educative Ask a Question

Rate Limiter Algorithms

Understand the working of various rate limiter algorithms.

We'll cover the following

Algorithms for rate limiting

The task of a rate limiter is directed by highly efficient algorithms, each of which has distinct advantages and disadvantages. However, there is always a choice to choose an algorithm or combination of algorithms depending on what we need at a given time. While different algorithms are used in addition to those below, we'll take a look at the following popular algorithms.

- Token bucket
- Leaking bucket
- Fixed window counter
- Sliding window log
- Sliding window counter

Token bucket algorithm

This algorithm uses the analogy of a bucket with a predefined capacity of tokens. The bucket is periodically filled with tokens at a constant rate. A token can be considered as a packet of some specific size. Hence, the algorithm checks for the token in the bucket each time we receive a request. There should be at least one token to process the request further.

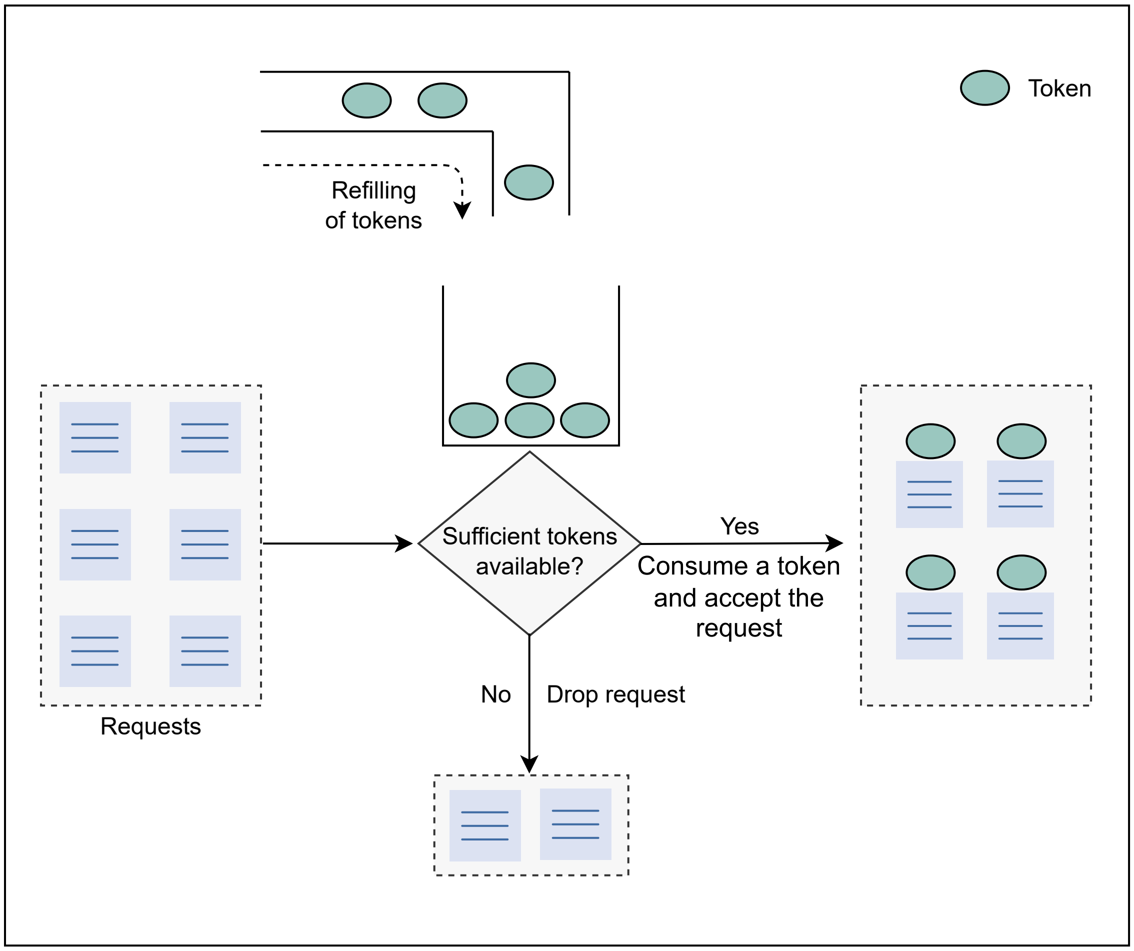
The flow of the token bucket algorithm is as follows:

Assume that we have a predefined rate limit of R and the total capacity of the bucket is C.

