inferno
inference service,
naturally optimized

Inferencing operational optimization

Model-based, dynamic global optimization

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IBM Research

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analysis

analyzer

- build functional and queueing models
- parameter estimation
- dynamic filtering

predictor

- time series analysis
- prediction analysis
- dynamic correction

decision making

optimizer

- create instance of optimization problem
- solve problem
- collaborative, hierarchical

knowledge

data repository

- objects containing information
- monitored, state, desired, status
- custom resources
- dynamic, efficient, persistent

manager

- set policies & objectives
- set parameters
- over-ride controls
- dashboard

management

observation

profiler

- benchmark models
- vary batch size, seq length, FW, precision, …

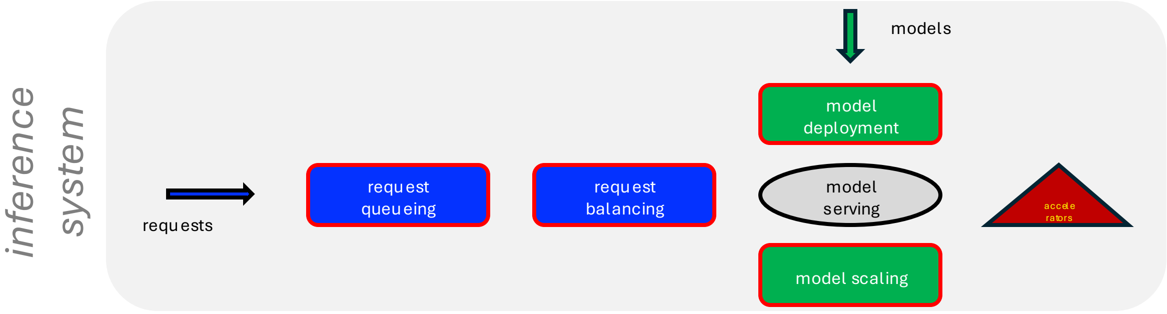
monitor

- collect real-time data
- GPUs, cluster, pods, serving FW, …
- publish to Prometheus

control

controller

- adjust knobs
- feedback correction
- rule-based supervision

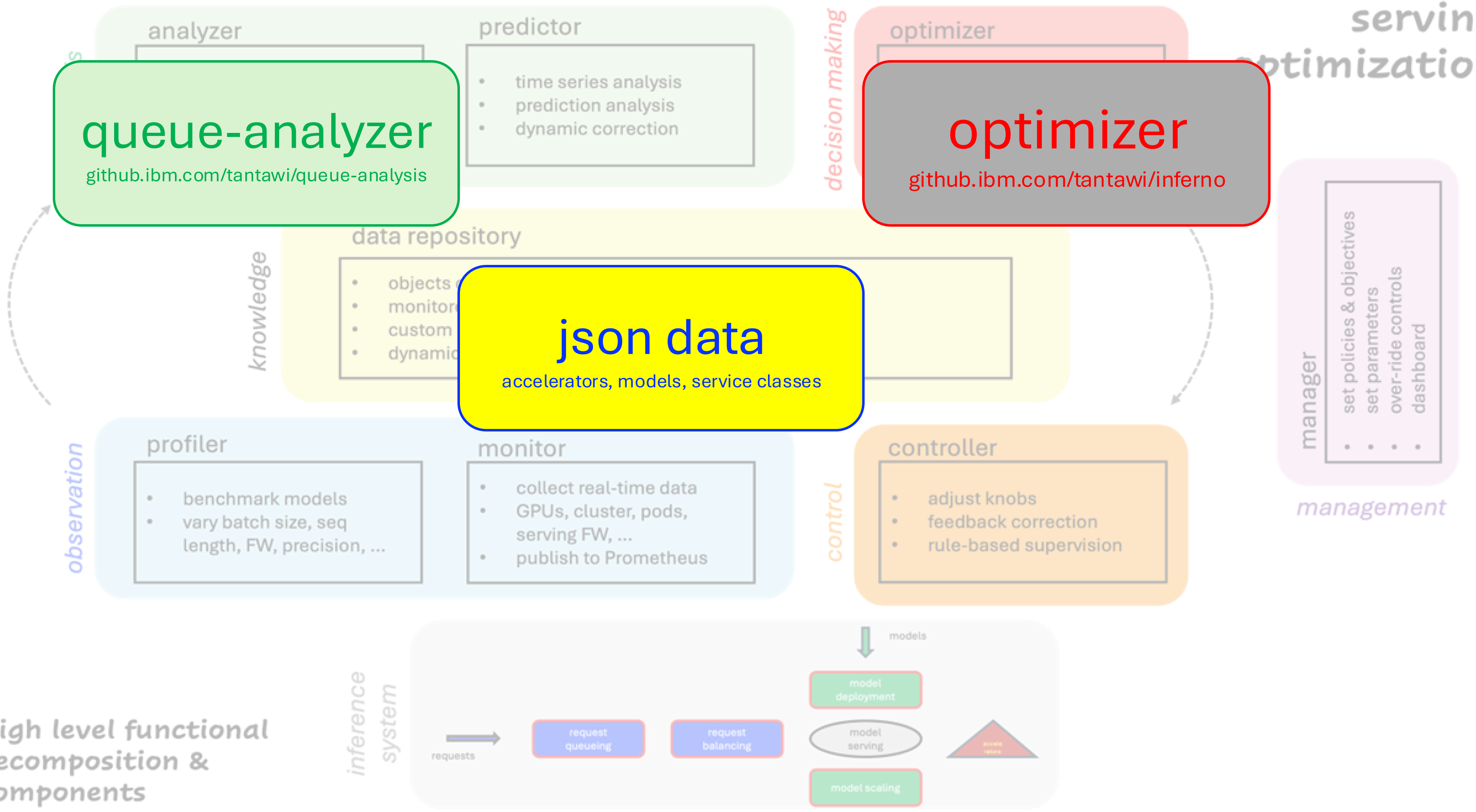

inference system
models
requests
request queueing
request balancing
model deployment
model serving
model scaling
accele rators

High level functional decomposition & components

cria

control runtime for inference automation

Inference serving optimization



analyzer
predictor
time series analysis
prediction analysis
dynamic correction
decision making
optimizer
knowledge
data repository
objects c
monitor
custom
dynamic
observation
profiler
benchmark models
vary batch size, seq length, FW, precision, ...
monitor
collect real-time data
GPUs, cluster, pods, serving FW, ...
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queue-analyzer

github.ibm.com/tantawi/queue-analysis

optimizer

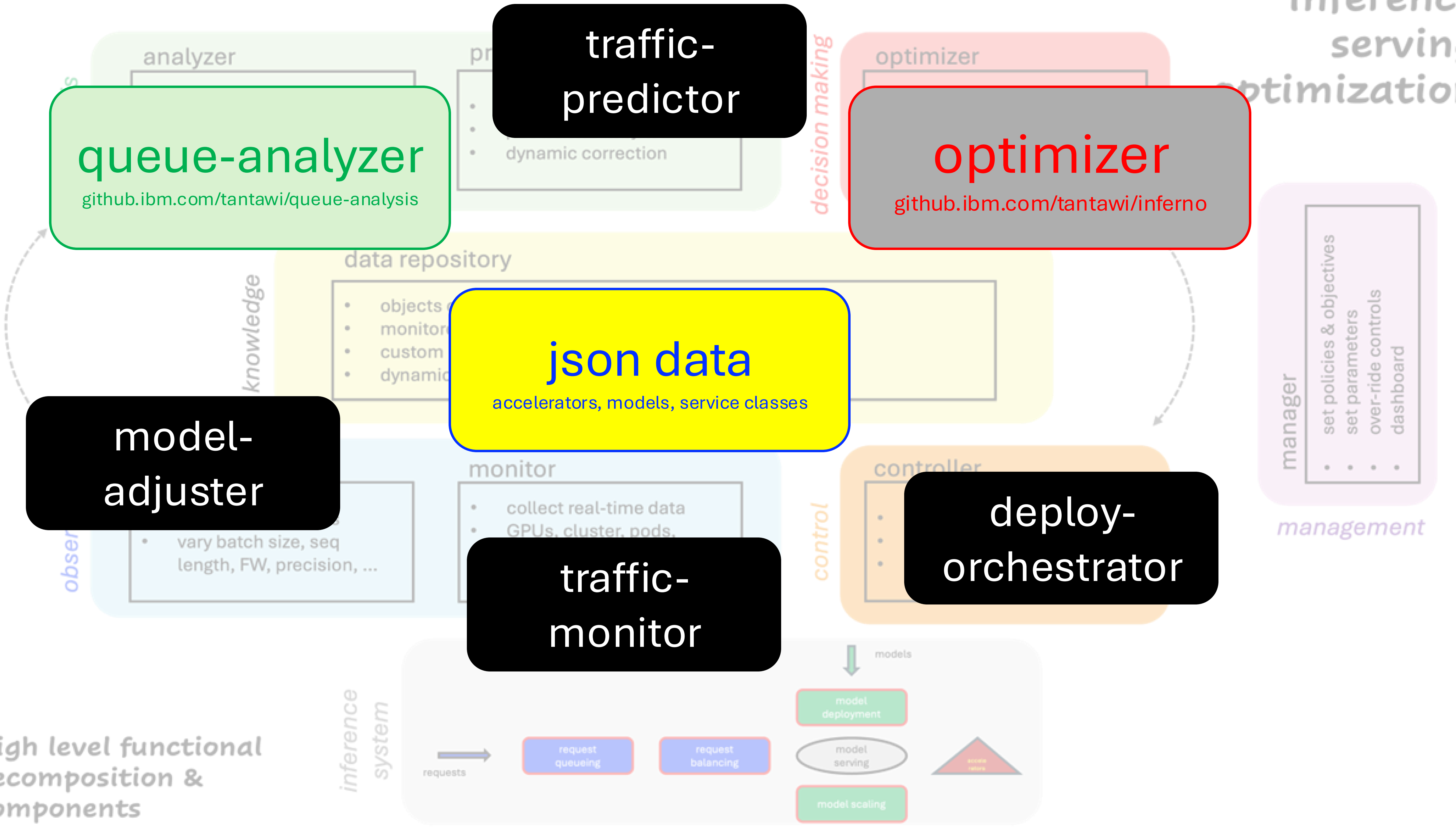
github.ibm.com/tantawi/inferno

json data

accelerators, models, service classes

High level functional decomposition & components

Inference serving optimization


analyzer
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dynamic correction
decision making
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data repository
knowledge
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GPUs, cluster, pods,
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inference system
models
model deployment
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request balancing
model serving
model scaling

queue-analyzer
github.ibm.com/tantawi/queue-analysis

traffic-predictor

optimizer
github.ibm.com/tantawi/inferno

json data
accelerators, models, service classes

model-adjuster

traffic-monitor

deploy-orchestrator

High level functional decomposition & components

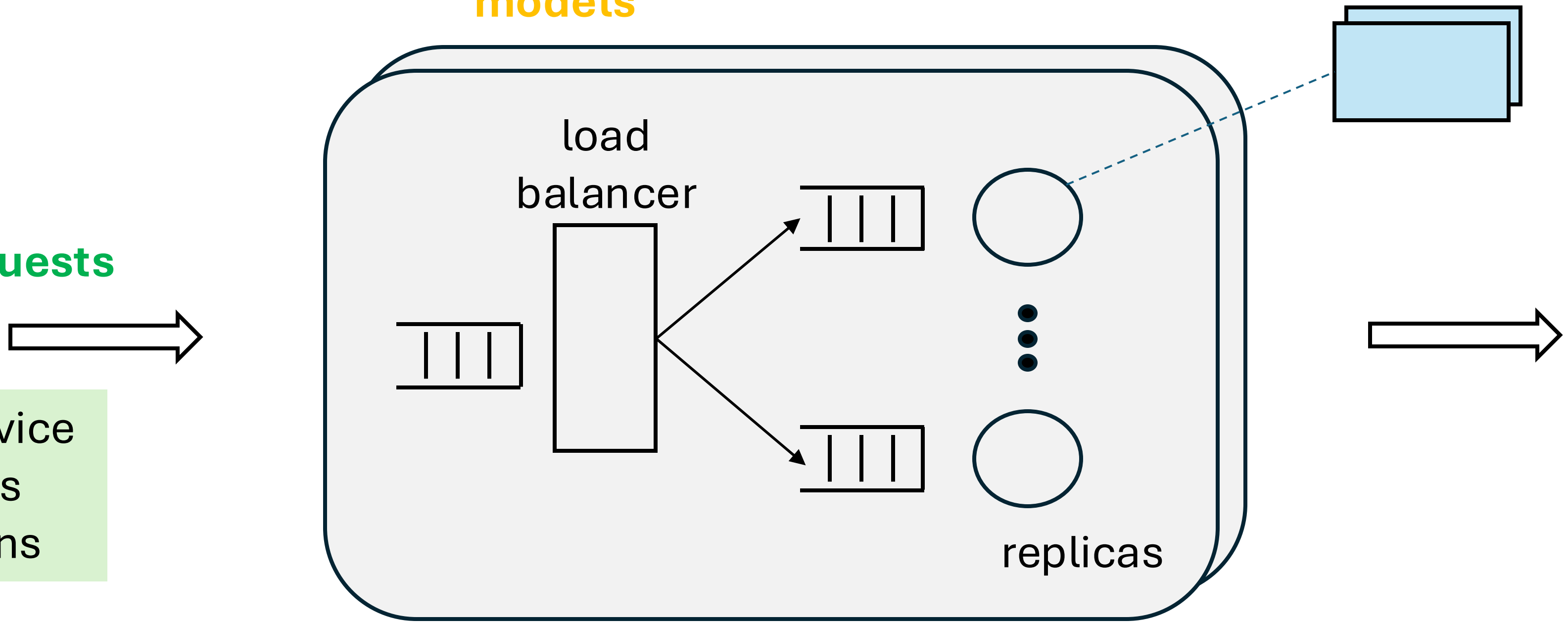
Problem scope

models

- memory demand
- performance characteristics (delay, throughput)

GPU types

- cost
- memory size
- memory BW



requests

- classes of service
- arrival patterns
- service patterns

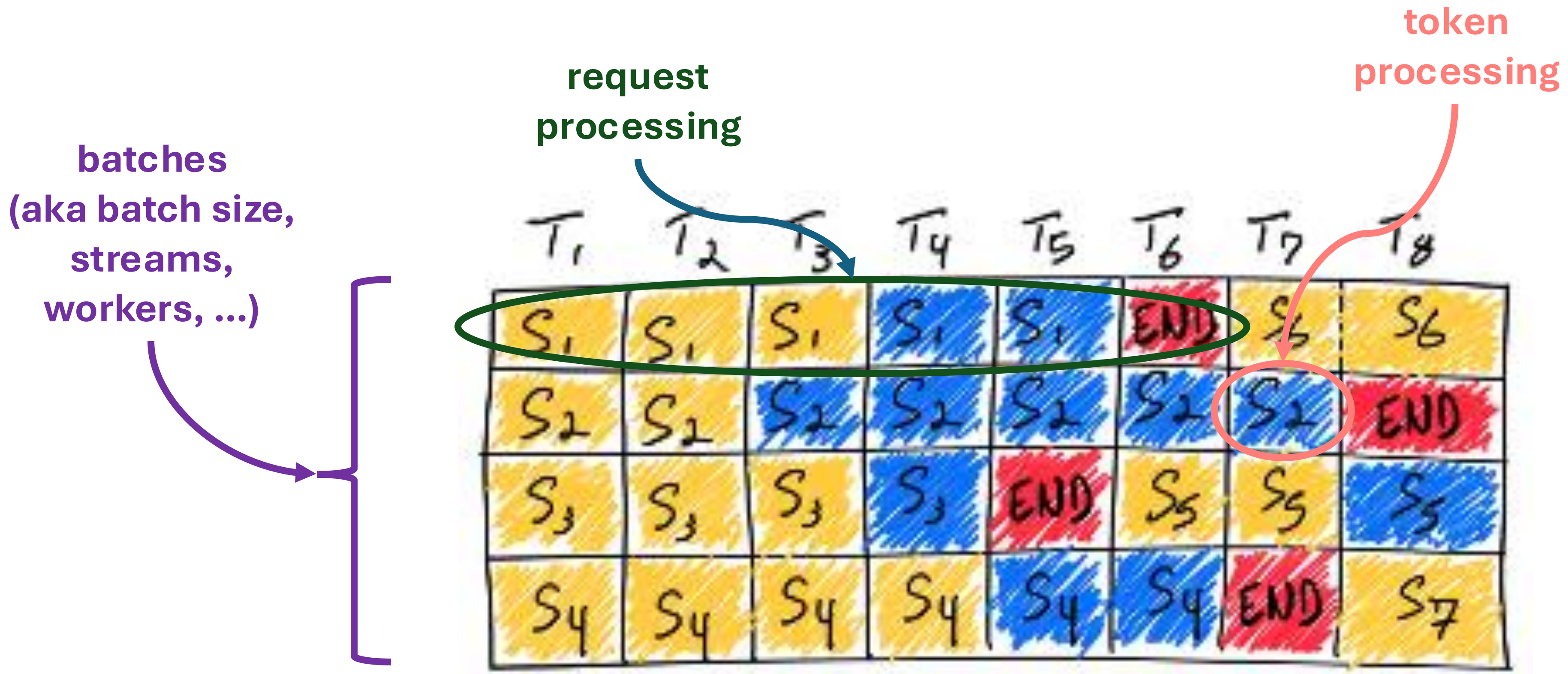
objectives

- min cost
- satisfy SLOs
- fairness, slack, power

decision variables

- GPU type
- number of replicas
- batch size

Request batching



batches (aka batch size, streams, workers, ...)

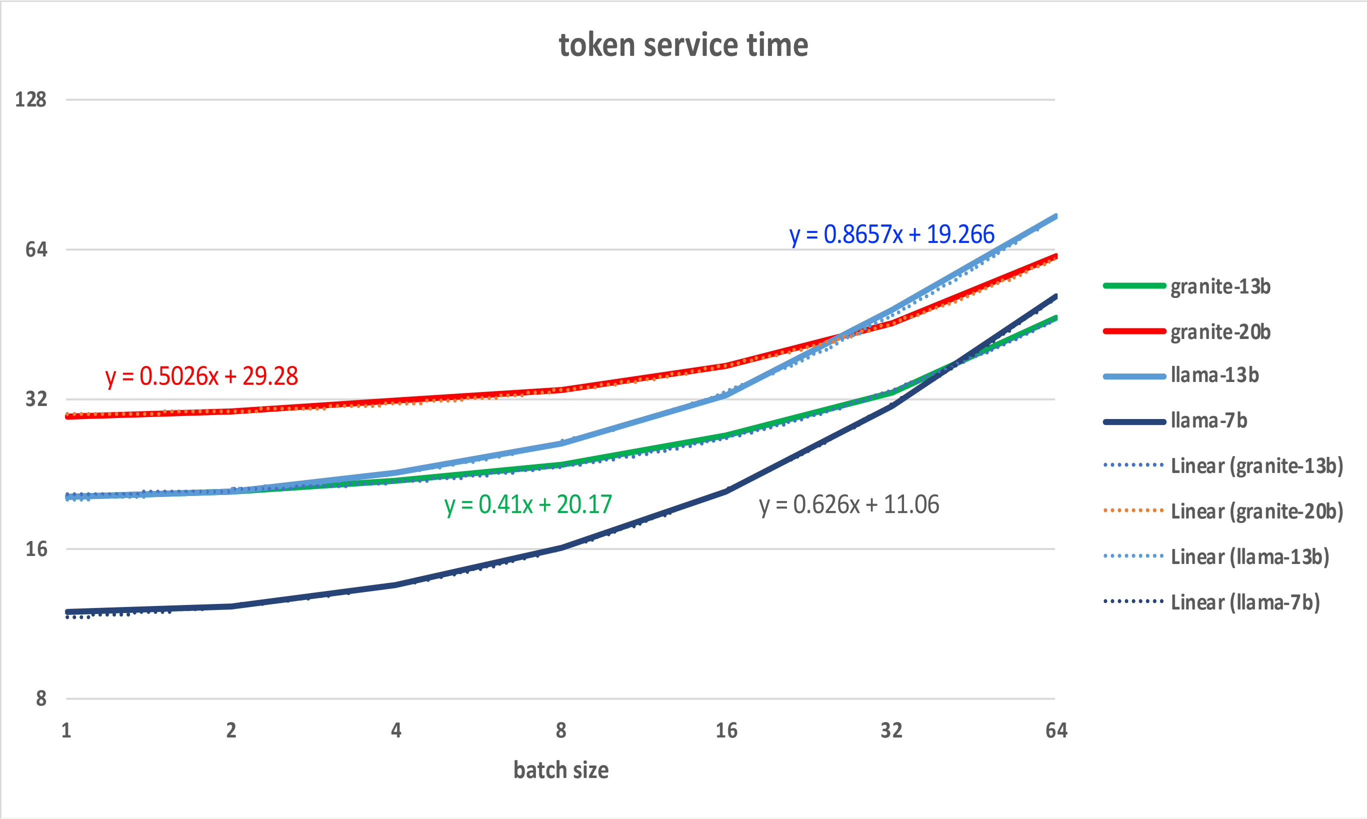
request processing

token processing

T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8
S_1	S_1	S_1	S_1	S_1	END	S_6	S_6
S_2	S_2	S_2	S_2	S_2	S_2	S_2	END
S_3	S_3	S_3	S_3	END	S_5	S_5	S_5
S_4	S_4	S_4	S_4	S_4	S_4	END	S_7

