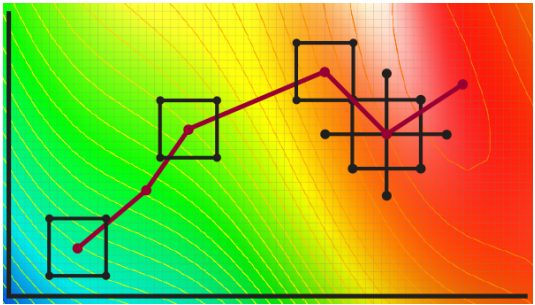
Experimentation for Improvement



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Design and Analysis of Experiments

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SOAP

Understanding interactions in the water-soap example

Understanding interactions in the water-soap example

- **Using soap** works better with warm water (instead of cold water)
  We say: "the effect of warm water enhances the effect of soap"

- **Warm water** works better with soap (instead of no soap)
  We say: "the effect of soap is enhanced by using warm water"

This interaction works in our favour.

The definition of "interaction"

The effect of one factor (for example, **A**) depends on the value, or the level, of another factor (**B**, for example).

Interactions are symmetrical (**AB** = **BA**)

These two alternatives provide the same effect:

- Using **(soap)** together with **(warm water)**
- Using **(warm water)** together with **(soap)**

Interactions don't always benefit us

Interactions can cancel out the effect of an improvement.

Interactions are important and do exist in real systems!

Ginger biscuits outcome variables

Three outcomes were measured:

1. Taste
2. Break strength (breakability)
3. Breakability after 1 week (measures "freshness" of biscuit)

Always measure as many things as you can during your experiments

- Even things you believe are not too important now
- We will learn more about disturbances later, these can affect your experiments.

Experiments are expensive to repeat!

Back to the ginger biscuits: taste!

- Try to choose outcome factors that are *not* subjective.
- But sometimes we have no choice.

A recipe for ginger biscuits

- 150 grams margarine
- 195 grams packed brown sugar
- 1 egg
- **B = 55 grams molasses or 55 grams of honey**
- 250 grams all-purpose flour
- 3 grams ground ginger
- 8 grams baking soda
- 3 grams salt
- 7 grams minced ginger

Baking time: 10 minutes at 350°C.

A = bake for 8 minutes or 14 minutes

[Flickr]

[Flickr]

