Right-Sizing and Auto-Scaling of MySQL Containers in Kubernetes

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JD.com

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About JD.com

China's largest online and overall retailer and biggest Internet company by revenue

- 300 million+ active users
- 2018 revenue: $67.2 billion

China's largest e-commerce logistics infrastructure and unrivalled nationwide fulfillment network

- 550+ warehouses
- Covering 99% of population
- Standard same-and next day delivery

First Chinese internet company to make the Fortune Global 500

Strategic partnerships

Tencent Walmart Google

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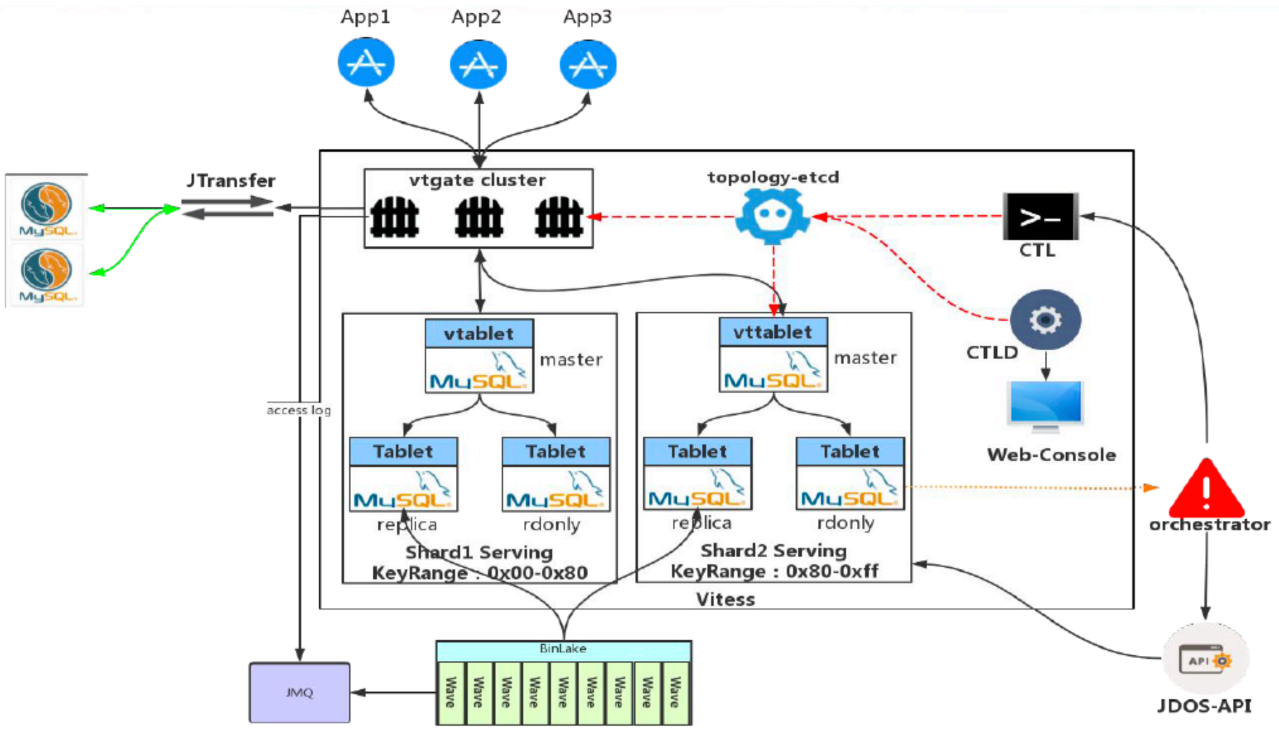
JD Elastic Database

- MySQL for key businesses by serving large volumes of complex transactional data at JD.
- MySQL databases in containers on JD Kubernetes platform
    - ❑ Thousands of physical serves and tens of thousands of containers
- Vitess for scalable management and scaling.