N	batch size
$\tau(N)$	token service (processing) time (ITL)
K	number of tokens per request

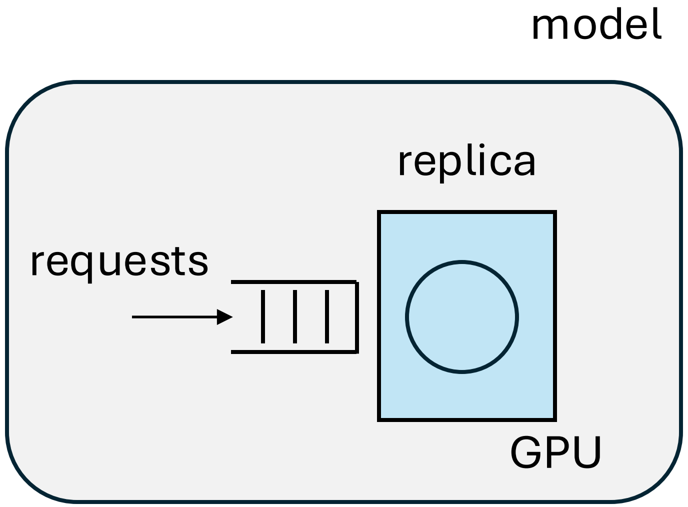
Fitting token service time

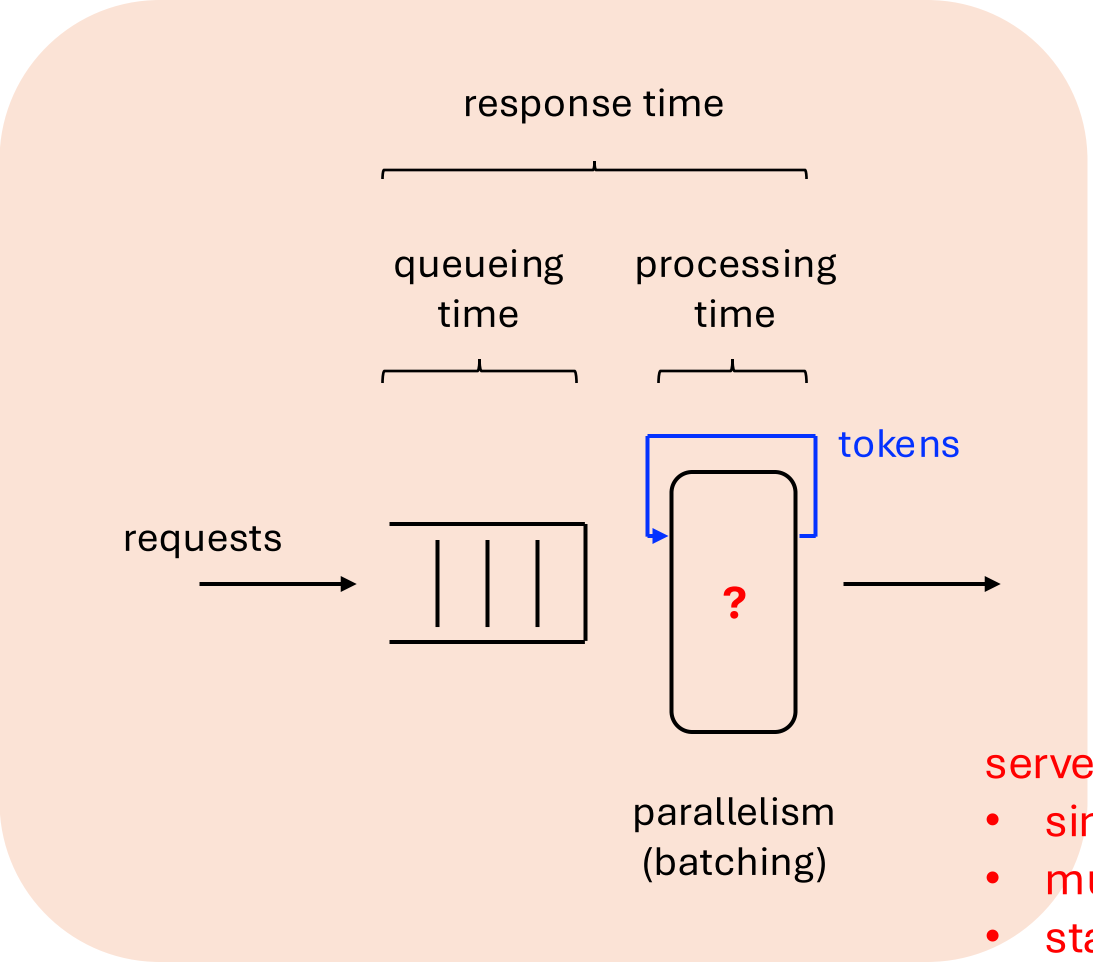


precision	fp16
accelerator	A100
tokens	1024
back	vLLM
accCount	1

$$\tau(N) \approx \alpha + \beta\, N$$

Queueing model of a model serving instance (replica)


model
replica
requests
GPU


response time
queueing time
processing time
tokens
requests
?
parallelism (batching)

avg request processing time =
avg num tokens per request *
avg token service time

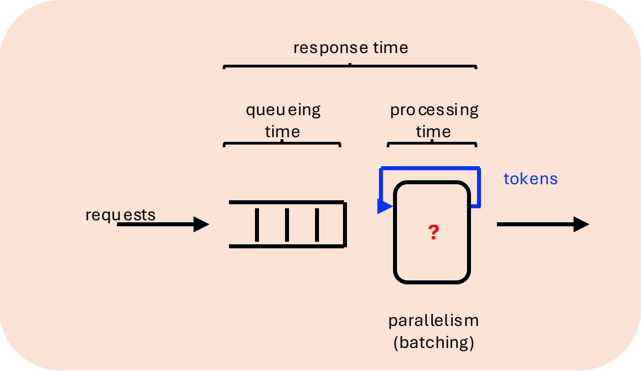
load = request rate * avg request processing time

avg token delay = avg request response time /
avg num tokens

server structure?

- single server
- multiple server
- state-dependent server
- queueing network

modeling batching

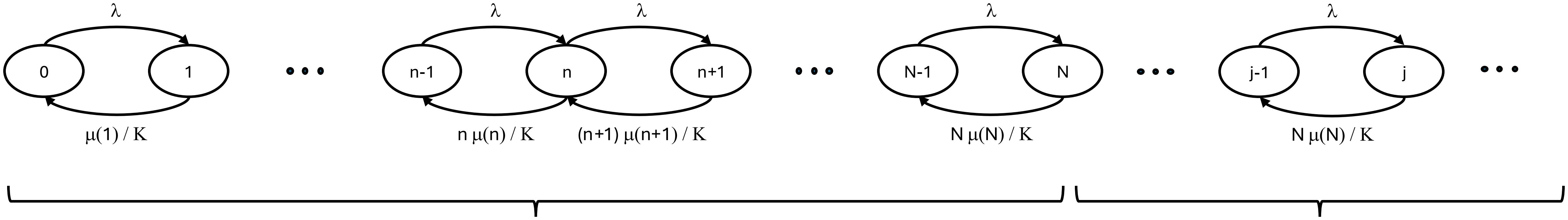

response time
queueing time
processing time
tokens
requests
?
parallelism (batching)

- Markovian assumptions

- state: number of requests in process
- λ request arrival rate
- K average number of tokens per request
- τ(n) average token service time given n batches
- N batch size (maximum)

$$\mu(n) = \frac{1}{\tau(n)}$$

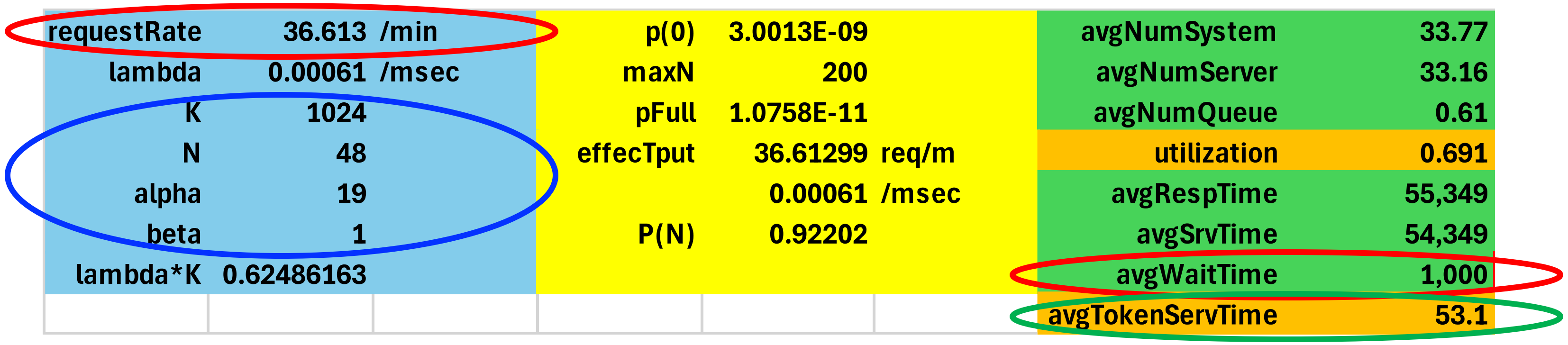
$$\tau(n) \approx \alpha + \beta\, n$$


λ
λ
λ
λ
λ
0
1
• • •
n-1
n
n+1
• • •
N-1
N
• • •
j-1
j
• • •
μ(1) / K
n μ(n) / K
(n+1) μ(n+1) / K
N μ(N) / K
N μ(N) / K

n requests processed in parallel

(j – N) requests waiting

rate limiting



requestRate	36.613	/min	p(0)	3.0013E-09		avgNumSystem	33.77
lambda	0.00061	/msec	maxN	200		avgNumServer	33.16
K	1024		pFull	1.0758E-11		avgNumQueue	0.61
N	48		effecTput	36.61299	req/m	utilization	0.691
alpha	19			0.00061	/msec	avgRespTime	55,349
beta	1		P(N)	0.92202		avgSrvTime	54,349
lambda*K	0.62486163					avgWaitTime	1,000
						avgTokenServTime	53.1

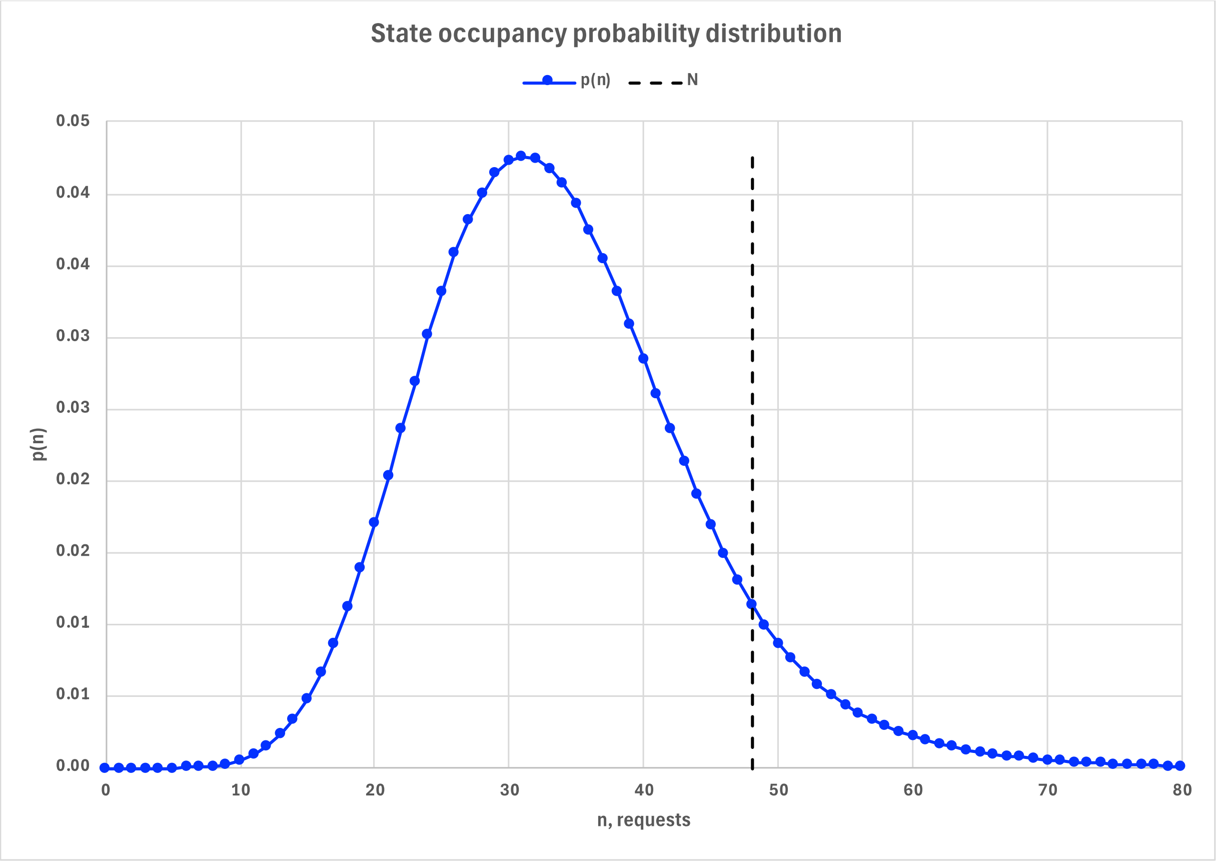
Find

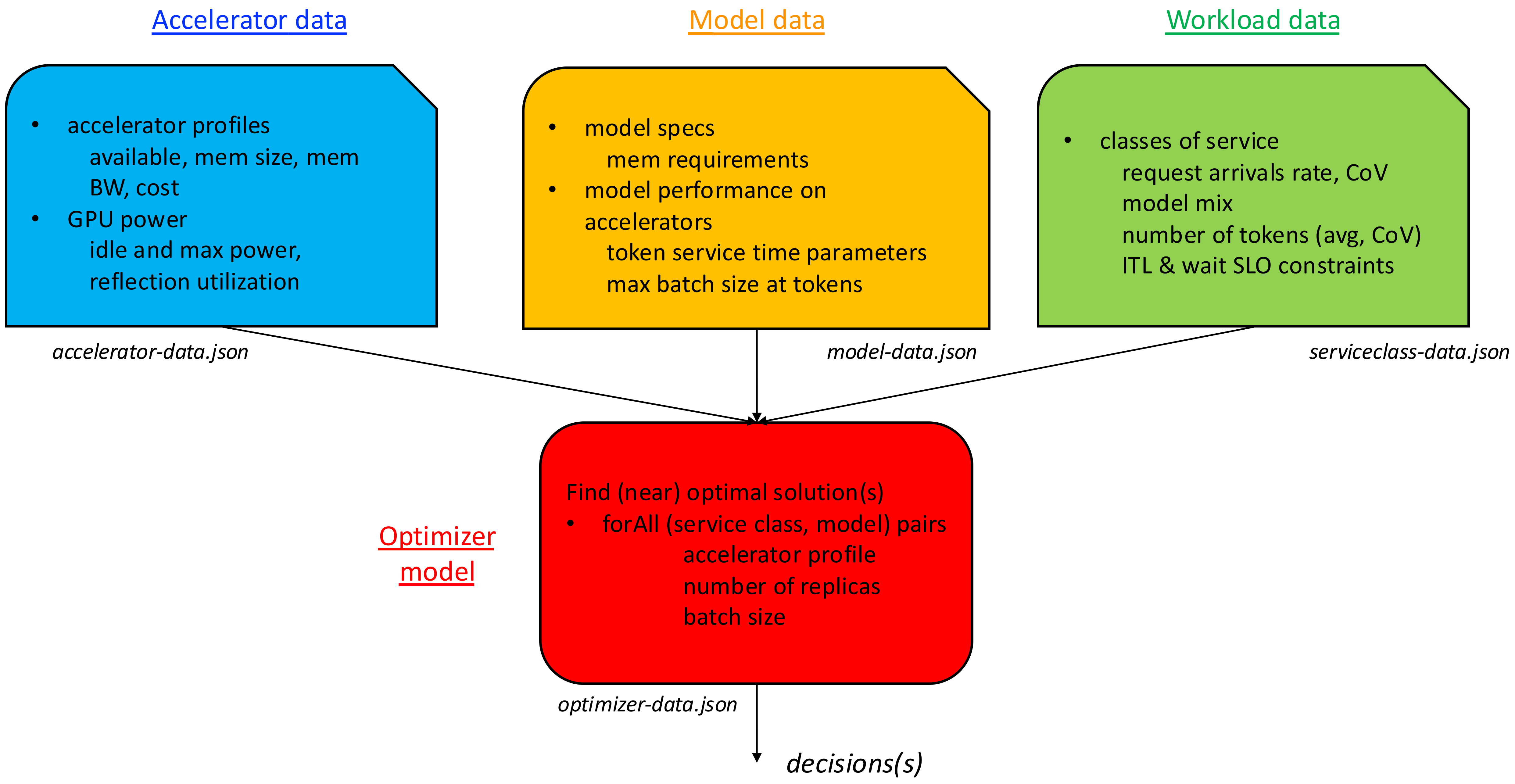
maximum request rate

s.t.

avgWaitTime <= target

target = 1.0 sec
requestRate = 36.613 req/min





Accelerator data

- accelerator profiles
  - available, mem size, mem BW, cost
- GPU power
  - idle and max power, reflection utilization

accelerator-data.json

Model data

- model specs
  - mem requirements
- model performance on accelerators
  - token service time parameters
  - max batch size at tokens

model-data.json

Workload data

- classes of service
  - request arrivals rate, CoV
  - model mix
  - number of tokens (avg, CoV)
  - ITL & wait SLO constraints

serviceclass-data.json

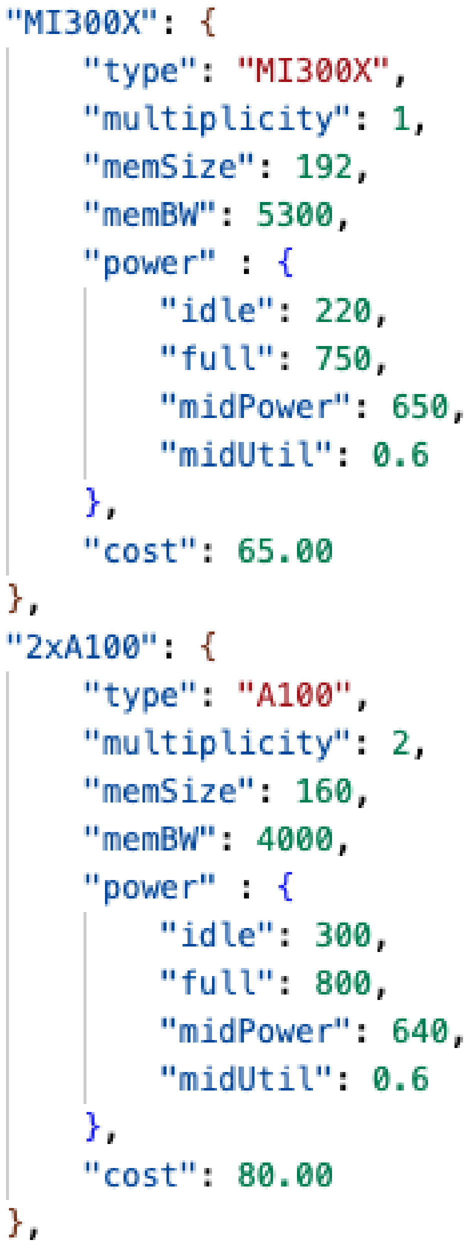
Optimizer model

Find (near) optimal solution(s)

- forAll (service class, model) pairs
  - accelerator profile
  - number of replicas
  - batch size

optimizer-data.json

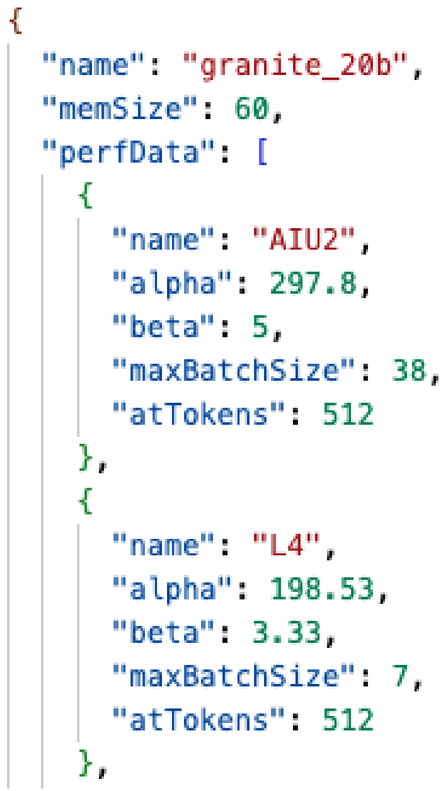
decisions(s)



```
"MI300X": {
    "type": "MI300X",
    "multiplicity": 1,
    "memSize": 192,
    "memBW": 5300,
    "power" : {
        "idle": 220,
        "full": 750,
        "midPower": 650,
        "midUtil": 0.6
    },
    "cost": 65.00
},
"2xA100": {
    "type": "A100",
    "multiplicity": 2,
    "memSize": 160,
    "memBW": 4000,
    "power" : {
        "idle": 300,
        "full": 800,
        "midPower": 640,
        "midUtil": 0.6
    },
    "cost": 80.00
},
```

