In the continuous-time domain, we have:

$$\frac{dV_o}{dt} = \frac{V_i - V_o}{RC} - 2\frac{I_s}{C}\sinh\left(\frac{V_o}{V_T}\right),$$ which is a non-linear ODE of the form:

$$\frac{dv}{dt} = \dot{v} = f(t, v).$$ How to solve? $\rightarrow$ Backward-Euler Method?

Backward-Euler: (BE)

$$v[n] = v[n-1] + T\dot{v}[n]$$, which is an implicit equation.

where v correspond to V_o ; T is the sampling interval, and n the index of the discretized element v.

So, in our case we have:

$$V_o[n] = V_o[n-1] + \frac{1}{F_s}\left[\frac{V_i[n] - V_o[n]}{RC} - 2\frac{I_s}{C}\sinh\left(\frac{V_o[n]}{V_T}\right)\right].$$

samplerate (Hz) Here, V_o and V_i are discretized output and input signal.

To resolve this equation, we have to :
- use Newton-Raphson method (NRM)* to solve the implicit equation.
- then, make a loop with the size of $(1, \text{len}(V_i))$ for calculate all the values of V_o.

We search $V_o[n]$: *

with NRM, we resolve this equation: $$0 = V_o[n-1] - V_o[n] + \frac{1}{F_s}\left[\frac{V_i[n] - V_o[n]}{RC} - 2\frac{I_s}{C}\sinh\left(\frac{V_o[n]}{V_T}\right)\right].$$

Since the only unknown is the value of the sample $V_o[n]$, Newton's method will find an approximate value of $V_o[n]$ for which the equation is verified.

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Newton Raphson method:

We have the equation:

$$V_0[n-1] - V_0[n] + \frac{1}{F_s}\left[\frac{V_i[n] - V_0[n]}{RC} - 2\,\frac{I_s}{C}\,\sinh\left(\frac{V_0[n]}{V_T}\right)\right] = 0$$

if we rewrite this equation
with the following variable changes: $V_0[n] = x$
$V_0[n-1] = a$
we have: $V_i[n] = b$

$$f(x) = a - x + \frac{1}{F_s}\left[\frac{b-x}{RC} - 2\,\frac{I_s}{C}\,\sinh\left(\frac{x}{V_T}\right)\right] = 0$$

Given $f(x)=0$, we have:

$$x_{n+1} = x_n - \frac{f(x_n)}{f'(x_n)} \quad \leftarrow \left(\text{while } \operatorname{abs}\left(\frac{x_n - x_{n-1}}{x_n}\right) < \underbrace{\text{relative\_error}}_{\text{we fix this parameter.}}\right)$$

Where x_{n+1} is the $n+1$ itteration for estimate the "right" value of x (that verified our error tolerance criterion)
for which $f(x)=0$ is verified.

And where $f'(x_n) = \frac{1}{F_s}\left(-\frac{2 I_s}{C V_T}\cosh\left(\frac{x}{V_T}\right) - \frac{1}{CR}\right) - 1$

$$= -\frac{1}{F_s}\left(\frac{2 I_s}{C V_T}\cosh\left(\frac{x}{V_T}\right) + \frac{1}{CR}\right) - 1$$