Exploiting Classes of Virtual Machines for Scalable IaaS Cloud Management

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Challenges of Cloud computing

- **Vision from a IaaS perspective:**
  → continuous growth
- **More VMs, more data, ...**
  → More data centers
  → Larger data centers
- **Growth by 10^2 in 15 years**
- **Scalability problems due to the infrastructure size:**
  - Monitoring of so many VMs
  - Management of infrastructure
    → placement of VMs over physical nodes

VM placement challenges

- **Large number of VMs**
- **→ Many physical nodes**
- **Multiple metrics**
- **Sampling at multiple times**
  - Complementary workload patterns

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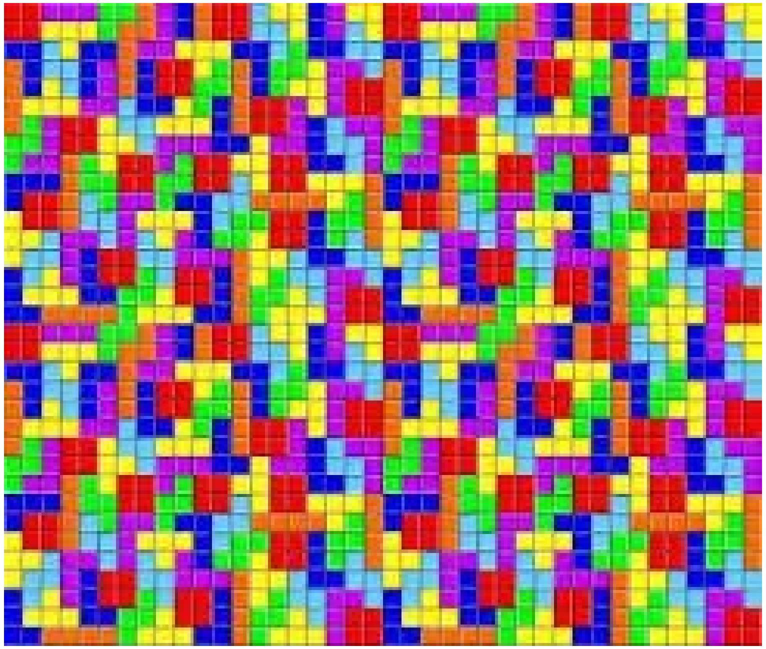
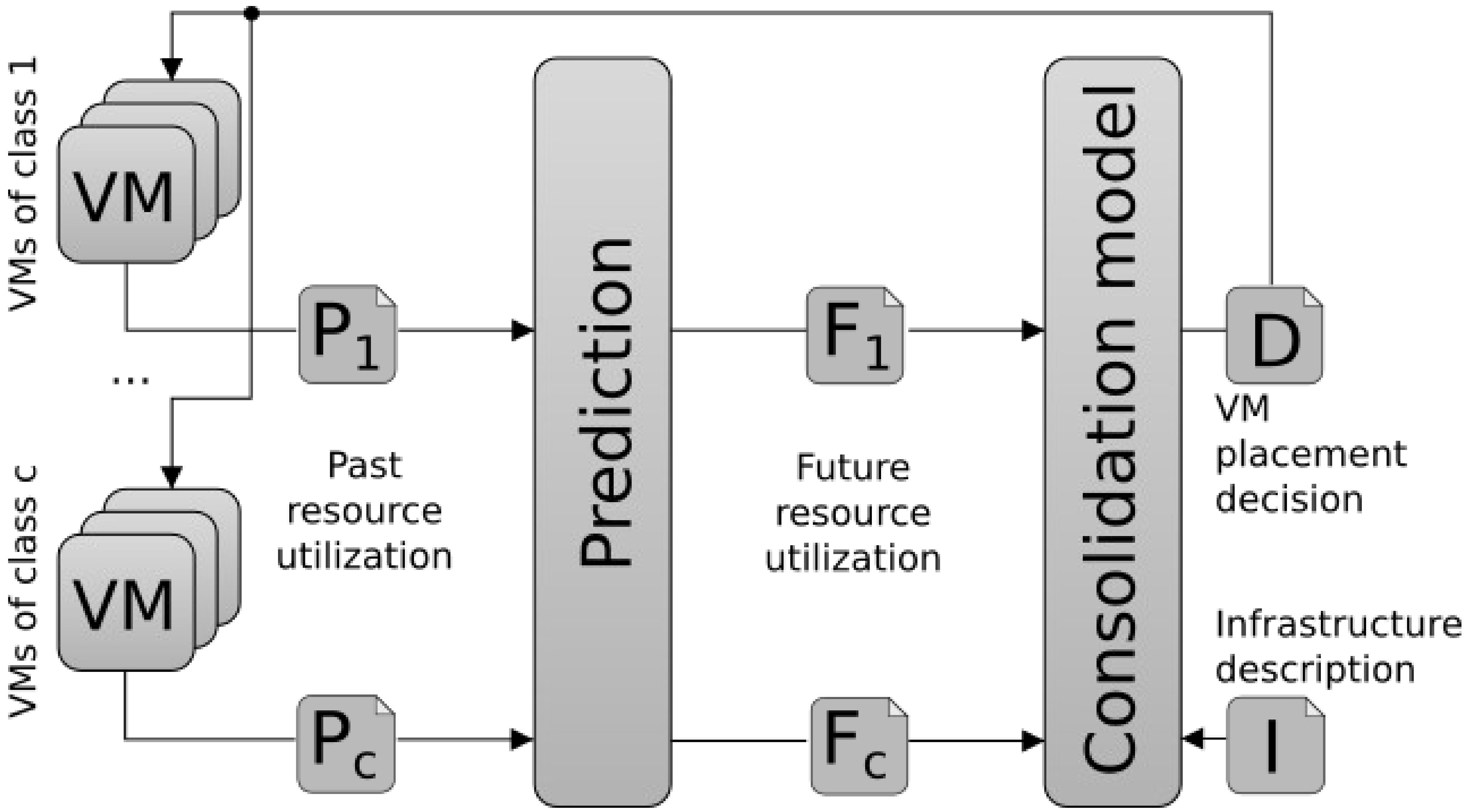
- **Sampling at multiple times**
  - Complementary workload patterns
- **→ A huge, multidimensional Tetris game...**