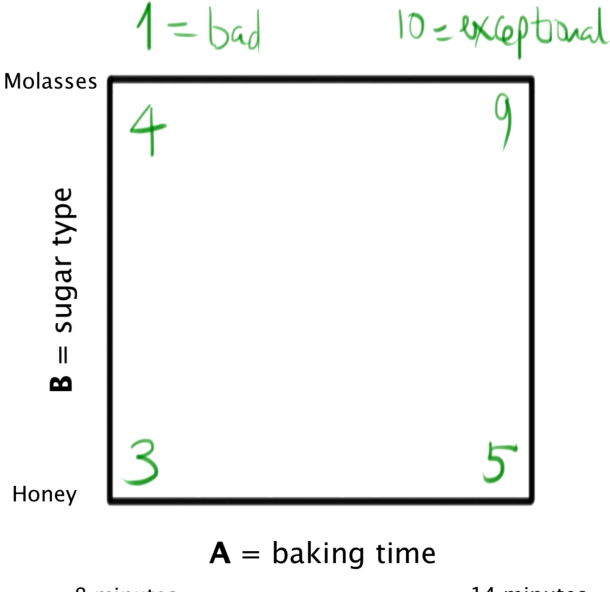
minced ginger

Factors considered

- **A: baking duration**
  - 8 minutes
  - 14 minutes

- **B: sugar type**
  - honey
  - molasses

Taste results



1 = bad

10 = exceptional

Molasses

4

9

B = sugar type

3

5

Honey

−

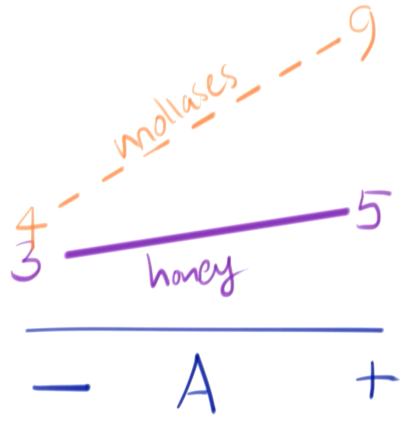
A = baking time

+

8 minutes

14 minutes

Taste results



1 = bad

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\−

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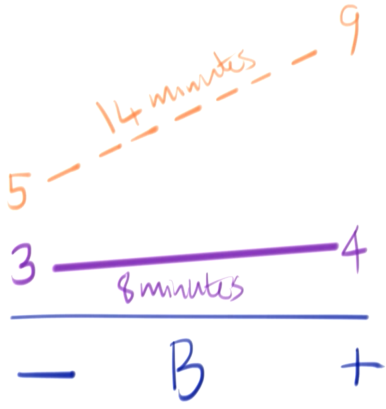
Honey

A = baking time

8 minutes

14 minutes

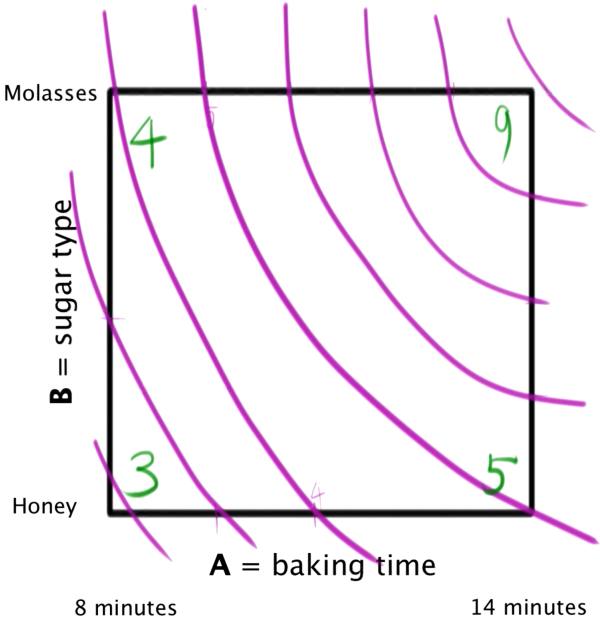
Taste results



The definition of "interaction"

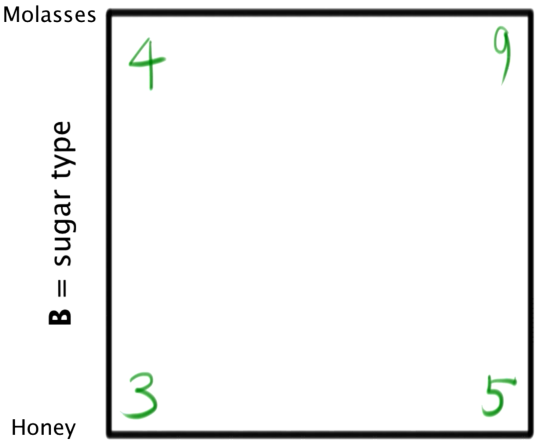
The effect of one factor (for example, **A**) depends on the value (or the level) of another factor **(B)**, for example.

Taste results



Curvature is evidence of interaction in the system

Taste results

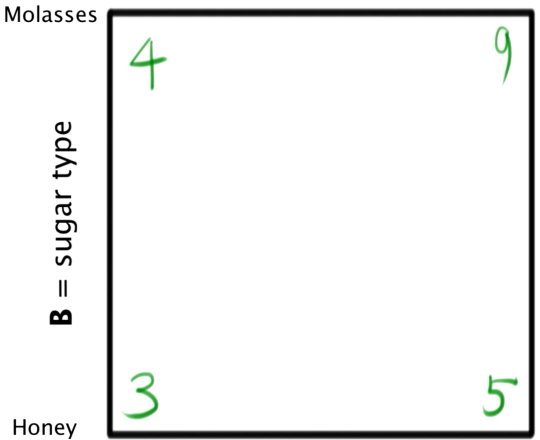


Main effects

Describes the effect of a factor on the outcome.