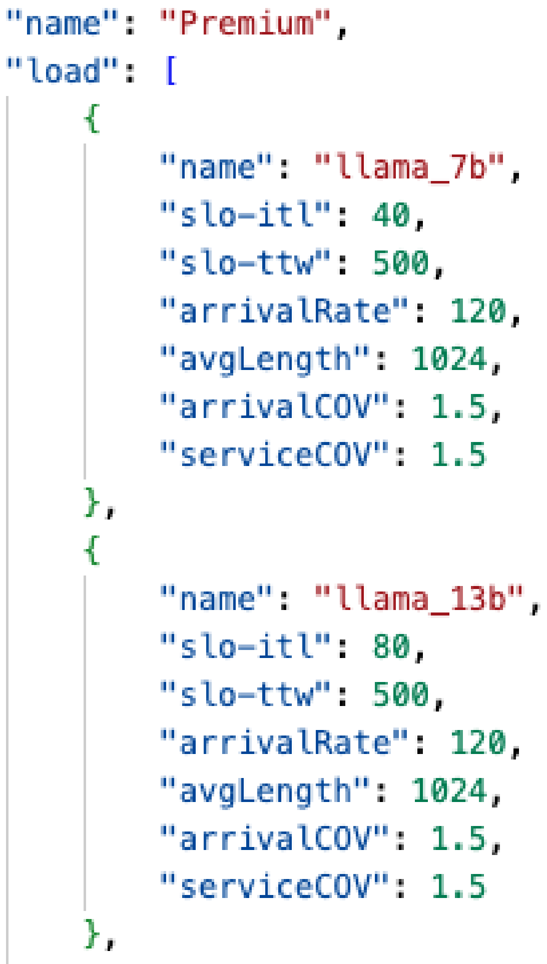
accelerator-data.json

model-data.json



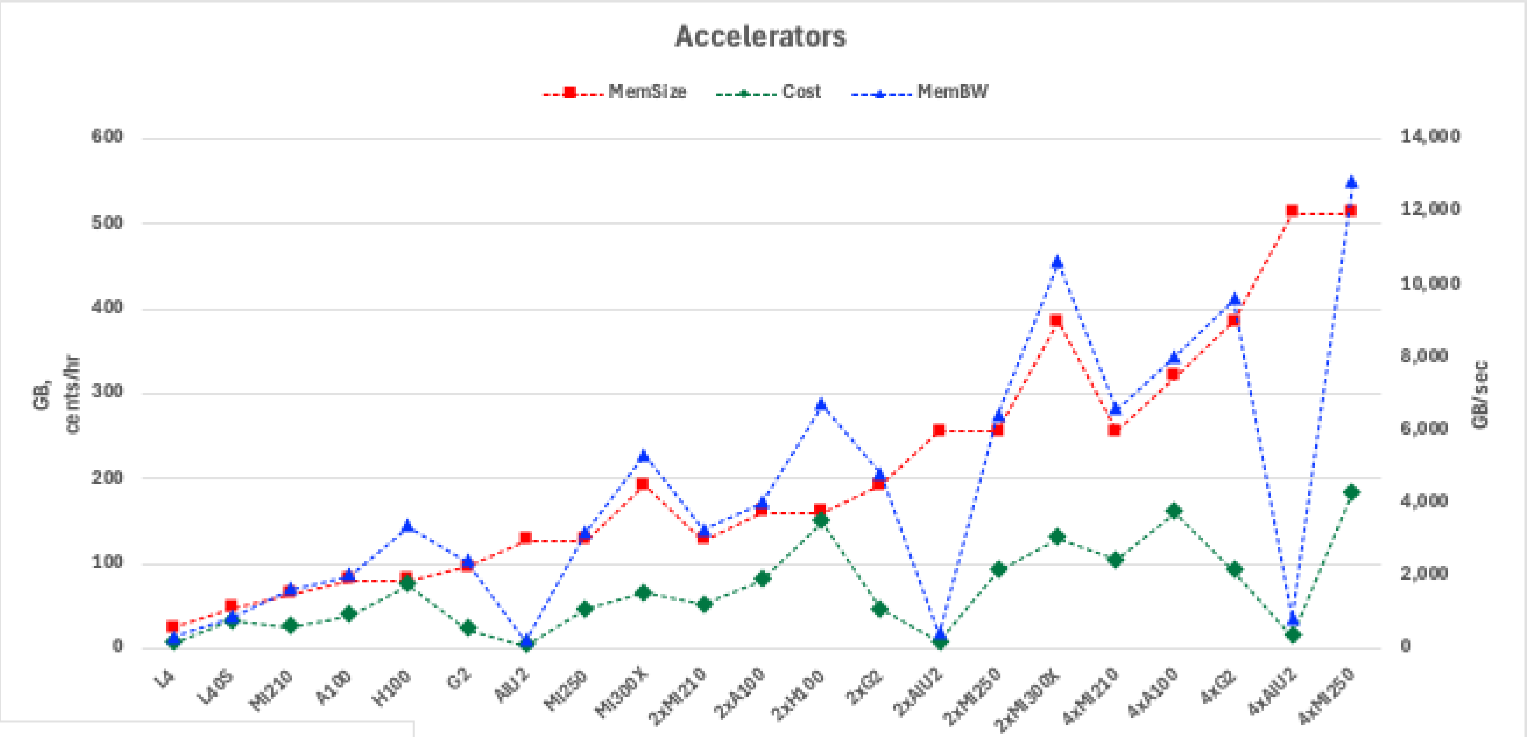
```
{
  "name": "granite_20b",
  "memSize": 60,
  "perfData": [
    {
      "name": "AIU2",
      "alpha": 297.8,
      "beta": 5,
      "maxBatchSize": 38,
      "atTokens": 512
    },
    {
      "name": "L4",
      "alpha": 198.53,
      "beta": 3.33,
      "maxBatchSize": 7,
      "atTokens": 512
    },
```

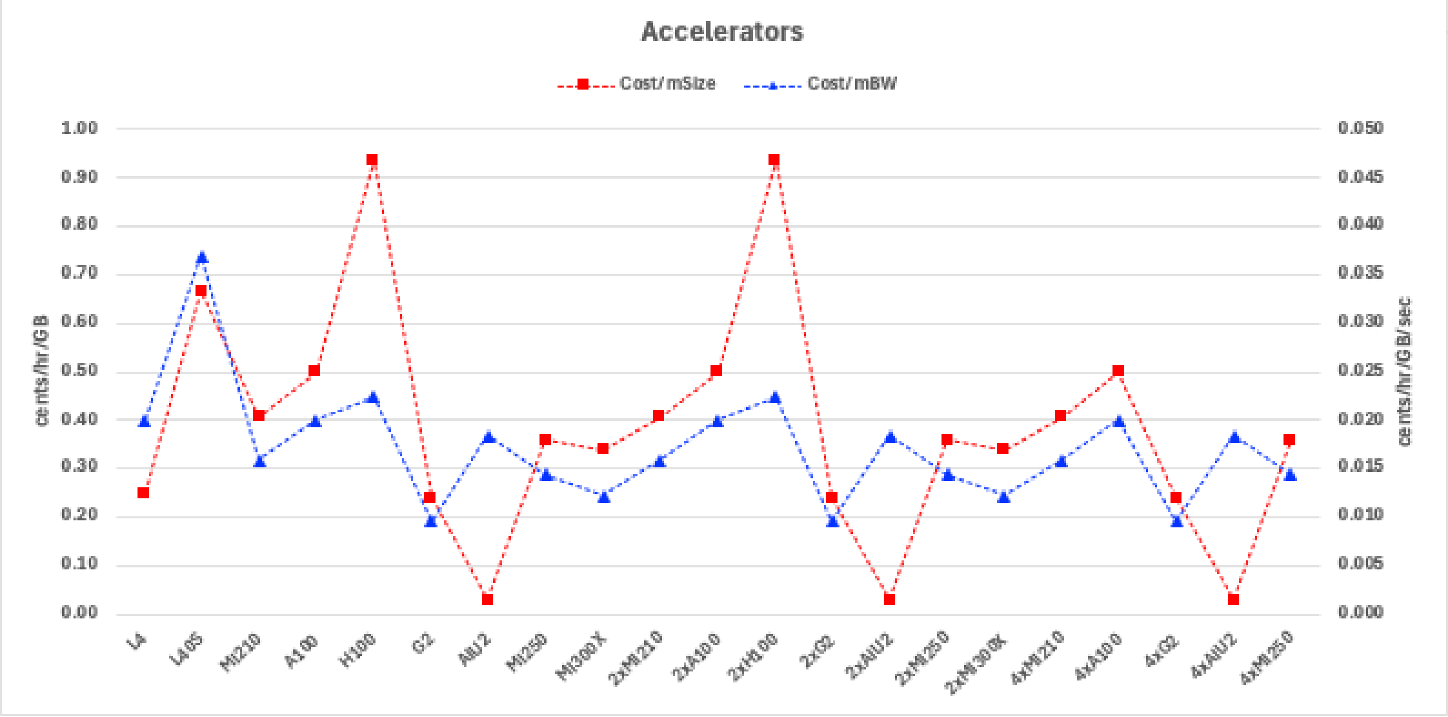
serviceclass-data.json



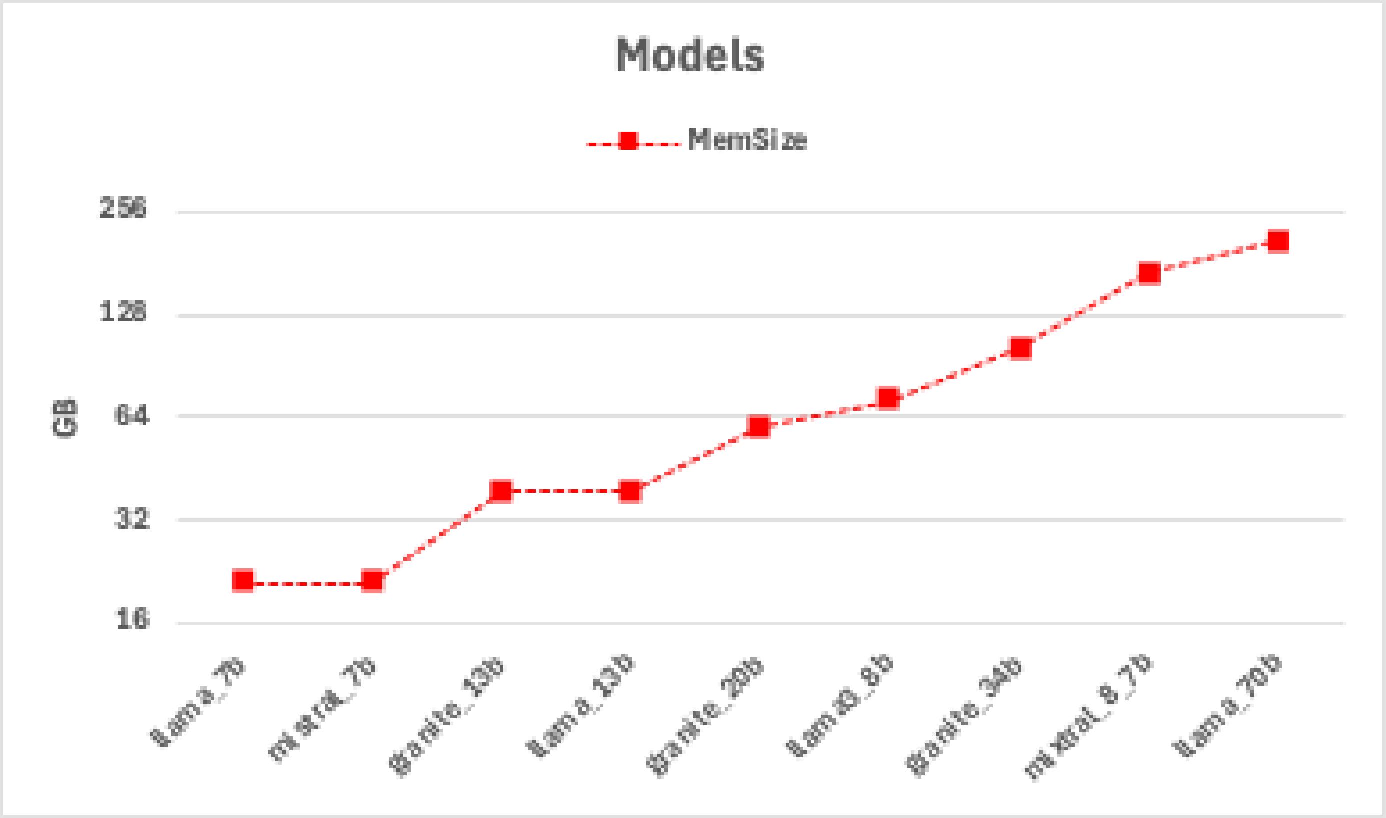
```
"name": "Premium",
"load": [
    {
        "name": "llama_7b",
        "slo-itl": 40,
        "slo-ttw": 500,
        "arrivalRate": 120,
        "avgLength": 1024,
        "arrivalCOV": 1.5,
        "serviceCOV": 1.5
    },
    {
        "name": "llama_13b",
        "slo-itl": 80,
        "slo-ttw": 500,
        "arrivalRate": 120,
        "avgLength": 1024,
        "arrivalCOV": 1.5,
        "serviceCOV": 1.5
    },
```