Reference scenario



Assumptions

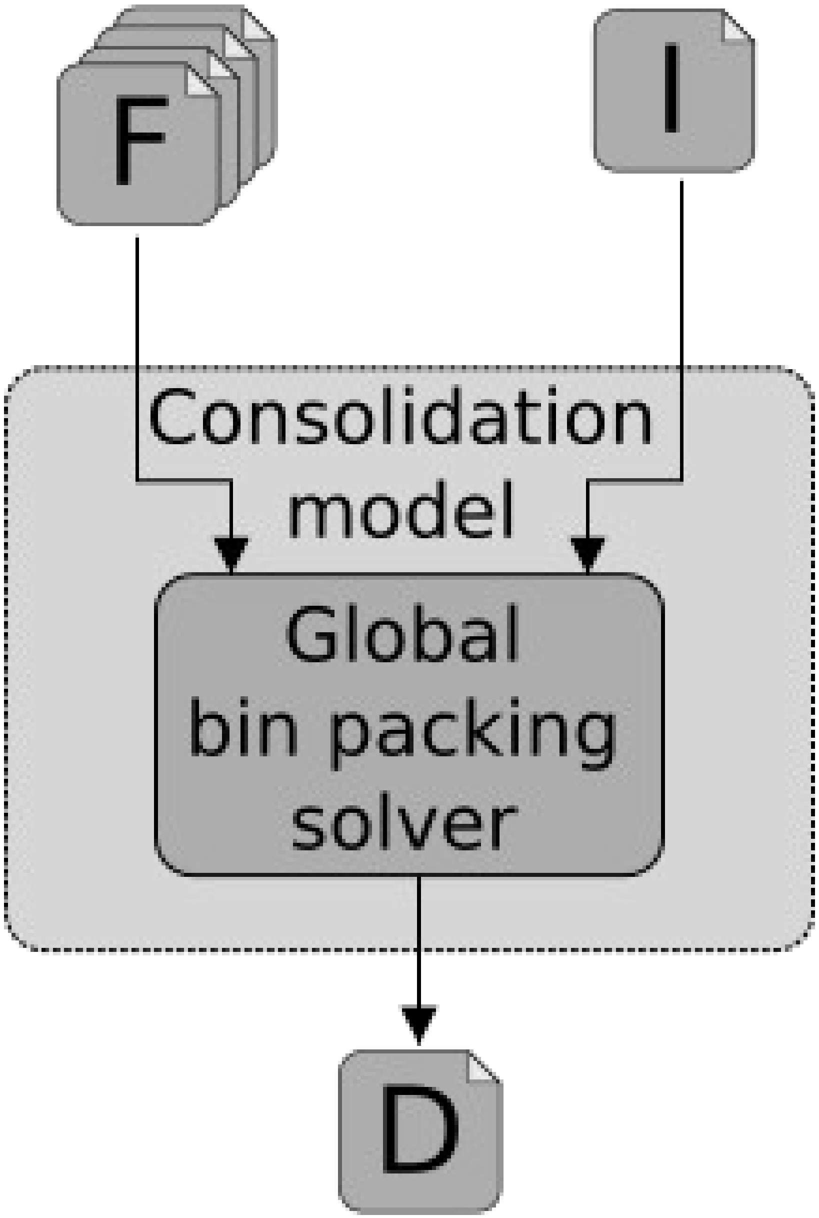
- **VM placement: periodic task**
  - We consider consolidation window of 24 hour
- **Cloud provider has knowledge of VMs classes**
  - Information from PaaS/SaaS provider to IaaS provider
  - e.g., Elastic map-reduce, Elastic load balancer
  - IaaS can monitor and classify VMs (proposals available in literature)

Consolidation models

- **Consolidation model:**
  - Solution of optimization problem
  - Input: future resource requirements (per-VM or per-class), Infrastructure description
- **Available solutions:**
  - Multi-dimensional bin packing (MBP)
  - First Fit Decreasing Heuristic (FFD) – special case of bin packing: we consider only one dimension
  - Class-based placement (CBP)

Multi-dimensional bin packing

- **Single bin-packing problem** for whole data center
- Classes of VMs not considered
- **Multi-dimensional** problem:
  - Multiple time intervals
  - ~~Multiple resources~~



Problem formulation

- **Objective function:**

$$\min \sum_{n \in N} O_n$$

Minimize number of nodes used

- **Subject to:**

$$\sum_{n \in N} I_{n,m} = 1 \quad \forall m \in M$$

1 VM in exactly one node

$$\sum_{m \in M} R_{m,t} I_{n,m} \leq V_n O_n \quad \forall n \in N, \forall t \in T$$