One of the largest Vitess deployments

Problems and Challenges

- Difficult to estimate the resource demand
- Dynamic demand
- Performance guarantee
- Multiple dimensional resources: CPU, Memory, Disk, I/O Bandwidth
- Stateful applications with a lot of data

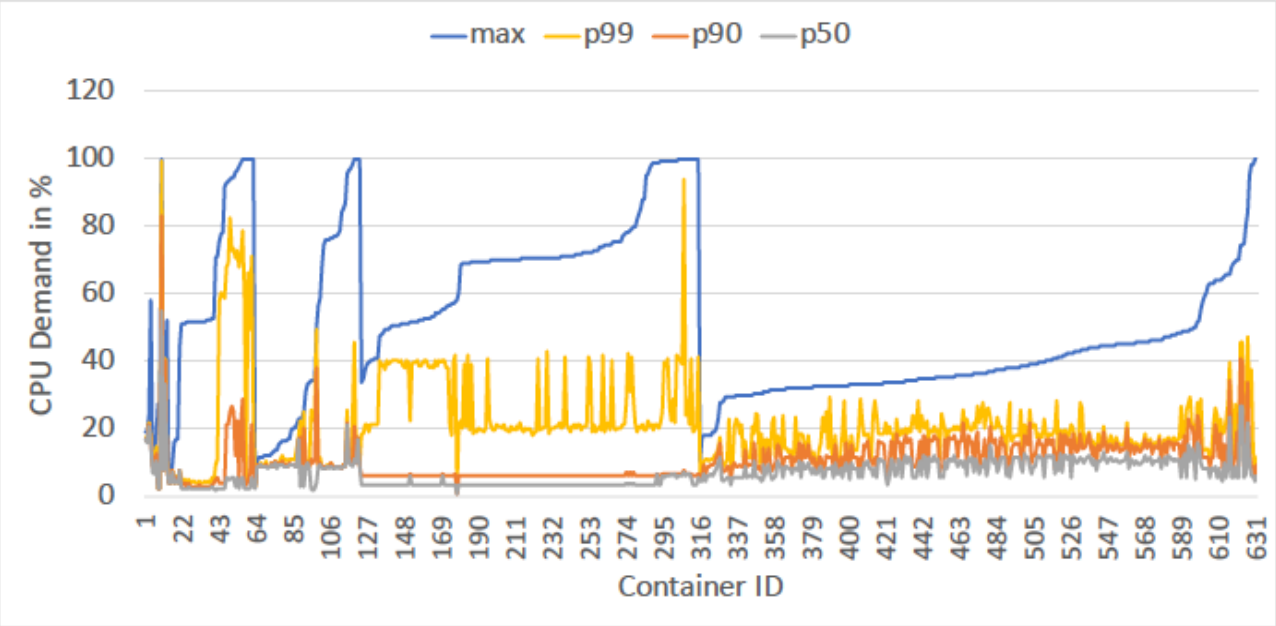
Workload Characterization

7 database systems and 631 containers

Application Name	Containers#	Days# (minutely)
DongDong	4	51
DistributedLog	6	51
OrderCancel	3	51
OrderTrace	49	42
TrainTicket	61	51
MallBill	192	51
SKUPrice	316	51

Table 1: Application details.

CPU Utilization



Key observations:

1. The 90–percentile utilization is about half or less of the maximum utilization.
2. Sizing based on 90-percentile utilization instead of the maximum utilization could lead to significant savings.

Right Sizing

- Estimate the workload demand

  New workload

  - Resource requirements
  - Meta-data based classification + group resource requirements

  Existing workload

  - Historical usage analysis + prediction (ARIMA, LSTM, ...)

- Sizing based on percentile and correlation between workloads
  - Use shared headroom to cope with peak demands
  - Adjust both request and limit

