In what ways can a model be “good”? A model can be...

- **Accurate**
  - Is the output of the model very near to correct?

- **Descriptively Realistic**
  - Is the model based on assumptions which are correct?

- **Precise**
  - Are the predictors of the model definite numbers?

- **Robust**
  - Is the model relatively immune to errors in the input data?

- **General**
  - Does the model apply to a wide variety of situations?

- **Fruitful**
  - Are the conclusions useful?
  - Does the model inspire other good models?
Accuracy

Definition: A model is accurate if the answers it gives are correct.


Accuracy

*Definition:* A model is **accurate** if the answers it gives are correct.

*Example.* Determining projected student populations.
Accuracy

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**Example.** Determining projected student populations. This year, there are 10 million people between 18–22 years old. \((P)\) This year, there are 5 million students. \((S)\) We might conjecture that in general, \(S = 0.5P\).
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Model Assumption 1:
Model Assumption 2:
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**Model Assumption 1:** Each college student is in 18–22 year old range.

**Model Assumption 2:** One of every two is enrolled in college.

If next year there are projected to be 11,000,000 18–22 year olds, we would estimate the college population to be of size \(E = \underline{\phantom{00000}}\).
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If this value is close to correct, we say our model is accurate. Otherwise, the model is **inaccurate**.

**Problem:**
Accuracy

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Problem: (We won’t whether we are accurate until next year!)

Question: Is this model descriptively realistic?
Descriptively Realistic

**Definition:** A mathematical model is descriptively realistic if it is deduced from a believable description of the system being modeled.
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*Example.* **Full moons.** A full moon appears to occur every 29 days.
Descriptively Realistic

*Definition:* A mathematical model is **descriptively realistic** if it is deduced from a believable description of the system being modeled.

*Example.* **Full moons.** A full moon appears to occur every 29 days. Let $M_L, M_N$ be the dates of the last and next full moons. Is the model

$$M_N = M_L + 29$$

descriptively realistic? _____ Why?
Example. A more descriptively realistic model would incorporate other age groups. Replace Assumptions 1 and 2 by:

Model Assumption 3: College students are either:

- 18–22 ($P_a$ of these)
- 23 or older ($P_b$ of these)
- 17 or younger ($P_c$ of these)
Descriptively Realistic

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- 23 or older ($P_b$ of these)
- 17 or younger ($P_c$ of these)

Model Assumption 4: The enrolled percentages for each age range is:

- 30% for people aged 18–22
- 3% for people aged 23 or older
- 1% for people aged 17 or younger

We would estimate the college population to be of size

$$E = 0.3P_a + 0.03P_b + 0.01P_c.$$
Precision

A model is **precise** if the prediction is

\[
\begin{align*}
\text{a definite number} \\
\text{a definite function} \\
\text{etc.}
\end{align*}
\]
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A model is

\[
\begin{align*}
\text{precise} & \quad \text{if the prediction is} \\
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& \cdot \quad \text{a set of functions}
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\[
\begin{align*}
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Circle one: The enrollment models are \boxed{\text{precise, imprecise}}. Why?
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Keep Assumption 1: Each college student is in 18–22 year old range.

Revise Assumption 2*: The percentage of 18–22 year olds in college is between 46% and 50%. (Historically)
Precision

A model is

- **precise** if the prediction is a definite number, a definite function, etc.
- **imprecise** if the prediction is a range of numbers, a set of functions, etc.

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Keep **Assumption 1**: Each college student is in 18–22 year old range.

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**Model Conclusion**: 

\[
(0.46)(11,000,000) \leq E \leq (0.5)(11,000,000) \\
5,060,000 \leq E \leq 5,500,000.
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\[5,060,000 \leq E \leq 5,500,000.\]

This model is imprecise, but perhaps more helpful than the precise answer from before.
Robustness and Percentage Error

**Definition:** A model is **robust** if it is relatively immune to errors in the input data.
Robustness and Percentage Error

**Definition:** A model is robust if it is relatively immune to errors in the input data.

![Diagram of model input and output error]

**Example.** If our population estimate (input) has an error of 10%, how much does our college enrollment estimate (output) change?
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![Diagram of input and output errors](model)

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**Ask:** Is the output error less than 10% or more than 10%?
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![Diagram showing input error being magnified by the model to output error]

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- Some models **magnify** the errors that exist in the input data; we say these models are **sensitive to error** or not robust.
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Make sure we understand: What does 10% error mean?
Percentage Error

**Definition:** Suppose you are finding the value of something. Let $v$ be its true value and $v'$ be the value predicted by a model or measured.
Percentage Error

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**Example.** Suppose that the census measures the 18-22 year old population to be 9,300,000 while the true population is 9,500,000.