$$y = \text{baseline} + 1.75x_{\text{A}} + \ldots$$

Taste results



Baking time: "main effect of A"

Molasses (B+): 9 – 4 = 5

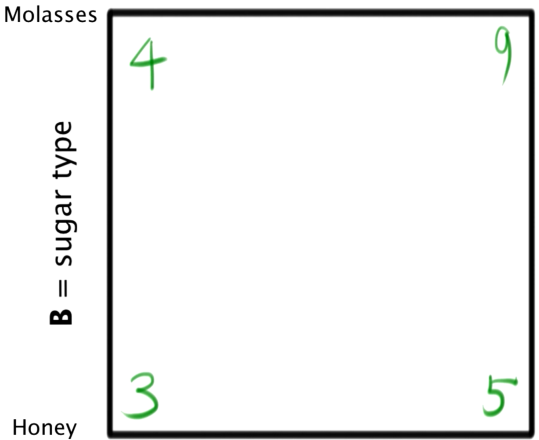
Honey (B–): 5 – 3 = 2

$$\text{Average} = \frac{(5+2)}{2} = \mathbf{3.5}$$

Report half the value: 0.5(3.5) = 1.75

$$y = \text{baseline} + 1.75x_{\text{A}} + \ldots$$

Taste results



Sugar type: "main effect of B"

Long time (A+): 9 – 5 = 4

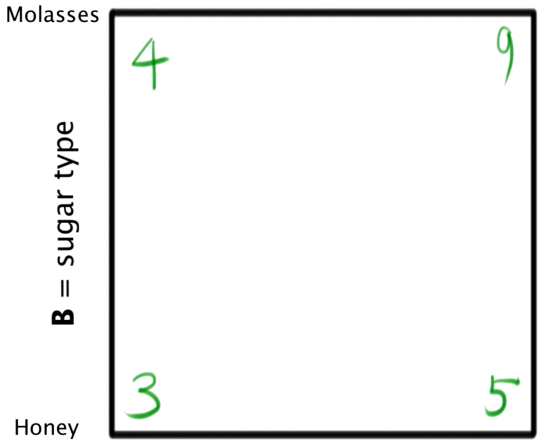
Short time (A–): 4 – 3 = 1

Average = $\frac{(4+1)}{2}$ = **2.5**

2.5 unit improvement in taste when switching from honey to molasses

$$y = \text{baseline} + 1.75x_{\text{A}} + 1.25x_{\text{B}} + \ldots$$

Taste results



Sugar type: "main effect of B"

Long time (A+): 9 – 5 = 4

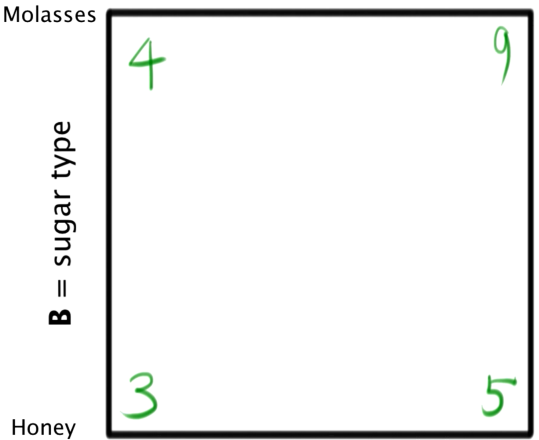
Short time (A–): 4 – 3 = 1

$$\text{Average} = \frac{(4+1)}{2} = \mathbf{2.5}$$

Report half the value: 0.5(2.5) = 1.25

$$y = \text{baseline} + 1.75x_A + 1.25x_B + 0.75x_Ax_B$$

Taste results



Interaction effect, the "AB effect"