Node capacity constraint

$$I_{n,m} = \{0,1\} \quad \forall n \in N, \forall m \in M$$

$$O_n = \{0,1\} \quad \forall n \in N$$

Resource requirement of VM *m* at time *t*

Decision variable: Node *n* is on/off

Available resources on node *n*

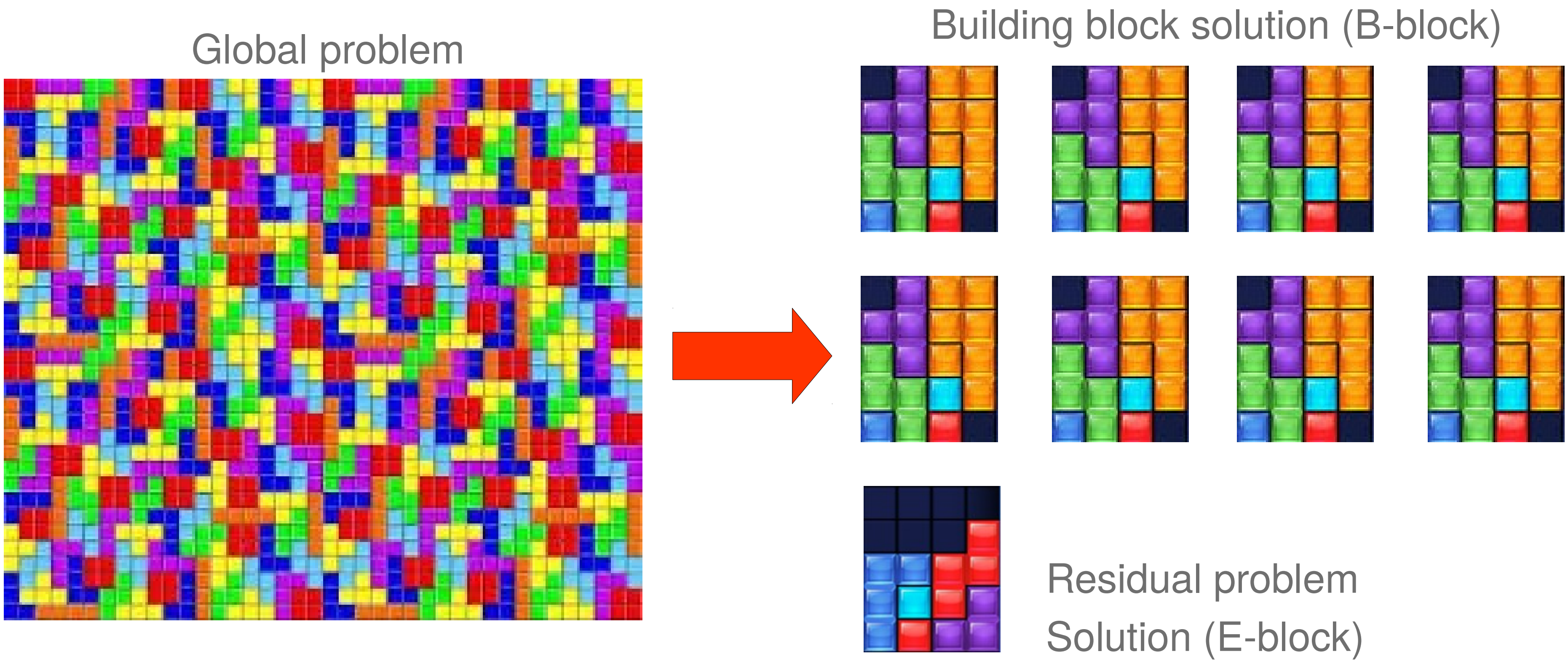
Decision variable: VM *m* on node *n*

Computational challenges

- **Number of node capacity constraints grows with:**
  - Number of nodes
  - Number of time intervals considered
- **Addressing scalability problems:**
  - Wall time limit on optimizer
  - Reduce number of time intervals (e.g., instead of 5min intervals can consider 1h, 4h, 12h, 1d...)
  - Use of heuristics instead of optimal solution
  - Special case: if only one time interval is considered multi-dimensional bin packing → bin packing (FFD)