Accelerators Specs



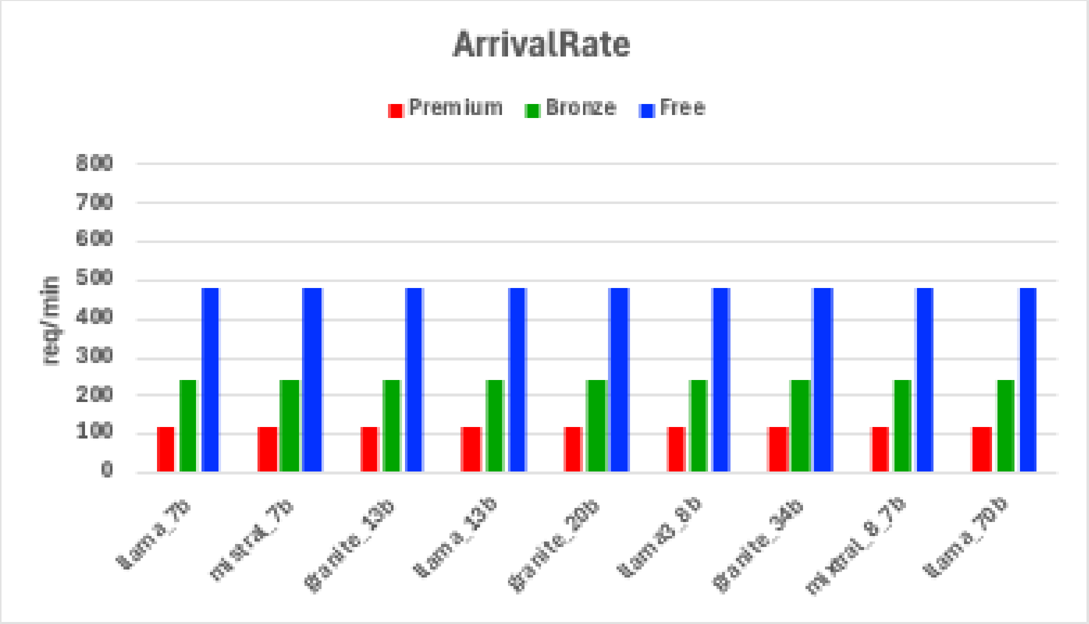


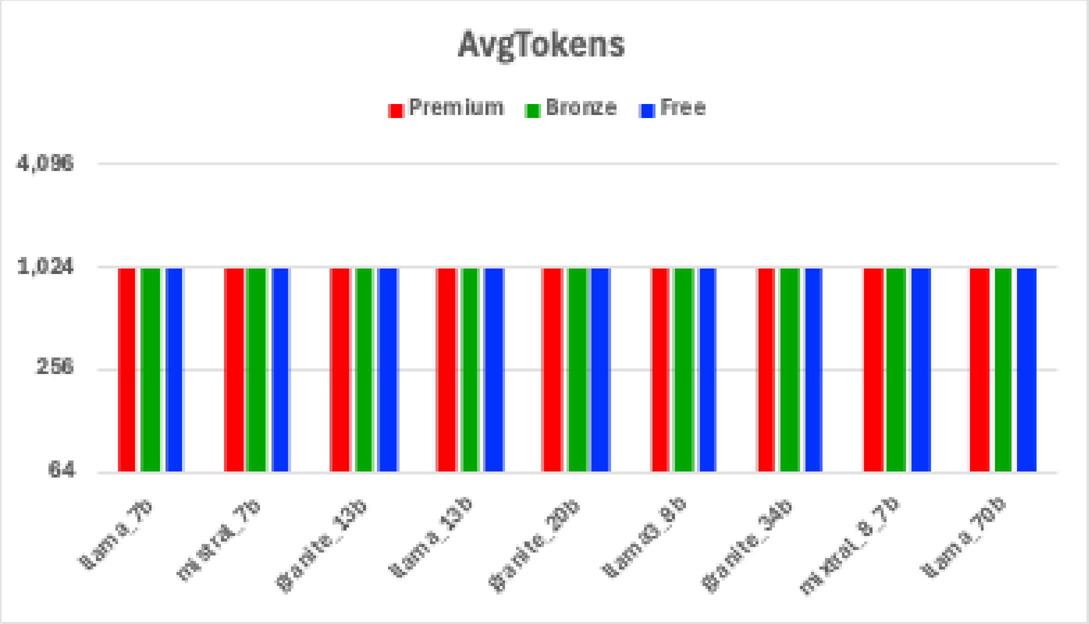
Models Specs



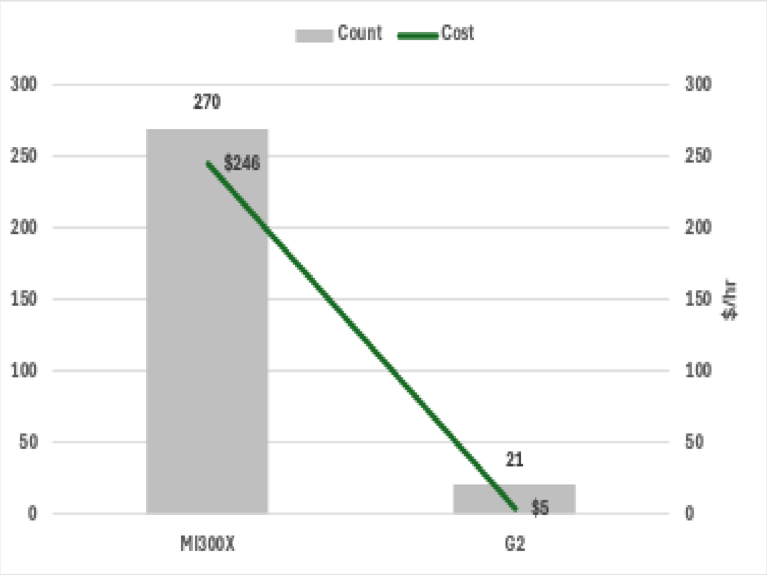
Unlimited accelerators

- capacity planning
- cloud deployment
- separable optimization

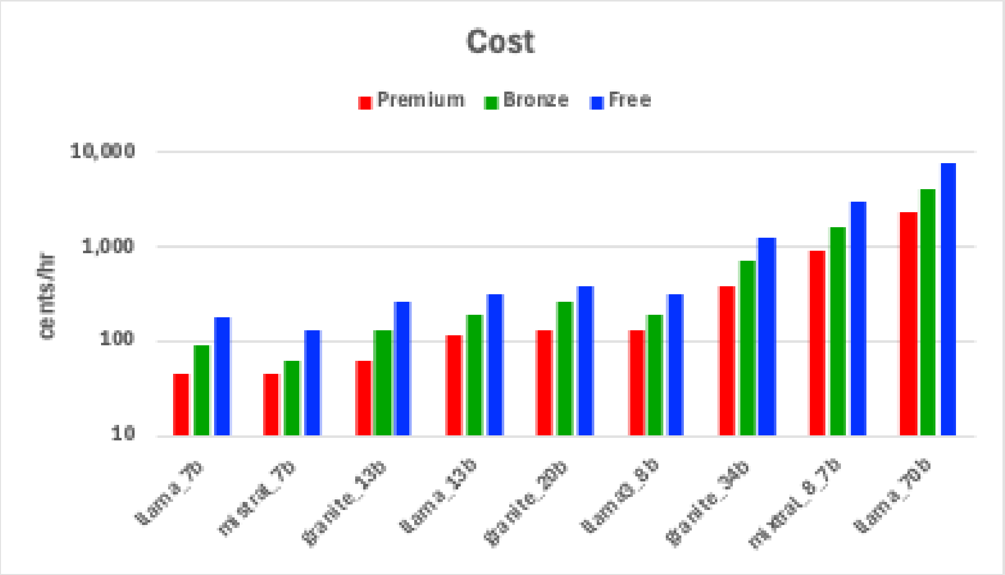


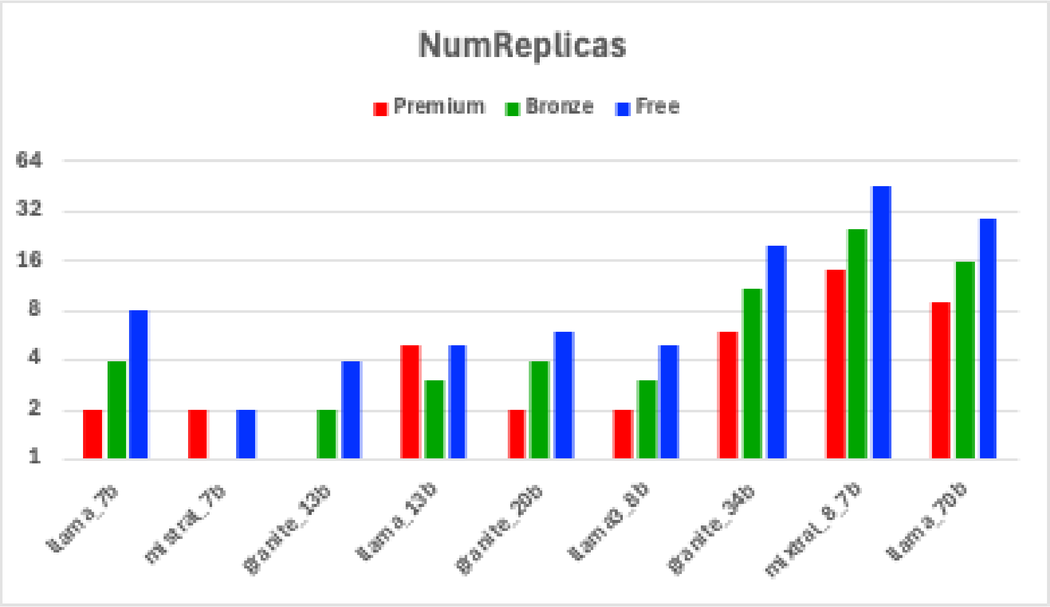


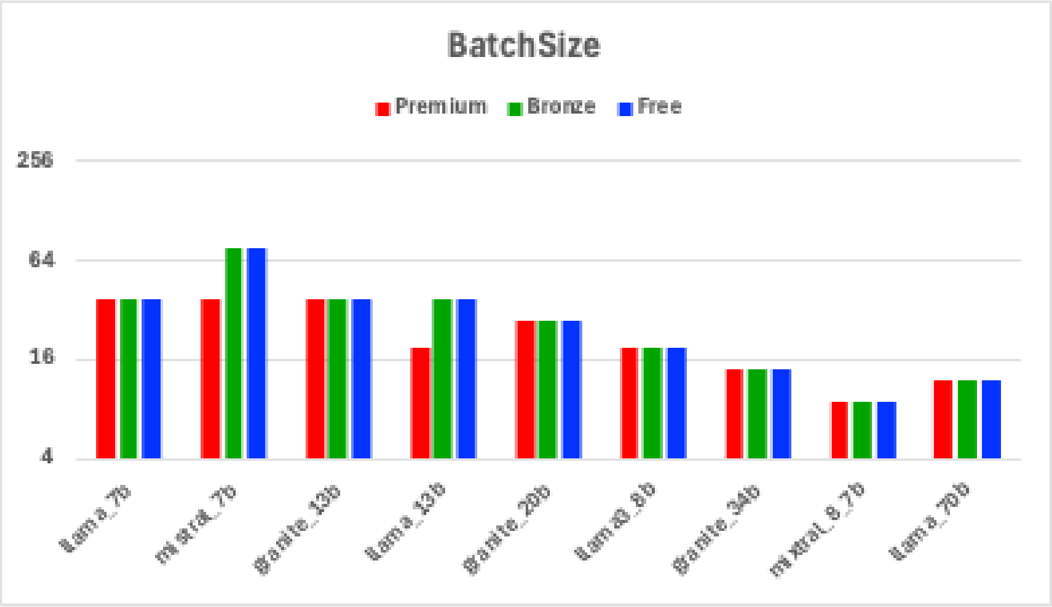
Accelerator			
	Premium	**Bronze**	**Free**
llama_7b	G2	G2	G2
mistral_7b	G2	MI300X	MI300X
granite_13b	MI300X	MI300X	MI300X
llama_13b	G2	MI300X	MI300X
granite_20b	MI300X	MI300X	MI300X
llama3_8b	MI300X	MI300X	MI300X
granite_34b	MI300X	MI300X	MI300X
mixtral_8_7b	MI300X	MI300X	MI300X
llama_70b	2xMI300X	2xMI300X	2xMI300X

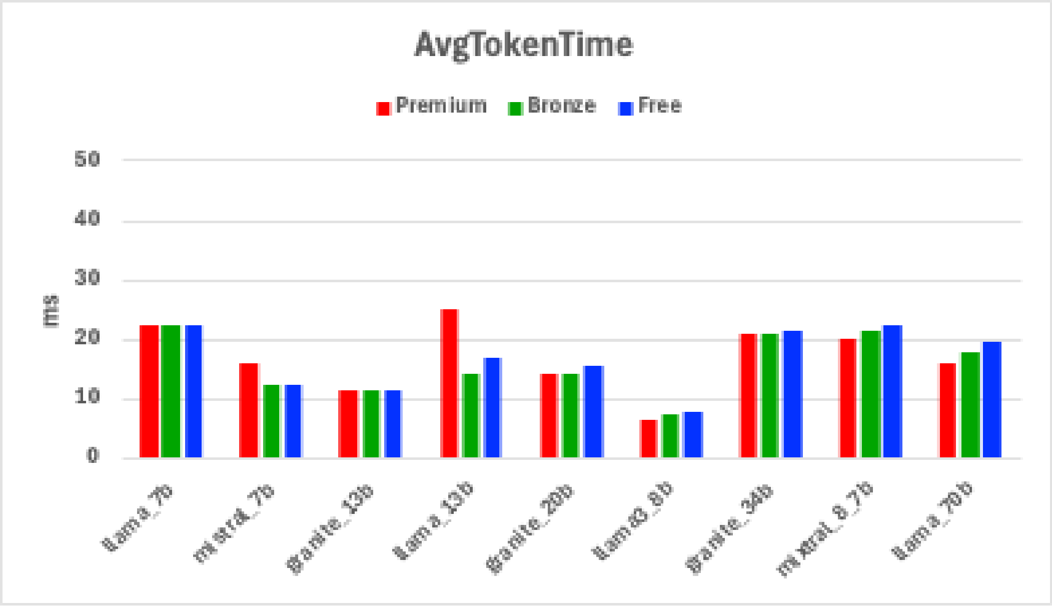


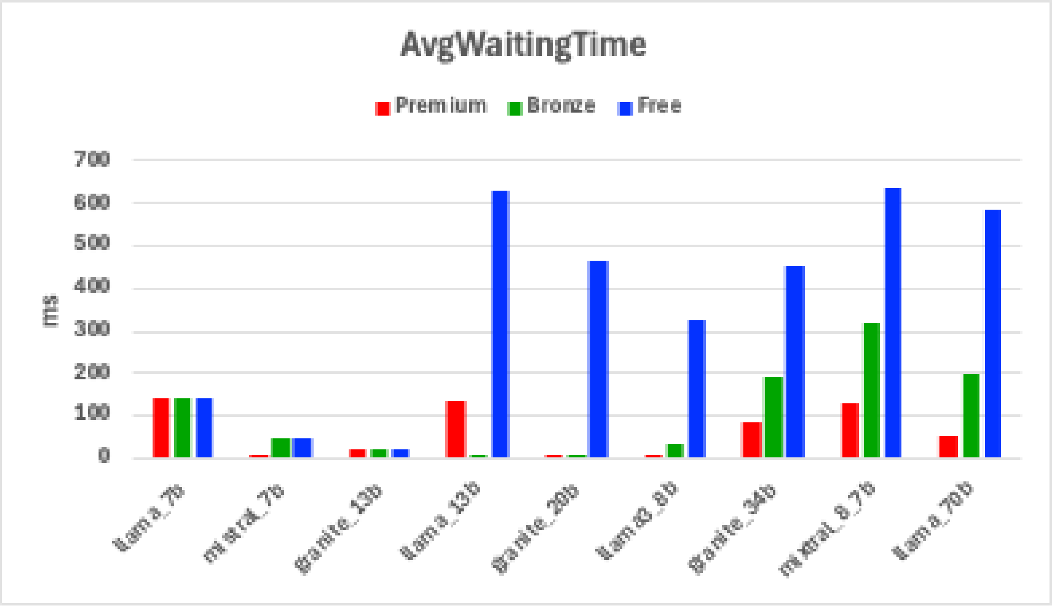
TotalCost
25,053.00




NumReplicas
Premium
Bronze
Free
64
32
16
8
4
2
1
llama_7b
mistral_7b
granite_13b
llama_13b
granite_20b
llama3_8b
granite_34b
mixtral_8_7b
llama_70b

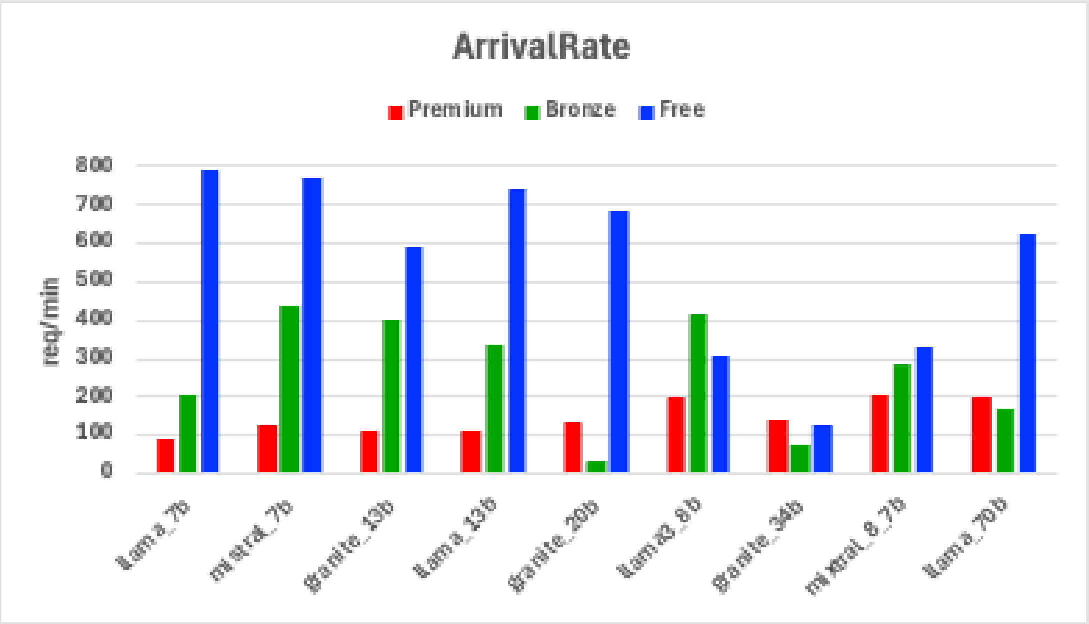

BatchSize
Premium
Bronze
Free
256
64
16
4
llama_7b
mistral_7b
granite_13b
llama_13b
granite_20b
llama3_8b
granite_34b
mixtral_8_7b
llama_70b

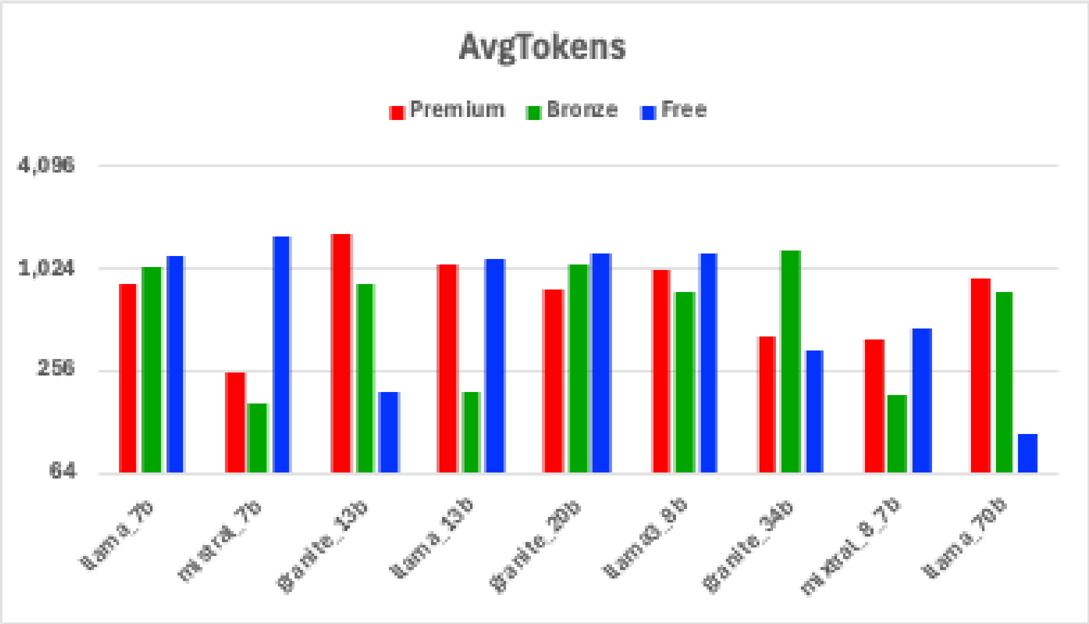

AvgTokenTime
Premium
Bronze
Free
ms
50
40
30
20
10
0
llama_7b
mistral_7b
granite_13b
llama_13b
granite_20b
llama3_8b
granite_34b
mixtral_8_7b
llama_70b


AvgWaitingTime
Premium
Bronze
Free
ms
700
600
500
400
300
200
100
0
llama_7b
mistral_7b
granite_13b
llama_13b
granite_20b
llama3_8b
granite_34b
mixtral_8_7b
llama_70b

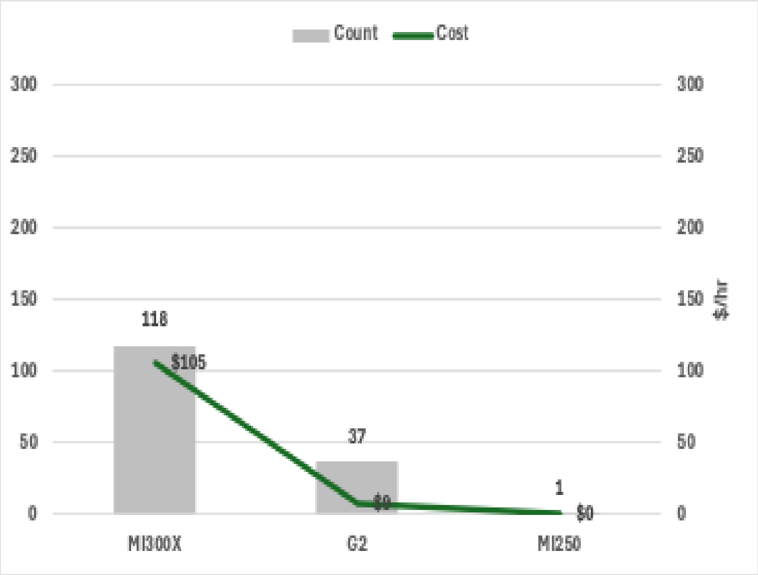
Unlimited accelerators - Dynamic

- change in request rates
- change in request lengths
- change/scale accelerators
- minimize change in accelerators and cost

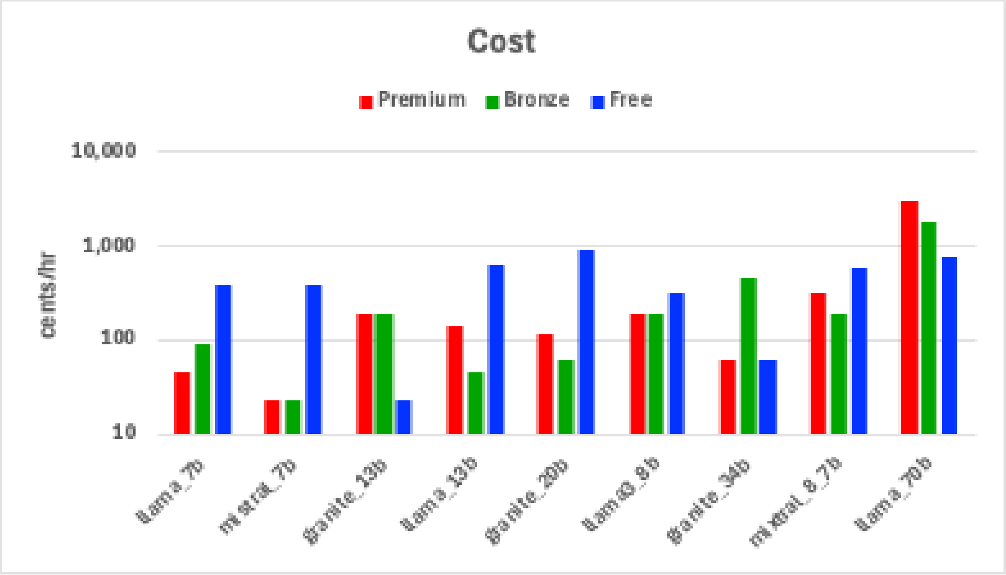


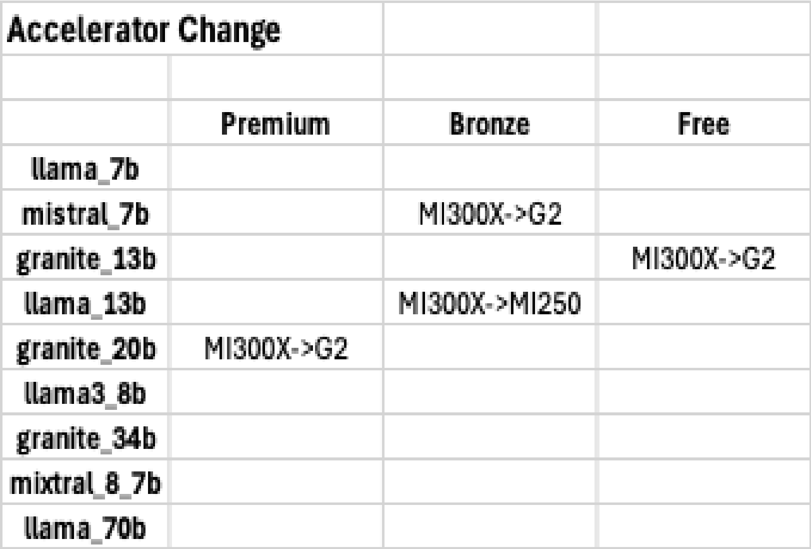


Accelerator Change			
	Premium	**Bronze**	**Free**
llama_7b			
mistral_7b		MI300X->G2	
granite_13b			MI300X->G2
llama_13b		MI300X->MI250	
granite_20b	MI300X->G2		
llama3_8b			
granite_34b			
mixtral_8_7b			
llama_70b			

