Temporal Performance Modeling of Serverless Computing Platforms

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Performant and Available Computing Systems (PACS) Lab

TOC

Introduction

Serverless Computing

- Runtime operation and management done by the provider
  - Reduces the overhead for the software owner
  - Provisioning
  - Scaling resources
- Software is developed by writing functions
  - Well-defined interface
  - Functions deployed separately

Serverless Computing

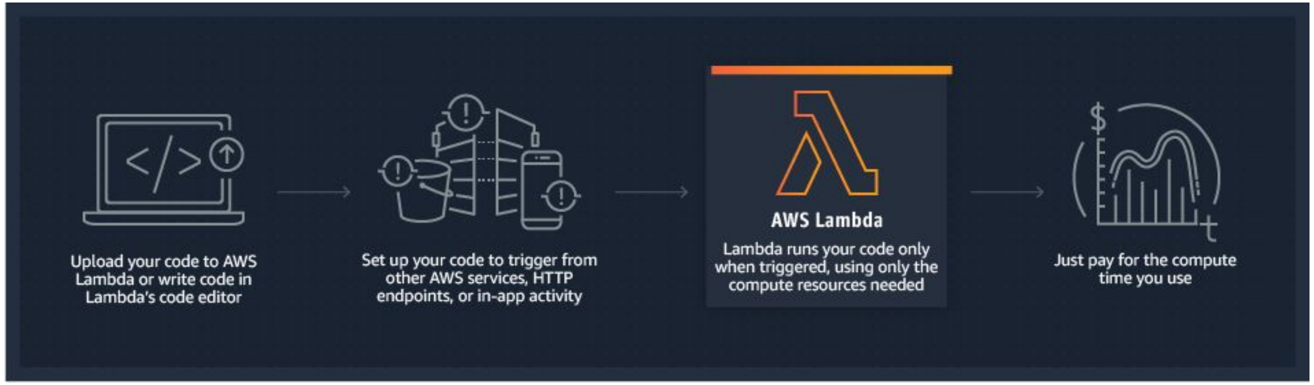

Upload your code to AWS Lambda or write code in Lambda's code editor
Set up your code to trigger from other AWS services, HTTP endpoints, or in-app activity
AWS Lambda
Lambda runs your code only when triggered, using only the compute resources needed
Just pay for the compute time you use

Image source: https://aws.amazon.com/lambda/

The Need for a Performance Model

- No previous work has been done for performance modelling of Serverless Computing platforms
- Accurate performance modelling can beneficial in many ways:
  - Ensure the Quality of Service (QoS)
  - Improve performance metrics
  - Predict/optimize infrastructure cost
  - Move from best-effort to performance guarantees
- It can benefit both serverless provider and application developer

System Description

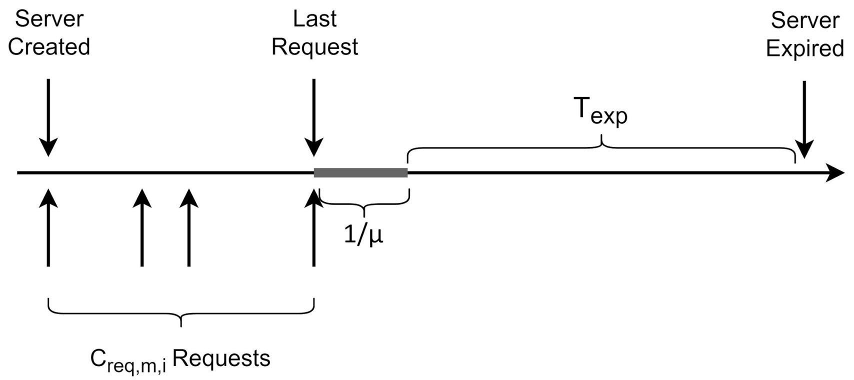
Function States, Cold Starts, and Warm Starts