Right Sizing of CPU Resources

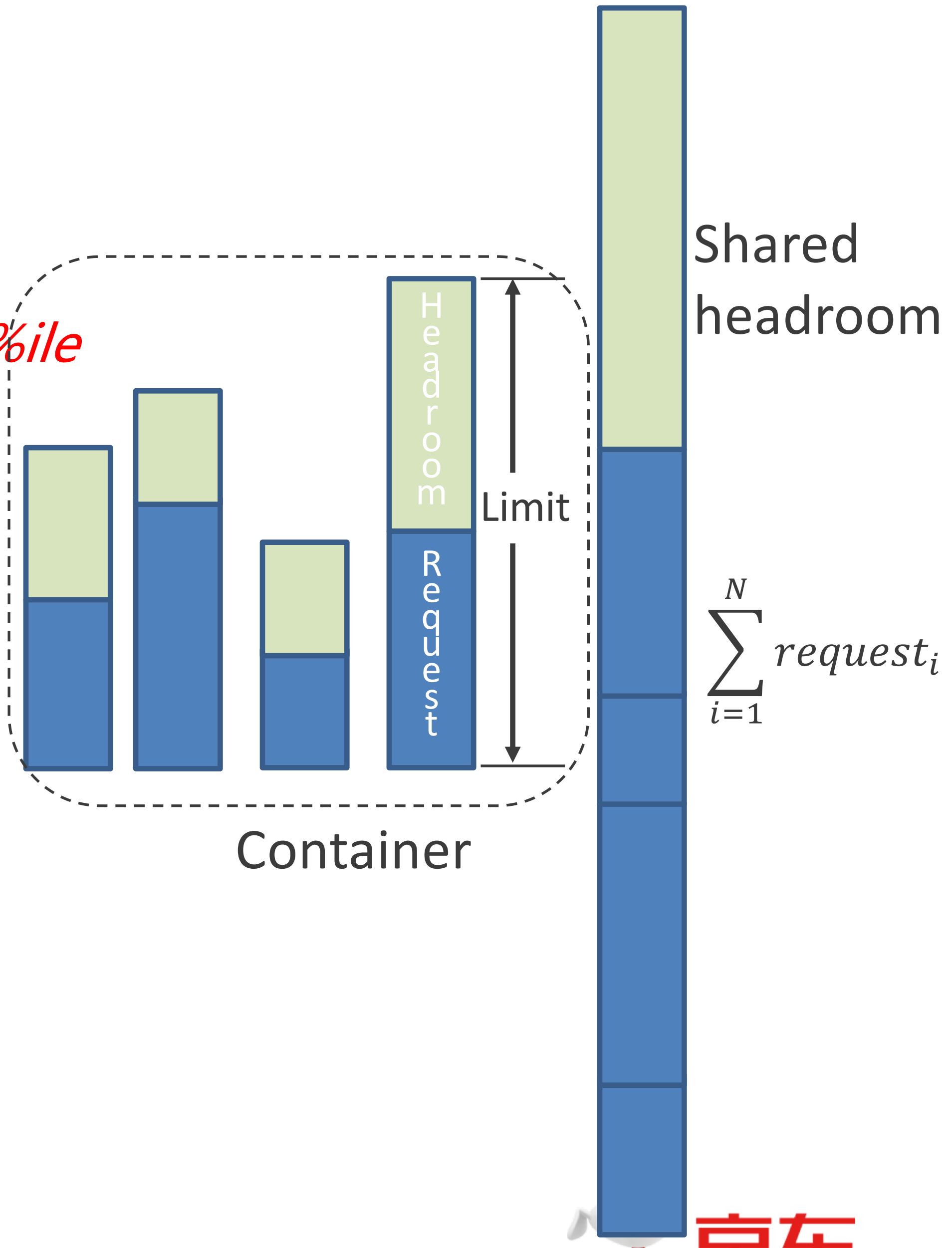
Container

- Tail bound based guaranteed resource: *request = x%ile*
- Maximum resources : *limit = y%ile*
- Headroom: *headroom = limit – request*

Host

- Request: *Request* = $\sum_{i=1}^{N} request_i$
- Shared headroom
  - *Headroom* <= $\sum_{i=1}^{N} headroom_i$
- Resource constraint:

  Request + Headroom <= Capacity



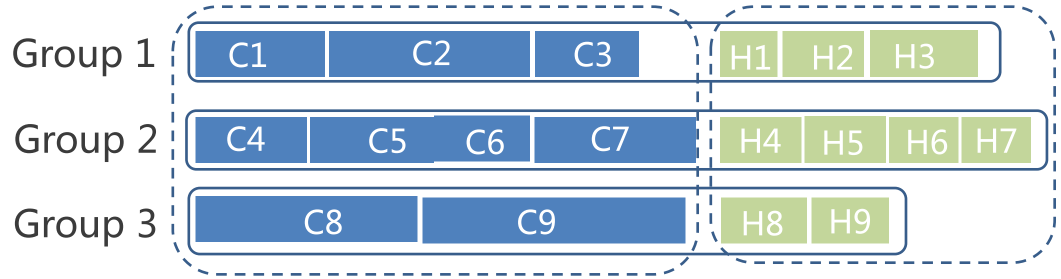
Right Sizing of CPU Resources

Request : $Request = \sum_{i=1}^{N} request_i$

Shared headroom

- Non-correlated containers:
  $Headroom = MAX_i\,(limit_i - request_i)$
- Correlated containers:
  $Headroom = SUM_i\,(limit_i - request_i)$

