A Model for Factor Growth In Allocated Memory of Golang's Slices

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Abstract

The purpose of this document is to analyze a use case program where Golang's slices are large enough to compromise the memory usage of the machine running the corresponding program, that is, near the values of 2 GB of RAM memory. Such case is analyzed with the aim of proposing an equation describing slices' behaviour, as well as an explanation to the memory usage throughout the various versions of the aforementioned program, each of them optimized in a different manner.

A Slice Growth Factor Function

The capacity of a slice reaches a point where it needs to increase. The form in which Golang grows the slice capacity x by a certain amount a can be expressed as:

$$a = \frac{x + 3(256)}{4}, \tag{1}$$

where the growth factor of the new capacity x after the addition of a can be 2.0 for *small* slices, which Golang sets as those with less length than 256, all the way until a factor of 1.25, for any slice with length equal or larger than 256. We can thus define a function that describes the behaviour of the growth factor given a and by defining the factor as y:

$$y = \frac{x + \frac{x+3(256)}{4}}{x} \tag{2}$$

If we further simplify the function,

$$\begin{aligned} y &= \frac{x + \frac{1}{4}\left(x + 3(256)\right)}{x} \\ &= 1 + \frac{\frac{x+3(256)}{4}}{x} \\ &= 1 + \frac{x + 3(256)}{4x} \\ &= 1 + \frac{x}{4x} + \frac{3(256)}{4x} \\ &= \frac{5}{4} + \frac{3(256)}{4x} \end{aligned} \tag{3}$$

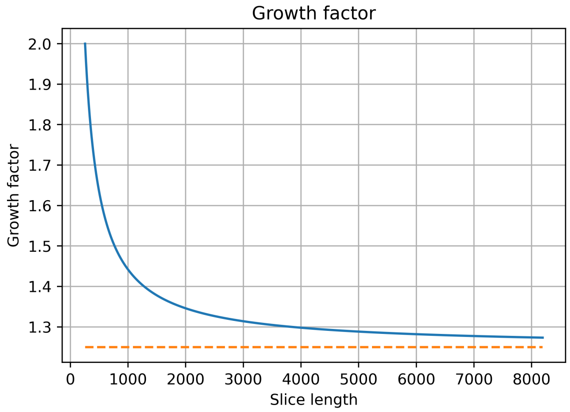
we reach a simplified form that can be decomposed to its elementary transformations of the function $f(x) = \frac{1}{x}$ by writing:

$$y = \frac{5}{4} + \frac{3}{4}(256)\left(\frac{1}{x}\right), \tag{4}$$

and which can be generalized as:

$$y = \alpha + \beta\gamma\left(\frac{1}{x}\right) \tag{5}$$

The equation in (5) with the constant values $\alpha = 1.25, \beta = 0.75$ and $\gamma = 256$ shows the following behaviour, where $256 \leq x < \infty$:



Growth factor plot

Function Breakdown

If we seek to reach an explanation of every constant involved in the function

$$y = \alpha + \beta\gamma\left(\frac{1}{x}\right) \quad \text{where } \alpha = 1.25, \beta = 0.75, \gamma = 256, \tag{6}$$

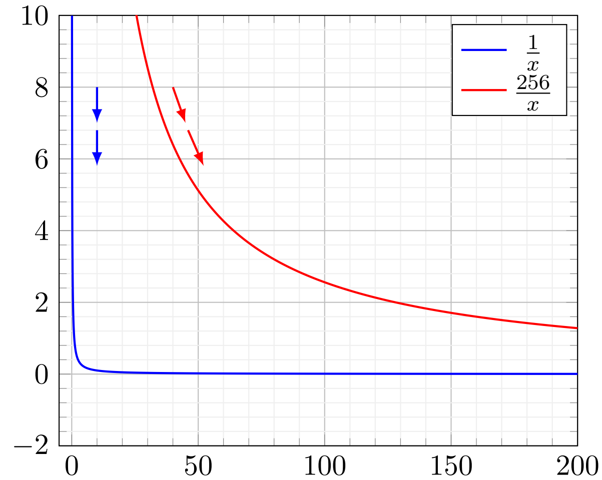
and the function form $\frac{1}{x}$, then let the only known data to be the maximum factor for *small* slices, that is $\lambda = 2.0$, the minimum possible factor as the slice length $x \to \infty$, that is, $\alpha = 1.25$, and the threshold of length $\gamma = 256$. Having said that, we know that as the slice length grows from 256 towards infinity, the factor approaches **but never goes further** α. Such statement is the definition of a function with a horizontal asymptote on the line $y = \alpha$. From that, we now have two possible intuitive approaches for building the function:

$$y = \frac{1}{x - \alpha} \tag{7}$$

or

$$y = \alpha + \frac{1}{x}, \tag{8}$$

which both have the same horizontal asymptote on the line $y = \alpha$. Nevertheless, we must choose Eq. (2) form to continue, if we consider the third constraint or known value $\gamma = 256$: by having the value γ separate what we will consider a *small* or *large* length, the factor y will then be shaped by γ. In other words, the factor y must coincide with the **the amount of times length x fits in** γ, or γ divided by x. Otherwise, the function shape would follow the form $y = \alpha + \frac{1}{x}$, and by making it to follow the form $y = \alpha\frac{\gamma}{x}$, we are making the transition from λ to α use less steep slopes, and thus, the time in x to reach α from λ increases, as shown in Figure .