- Function States:
    - **Initializing**: Performing initialization tasks to prepare the function for incoming requests. Includes infrastructure initialization and application initialization.
    - **Running**: Running the tasks required to process a request.
    - **Idle**: Provisioned instance that is not running any workloads. The instances in this state are not billed.
- Cold Start Requests:
    - A request that needs to go through initialization steps due to lack of provisioned capacity.
- Warm Start Requests:
    - Only includes request processing time since idle instance was available

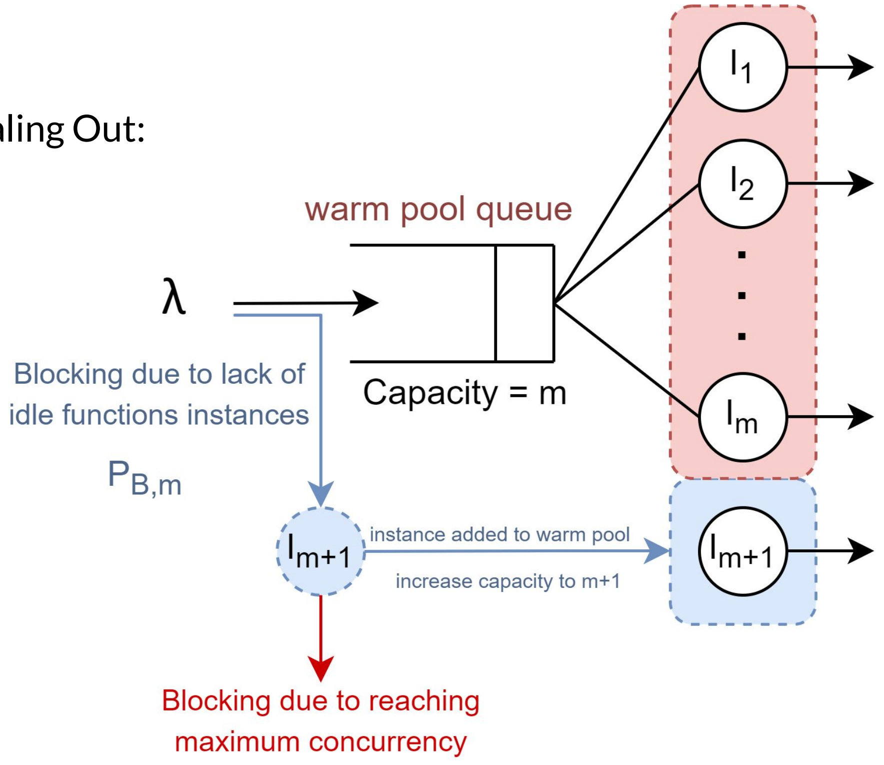
Autoscaling

Expiration Threshold

Scaling In:



Scaling Out:



warm pool queue
λ
Capacity = m
I_1
I_2
I_m
Blocking due to lack of idle functions instances
$P_{B,m}$
I_{m+1}
instance added to warm pool
increase capacity to m+1
I_{m+1}
Blocking due to reaching maximum concurrency