1. The algorithm adds a new token to the bucket after every $\frac{1}{R}$ seconds.

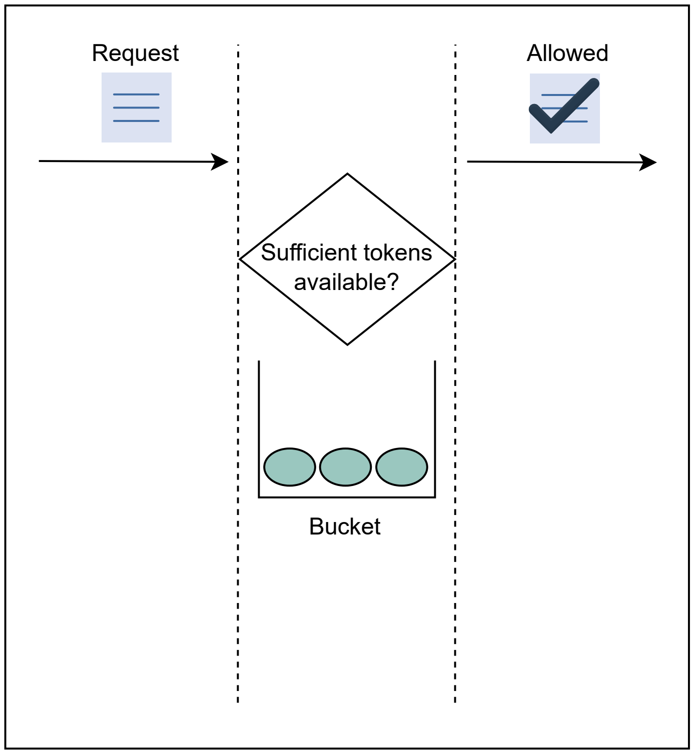
2. The algorithm discards the new incoming tokens when the number of tokens in the bucket is equal to the total capacity C of the bucket.
3. If there are N incoming requests and the bucket has at least N tokens, the tokens are consumed, and requests are forwarded for further processing.
4. If there are N incoming requests and the bucket has a lower number of tokens, then the number of requests accepted equals the number of available tokens in the bucket.

The following illustration represents the working of the token bucket algorithm.


Token
Refilling of tokens
Requests
Sufficient tokens available?
Yes
Consume a token and accept the request
No
Drop request

How the token bucket algorithm works

The following illustration demonstrates how token consumption and rate-limiting logic work. In this example, the capacity of the bucket is three, and it is refilled at a rate of three tokens per minute.



Initially, there are three tokens in the bucket. A request arrives within a minute and consumes a token from the bucket

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Essential parameters

We require the following essential parameters to implement the token bucket algorithm:

- **Bucket capacity (C):** The maximum number of tokens that can reside in the bucket.
- **Rate limit (R):** The number of requests we want to limit per unit tim
- **Refill rate $(\frac{1}{R})$:** The number of tokens put into the bucket per unit time.

- **Requests count (N):** This parameter tracks the number of incoming requests and compares them with the bucket's capacity.

Advantages

- This algorithm can cause a burst of traffic as long as there are enough tokens in the bucket.
- It is space efficient. The memory needed for the algorithm is nominal due to limited states.

Disadvantages

- Choosing an optimal value for the essential parameters is a difficult task.