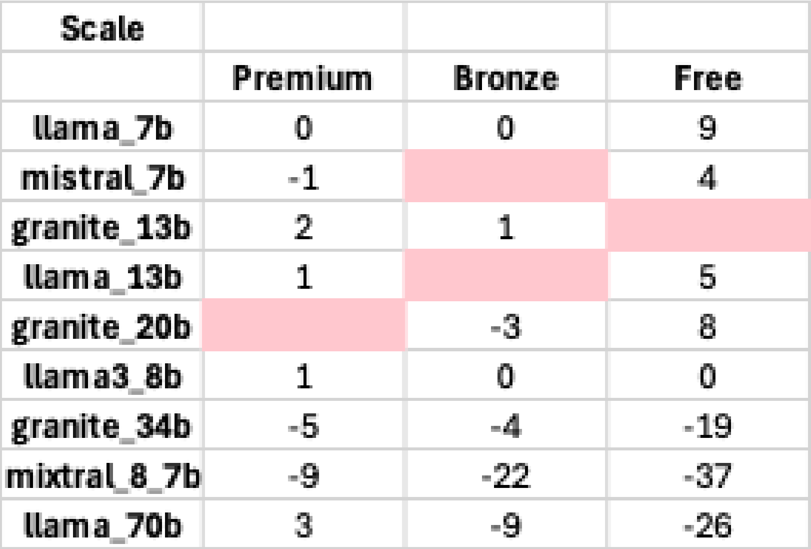


TotalCost
11,427.00

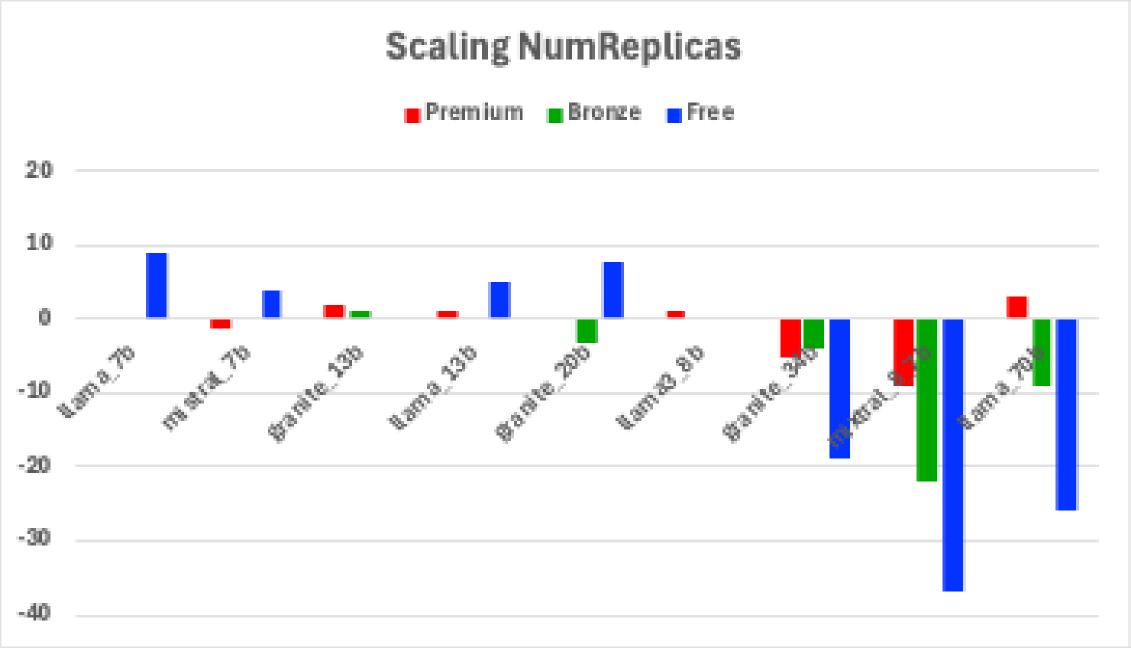


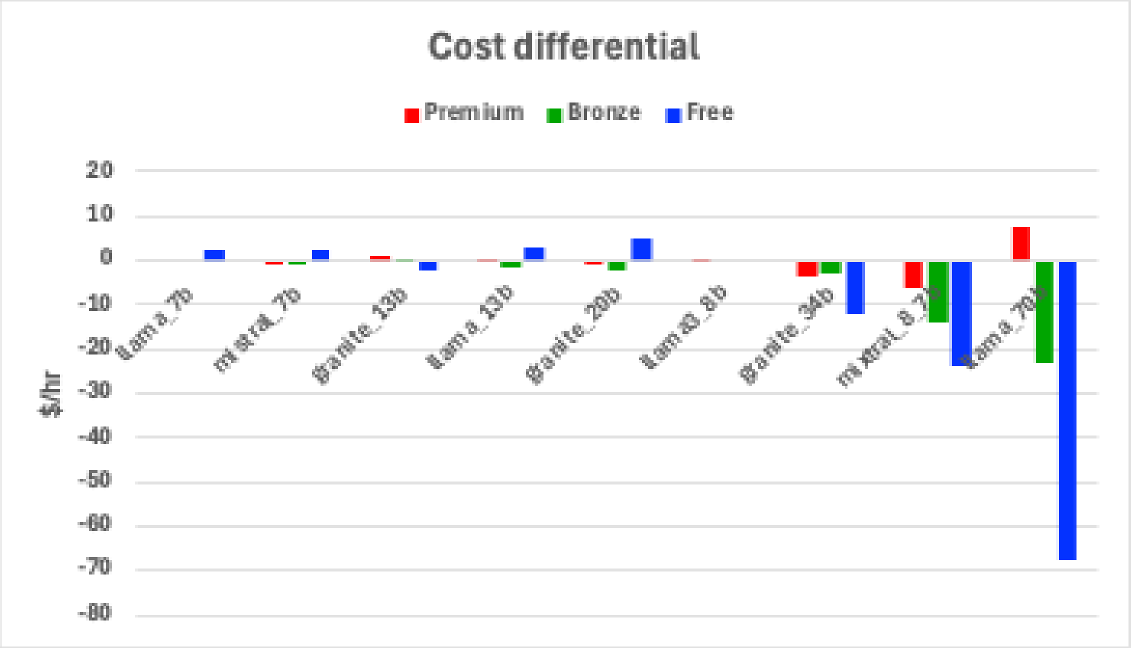


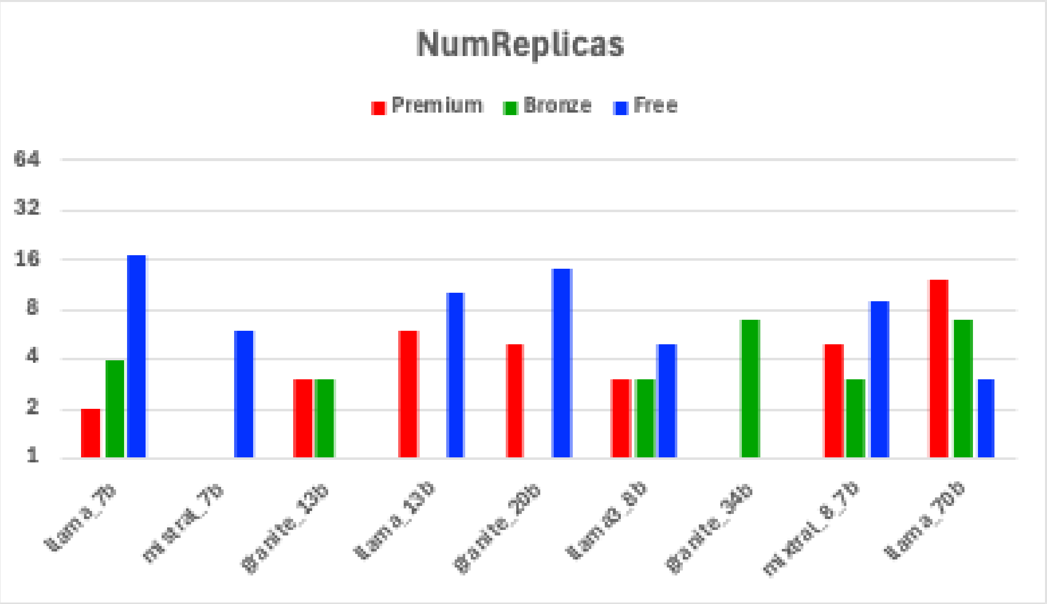
Accelerator Change			
	Premium	Bronze	Free
llama_7b			
mistral_7b		MI300X->G2	
granite_13b			MI300X->G2
llama_13b		MI300X->MI250	
granite_20b	MI300X->G2		
llama3_8b			
granite_34b			
mixtral_8_7b			
llama_70b			

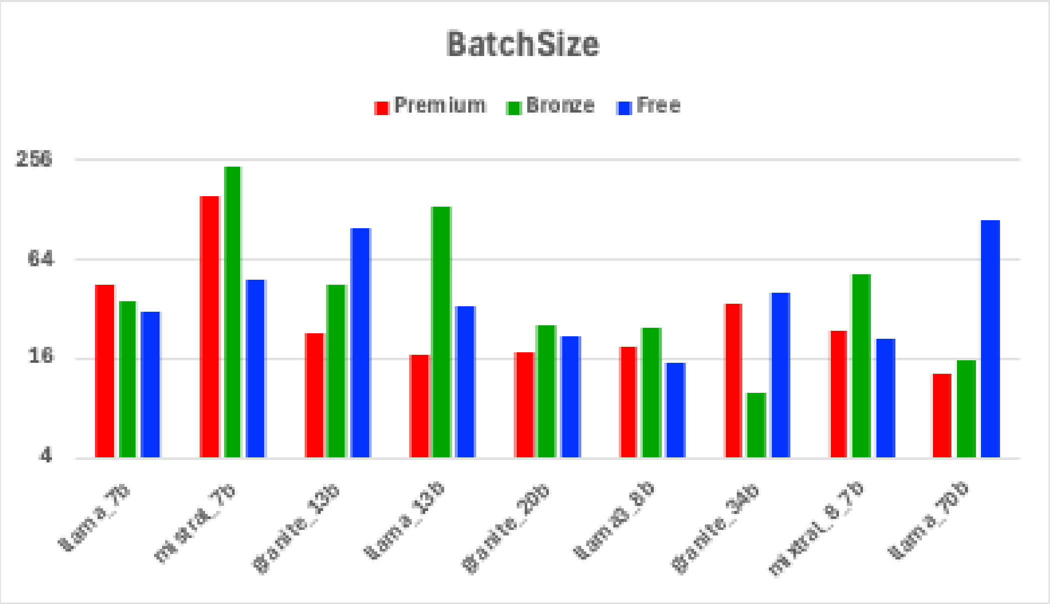


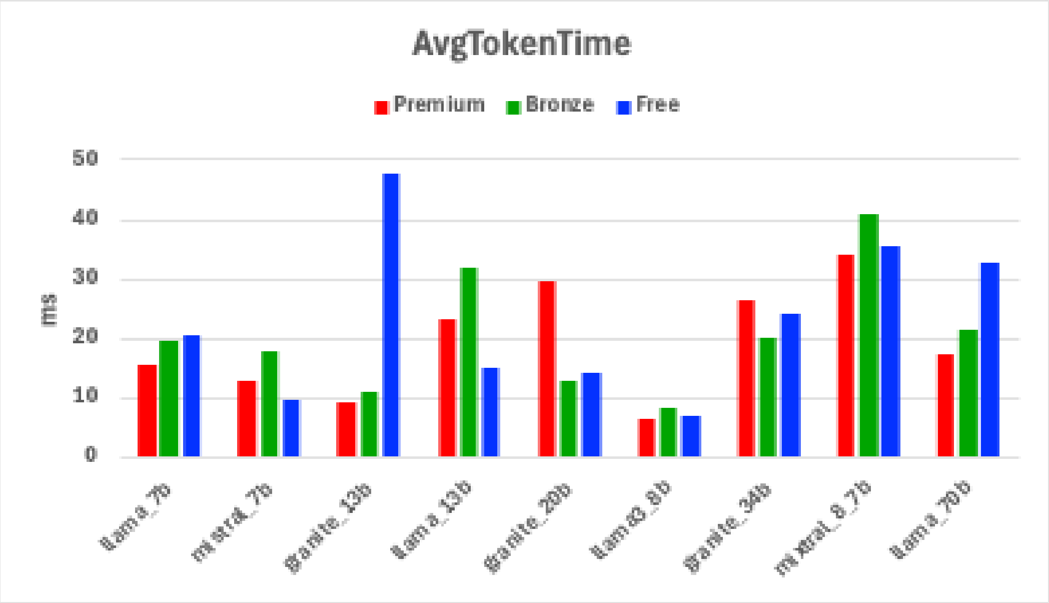
Scale			
	Premium	Bronze	Free
llama_7b	0	0	9
mistral_7b	-1		4
granite_13b	2	1	
llama_13b	1		5
granite_20b		-3	8
llama3_8b	1	0	0
granite_34b	-5	-4	-19
mixtral_8_7b	-9	-22	-37
llama_70b	3	-9	-26

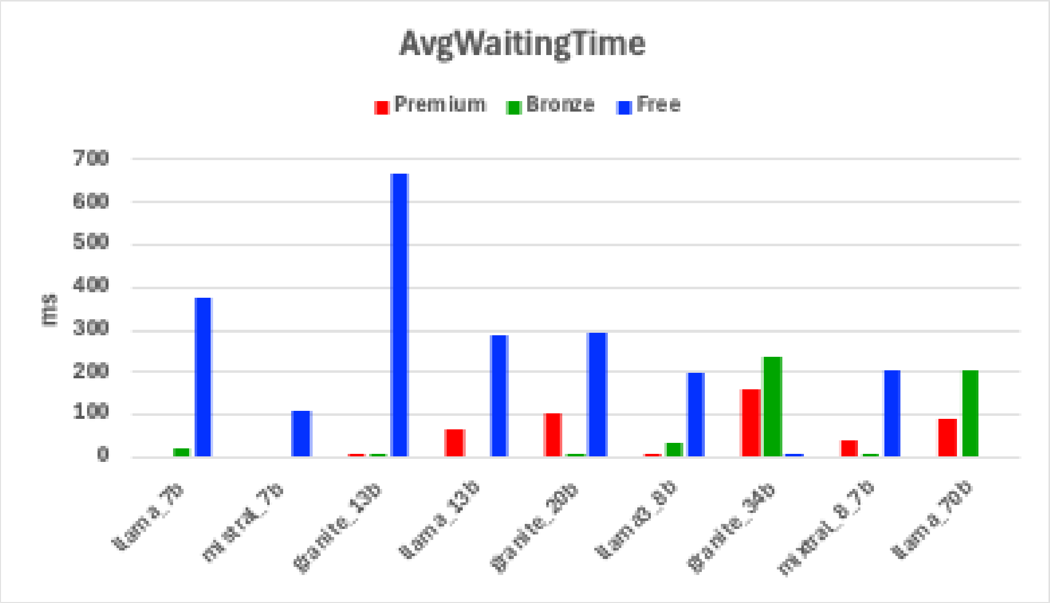


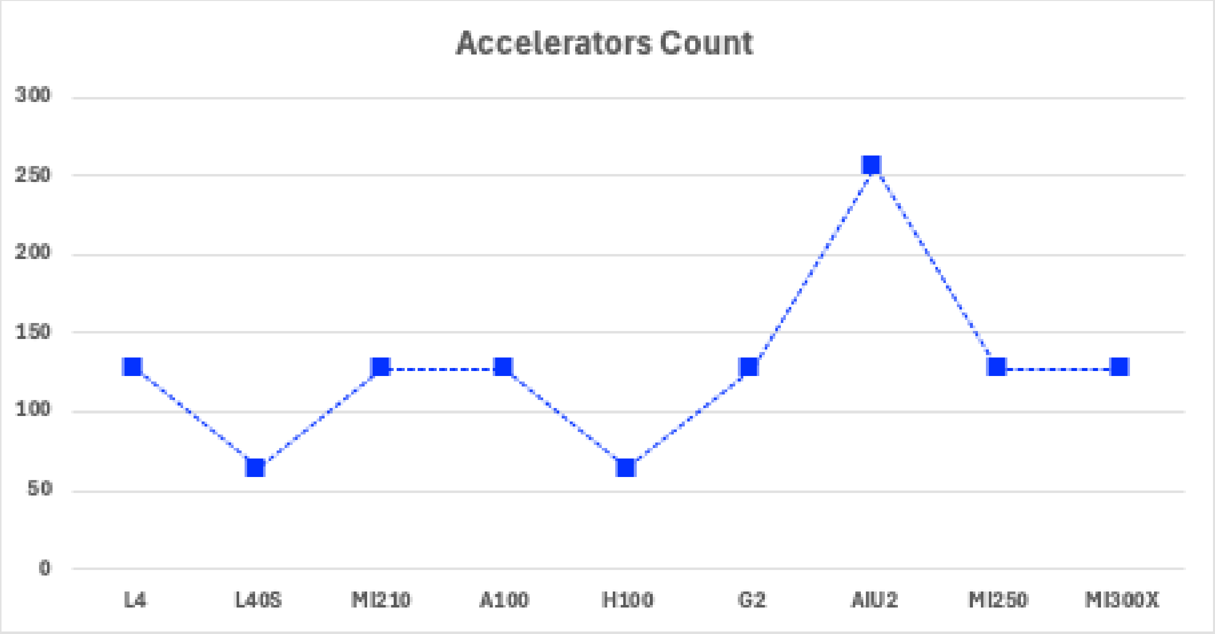



NumReplicas
Premium
Bronze
Free
64
32
16
8
4
2
1
llama_7b
mistral_7b
granite_13b
llama_13b
granite_20b
llama3_8b
granite_34b
mixtral_8_7b
llama_70b


BatchSize
Premium
Bronze
Free
256
64
16
4
llama_7b
mistral_7b
granite_13b
llama_13b
granite_20b
llama3_8b
granite_34b
mixtral_8_7b
llama_70b

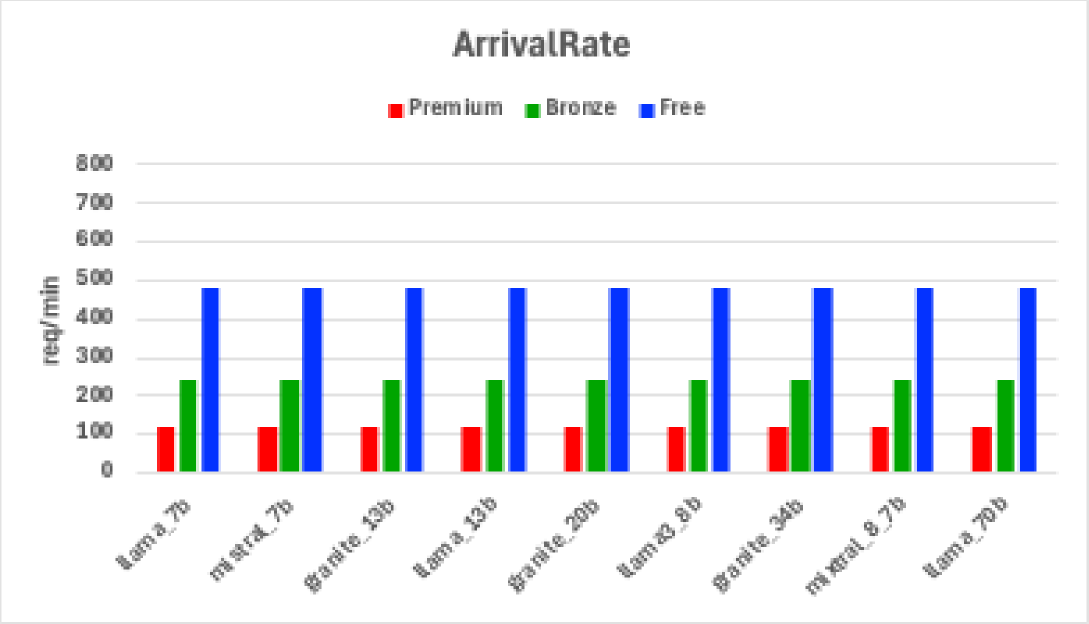

AvgTokenTime
Premium
Bronze
Free
ms
50
40
30
20
10
0
llama_7b
mistral_7b
granite_13b
llama_13b
granite_20b
llama3_8b
granite_34b
mixtral_8_7b
llama_70b

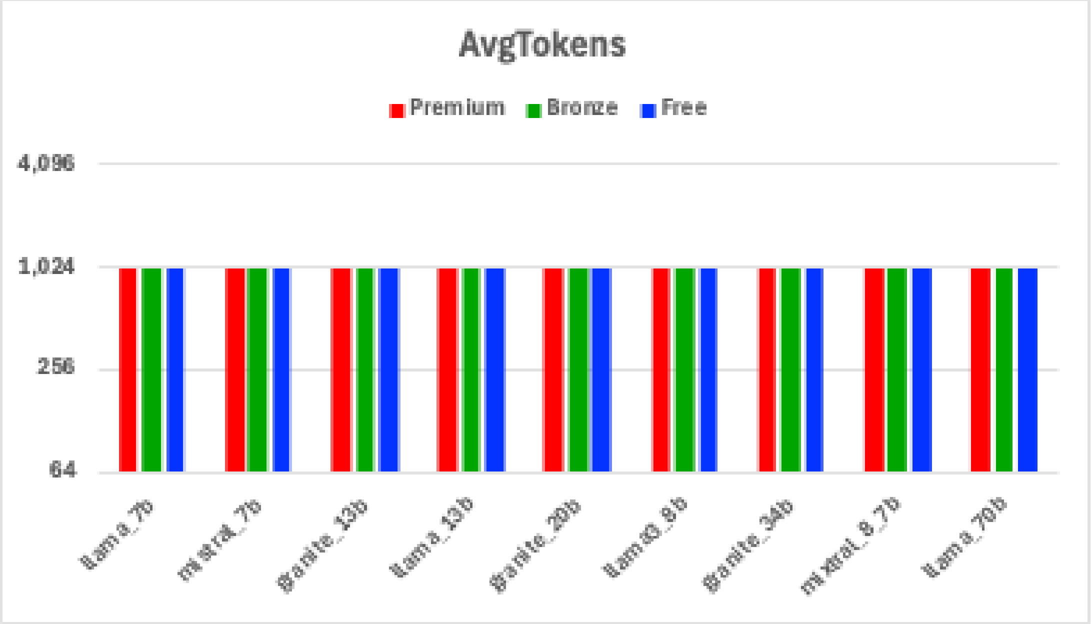

AvgWaitingTime
Premium
Bronze
Free
ms
700
600
500
400
300
200
100
0
llama_7b
mistral_7b
granite_13b
llama_13b
granite_20b
llama3_8b
granite_34b
mixtral_8_7b
llama_70b