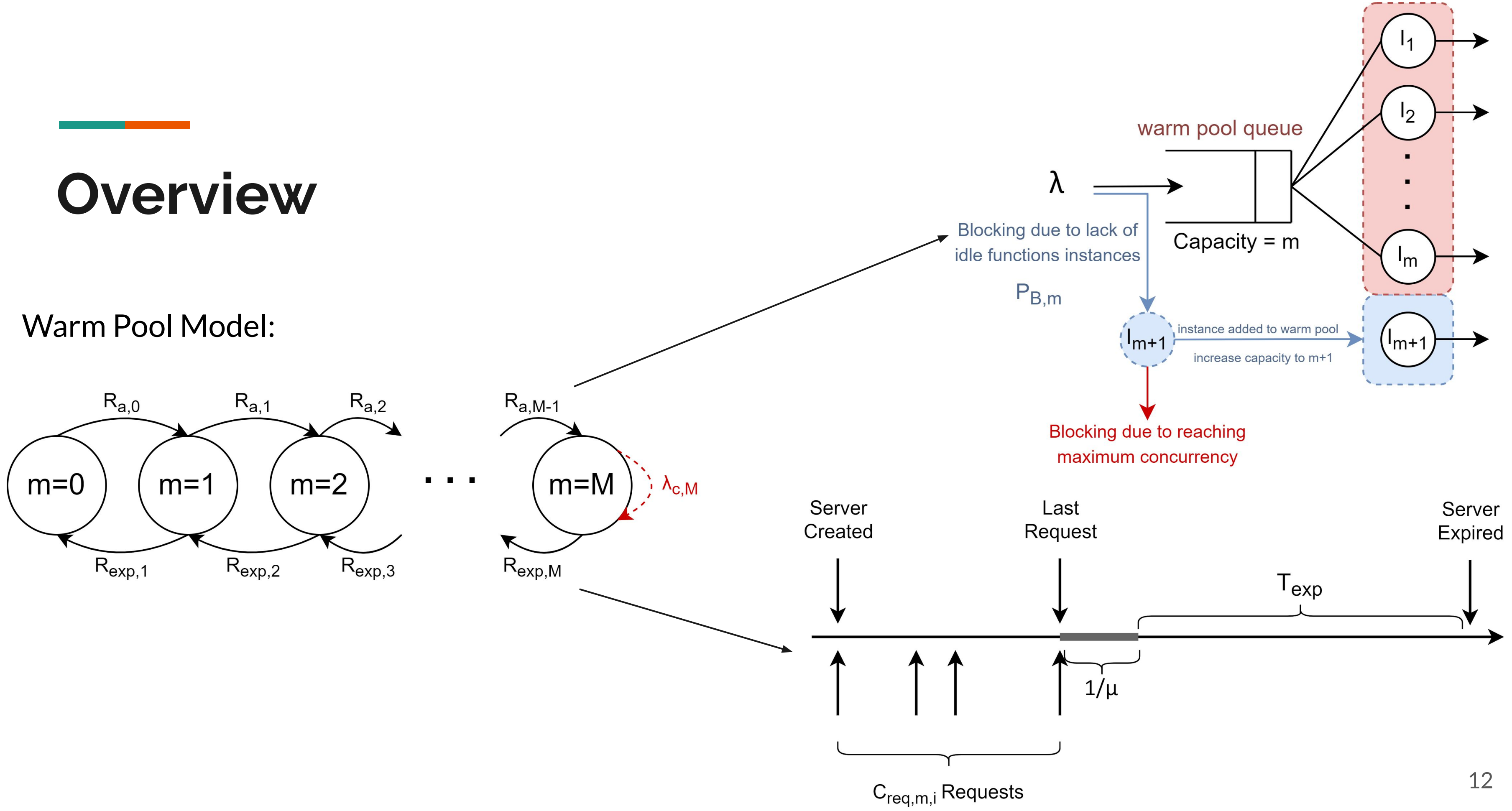
Other Important Characteristics

- **Initialization Time:** The amount of time instance spends in the initializing state.
- **Response Time:** No queuing, so it is equal to service time. It remains stable throughout time for cold and warm start requests.
- **Maximum Concurrency Level:** Maximum number of instances that can be in the state *running* in parallel.
- **Request Routing:** To facilitate scaling in, requests are routed to recently created instances first.

Analytical Modelling

Overview

Warm Pool Model:



- Cold Start Rate
  - The system behaves like an Erlang Loss System (M/G/m/m).
  - The blocked requests are either rejected (reached maximum concurrency level) or cause a cold start (and thus the creation of a new instance)
- Arrival Rate for Each Instance
  - Requests blocked by instance n are either processed by instance n+1 or blocked by it.
  - The difference between blocked rates gives us individual arrival rates.
- Server Expiration Rate
  - Can be calculated knowing individual arrival rates and expiration threshold.
- Warm Pool Model
  - Each state represents the number of instances in the warm pool.