Constraints: $Request + Headroom <= Capacity$

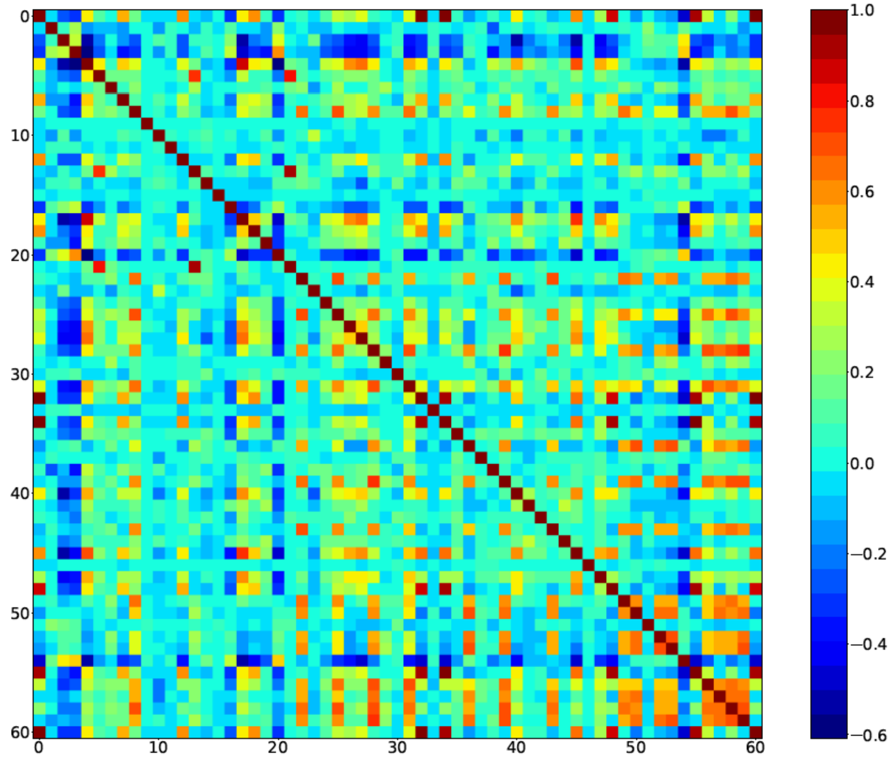


Request = C1+C2+…+C9 **Headroom** = MAX (H1+H2+H3, H4+H5+H6+H7, H8+H9)