Point to Ponder

Question

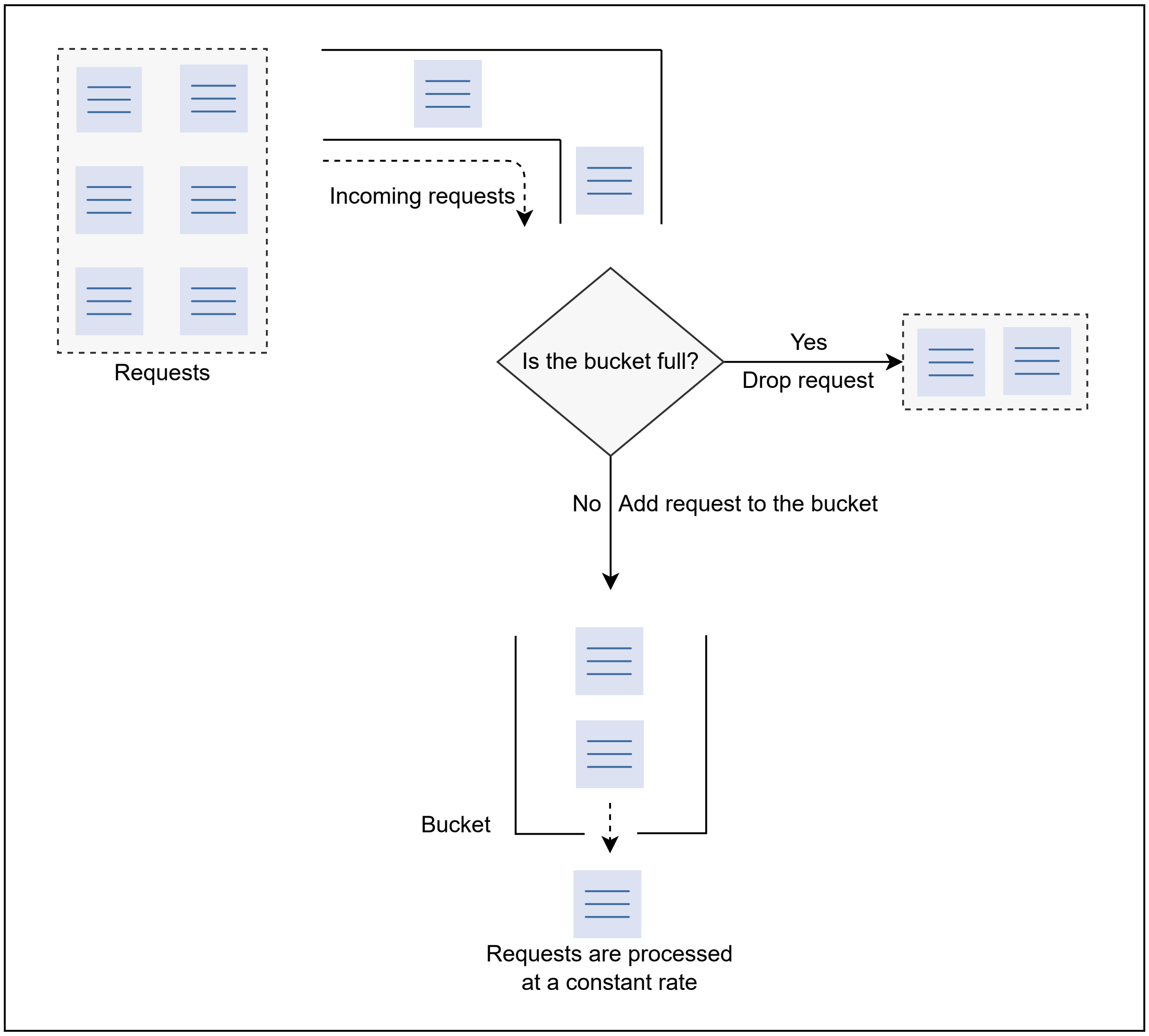
Apart from permitting bursts, can the token bucket algorithm surpass the limit at the edges?