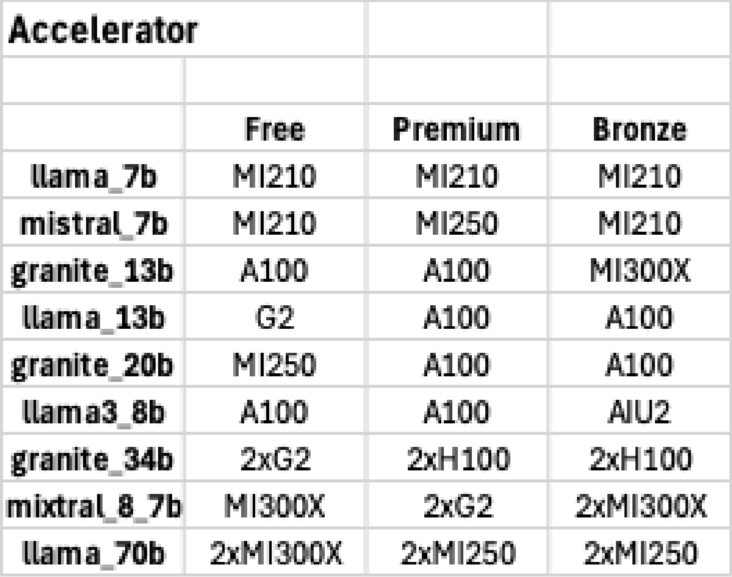


Limited accelerators

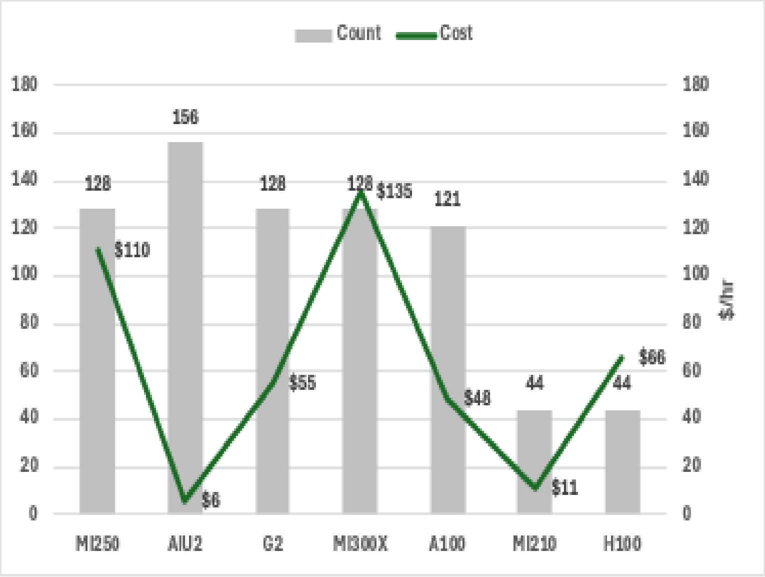
- cluster deployment
- greedy optimization



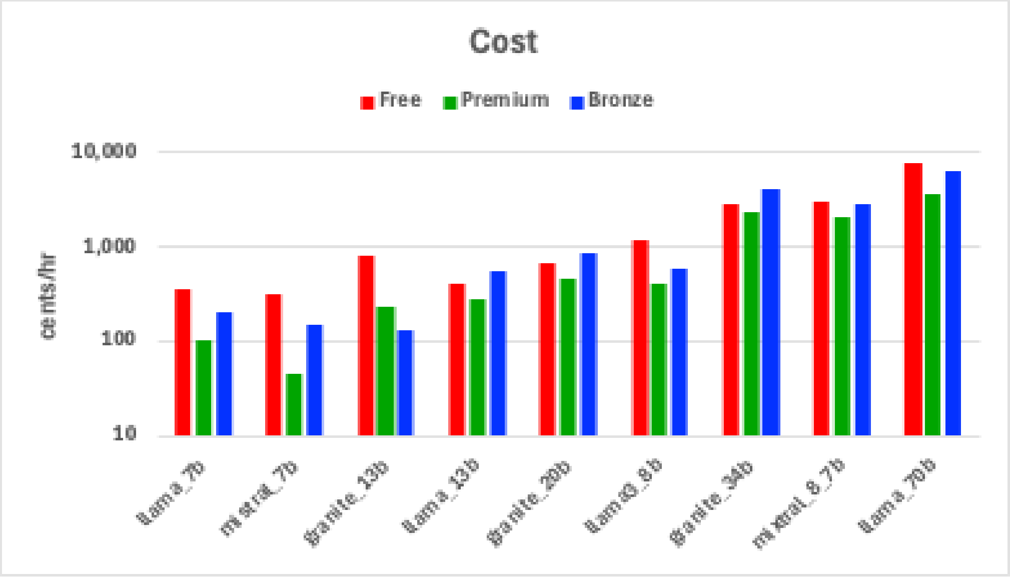


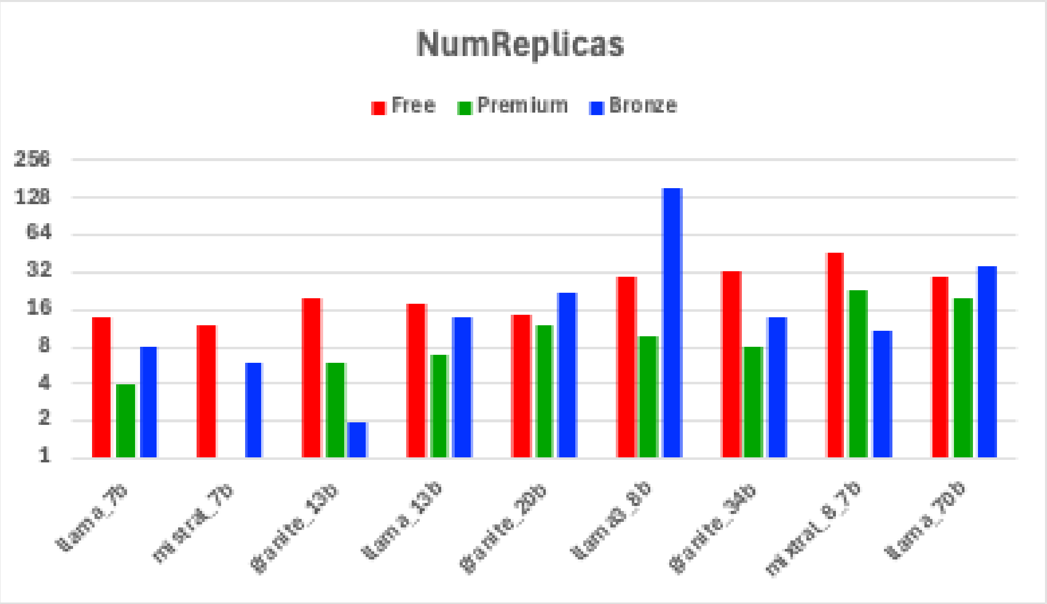


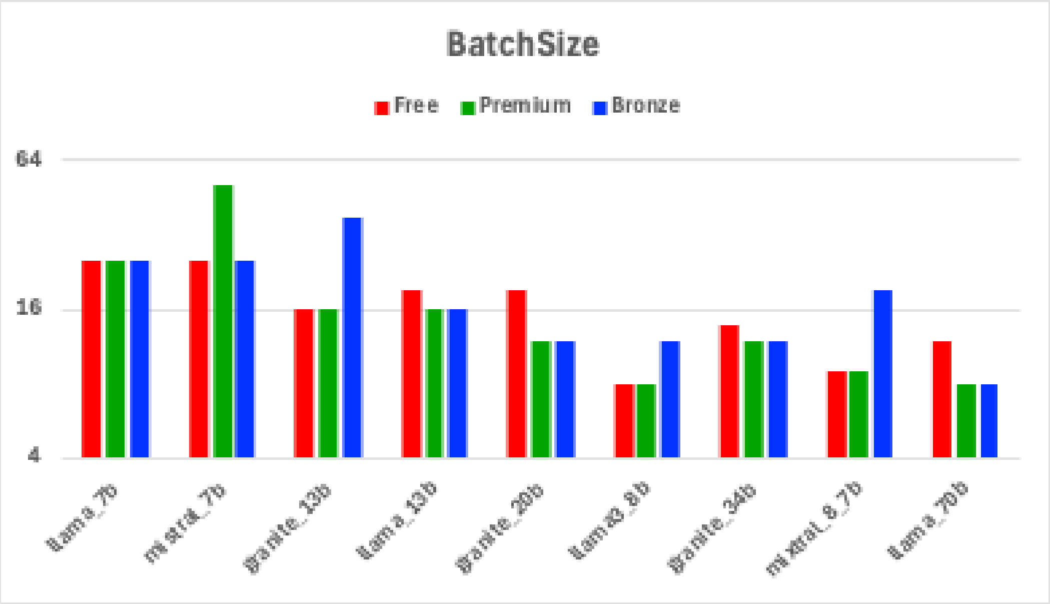
Accelerator			
	Free	**Premium**	**Bronze**
llama_7b	MI210	MI210	MI210
mistral_7b	MI210	MI250	MI210
granite_13b	A100	A100	MI300X
llama_13b	G2	A100	A100
granite_20b	MI250	A100	A100
llama3_8b	A100	A100	AIU2
granite_34b	2xG2	2xH100	2xH100
mixtral_8_7b	MI300X	2xG2	2xMI300X
llama_70b	2xMI300X	2xMI250	2xMI250

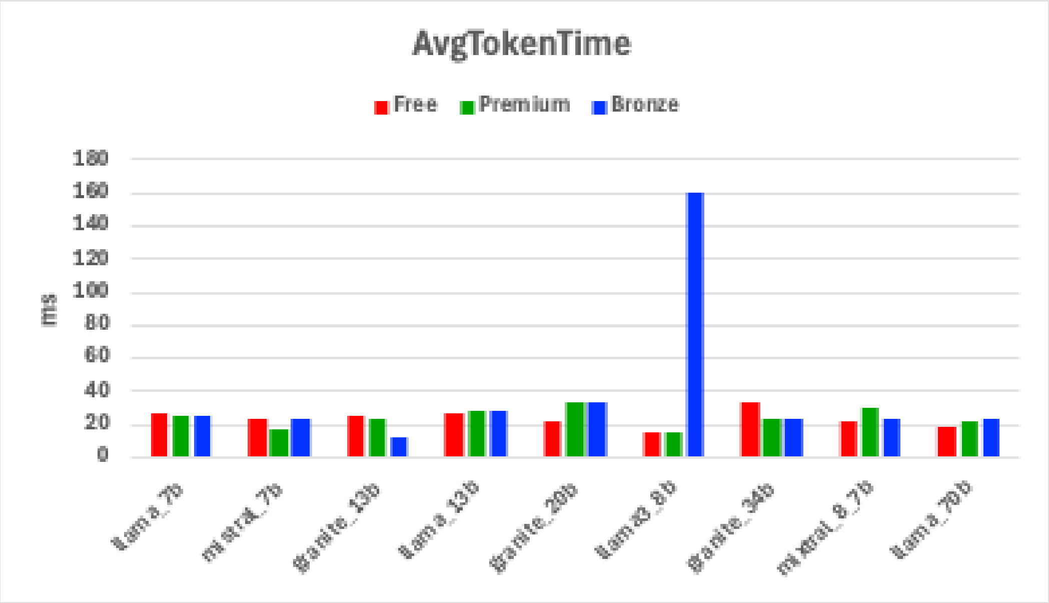


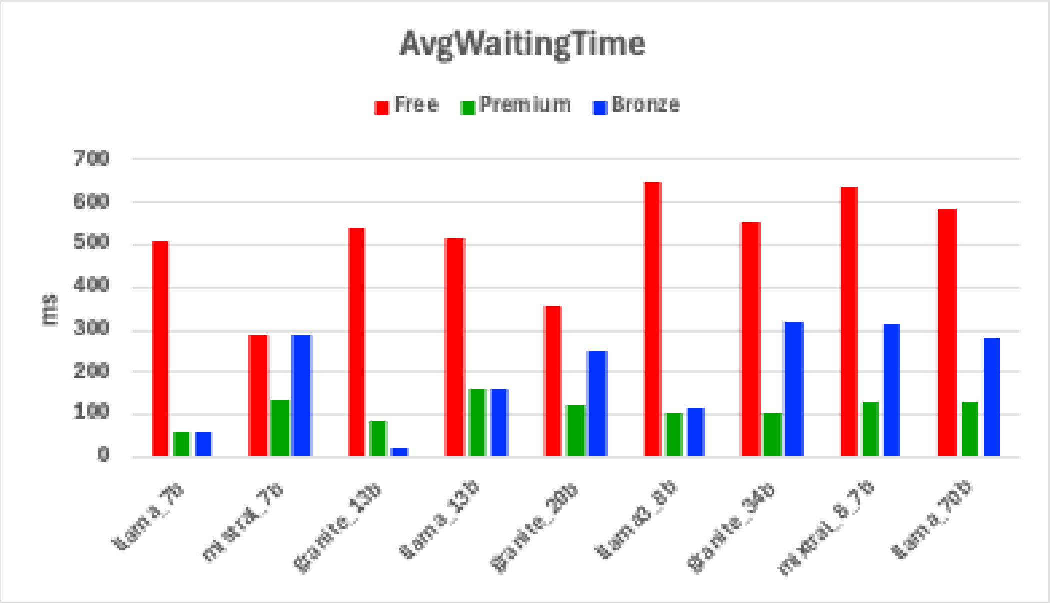
TotalCost
43,203.00

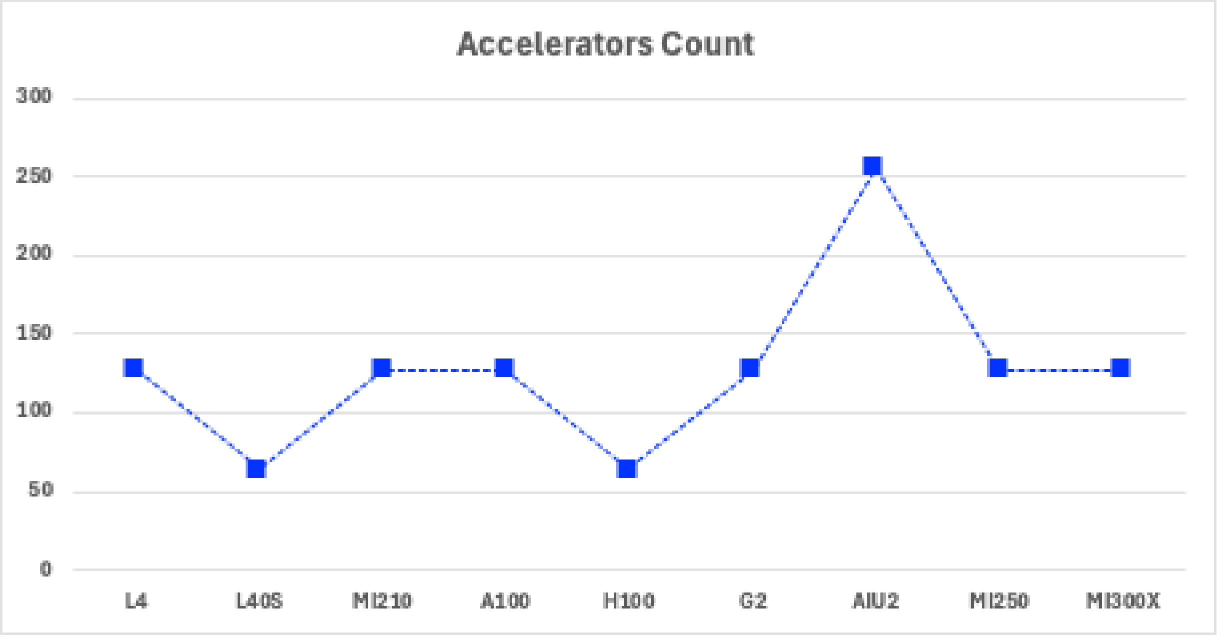



NumReplicas
Free
Premium
Bronze
256
128
64
32
16
8
4
2
1
llama_7b
mistral_7b
granite_13b
llama_13b
granite_20b
llama3_8b
granite_34b
mixtral_8_7b
llama_70b


BatchSize
Free
Premium
Bronze
64
16
4
llama_7b
mistral_7b
granite_13b
llama_13b
granite_20b
llama3_8b
granite_34b
mixtral_8_7b
llama_70b

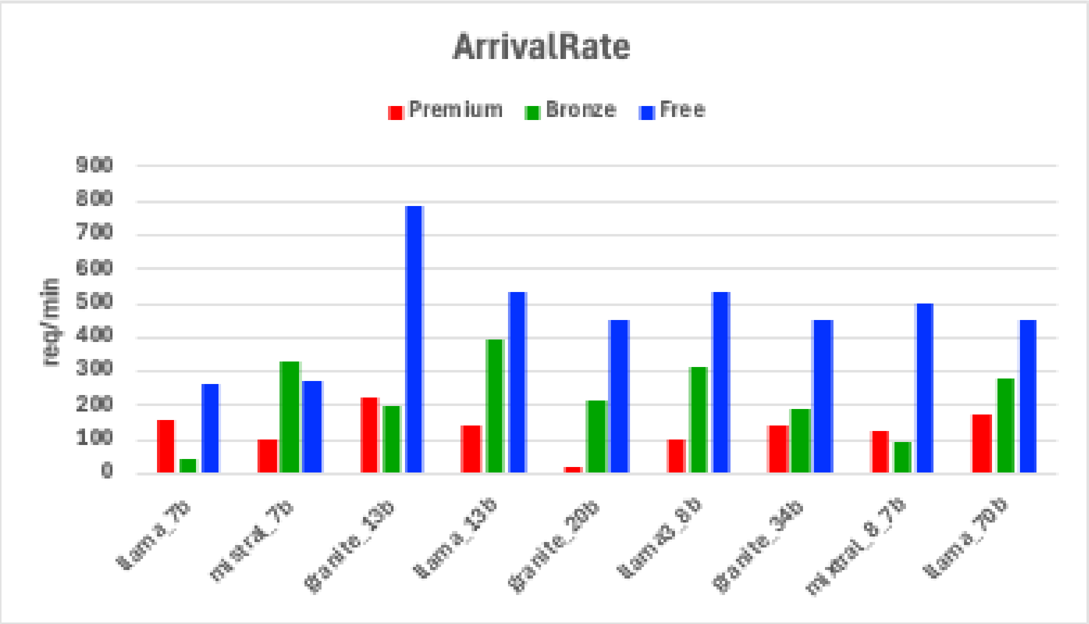

AvgTokenTime
Free
Premium
Bronze
ms
180
160
140
120
100
80
60
40
20
0
llama_7b
mistral_7b
granite_13b
llama_13b
granite_20b
llama3_8b
granite_34b
mixtral_8_7b
llama_70b

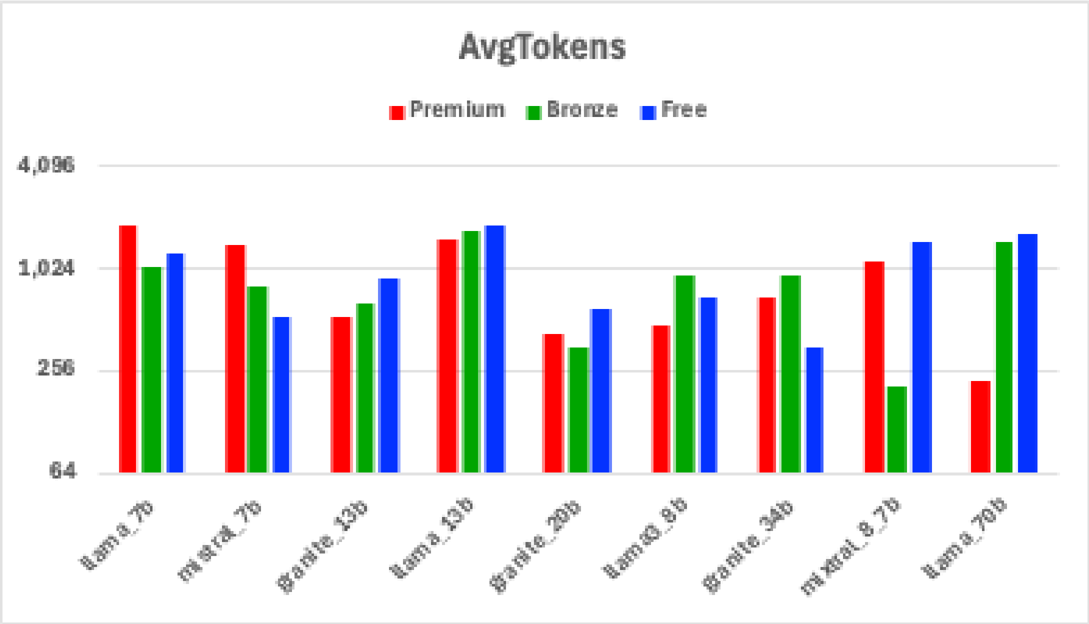

AvgWaitingTime
Free
Premium
Bronze
ms
700
600
500
400
300
200
100
0
llama_7b
mistral_7b
granite_13b
llama_13b
granite_20b
llama3_8b
granite_34b
mixtral_8_7b
llama_70b