Total = C1+C2+…+C9+H4+H5+H6+H7

max_of_sum < sum_of_max

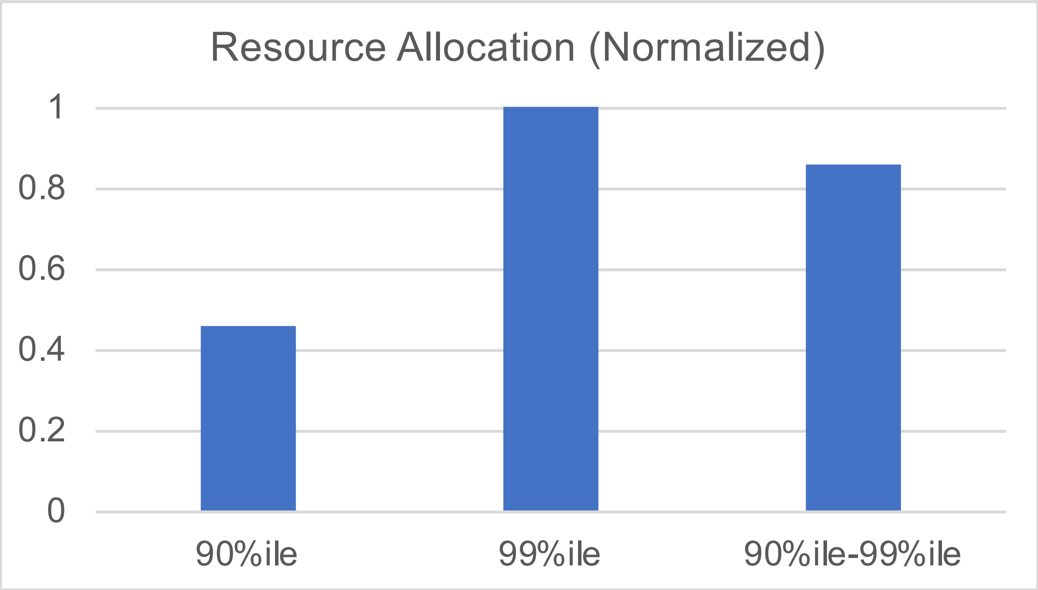
Correlation Analysis

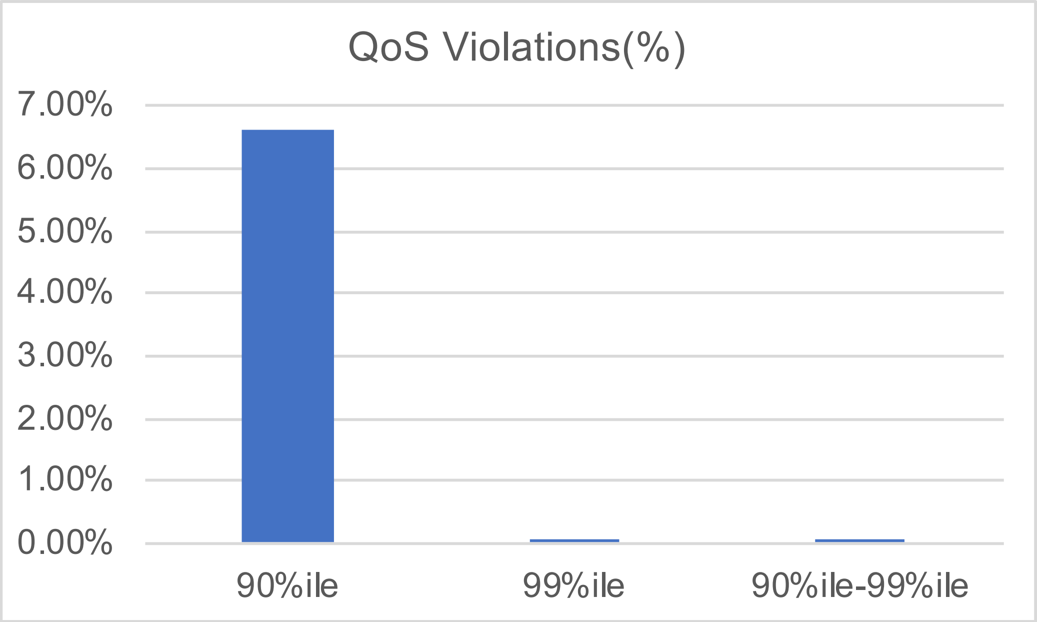


A large number of containers do not have strong correlation!

