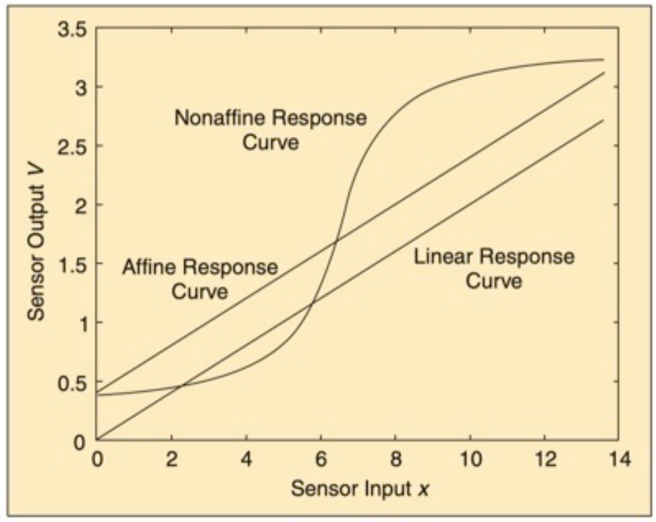
Sensor specifications



What is a sensor?

A Sensor is a device that provides data (measurements) about a physical system.

Examples :

- accelerometer
- gyroscope
- LIDAR
- our eyes, etc.

In practice, sensors usually convert physical signals to volts. The reason:

- volts signals can be easily amplified (electrical circuits is the basis of our technological advance)
- volts signals can be recorded by computers

Developing "good" sensors is a major effort. All sensors have limitations (e.g., environmental temperature range for nominal performance). Major tasks in developing a sensor are:

- Identify sensor's purpose

- Obtain the best possible performance despite design limitations.

- Identify sensor's specifications

↓

a.k.a., properties

- Static sensor specifications
  (independent of time;
  related to the static
  response of the sensor)

- Dynamic sensor specifications
  (related to the transient
  response of the sensor;

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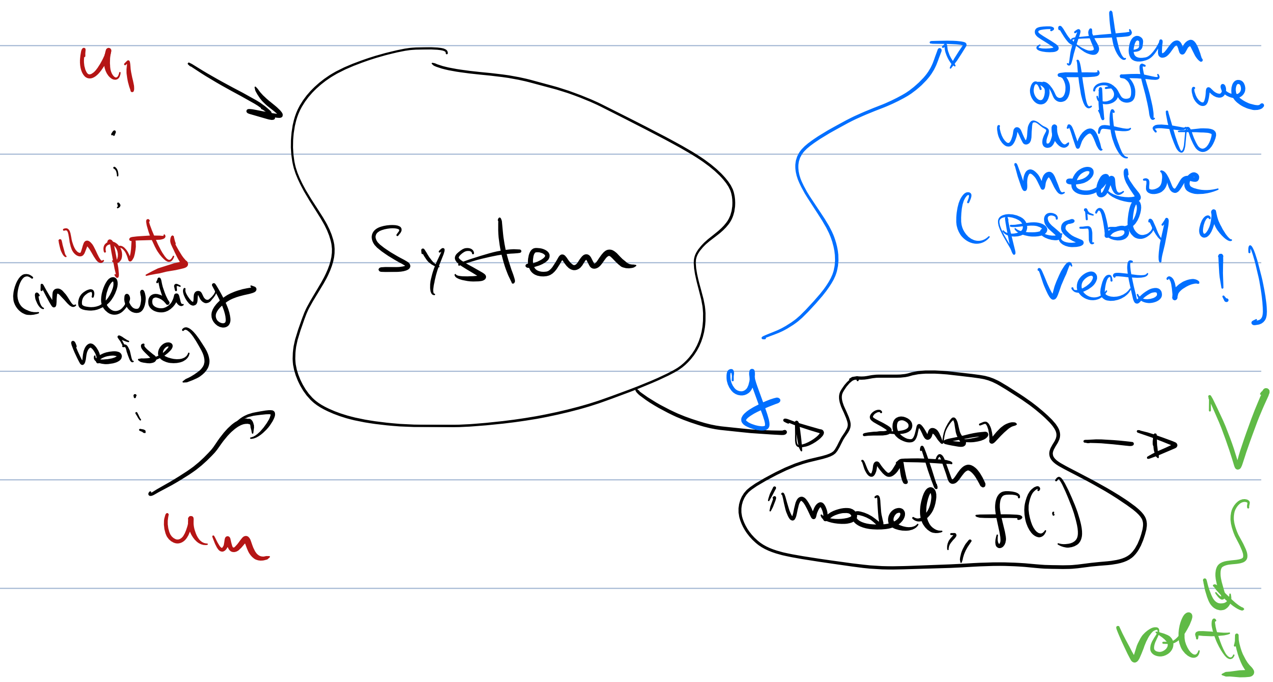
Static sensor specifications