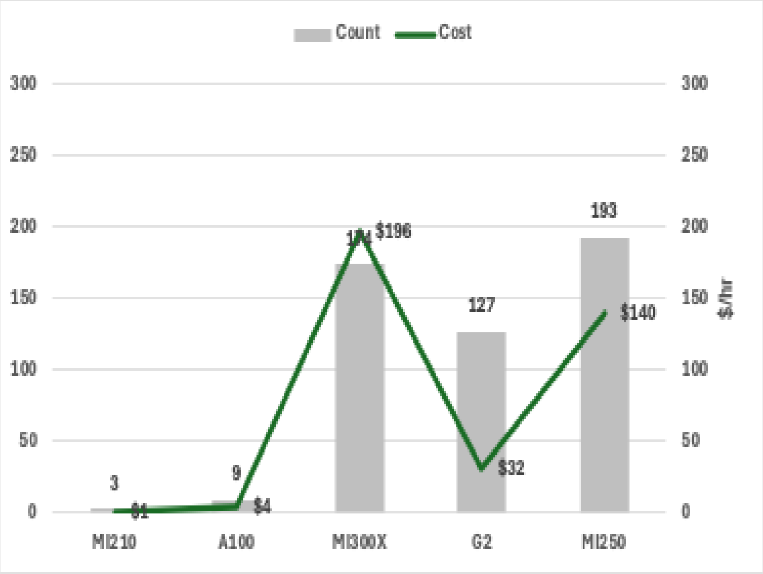
Limited accelerators - Dynamic

- change in request rates
- change in request lengths
- change/scale accelerators
- minimize change in accelerators and cost

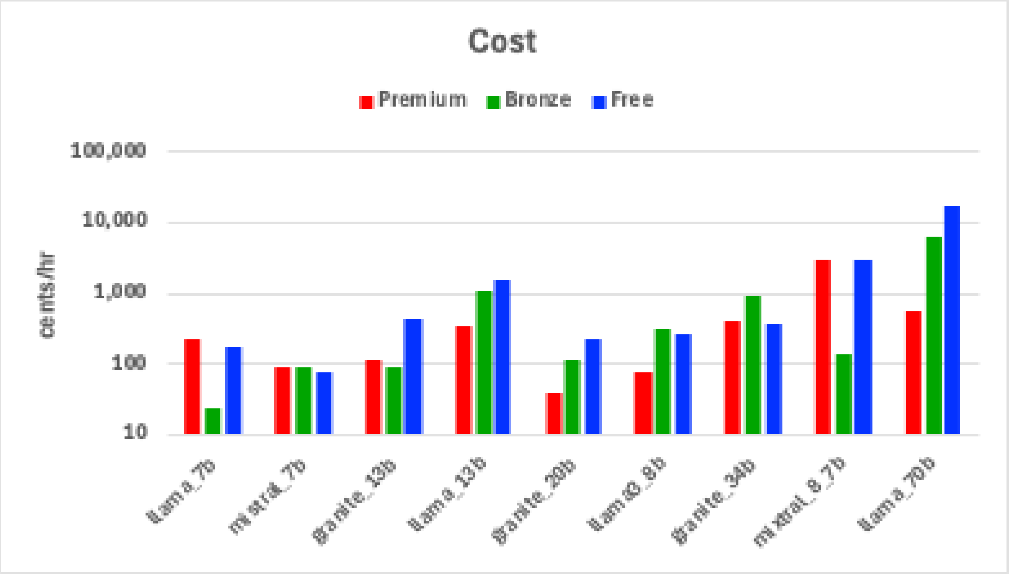


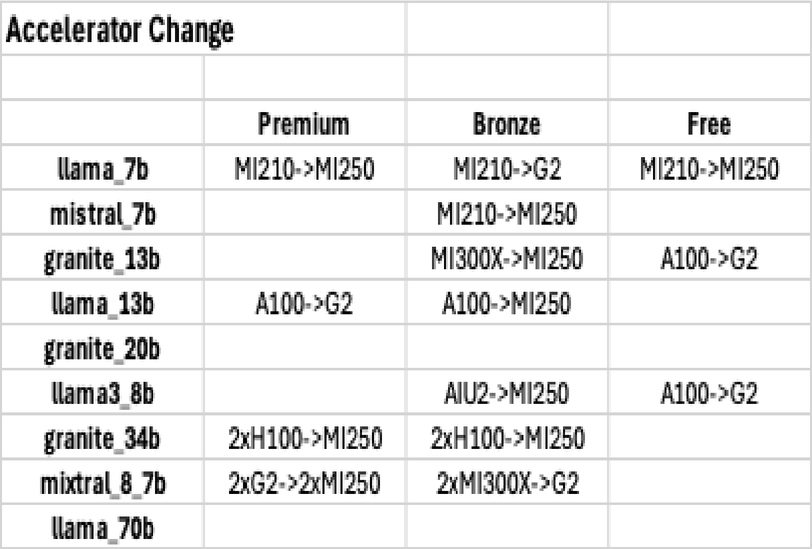


Accelerator Change			
	Premium	Bronze	Free
llama_7b	MI210->MI250	MI210->G2	MI210->MI250
mistral_7b		MI210->MI250	
granite_13b		MI300X->MI250	A100->G2
llama_13b	A100->G2	A100->MI250	
granite_20b			
llama3_8b		AIU2->MI250	A100->G2
granite_34b	2xH100->MI250	2xH100->MI250	
mixtral_8_7b	2xG2->2xMI250	2xMI300X->G2	
llama_70b			

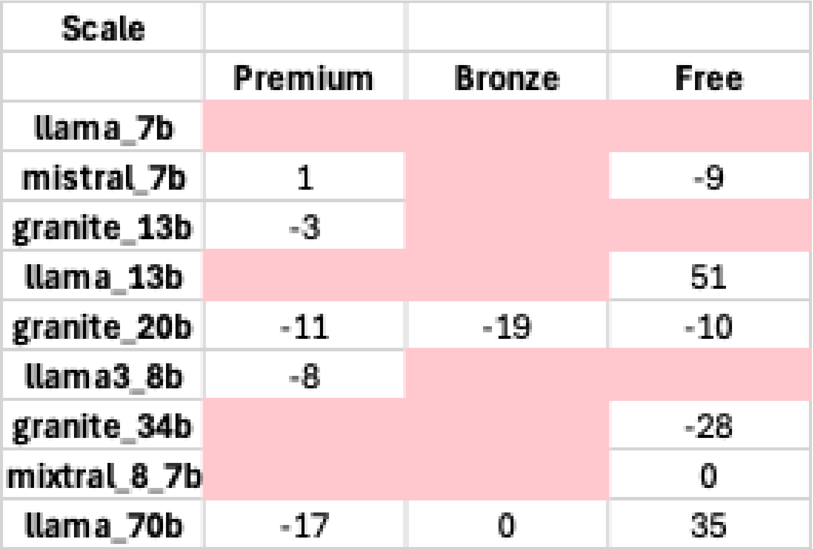


TotalCost
37,272.00

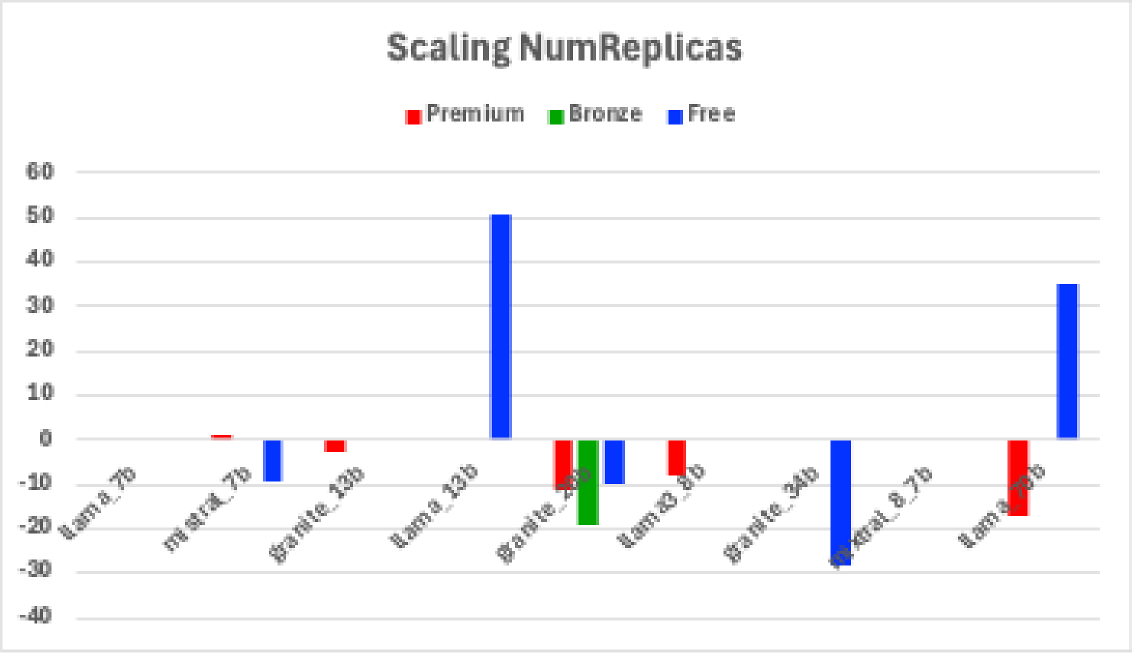


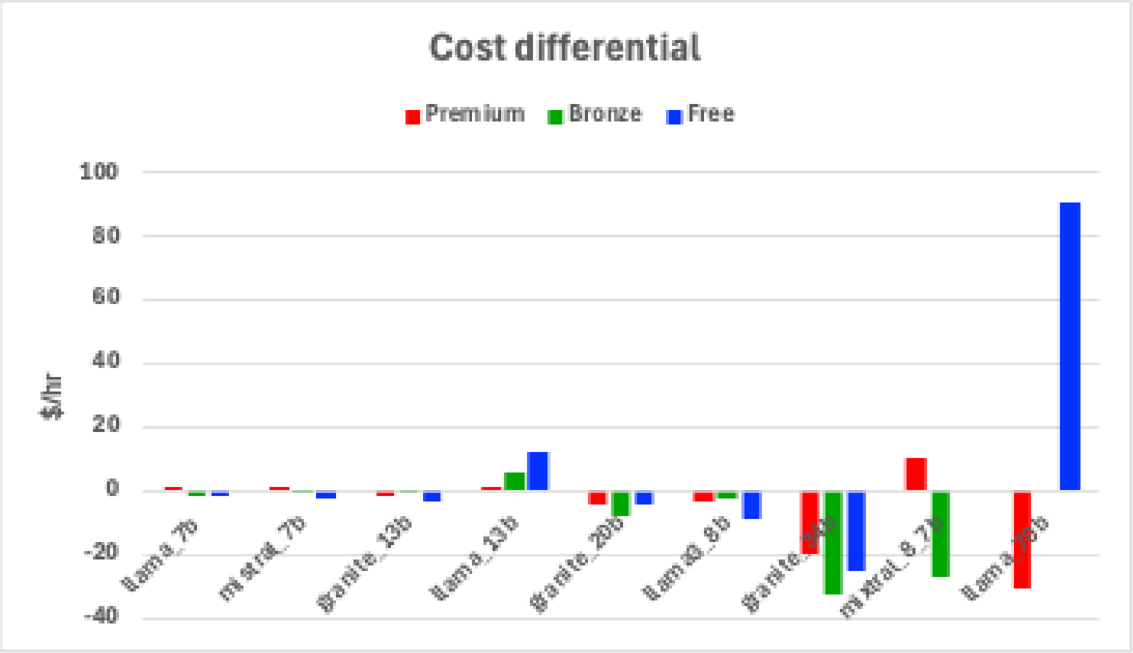


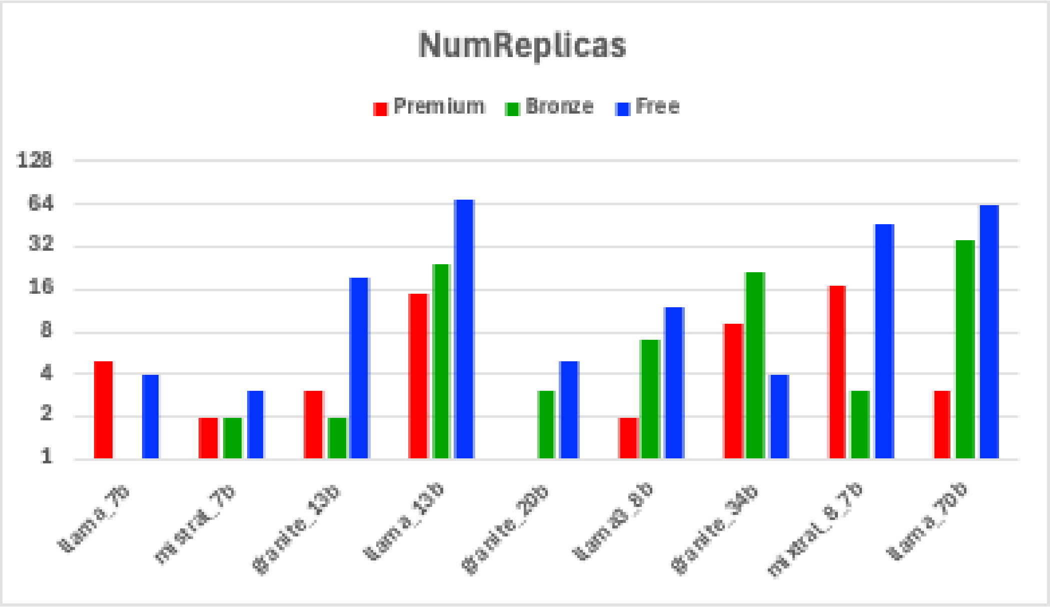
Accelerator Change			
	Premium	Bronze	Free
llama_7b	MI210->MI250	MI210->G2	MI210->MI250
mistral_7b		MI210->MI250	
granite_13b		MI300X->MI250	A100->G2
llama_13b	A100->G2	A100->MI250	
granite_20b			
llama3_8b		AIU2->MI250	A100->G2
granite_34b	2xH100->MI250	2xH100->MI250	
mixtral_8_7b	2xG2->2xMI250	2xMI300X->G2	
llama_70b			

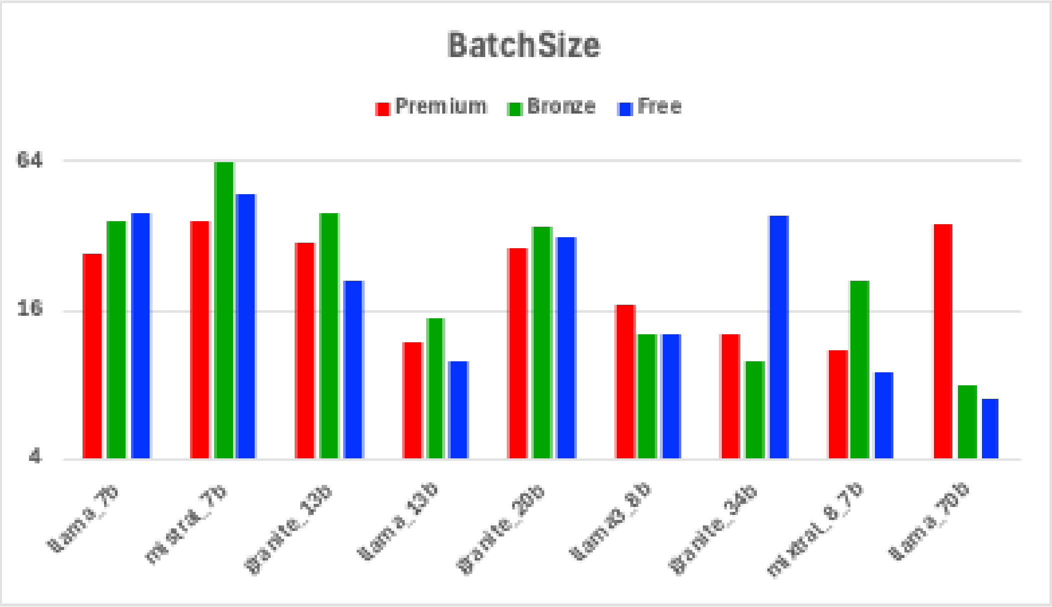


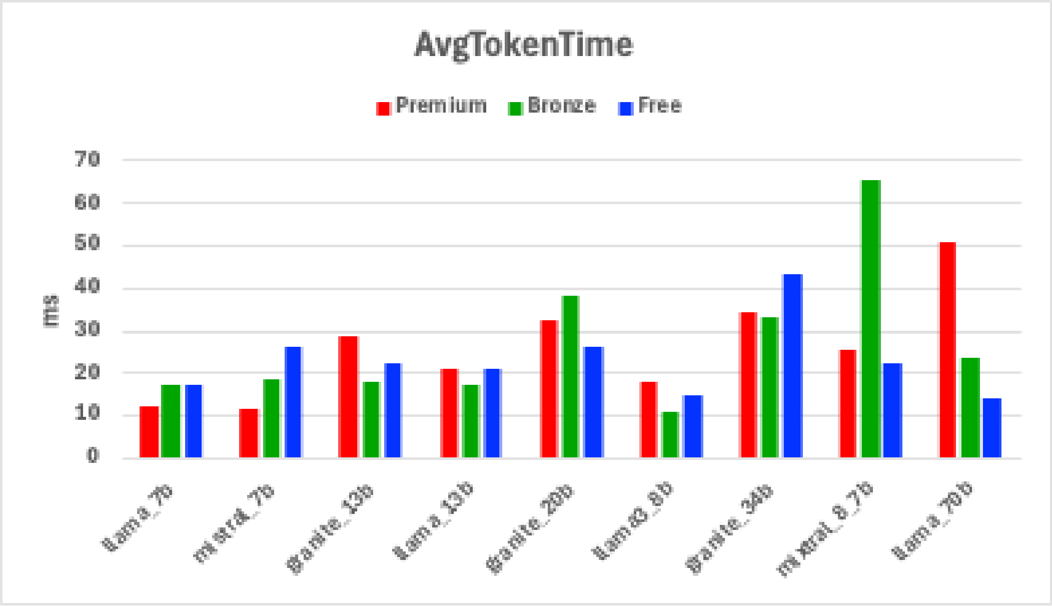
Scale			
	Premium	Bronze	Free
llama_7b			
mistral_7b	1		-9
granite_13b	-3		
llama_13b			51
granite_20b	-11	-19	-10
llama3_8b	-8		
granite_34b			-28
mixtral_8_7b			0
llama_70b	-17	0	35

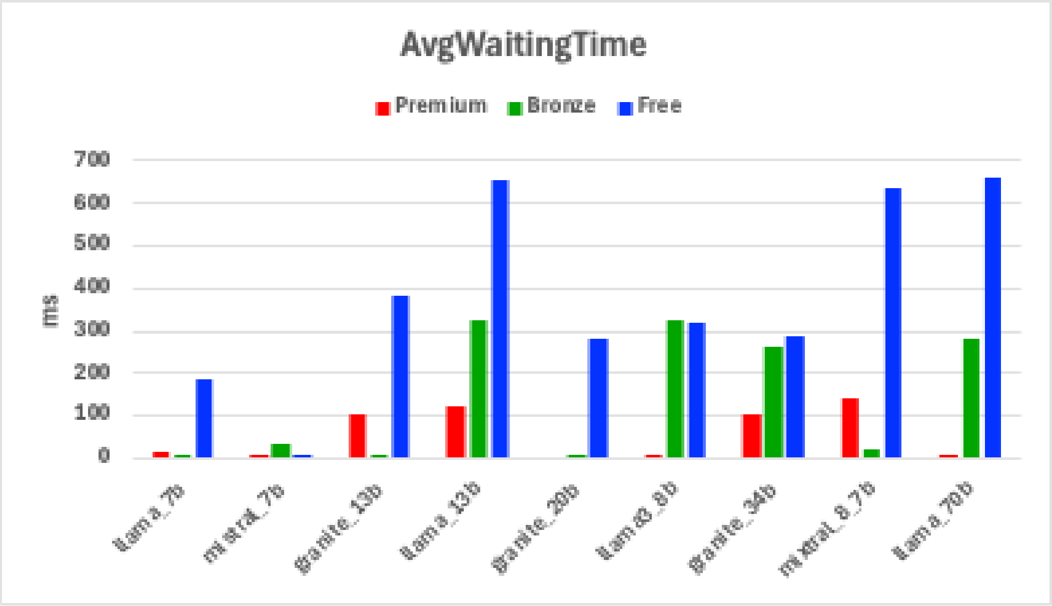





NumReplicas
Premium
Bronze
Free
128
64
32
16
8
4
2
1
llama_7b
mistral_7b
granite_13b
llama_13b
granite_20b
llama3_8b
granite_34b
mixtral_8_7b
llama_70b