Experimental Evaluation

Comparison of Different Sizing Methods





Randomly schedule 18 containers among 563 containers

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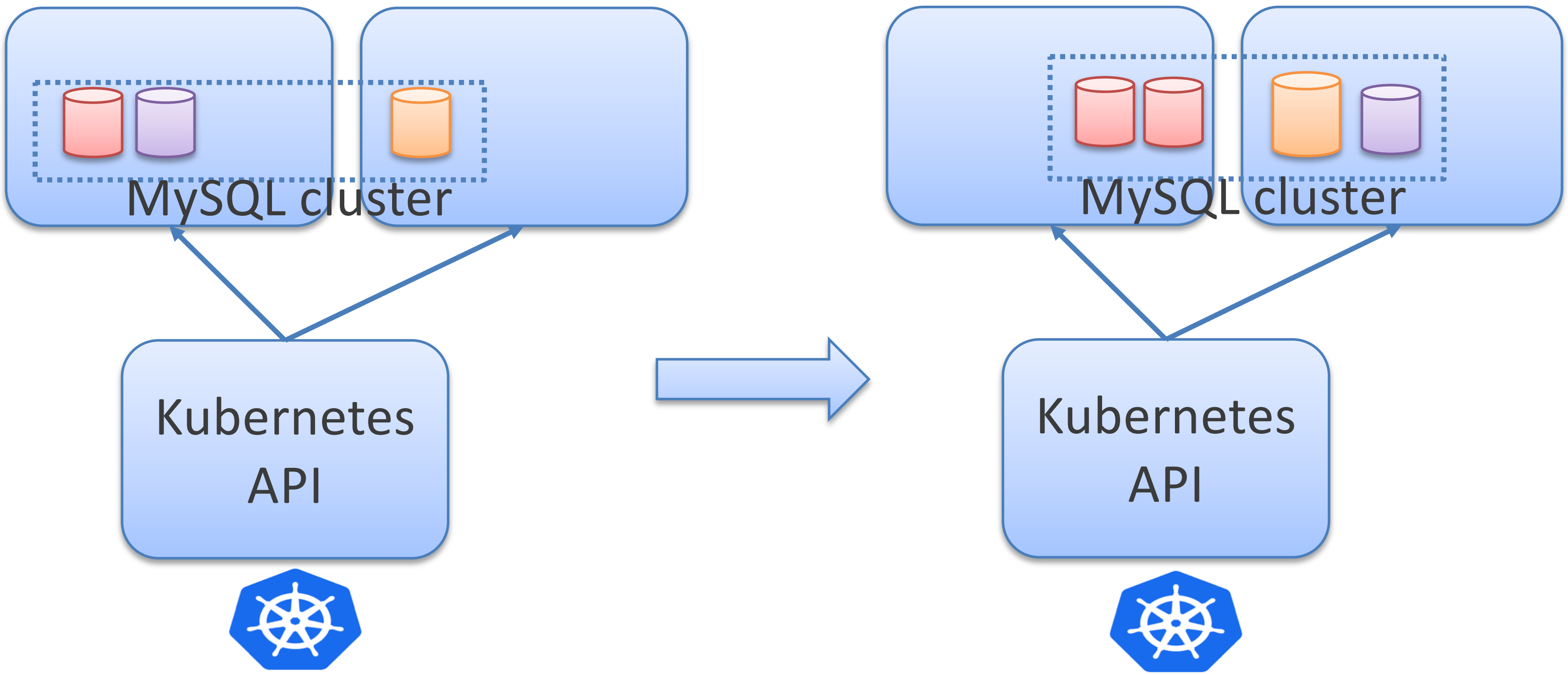
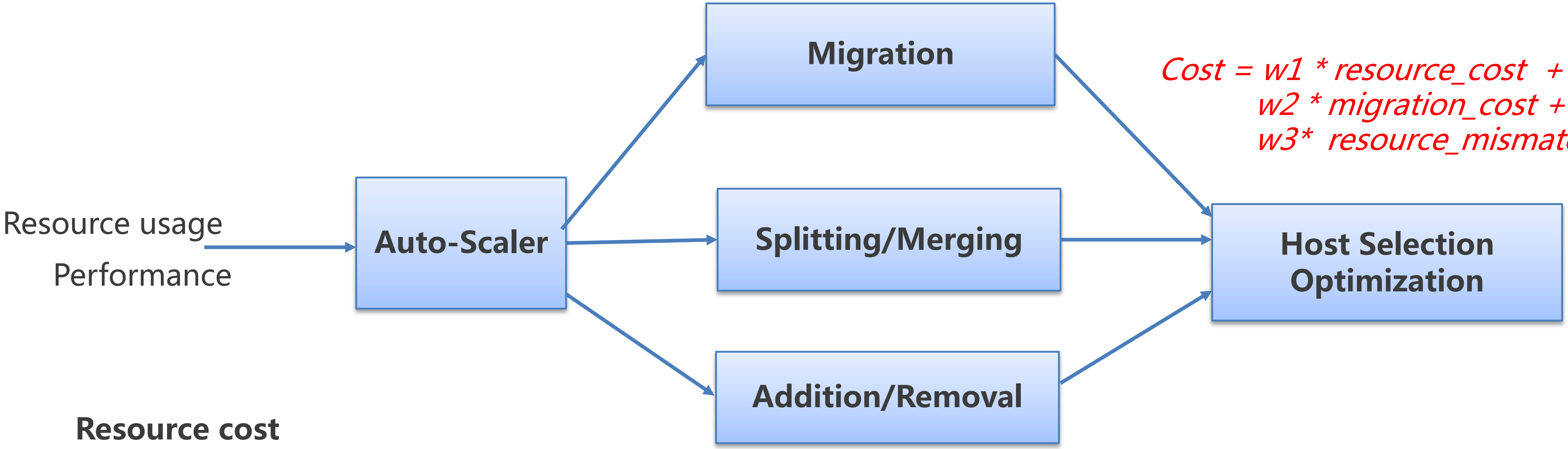
Auto Scaling

- Split or merge instances
- Add or remove instances
- Migrate or consolidate instances



Auto-Scaling: Overview and Cost Models



*Cost = w1 * resource_cost +*
*w2 * migration_cost +*
w3 resource_mismatch_cost*

Resource cost

$$\sum_{i=1}^{M} C_i\ (90\%ile) + \underset{i}{\mathrm{Max}} \sum_{j=1}^{N_i} [C_{i,j}\ (99\%ile) \ - C_{i,j}\ (90\%ile)]$$

Migration cost: *k * database size*

Resource usability: *balancing, availability, anti-affinity*

Host Selection: Multi-Resource Balance

K8S: BalancedResourceAllocation = 10 – abs(cpuRemaingFraction-memoryRemainingFraction)*10