(next lecture: dynamic)

"Specifying" a sensor means identifying the sensor's "model":



$$\boxed{\text{Sensor model: } V = f(y)}$$

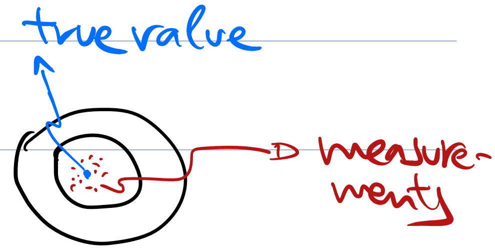
<u>Note:</u> $u_1, \ldots, u_m$ do not appear in f.
That is, for identifying sensor specifications we focus on the map from y to V only.

- y is the input to the model $f(\cdot)$

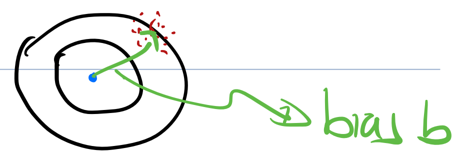
Accuracy and Precision

Sensor performance is usually described in terms of:

- Accuracy



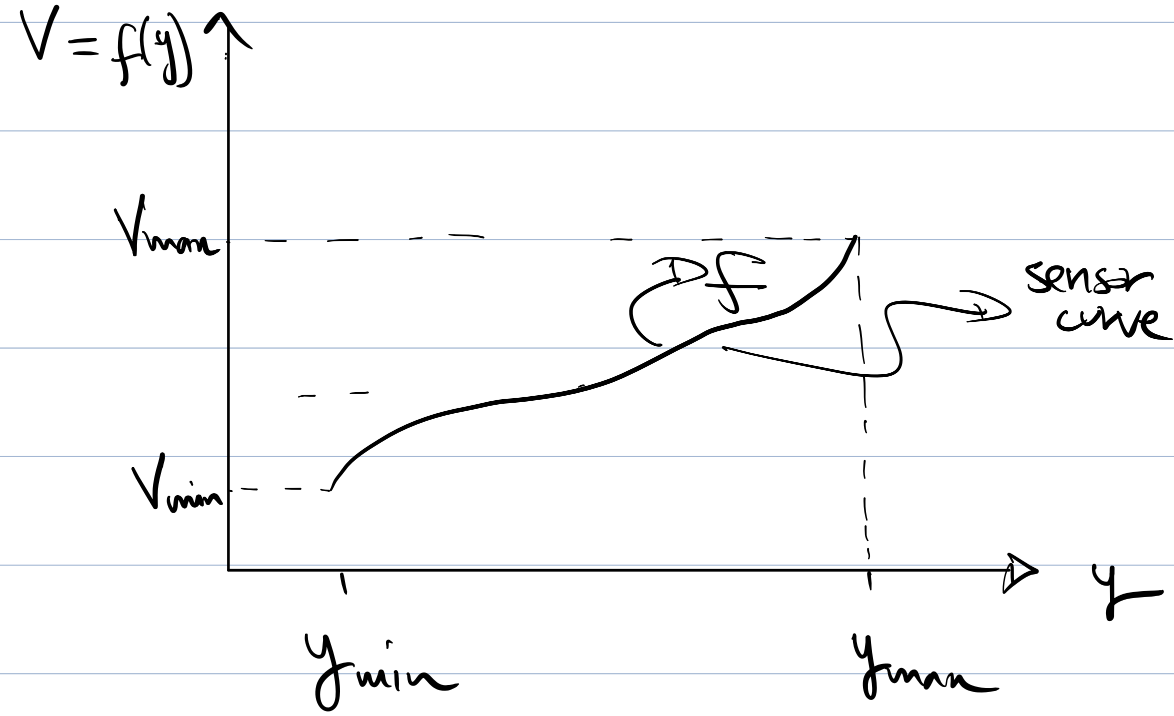
- Precision



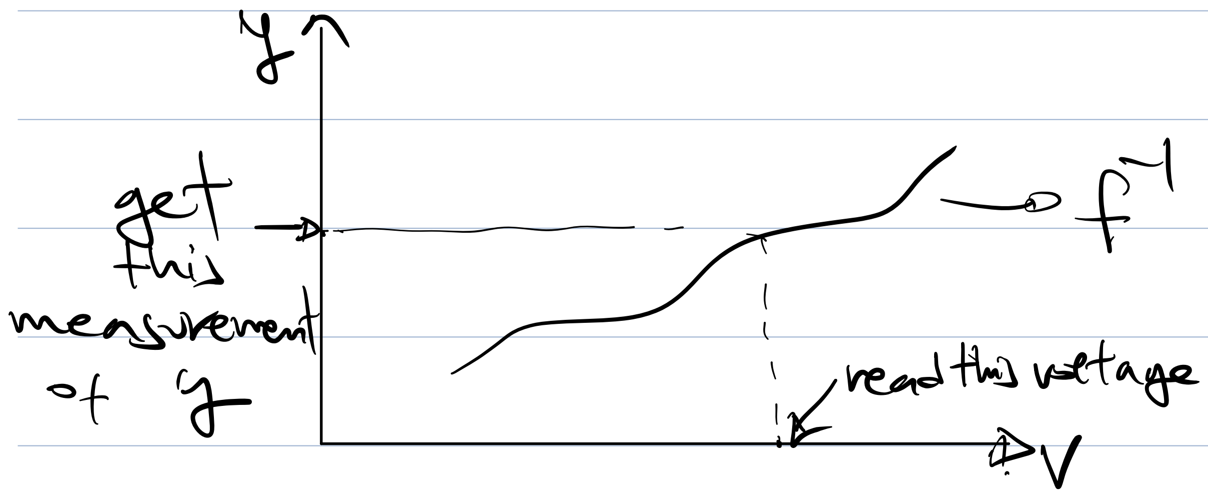
Good accuracy $\Rightarrow$ good precision

Sensor Curve

Assume (for simplicity) that y is scalar, between y_{min} and y_{max}.

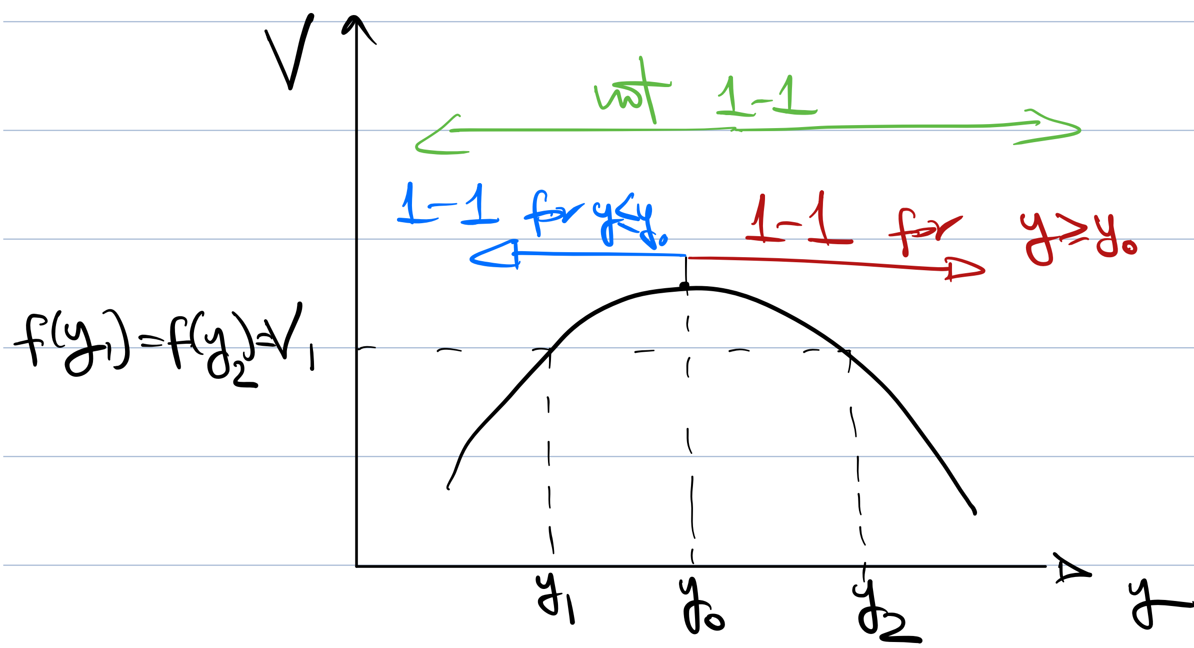


The sensor curve is a property of the sensor.
By inverting $V = f(y)$ we <u>may</u> be able to determine y $(y = f^{-1}(V))$



Why we "may be able to" determine y by inverting $f(\cdot)$?