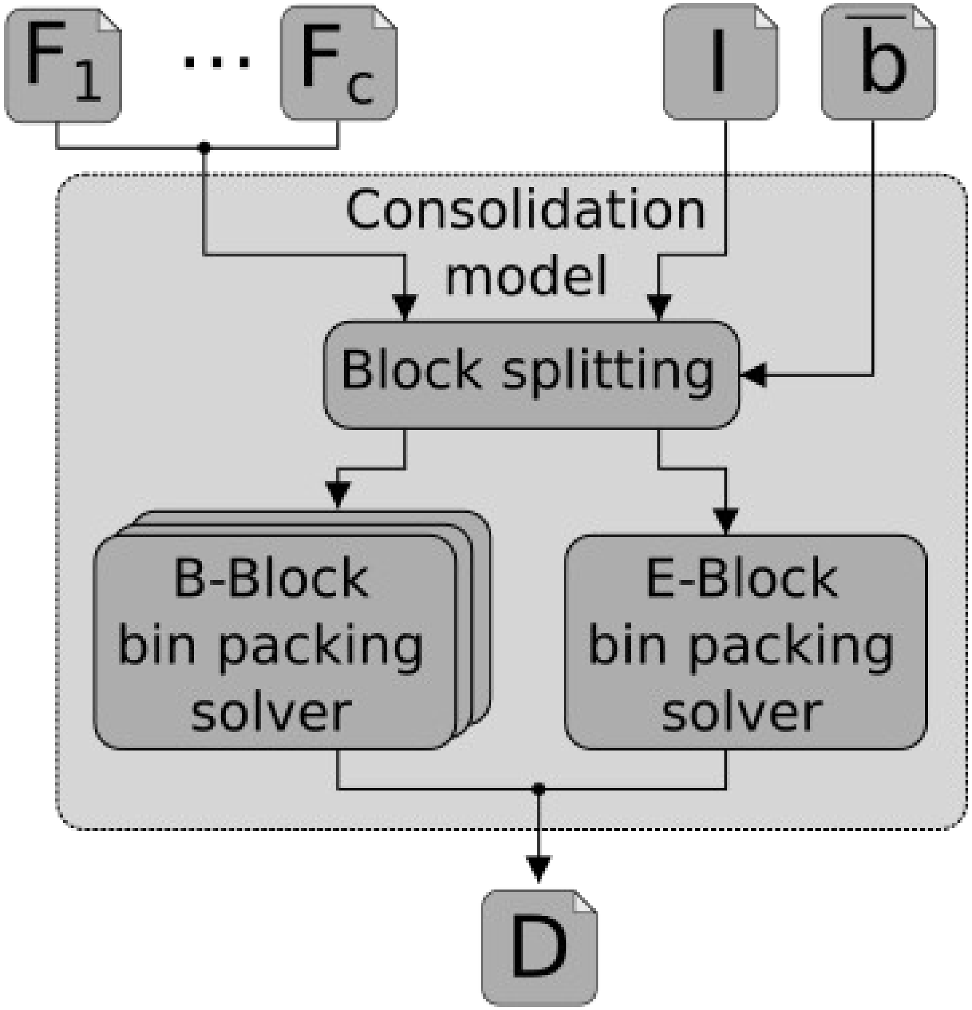
Class-based VM placement

- Build a small consolidation solution (B-block)
- Replicate solution as a building block
- Solve residual problem (E-Block)



Class-based VM placement

- **Additional input:** → number of B-blocks $\bar{b}$
- **Choice: $\bar{b}$=n. of VMs in class with minimum cardinality**
- **Impact of $\bar{b}$** → open issue
- **Two bin packing problems (B- E-blocks)**
- **Major dimensionality reduction**



B-block problem formulation

- **Objective function:**

$$min \sum_{n \in N_b} O_n$$

Minimize number of nodes used

- **Subject to:**

$$\sum_{n \in N_b} I_{n,m} = 1 \quad \forall m \in M_b$$

$$\sum_{c \in C} \sum_{m \in B_c} R_{c,t} I_{n,m} \leq V_n O_n \quad \forall n \in N_b, \forall t \in T$$

$$I_{n,m} = \{0,1\} \quad \forall n \in N, \forall m \in M_b$$

$$O_n = \{0,1\} \quad \forall n \in N_b$$

Set of VMs in B-Block

Resource requirement for class *c* at time *t*

Class-based node capacity constraint

Set of VM classes

Set of VMs of class *c* in B-Block

Set of Nodes for B-Block

- **E- block problem formulation is similar**

Experimental setup

- **Number of VMs from 150 to 1200**
- **44 classes, each class [8-50] VMs**
- **Focus on CPU (only trace available) – Utilization: [0-100%]**
- **Each physical node has capacity of 800%**
- **Time intervals considered:**
  - 5m (288 int.)
  - 1h (24 int.)
  - 12h (2 int.)
  - 1d (1 int.)
- **IBM ILOG CPLEX Optimizer v12**
- **Maximum time for consolidation: 1800s (30m)**