Optimization：similarity between the request resource and available resources

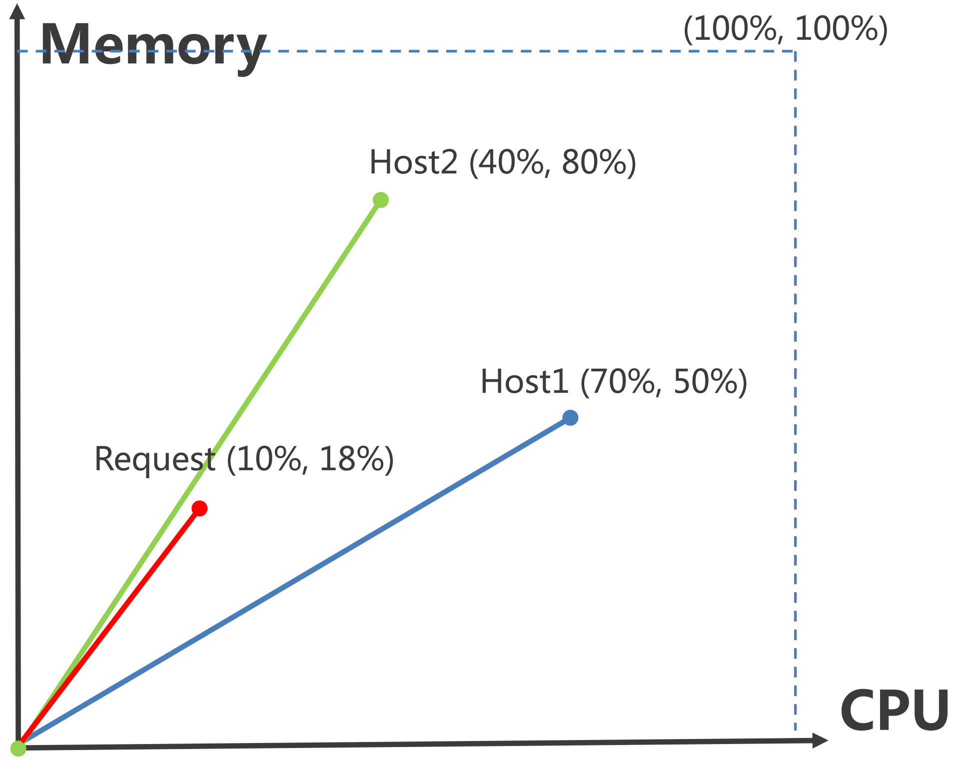
$$\text{similarity} = \cos(\theta) = \frac{\mathbf{A} \cdot \mathbf{B}}{\|\mathbf{A}\|\|\mathbf{B}\|} = \frac{\sum_{i=1}^{n} A_i B_i}{\sqrt{\sum_{i=1}^{n} A_i^2} \sqrt{\sum_{i=1}^{n} B_i^2}},$$

Host available resources： (U_{CPU}, U_{MEM})

Pod resource request： (R_{CPU}, R_{MEM})

Metric:

$$\frac{(R_{CPU}U_{CPU} + R_{MEM}U_{MEM})}{\sqrt{R_{CPU}^2 + R_{MEM}^2}\sqrt{U_{CPU}^2 + U_{MEM}^2}}$$