Show Answer

The leaking bucket algorithm

The **leaking bucket algorithm** is a variant of the token bucket algorithm with slight modifications. Instead of using tokens, the leaking bucket algorithm uses a bucket to contain incoming requests and processes them at a constant outgoing rate. This algorithm uses the analogy of a water bucke leaking at a constant rate. Similarly, in this algorithm, the requests arrive at a variable rate. The algorithm process these requests at a constant rate in a first-in-first-out (FIFO) order.

Let's look at how the leaking bucket algorithm works in the illustration below:



How the leaking bucket algorithm works

Essential parameters

The leaking bucket algorithm requires the following parameters.

- **Bucket capacity (C):** This determines the maximum capacity of the bucket. The algorithm will discard the incoming requests when the bucket reached its maximum limit of C.

- **Inflow rate (R_{in}):** This parameter shows the inflow rate of requests. This is a varying quantity that depends on the application and nature of requests. We use this parameter to find the initial capacity of the bucket.
- **Outflow rate (R_{out}):** This determines the number of requests processed per unit time.

Advantages

- Due to a constant outflow rate (R_{out}), it avoids the burst of requests, unlike the token bucket algorithm.
- This algorithm is also space efficient since it requires just three states: inflow rate (R_{in}), outflow rate (R_{out}), and bucket capacity (C).
- Since requests are processed at a fixed rate, it is suitable for applications with a stable outflow rate.

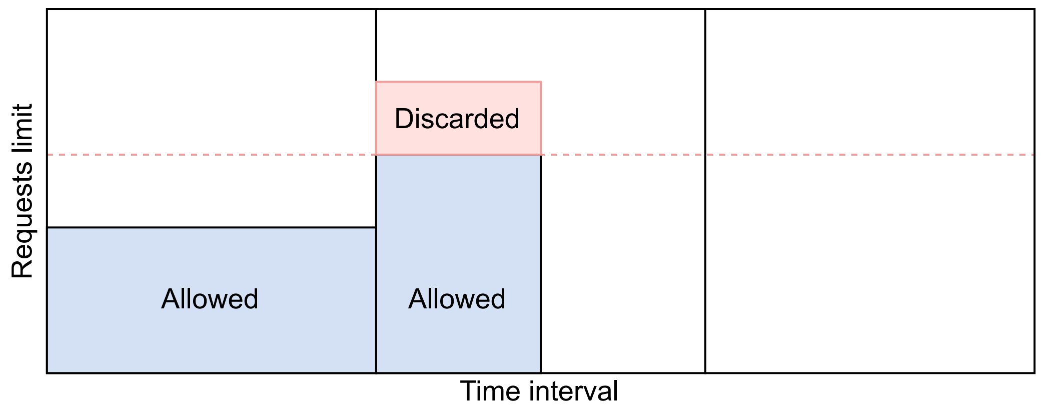
Disadvantages

- A burst of requests can fill the bucket, and if not processed in the specified time, recent requests can take a hit.
- Determining an optimal bucket size and outflow rate is a challenge.