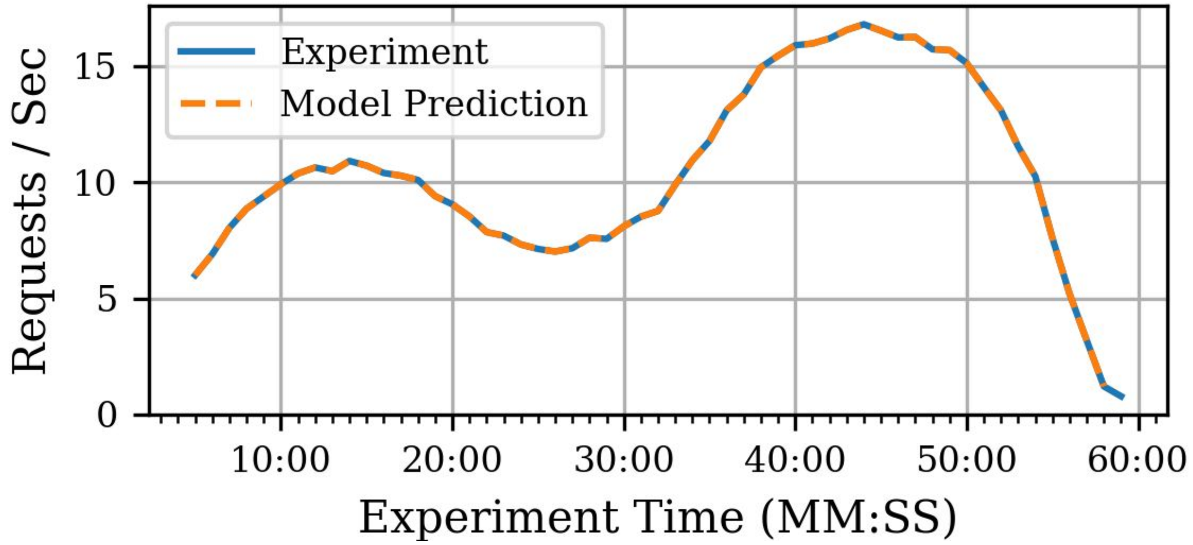
- For each state, we can also calculate:
  - **Probability of Rejection:** Probability of being blocked when reaching maximum concurrency.
  - **Probability of Cold Start:** Probability of being blocked in other states.
  - **Average Response Time:** $RT_{avg} = RT_w(1 - P_B) + RT_c P_{cld}$
  - **Mean Number of Instances in Warm Pool:**
    - Running
    - Idle
  - **Utilization:** Ratio of instances in *running* state over all instances.
- All predictions can be found in a time-bounded fashion (e.g., answers the question “what happens to my QoS in the next 5 minutes?”)