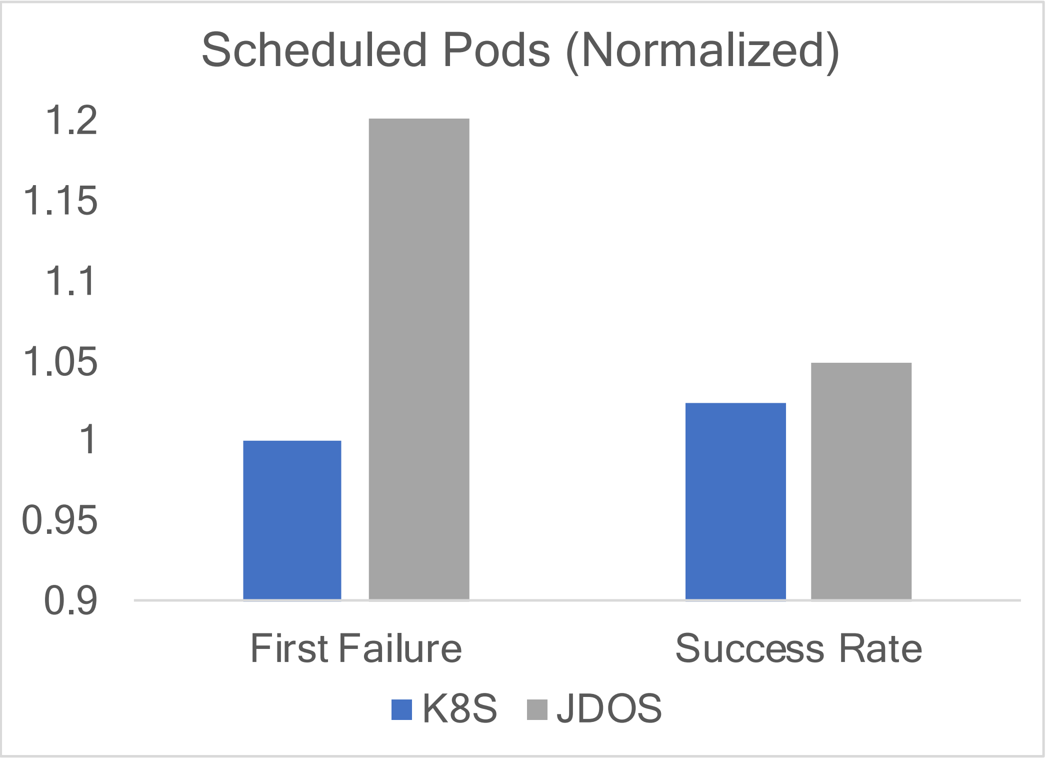
Experimental Evaluation

Setup

- 4,857 servers (8 configurations)
- 25,000 containers (120 configurations)

Results

- **Schedule 5%-20% more containers than K8S**
- **Comparable performance with K8S**



Host Selection: Resource Availability

K8S :

LeastRequestedPriority = cpu((capacity – sum(requested)) 10 / capacity) + memory((capacity – sum(requested)) 10 / capacity) / 2

Optimization: dynamic variable weights

$$w_{cpu} * \text{cpuAvailFraction} + w_{mem} * \text{memAvailFraction}$$

Algorithm 1:

Weighted sum of CPU : $\text{cpuFraction} = \sum_i f_i * \text{cpuFraction}_i$

Weight sum of memory : $\text{memFraction} = \sum_i f_i * \text{memFraction}_i$

$$w_{cpu} = \frac{\text{cpu}Fraction}{cpuFraction + memFraction}$$

$$w_{mem} = \frac{memFraction}{cpuFraction + memFraction}$$

Algorithm 2: Hosts with stable resource usage are more usable.

MAD- Median Absolute Deviation

$$w_{cpu} = 1 - \text{median}(\,|\text{cpuUtil}_i - median\,(\text{cpuUtil}_i)|)$$

$$w_{mem} = 1 - \text{median}(\,|\text{memUtil}_i - median\,(\text{memUtil}_i)|)$$

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Host Selection: Correlation-awareness

X : existing pods resource usage

Y : new pod resource usage

Anti-affinity: If Y can be predicted by Y, X and Y are highly correlated. We should avoid placing them on the same host.

$$\mathbf{X} = \begin{bmatrix} 1 & x_{1,1} & \cdots & x_{1,k} & \cdots & x_{1,K} \\ \vdots & \vdots & \ddots & \vdots & \ddots & \vdots \\ 1 & x_{n,1} & \cdots & x_{n,k} & \cdots & x_{n,K} \\ \vdots & \vdots & \ddots & \vdots & \ddots & \vdots \\ 1 & x_{N,1} & \cdots & x_{N,k} & \cdots & x_{N,K} \end{bmatrix} \qquad \mathbf{y} = \begin{bmatrix} y_1 \\ \vdots \\ y_n \\ \vdots \\ y_N \end{bmatrix}$$

Multi-regression analysis $\mathbf{b} = (\mathbf{X}^{\mathrm{T}}\mathbf{X})^{-1}\mathbf{X}^{\mathrm{T}}\mathbf{y} \qquad \widehat{\mathbf{y}} = \mathbf{X}\mathbf{b}$

Correlation

$$\frac{\sum_{i=1}^{n}(\mathbf{y}_i - m_Y)^2(\widehat{\mathbf{y}}_i - m_{\widehat{Y}})^2}{\sum_{i=1}^{n}(\mathbf{y}_i - m_Y)^2\sum_{i=1}^{n}(\widehat{\mathbf{y}}_i - m_{\widehat{Y}})^2}$$

Conclusions

- Running MySQL in containers on Kubernetes and using Vitess cluster management is the foundation of MySQL resource optimization and management.
- Statistical analysis and prediction based resource sizing and scaling approaches are useful to improve resource utilization of containerized MySQL.
- **Kubernetes + Vitess + Advanced Resource Optimization Algorithms** have significantly improved the resource efficiency and reduced the operations and maintenance costs of running large scale MySQL clusters at JD.

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System Architecture