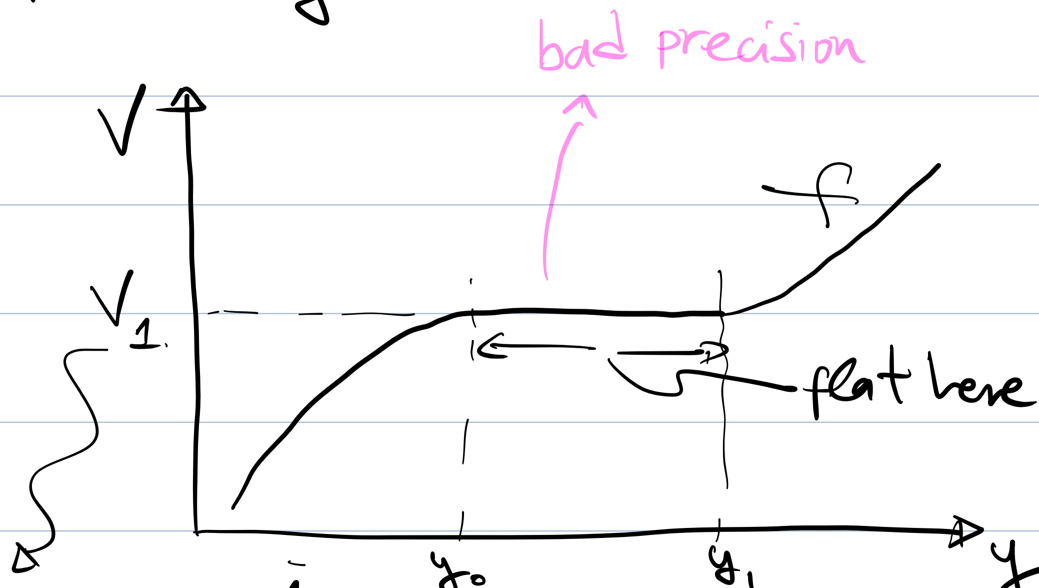
- Sometimes, we have an ambiguous sensor curve (f is not 1-1):



Need to limit input y to either left or right of y_0 to avoid ambiguity.

(i.e., sensor should be used only on systems where y is either always $\leq y_0$ or $\geq y_0$).

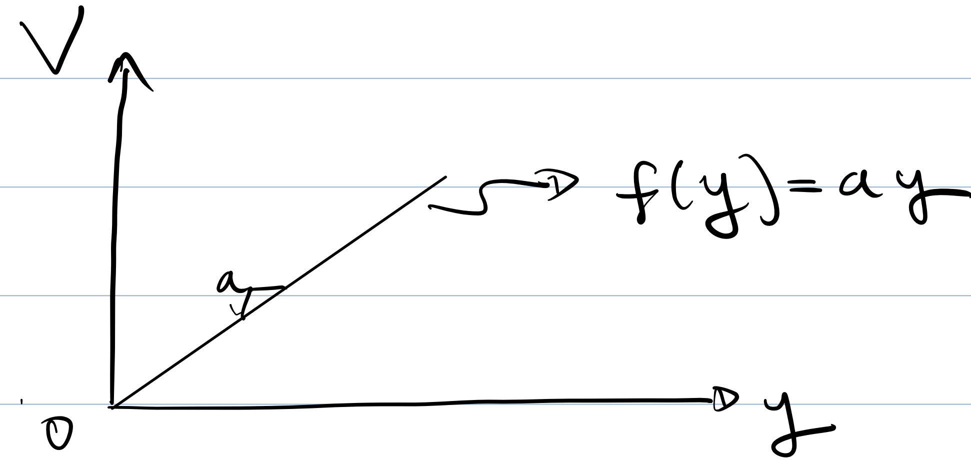
- Similarly, sensor curve has a flat region



if you see V_1, then y could be anywhere in $[y_0, y_1]$.

