> )	U(1, 64)
Application	# tasks per workflow ( <i>n</i> )	U(4, 128)
	maximum width	{2, 4, 8, 16, 32}
	out degree of a node	U(0, 8)
	comm. to comp. ratio (CCR)	$\leq 0.2$
Resource	# resources	U(4, 64)
	failure rate	{0.1%, 0.5%, 2.0%}
	heterogeneity	{100%, 200%, 400%}
	mean time to repair (MTTR)	U(10, 100)

## › Profit rate

$$pr_i = \frac{v(t)_i - (oc \sum_{j=1}^n w_{j,*} + pd_j)}{VMAX_i - (oc \sum_{j=1}^n w_{j,*})} \quad \overline{pr} = \frac{\sum_{i=1}^M pr_i}{M}$$

## › Response rate

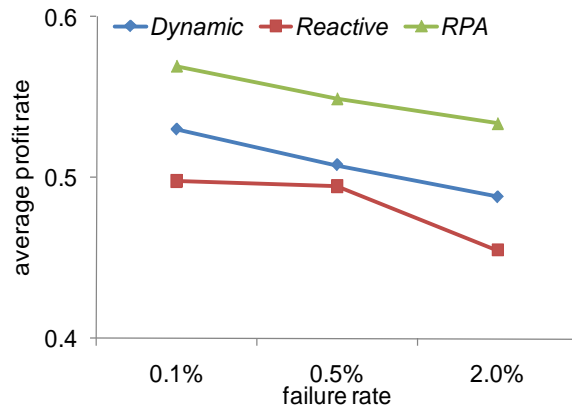
$$rr_i = \frac{TMIN_i}{t_i} \quad \overline{rr} = \frac{\sum_{i=1}^M rr_i}{M}$$

where  $M$  is the total number of workflow applications processed

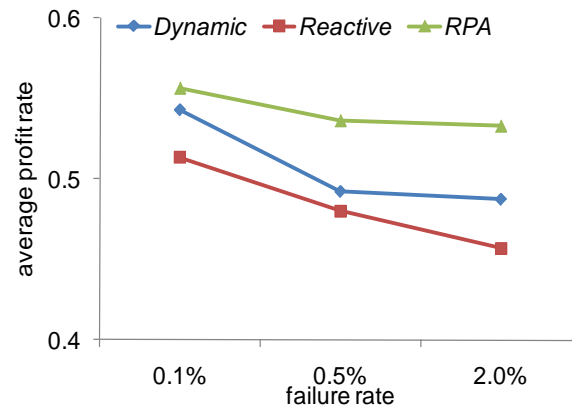
## › Average profit rates

- **RPA : 55%**
- Dynamic: 49%
- Reactive: 48%

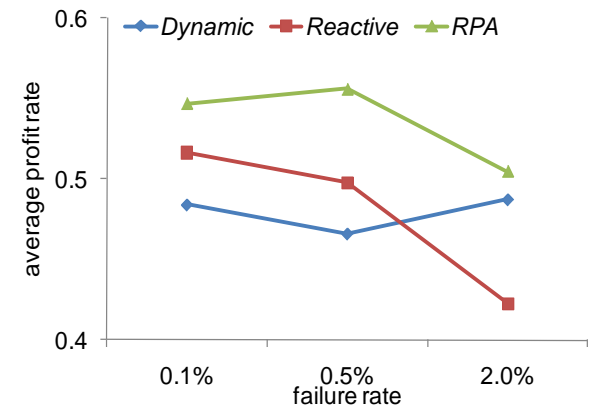
## › Different resource heterogeneity values



(a) 100%



(b) 200%

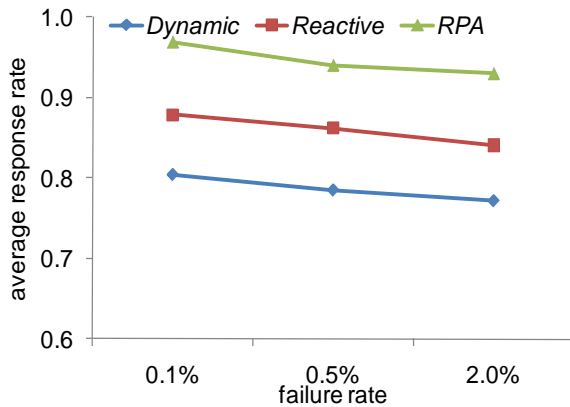


(c) 400%

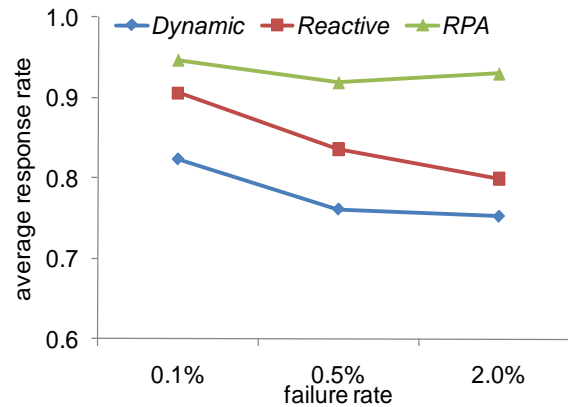
## › Average response rates

- **RPA : 93%**
- Dynamic: 77%
- Reactive: 85%

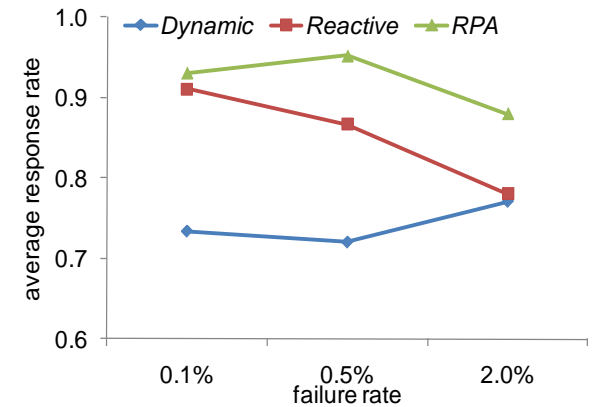
## › Different resource heterogeneity values



(a) 100%



(b) 200%



(c) 400%

## › Market-based resource allocation

- Pricing-based methods can reveal the true needs of users and allocate resources efficiently [Sigecom Ex. 05]

## › Time-varying resource valuation

- Changing values for prioritizing & scheduling jobs
- Penalty when the value is not realized [CCGrid 02, HPDC 04]
- In our model, penalty is implicitly reflected in the cost of physical resource usage
- Our utility function is time-varying and dependency aware

- › A resource failure causes delay not only in the completion of the task running on it, but also in the completion of that task's successors and eventually the makespan of corresponding workflow recursively.
- › This recursive impact of resource unreliability on workflow execution is a serious limiting factor in cost efficiency in LSDSs.
- › Replication is an appealing solution for reliable workflow execution.
- › The cost-aware replication incorporated into RPA is an intuitive cost optimization technique for workflow execution in LSDSs.