Fixed window counter algorithm

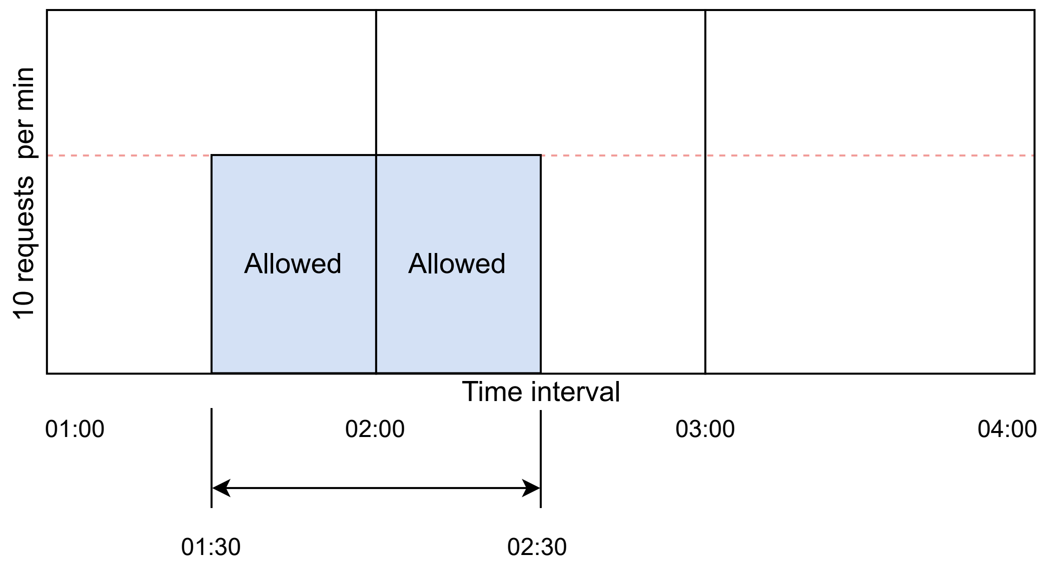
This algorithm divides the time into fixed intervals called **windows** and assigns a counter to each window. When a specific window receives a request, the counter is incremented by one. Once the counter reaches its limit, new requests are discarded in that window.

As shown in the below figure, a dotted line represents the limit in each window. If the counter is lower than the limit, forward the request; otherwise, discard the request.



Fixed window counter algorithm: Discard the request exceeding the limit

There is a significant problem with this algorithm. A burst of traffic greater than the allowed requests can occur at the edges of the window. In the below figure, the system allows a maximum of ten requests per minute. However, the number of requests in the one-minute window from 01:30 to 02:30 is 20, which is greater than the allowed number of requests.



Edge case problem in the fixed window counter algorithm. The number of requests in one minute from 01:30 to 02:30 exceeds the predefined limit of 10 requests per minute

Essential parameters

The fixed window counter algorithm requires the following parameters:

- **Window size (W):** It represents the size of the time window. It can be a minute, an hour, or any other suitable time slice.
- **Rate limit (R):** It shows the number of requests allowed per time window.
- **Requests count (N):** This parameter shows the number of incoming requests per window. The incoming requests are allowed if N is less than or equal to R.

Advantages

- It is also space efficient due to constraints on the rate of requests.
- As compared to token bucket-style algorithms (that discard the new requests if there aren't enough tokens), this algorithm services the new requests.

Disadvantages

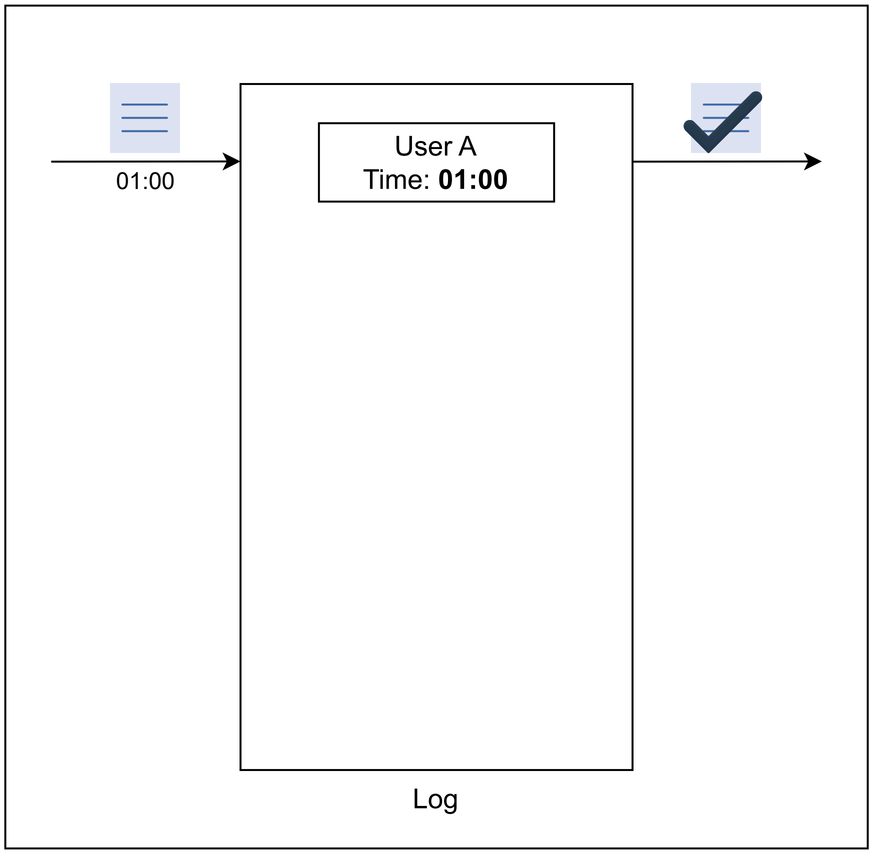
- A consistent burst of traffic (twice the number of allowed requests per window) at the window edges could cause a potential decrease in performance.