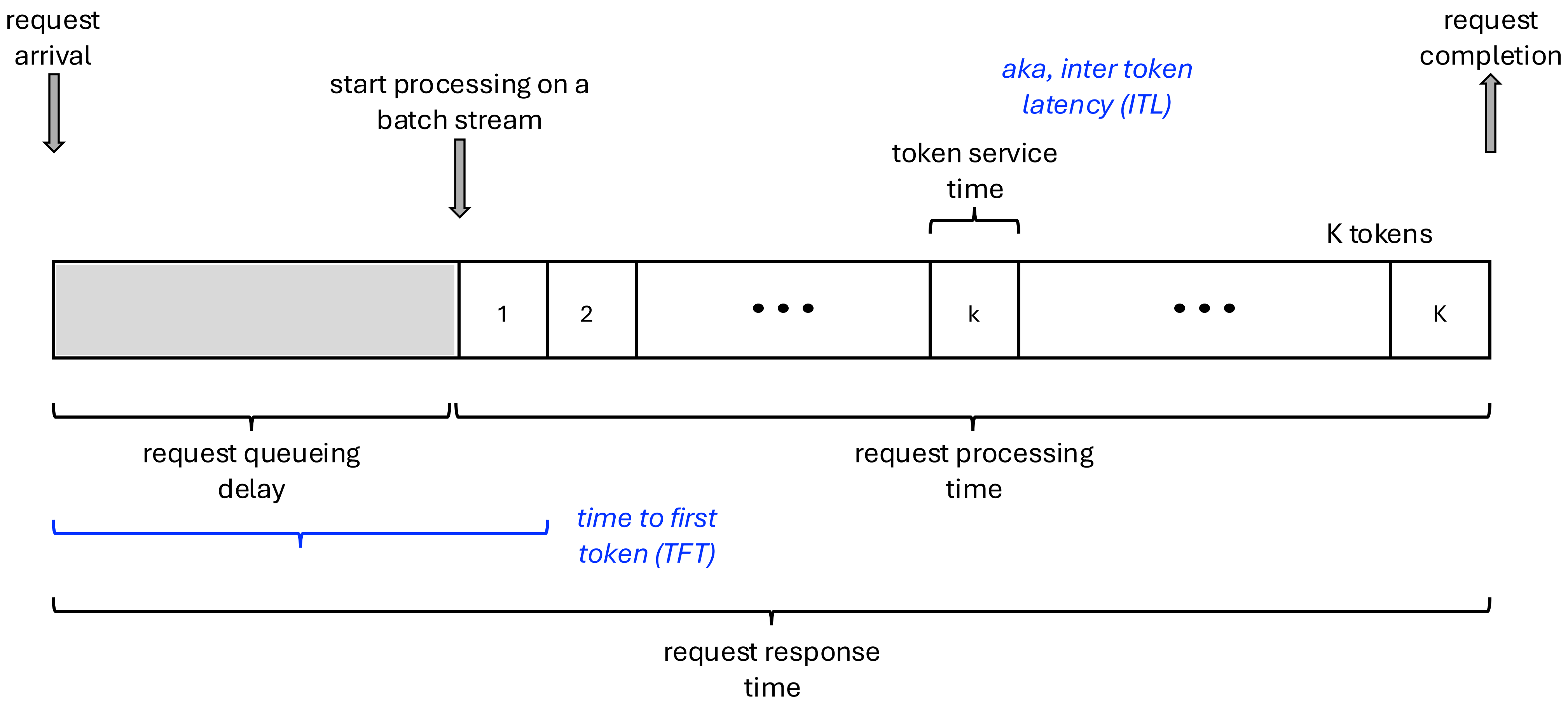

BatchSize
Premium
Bronze
Free
64
16
4
llama_7b
mistral_7b
granite_13b
llama_13b
granite_20b
llama3_8b
granite_34b
mixtral_8_7b
llama_70b


AvgTokenTime
Premium
Bronze
Free
ms
70
60
50
40
30
20
10
0
llama_7b
mistral_7b
granite_13b
llama_13b
granite_20b
llama3_8b
granite_34b
mixtral_8_7b
llama_70b


AvgWaitingTime
Premium
Bronze
Free
ms
700
600
500
400
300
200
100
0
llama_7b
mistral_7b
granite_13b
llama_13b
granite_20b
llama3_8b
granite_34b
mixtral_8_7b
llama_70b

Backup

Request timing & definitions



request arrival

start processing on a batch stream

aka, inter token latency (ITL)

token service time

request completion

K tokens

request queueing delay

request processing time

time to first token (TFT)

request response time

amortize delay over all tokens

$$token\ delay = \frac{request\ response\ time}{K}$$

$$token\ delay \cong ITL + \frac{TFT}{K}$$

Objectives

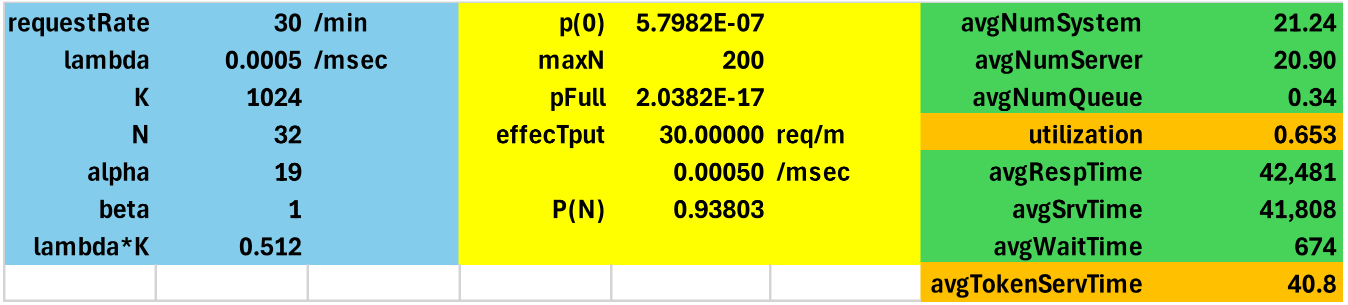
☑

- Optimize operational cost/performance/power
  - assignment of accelerator types
  - model replicas
  - model batch decision
  - meet SLOs
  - min cost and power
- Capacity planning and/or model placement & accelerator allocation

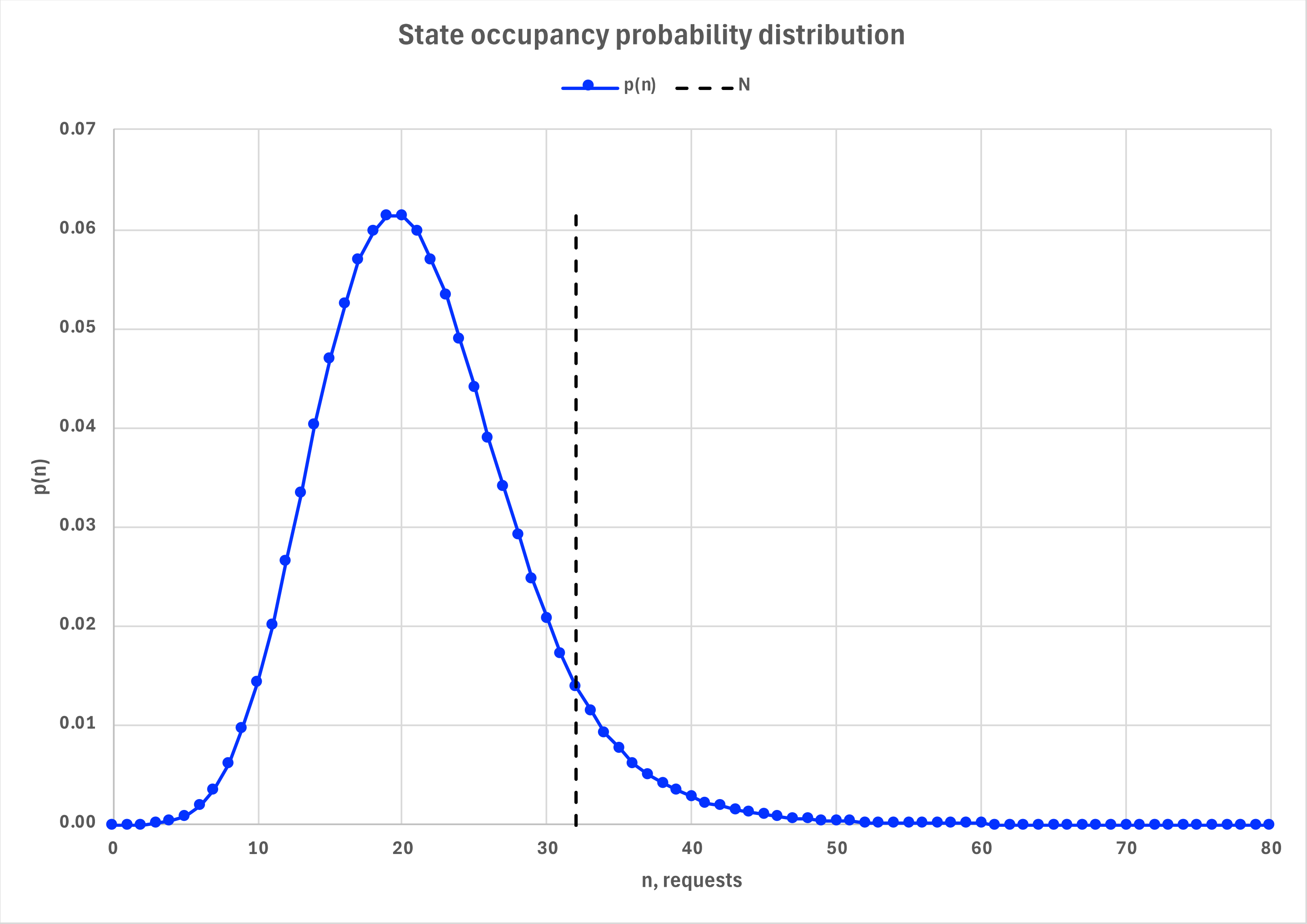
✗

- Inference model optimization
- Improve model accuracy, efficiency, compute/memory requirements, …
- Explore mechanisms for request queueing, balancing, …
- Model sharing, adapters, multiplexing, …
- GPU slicing mechanisms, DRA, migration, …

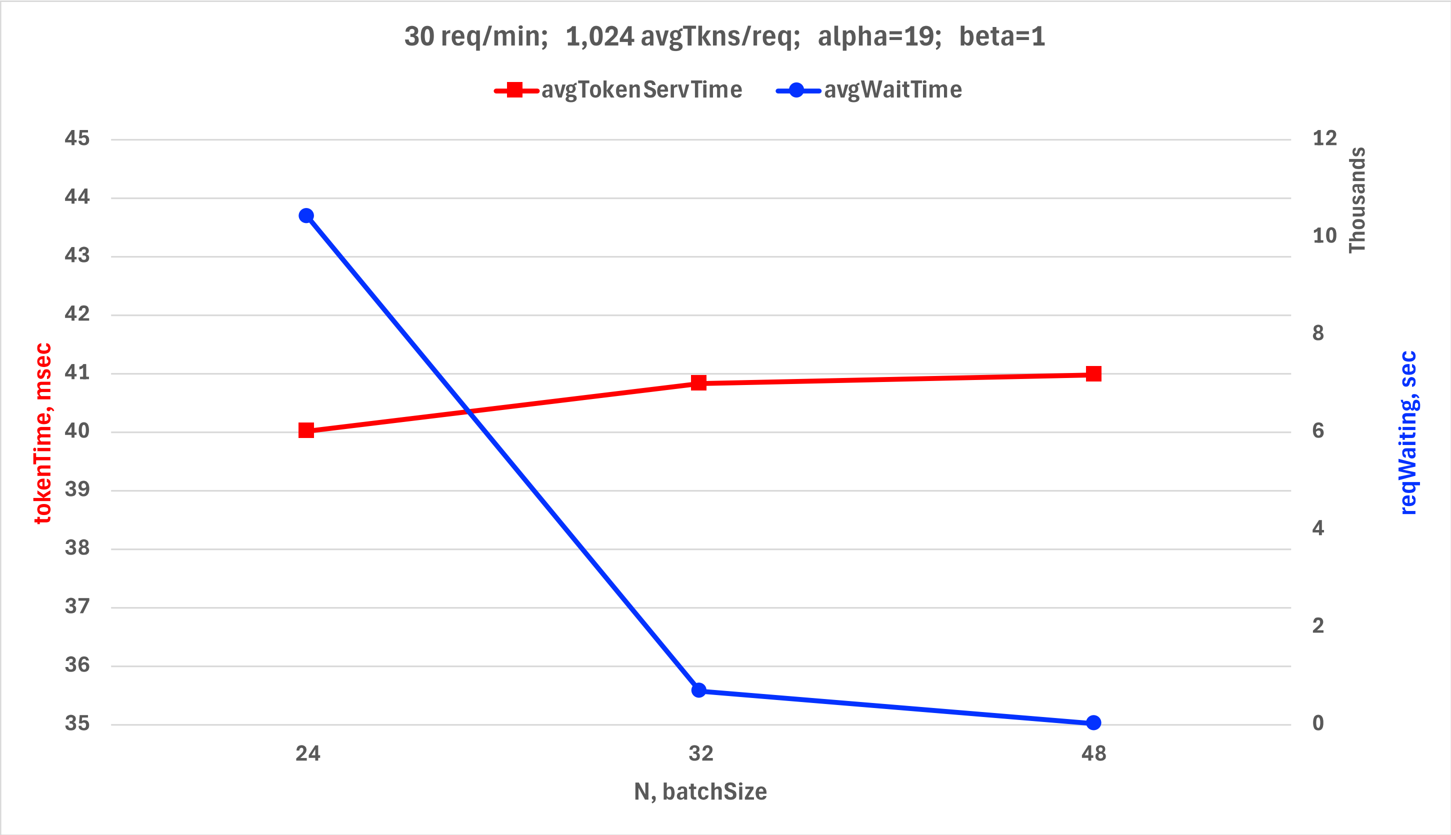
sample case

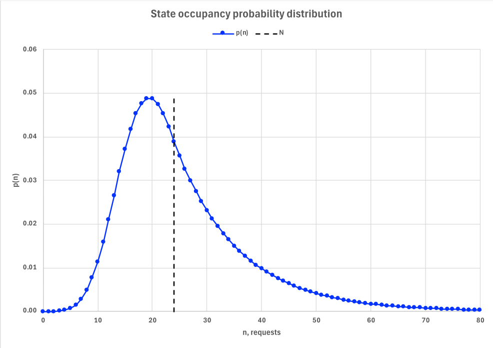


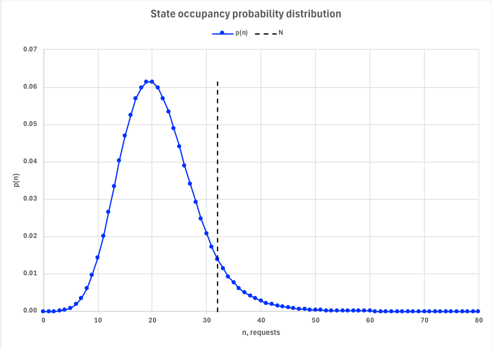
requestRate	30	/min	p(0)	5.7982E-07		avgNumSystem	21.24
lambda	0.0005	/msec	maxN	200		avgNumServer	20.90
K	1024		pFull	2.0382E-17		avgNumQueue	0.34
N	32		effecTput	30.00000	req/m	utilization	0.653
alpha	19			0.00050	/msec	avgRespTime	42,481
beta	1		P(N)	0.93803		avgSrvTime	41,808
lambda*K	0.512					avgWaitTime	674
						avgTokenServTime	40.8

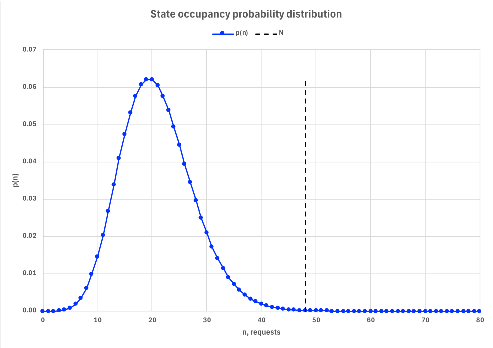


impact of batch size

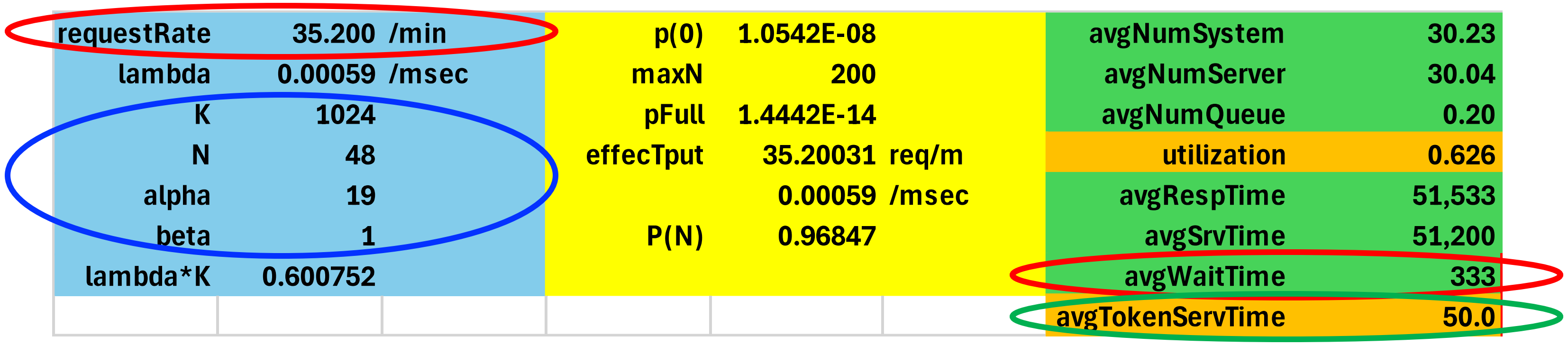








ITL limiting



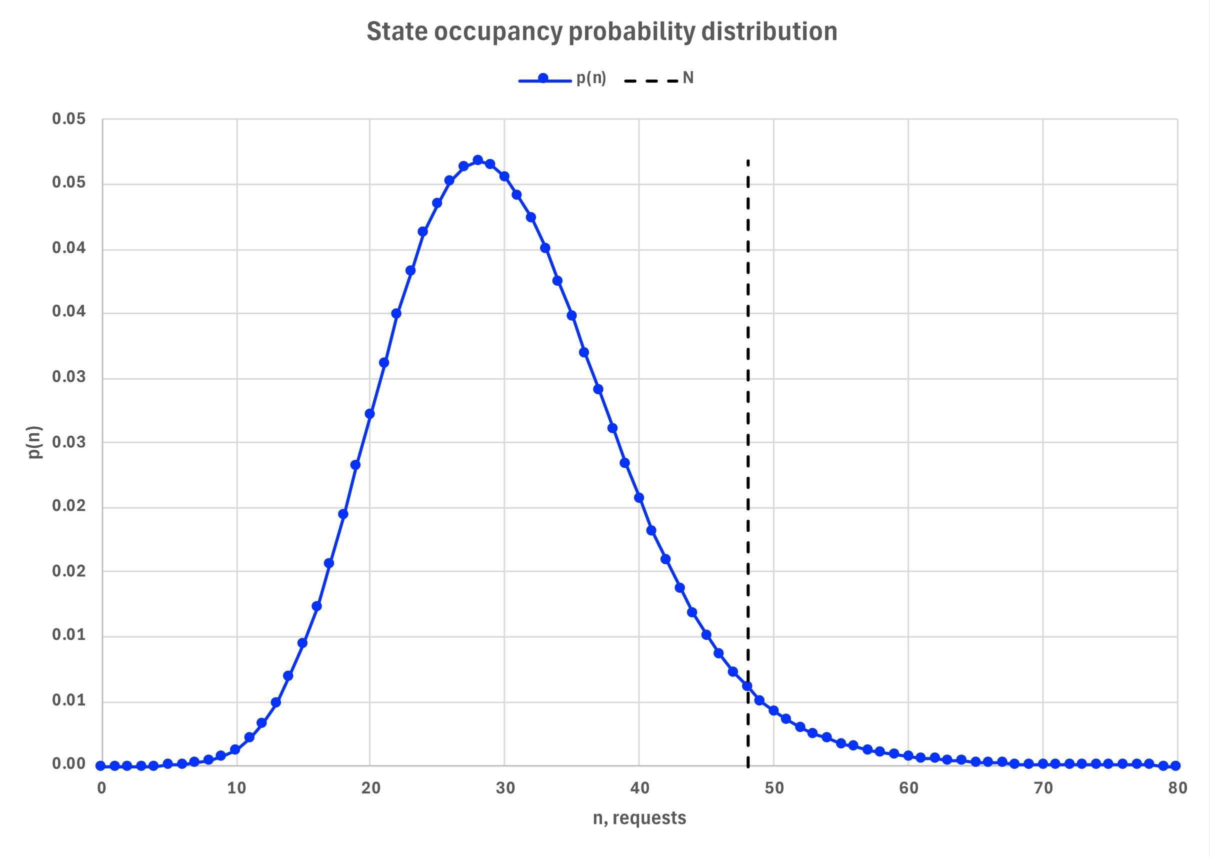
requestRate	35.200	/min	p(0)	1.0542E-08		avgNumSystem	30.23
lambda	0.00059	/msec	maxN	200		avgNumServer	30.04
K	1024		pFull	1.4442E-14		avgNumQueue	0.20
N	48		effecTput	35.20031	req/m	utilization	0.626
alpha	19			0.00059	/msec	avgRespTime	51,533
beta	1		P(N)	0.96847		avgSrvTime	51,200
lambda*K	0.600752					avgWaitTime	333
						avgTokenServTime	50.0

Find

maximum request rate

s.t.

avgTokenServTime <= target

target = 50 msec
requestRate = 35.2 req/min