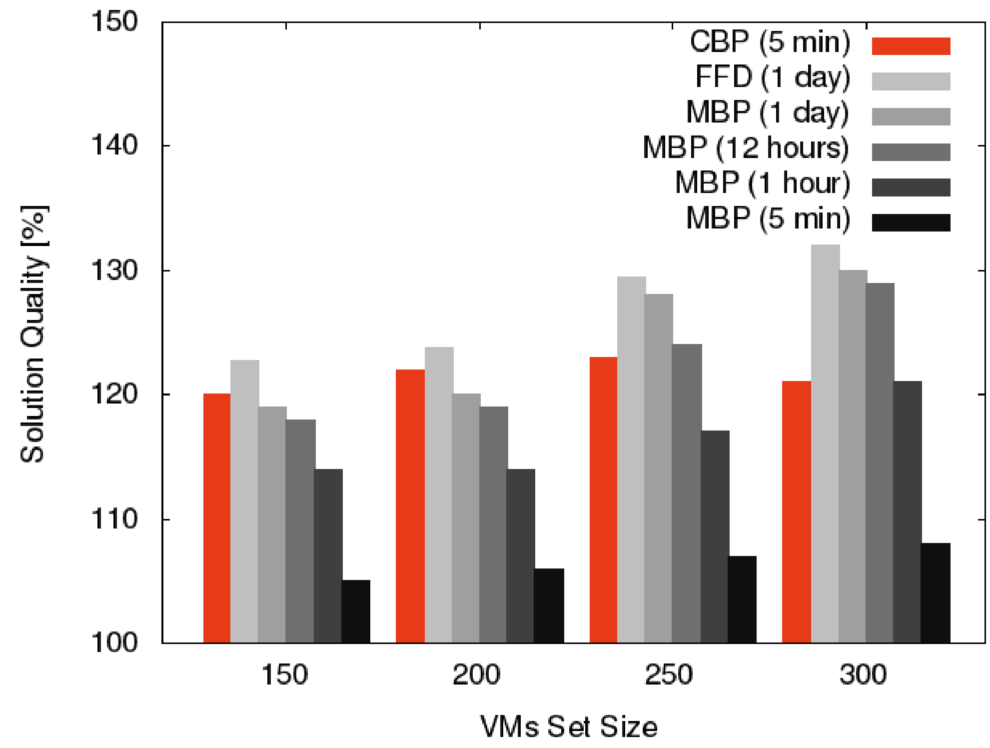
Experimental results

- **MBP:**
  - Optimal solution only for small problems (≤ 200)
  - Reducing dimensionality improves scalability
  - No acceptable solutions for large problems (≥1200)
- **CBP:**
  - Always reaches solution even with 5m time interval
  - Solves to optimality for medium problems (≤ 700)

VMs	CBP 5m	MBP 1d	MBP 12h	MBP 1h	MBP 5m
150	S/S	S	S	S	S
200	S/S	S	S	S	S
250	S/S	L	L	L	L
300	S/S	L	L	L	L
400	S/S	L	L	L	**N**
500	S/S	L	L	L	**N**
600	S/S	L	L	**N**	**N**
700	S/S	L	L	**N**	**N**
800	L/S	L	L	**N**	**N**
900	L/S	L	L	**N**	**N**
1000	L/S	L	L	**N**	**N**
1100	L/S	L	**N**	**N**	**N**
1200	L/S	**N**	**N**	**N**	**N**

Solution quality: small number of VMs

- **Solution quality: relative to LP relaxation of the problem**
  - Lower is better
- **FFD: low quality results**
- **MBP:**
  - 5m: best solution
  - Time interval reduction → lower quality
  - VM set size growth → lower quality
- **CBP quality remains stable with problem size**