Sliding window log algorithm

The **sliding window log algorithm** keeps track of each incoming request. When a request arrives, its arrival time is stored in a hash map, usually known as the log. The logs are sorted based on the time stamps of incoming requests. The requests are allowed depending on the size of the log and arrival time.

The main advantage of this algorithm is that it doesn't suffer from the edge conditions, as compared to the **fixed window counter** algorithm.

Let's understand how the sliding window log algorithm works in the illustration below. Assume that we have a maximum rate limit of two requests in a minute.



A new request arrives at 01:00. Its arrival time is added to the log and the request is accepted. The time window is marked from 01:00 to 02:00

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Essential parameters

The following parameters are required to implement the sliding window lc algorithm:

- **Log size (L):** This parameter is similar to the rate limit (R) as it determines the number of requests allowed in a specific time frame.

- **Arrival time (T):** This parameter tracks incoming requests' time stamps and determines their count.
- **Time range (T_r):** This parameter determines the time frame. The time stamps of the old requests are deleted if they do not fall in this range. The start time of the window is defined based on the first incoming request and expires after one minute. Similarly, when another request after the expiry time arrives the window ranges are updated accordingly.

Advantages

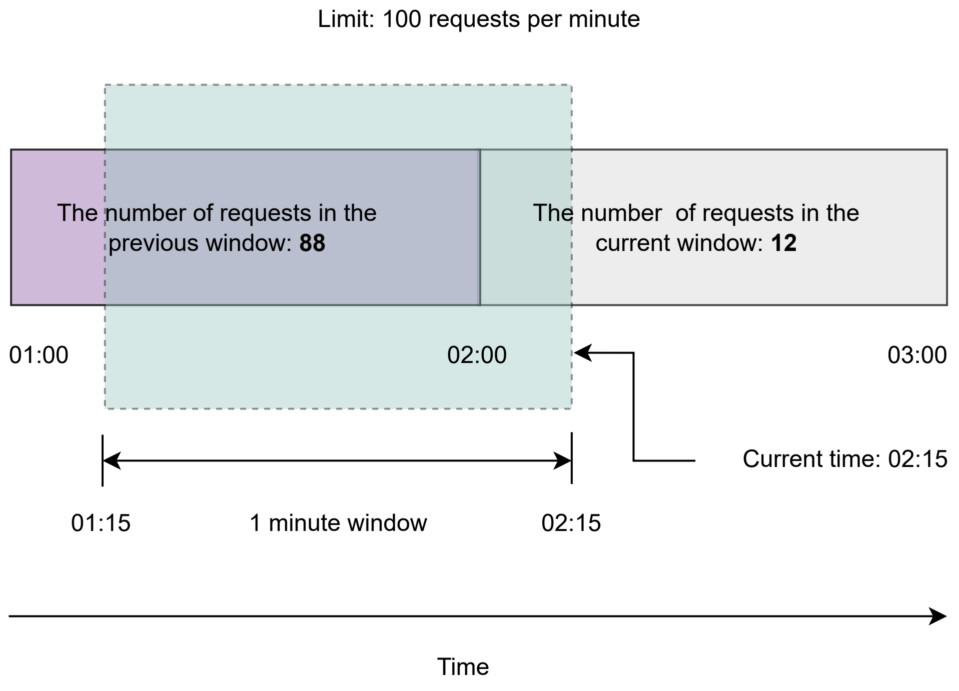
- The algorithm doesn't suffer from the boundary conditions of fixed windows.