Experimental Validation

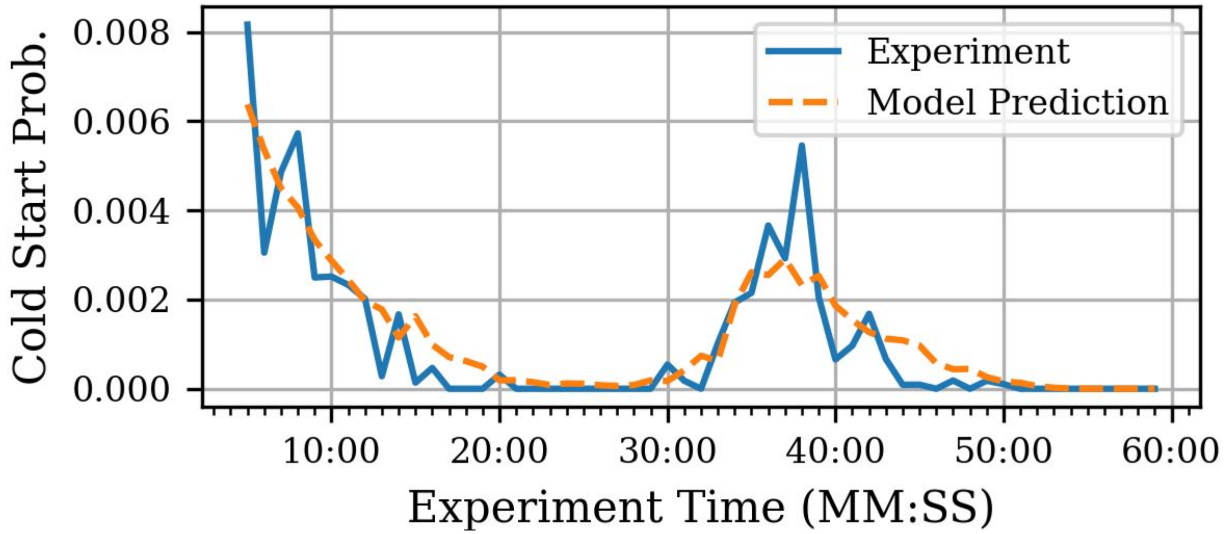
Experimental Setup

- Experiments done on AWS Lambda
    - Python 3.6 runtime with 128MB of RAM on us-east-1 region
    - A mixture of CPU and IO intensive tasks
- Client was a virtual machine on Compute Canada Arbutus
    - 8 vCPUs, 16GB of RAM, 1000Mbps connectivity, single-digit milliseconds latency to AWS servers
    - Python with in-house workload generation tool *pacswg*
    - Official *boto3* library for API communication
    - Communicated directly with Lambda API, no intermediary interfaces like API Gateway
- Predictions are made 5 minutes into the future
- Assumed oracle request pattern prediction

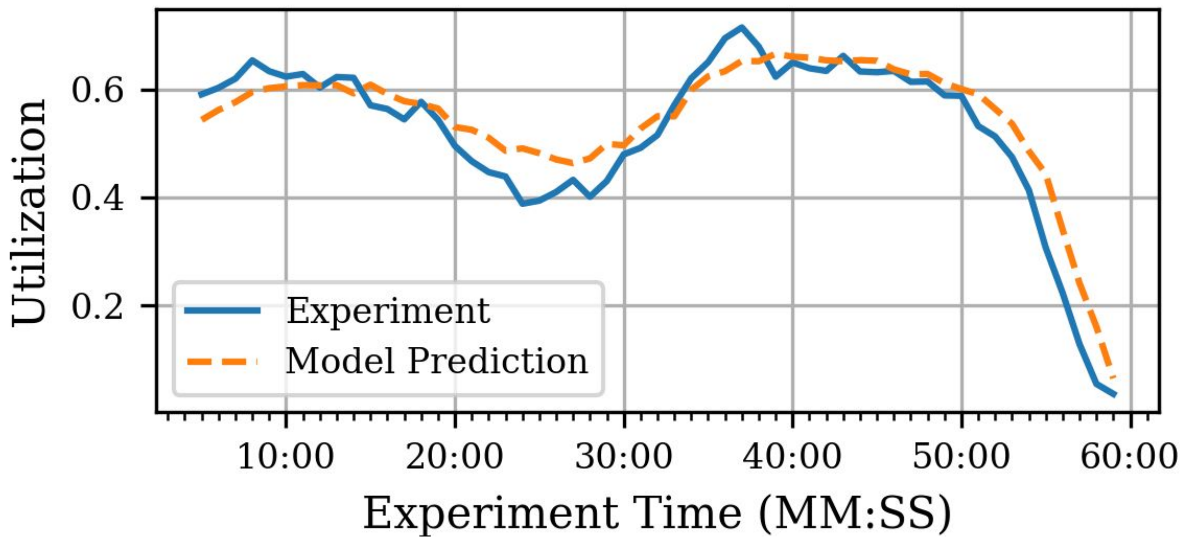
Sample Workload



Experimental Results



Experimental Results (2)