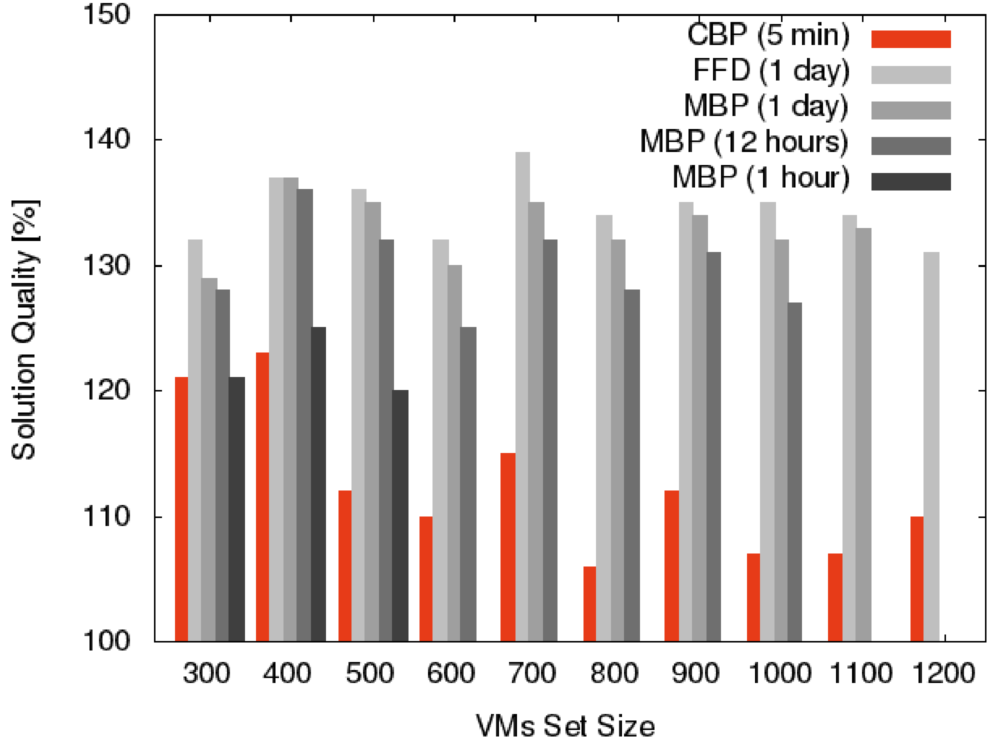
Computation time

- FFD: very fast but inaccurate
- When problem size grows, MBP becomes slower
  may result in sub-optimal solutions (quality reduction)
- CBP: very fast → scalable solution for larger problems

Consolidation model	150 VMs	200 VMs	250 VMs	300 VMs
CBP 5m (B/E)	0.43/0.46	0.49/0.28	0.54/0.49	0.98/0.40
FFD 1d	0.05	0.05	0.06	0.07
MBP 1d	0.21	11.36	45.28	147.73
MBP 12h	4.13	79.39	**1800(L)**	**1800(L)**
MBP 1h	32.87	91.20	**1800(L)**	**1800(L)**
MBP 5 min	233.09	270.59	**1800(L)**	**1800(L)**

Solution quality: large number of VMs

- **MBP:**
  - VM set size growth
    - → lower quality
    - → need time interval reduction
- **FFD: always worst performing**
- **CBP:**
  - VM set size growth
    - → always reaches solution
    - → solution quality improves



Conclusions and future work

- **The challenge of VM placement in cloud computing**
- **Proposal of Class-based placement technique**
- **Better scalability compared to alternatives:**
  - Can manage larger problems
  - Higher quality solution within the same time frame
- **Future work:**
  - New experiments: larger data centers, more resources
  - Analysis of B-block size ($\bar{b}$ parameter): impact on performance, automatic estimation
  - Different optimization strategies (e.g., dynamic programming)

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