Therefore, if we plug in γ inside our two possible approaches' terms divided by x, we get:

$$y = \frac{\gamma}{x - \alpha} \tag{9}$$

or

$$y = \alpha + \frac{\gamma}{x}, \tag{10}$$

From these two probable approaches, we now can identify that Eq. (9) would indeed fulfill the condition of the asymptote on $y = \alpha$, but would not satisfy the condition of the factor being determined by the amount of times length x fits in $y = \gamma$ or $\frac{\gamma}{x}$, since Eq. (9) describes a factor determined by the amount of times x minus α would fit inside γ ($\frac{\gamma}{x-\alpha}$). Therefore, the approach that fulfills both the asymptotic condition and the factor being determined by $\frac{\gamma}{x}$ would be Eq. (10).

Now that we have proceeded to build our function following Eq. (10), the only missing constant to conclude is β in order to achieve Eq. (5) intuitively from the known data. For this purpose, let us go back to our constraints: from having λ as the maximum possible factor when length $x = \gamma$, we have also one certain point to be reached by the function we seek to build, that is, the coordinates (γ, λ) or

$(256, 2)$. Having said that, we have the values $y = 2$ and $x = 256$ standing as known. From this, we can plug in values $\alpha = 1.25$, $\gamma = 256$ and $x = 256$ in the function we have built so far:

$$\begin{aligned} f &= \alpha + \gamma\left(\frac{1}{x}\right) \\ 2.25 &= 1.25 + 256\left(\frac{1}{256}\right) \end{aligned} \tag{11}$$

which means

$$\begin{aligned} 2.25 &\neq 2.0 \\ f &\neq y \end{aligned} \tag{12}$$

In Eq. (12), we conclude that the function f we have built up until this point gives us the coordinates $(256, 2.25)$ instead of the desired $(256, 2)$. Therefore, some factor β is missing inside the function we got so that the condition of having the coordinates $(256, 2)$ belong to our final function is fulfilled. The intuitive approach might be to add this missing value β to f, reaching

$$f = \alpha + \gamma\left(\frac{1}{x}\right) + \beta, \tag{13}$$

but the addition of β to function f would mean to move the asymptote to the horizontal line $y = \alpha + \beta$, and with this, f would not be satisfying the condition of having a horizontal asymptote on line $y = \alpha$. Therefore, β must not be included in f by addition. That leaves us with the aim of including β in f without moving the asymptote. One of the possible transformations that does not move the asymptote we have so far but indeed changes the output value of f as we desire is the multiplication of the term $\frac{\gamma}{x}$ by the required β. In this way, we reach the form

$$f = \alpha + \beta\gamma\left(\frac{1}{x}\right), \tag{14}$$

which includes the missing transformation of f by a value of β so as to fulfill the condition of having $(256, 2)$ belong to our final function, allowing us to solve for β if we return to our known values of $\alpha = 1.25$, $\gamma = 256$, $x = 256$ and $y = 2$, and plug them in Eq. (14):

$$\begin{aligned} y &= \alpha + \beta\gamma\left(\frac{1}{x}\right) \\ 2 &= 1.25 + \beta(256)\left(\frac{1}{256}\right) \\ 2 &= 1.25 + \beta(1) \\ \beta &= 2 - 1.25 \\ \beta &= 0.75 \end{aligned} \tag{15}$$

Thus, we have a function that fulfills our initial conditions:

- Asymptote on line $y = \alpha$ as $x \to \infty$.
- A function that determines the output factor with respect to 256 as $x \to \infty$, which follows the form $\frac{256}{x}$.
- One of the points reached by the function is $(256, 2)$.

And said function is:

$$\begin{gathered} y = \alpha + \beta\gamma\left(\frac{1}{x}\right) \\ \text{where } \alpha = 1.25, \beta = 0.75, \gamma = 256, \end{gathered} \tag{16}$$

which coincides with Eq. (3) that follows Golang's documentation. We can now conclude that the *smooth* transition from a factor of 2 for slices of length 256 towards a factor of 1.25 for slices of length ∞ can be built intuitively by stating the three conditions set for the factor's behaviour.