Disadvantages

- It consumes extra memory for storing additional information, the time stamps of incoming requests. It keeps the time stamps to provide a dynamic window, even if the request is rejected.

Sliding window counter algorithm

Unlike the previously fixed window algorithm, the **sliding window counter algorithm** doesn't limit the requests based on fixed time units. This algorithm takes into account both the fixed window counter and sliding window log algorithms to make the flow of requests more smooth. Let's look at the flow of the algorithm in the below figure.


Limit: 100 requests per minute
The number of requests in the previous window: **88**
The number of requests in the current window: **12**
01:00
02:00
03:00
Current time: 02:15
01:15
1 minute window
02:15
Time

A sliding window counter algorithm, where the green shaded area shows the rolling window of 1 minute

In the above figure, we've 88 requests in the previous window while 12 in the current window. We've set the rate limit to 100 requests per minute. Further, the rolling window overlaps 15 seconds with the current window. Now assume that a new request arrives at 02:15. We'll decide which request to accept or reject using the mathematical formulation:

$$Rate = R_p \times \frac{time\ frame - overlap\ time}{time\ frame} + R_c$$

Here, R_p is the number of requests in the previous window, which is 88. R_c is the number of requests in the current window, which is 12. The $time\ frame$ is 60 seconds in our case, and $overlap\ time$ is 15 seconds.

$$Rate = 88 \times \frac{60-15}{60} + 12$$

$$Rate = 78 < 100$$

As 78 is less than 100, so the incoming request is allowed.

Essential parameters

This algorithm is relatively more complex than the other algorithms described above. It requires the following parameters:

- **Rate limit** (R) It determines the number of maximum requests allowed per window.
- **Size of the window** (W)**:** This parameter represents the size of a time window that can be a minute, an hour, or any time slice.
- **The number of requests in the previous window** (R_p)**:** It determines the total number of requests that have been received in the previous time window.
- **The number of requests in the current window** (R_c)**:** It represents the number of requests received in the current window.
- **Overlap time** (O_t)**:** This parameter shows the overlapping time of the rolling window with the current window.

Advantages

- The algorithm is also space efficient due to limited states: the number of requests in the current window, the number of requests in the previous window, the overlapping percentage, and so on.
- It smooths out the bursts of requests and processes them with an approximate average rate based on the previous window.

Disadvantages

- This algorithm assumes that the number of requests in the previous window is evenly distributed, which may not always be possible.

A comparison of rate-limiting algorithms

The two main factors that are common among all the rate-limiting algorithms are:

- **Memory:** This feature refers to the number of states an algorithm requires to maintain for a normal operation. For example, if one

algorithm requires fewer variables (states) than the other, it is more space efficient.
- **Burst:** This refers to an increase of traffic in a unit time exceeding the defined limit.

The following table shows the space efficiency and burst of traffic for all algorithms that have been described in this lesson.

A Comparison of Rate-limiting Algorithms

Algorithm	Space efficient	Allows burst?
Token bucket	Yes	Yes, it allows a burst of traffic within defined limit.
Leaking bucket	Yes	No
Fixed window counter	Yes	Yes, it allows bursts at the edge of the time window and can exceed the defined limit.
Sliding window log	No, maintaining the log requires extra storage.	No
Sliding window counter	Yes, but it requires relatively more space than other space efficient algorithms.	Smooths out the burst

Note: Locking is not always bad by employing the above algorithms. If there is little contention on a lock, acquiring the lock takes little time. If we have high lock contention, a careful analysis is required

> to manage the situation, possibly by sharding the data and using multiple / finer-grained locks.

Conclusion