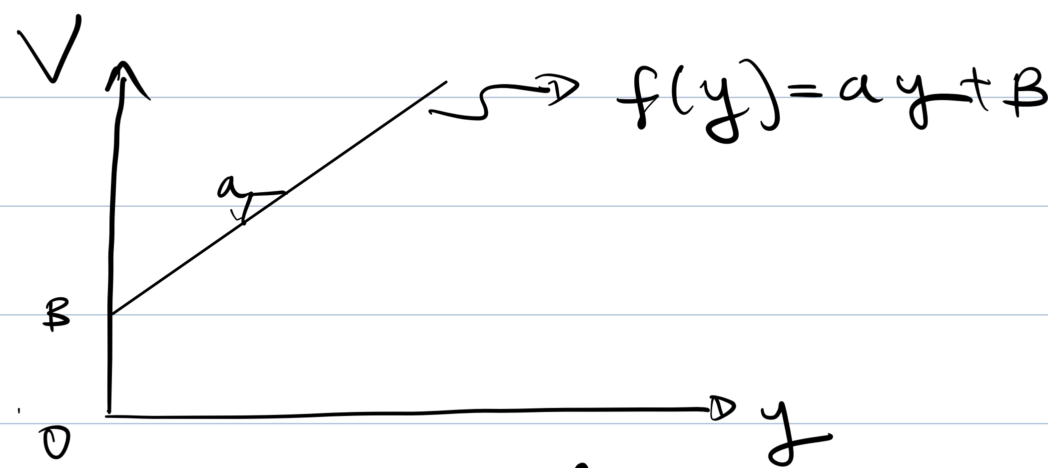
$\Longrightarrow$ Need to focus on strictly monotone part of sensor curve

Ideally, instead, a sensor curve is linear (and, thus, 1-1):



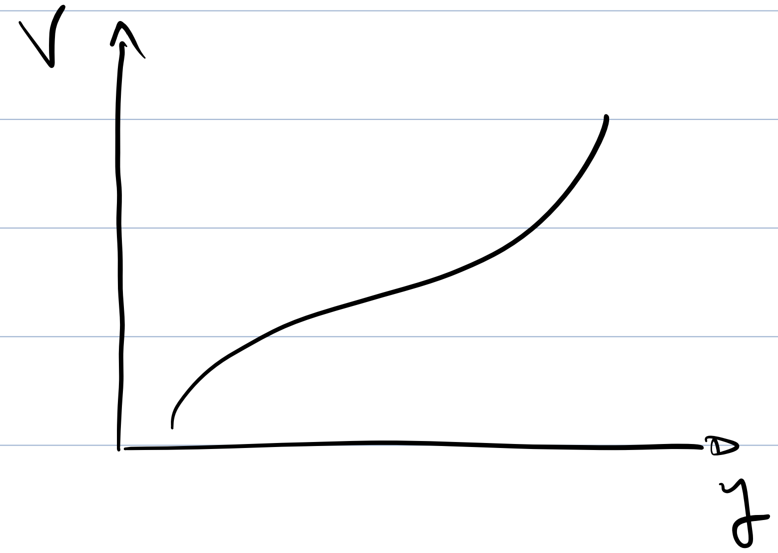
$V = ay$ (a = slope)

In the linear case, when $y=0$, then $V=0$ (and vice versa). Instead, when the sensor curve is affine:



then, if $y=0$, then $V=\beta$.

Most sensor curves are neither linear nor affine. They are non-linear:



Finding the sensor curve

Assume you can conduct experiments where y is known (or observed by a sensor whose specifications you already know).

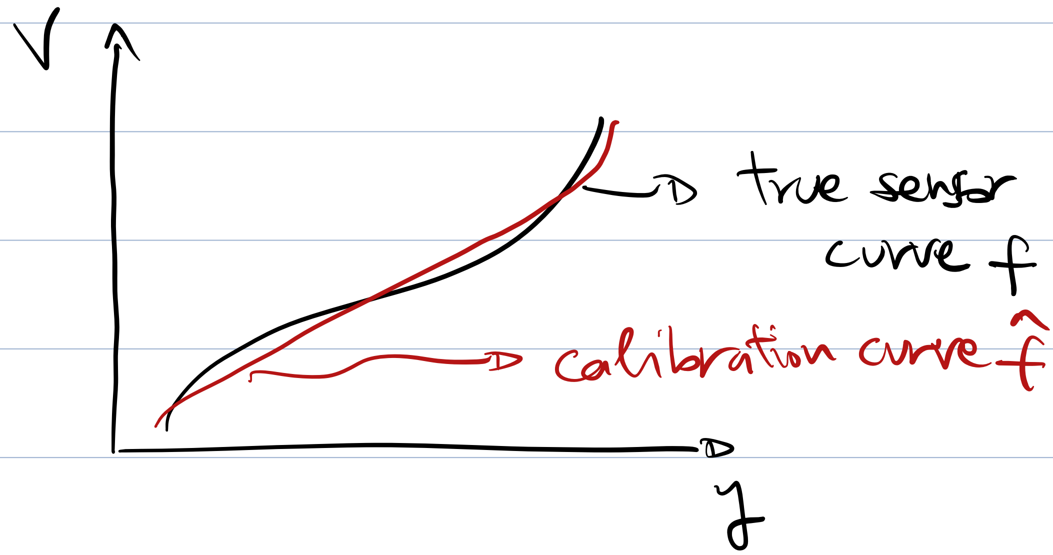
Then, to determine f, you may:
vary y, measure V, and plot the data.