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Most of the time, we discuss the **absolute value** of percentage error. In other words, 5% error means the error is either –5% or 5%.
Percentage Error

Example. How robust is our $E = 0.5P$ model?
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Suppose that we prepare for a $+5\%$ error in population.
Percentage Error

Example. How robust is our $E = 0.5P$ model?

Suppose that we prepare for a $\pm 5\%$ error in population.

Recall: Population Estimate $P' = 11,000,000$.

Calculating the true population $P$ based on a $\pm 5\%$ error in $P'$:
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\frac{11,000,000 - P}{P} = 0.05 \implies 11,000,000 - P = 0.05P \implies 11,000,000 = 1.05P \implies P = 10,475,190
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Note: The true population $P$ is less than the estimate $P'$ because our estimate was 5% too high.
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Note: The true population $P$ is less than the estimate $P'$ because our estimate was $5\%$ too high.

How does this impact the true student enrollment $E$?

$$E = 0.5P = 0.5(10,475,190) = 5,238,095,$$
Percentage Error

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which is an error of:

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This highlights the principle of “Error In equals Error Out”
Percentage Error

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Example. How robust is our $E = 0.3P_a + 0.03P_b + 0.01P_c$ model? Suppose that we prepare for a ±10% error in each population $P_i$, where the true values are: $P_a = 10$ mil., $P_b = 90$ mil, $P_c = 50$ mil.
**Percentage Error**

**Example.** How robust is our \( E = 0.3P_a + 0.03P_b + 0.01P_c \) model?

Suppose that we prepare for a ±10% error in each population \( P_i \), where the true values are: \( P_a = 10 \text{ mil.}, \ P_b = 90 \text{ mil.}, \ P_c = 50 \text{ mil.} \).

If each pop. est. \( P_i \) is a 10% **overestimate** of the true value \( P'_i \), \( P'_a = 11, \ P'_b = 99, \) and \( P'_c = 55 \).
Percentage Error

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If each pop. est. $P_i$ is a $10\%$ overestimate of the true value $P_i'$, $P_a' = 11$, $P_b' = 99$, and $P_c' = 55$.

Then comparing the true enrollment to the estimated enrollment $E'$:

$E = 0.3(10) + 0.03(90) + 0.01(50) = 6.2$

$E' = 0.3(11) + 0.03(99) + 0.01(55) = 6.82$

Percentage error: $\frac{6.82-6.2}{6.2} = \frac{62}{62} = 10\%$;
Percentage Error

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Percentage error: $\frac{6.82-6.2}{6.2} = \frac{0.62}{6.2} = 10\%$; Again ________________

Alternatively, $P_a'$ $10\%$ underestimate, and $P_b'$, $P_c'$ $10\%$ overestimate:

$P_a' = 9$, $P_b' = 99$, and $P_c' = 55$. 
Percentage Error

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$E' = 0.3(9) + 0.03(99) + 0.01(55) = 6.22$

Percentage error: $\frac{6.22 - 6.2}{6.2} = \frac{0.02}{6.2} = 0.3\%$. 
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Generality

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Model Assumption: Each college student is in 18–22 year old range.

Model Assumption: Each college will have its enrollment change by the same ratio, next year’s 18–22 year old population over this year’s.
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Suppose that Queens College has 20,000 students and suppose that Private UNnamed Kansas College has 2,000 students this year.

If the year-to-year change in 18–22 year old population is 10%, then QC would gain 2,000 students while PUNK College would gain 200.
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The projected enrollment in all colleges would be:

\[ E = (1.1)S_1 + (1.1)S_2 + \cdots + (1.1)S_n \]

\[ = (1.1)(S_1 + S_2 + \cdots + S_n) \]

\[ = (1.1)S \]
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It is complicated to estimate total enrollment using this model.
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This model is more general because it applies to individual colleges.
Fruitfulness

*Definition:* A model is **fruitful** if either

- Its conclusions are useful.
- It inspires other good models.
Fruitfulness

**Definition:** A model is **fruitful** if either

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Our college enrollment model is fruitful in multiple ways:

- Planning for demand for educational grants, dormitory space, teacher hiring, etc.
- The ideas we implemented are transferrable to other situations.
Fruitfulness

*Definition:* A model is **fruitful** if either

- Its conclusions are useful.
- It inspires other good models.

Our college enrollment model is fruitful in multiple ways:

- Planning for demand for educational grants, dormitory space, teacher hiring, etc.
- The ideas we implemented are transferrable to other situations.

**Example.** How many automobiles would be junked in a given year?

- Cars play the role of people.
- Partitioning by age of cars gives better results
The Advantage of Inaccuracy

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Your approach will depend on the particular application and your scale:

- If you visit the same places every day, run the expensive model **once initially** in order to save money in the long run.
- If you visit different places every day, run the inexpensive algorithm daily. (Unless you’re UPS or FedEx.)