Conclusion

Conclusion

- Accurate and tractable analytical performance model
- Ability to predict important performance/cost related metrics
- Can predict QoS
- Can benefit serverless providers
    - Ability to predict QoS under different loads on deployment time
    - Can be used in the management to prevent performance degradation
- Could be useful to application developers
    - Predict how their system will perform in the immediate future
    - Help them optimize their memory configuration to occur minimal cost that satisfies performance requirements throughout their daily request patterns
- Can be used in the management systems to warm-up instances to prevent SLA violations

Summary

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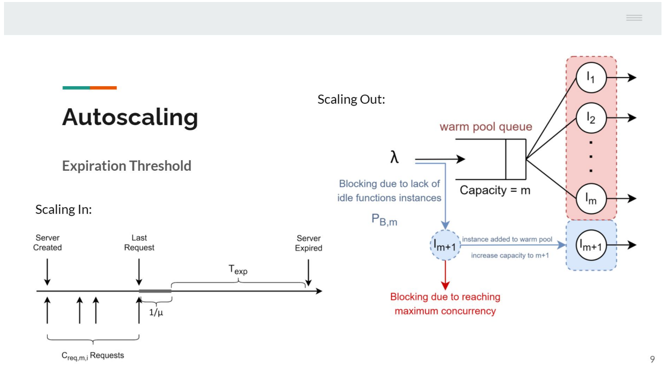

$$
\begin{array}{c|cccccc}
 & \xrightarrow{} \text{to state } (,j) & & & & & \\
\hline
\downarrow & -R_{a,0} & R_{a,0} & 0 & \cdots & & 0 \\
\text{from} & R_{exp,1} & -(R_{exp,1}+R_{a,1}) & R_{a,1} & 0 & & \\
\text{state} & 0 & \cdots & -(R_{exp,2}+R_{a,2}) & 0 & \cdots & \vdots \\
(i,) & \vdots & & & \ddots & & \vdots \\
 & & & R_{exp,M-1} & -(R_{exp,M-1}+R_{a,M-1}) & & R_{a,M-1} \\
 & 0 & & \cdots & 0 & R_{exp,M} & -R_{exp,M}
\end{array}
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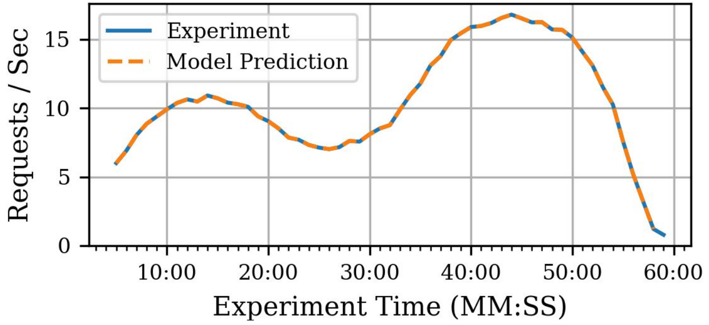
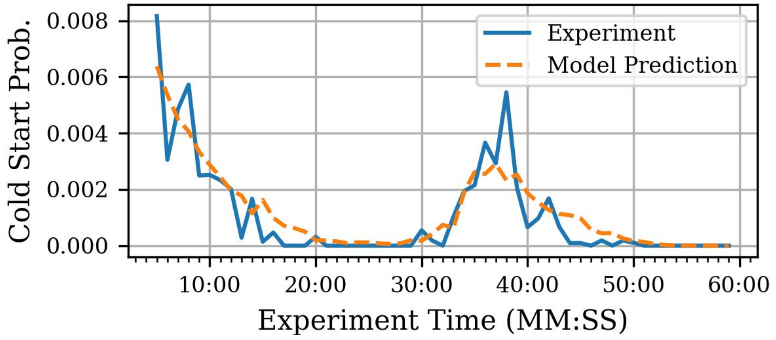

Experiment
Model Prediction
Requests / Sec
10:00
20:00
30:00
40:00
50:00
60:00
Experiment Time (MM:SS)


Experiment
Model Prediction
Cold Start Prob.
10:00
20:00
30:00
40:00
50:00
60:00
Experiment Time (MM:SS)