Note: Not as simple as that:

- noise will corrupt the approximation of the real curve

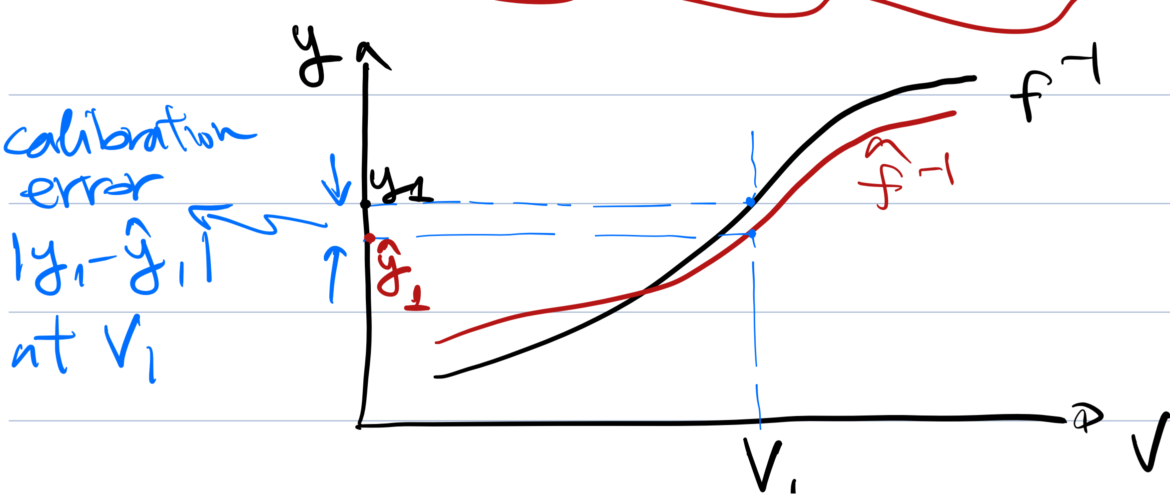
Calibration curve (approximated sensor curve)

Calibration curve is the approximation to the sensor curve that we get when we experementally determine the sensor curve.



$$f \simeq \hat{f}$$

What matter most is not the error $\|f - \hat{f}\|$
BUT the error $\|f^{-1} - \hat{f}^{-1}\|$



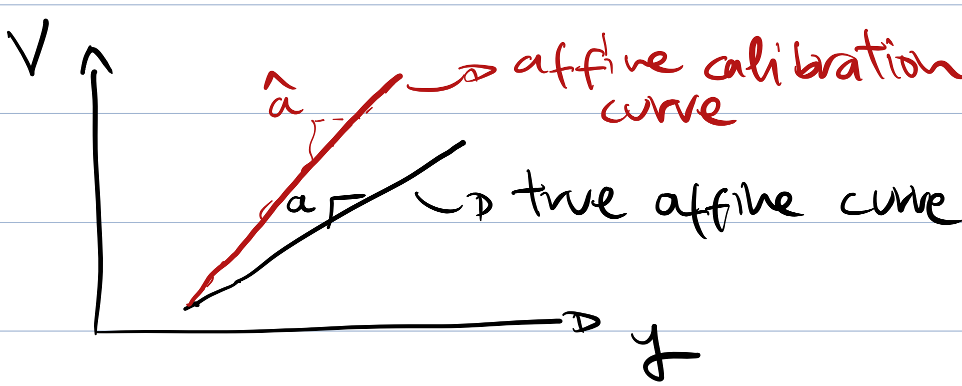
Ideally, $|f^{-1}(v) - \hat{f}^{-1}(v)| = 0 \ \forall v.$

(i.e, $\| f^{-1} - \hat{f}^{-1} \| = 0$)

Note: Calibration accuracy is different from the sensor accuracy we defined earlier (see accuracy vs. precision discussion).

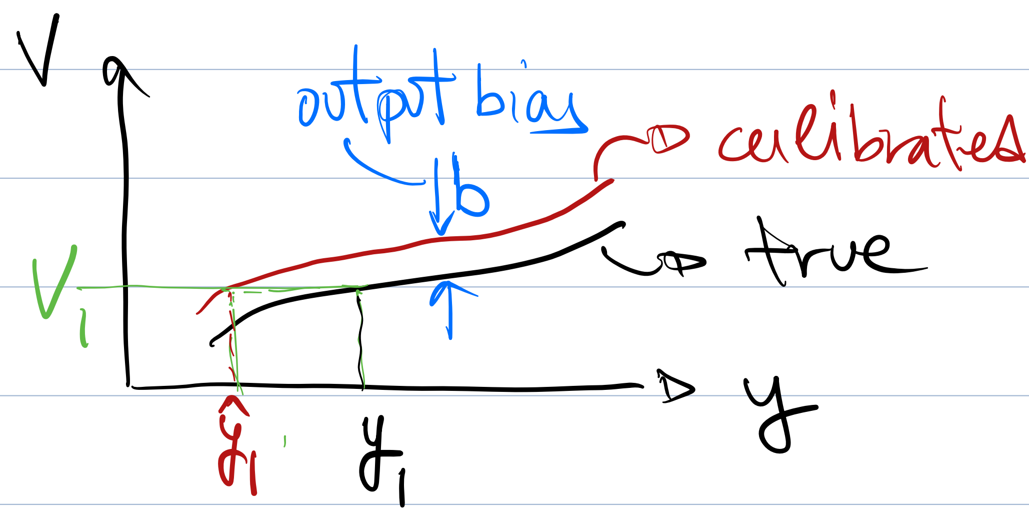
Calibration errors

- Scale factor error

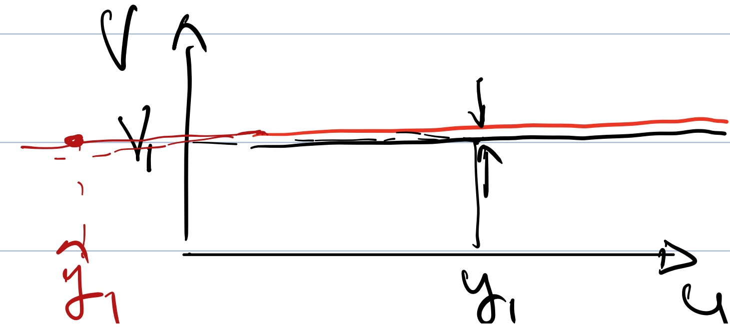


$\longrightarrow$ $|a - \hat{a}|$ is the scale factor error

• <u>Bias</u>: calibration curve is vertically shifted.

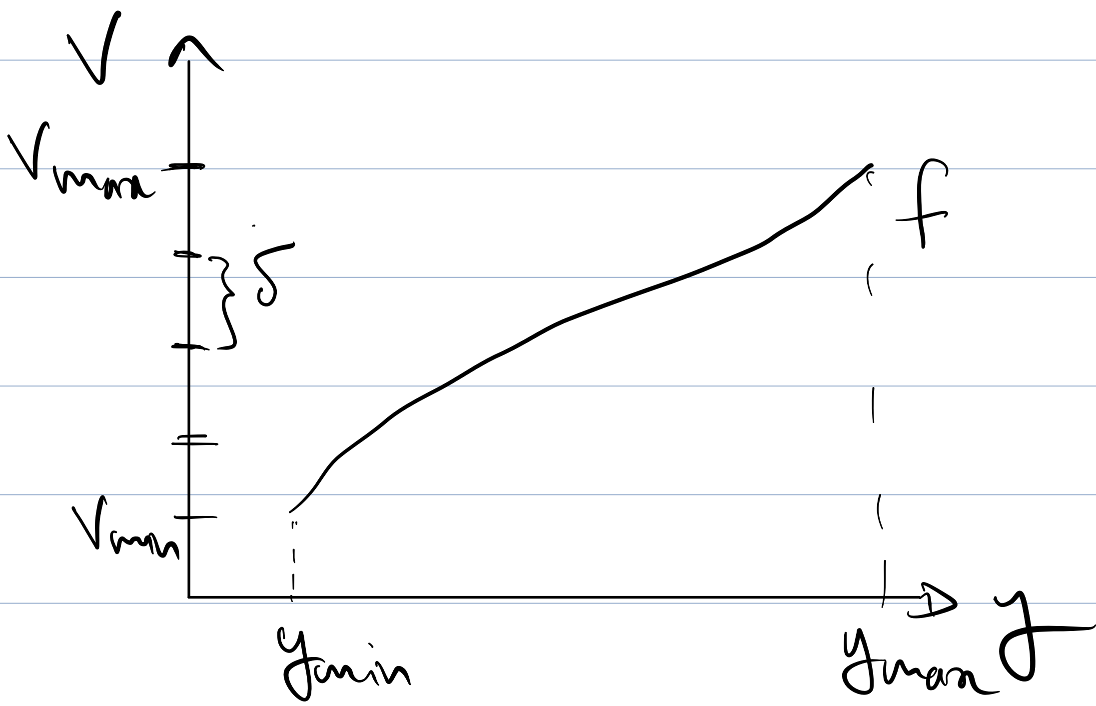


Notice that even a small bias b can result to large $\|f^{-1} - \hat{f}^{-1}\|$ (see $|\hat{y}_1 - y_1|$).



Quantization

Suppose we know the sensor curve but we digitally quantize the data.



Output range = $[V_{min}, V_{max}]$

Input range = [y_{min}, y_{max}]

$$\delta = \text{bin size} = \frac{V_{max} - V_{min}}{N}$$

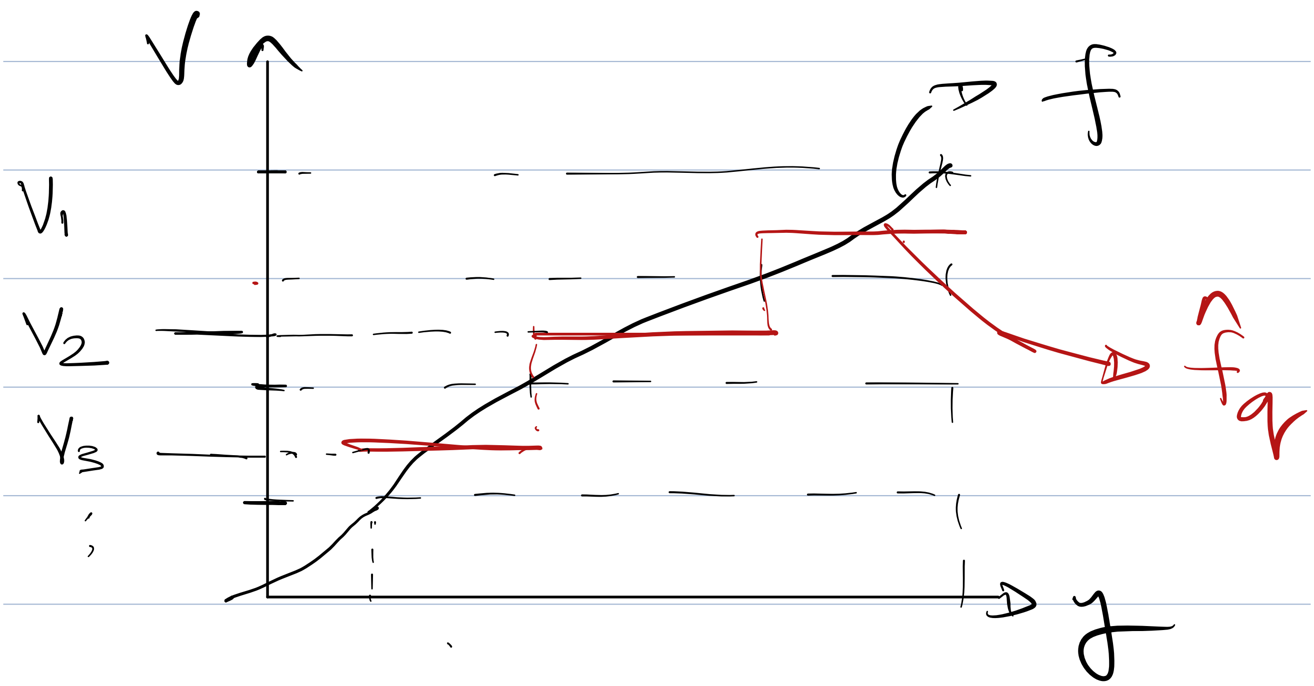
= quantization resolution,

where N = number of bins

$\log_2 N$ = bits we allocate

- Quantization error $\leq \frac{1}{2}\delta$.

- Quantized sensor curve



$\hat{f}_q$ is the quantized sensor curve.

<u>Note</u>: $\hat{f}_q$ has many flat regions $\Rightarrow$ need for $N \gg 1$

Summary:

Calibration accuracy is affected by:

- noise
- (non-linearity)
- scale factor error
- bias
- quantization.