Molasses (B+): 9 – 4 = 5

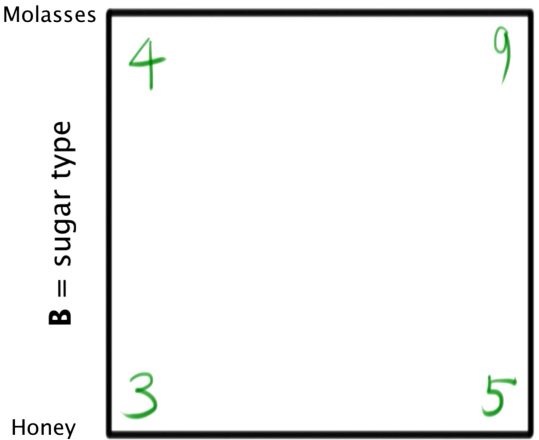
Honey (B–): 5 – 3 = 2

Interaction = $\frac{(5-2)}{2} = 1.5$

Report half the value: 0.5(1.5) = 0.75

$$y = \text{baseline} + 1.75x_{\text{A}} + 1.25x_{\text{B}} + 0.75x_{\text{A}}x_{\text{B}}$$

Taste results

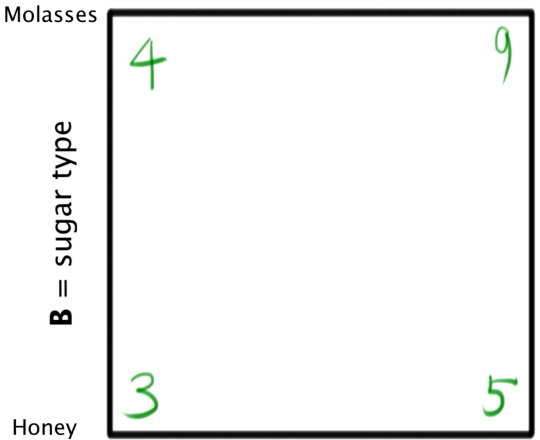


Interaction effect, the "BA effect"

"how differently factor B changes at the 2 levels of A"

$$y = \text{baseline} + 1.75x_A + 1.25x_B + 0.75x_Ax_B$$

Taste results



Interaction effect, the "BA effect"

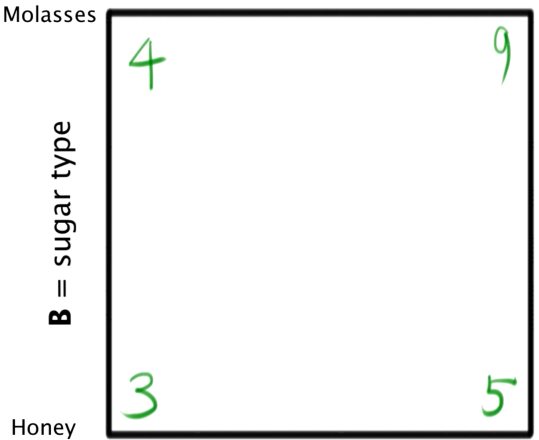
Long time (A+): 9 – 5 = 4

Short time (A–): 4 – 3 = 1

$$\text{Interaction} = \frac{(4-1)}{2} = 1.5$$

Report half the value: 0.5(1.5) = 0.75

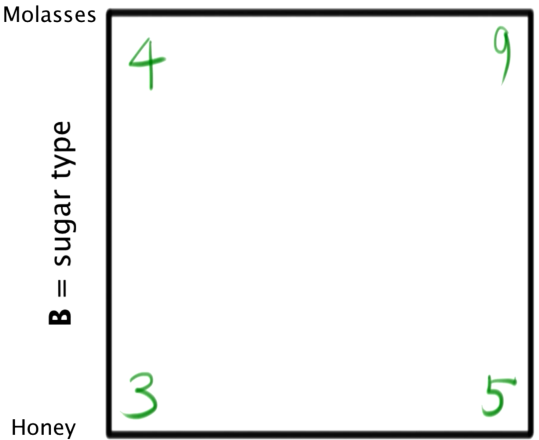
Taste results prediction model



$$y = \text{baseline} + 1.75x_A + 1.25x_B + 0.75x_Ax_B$$

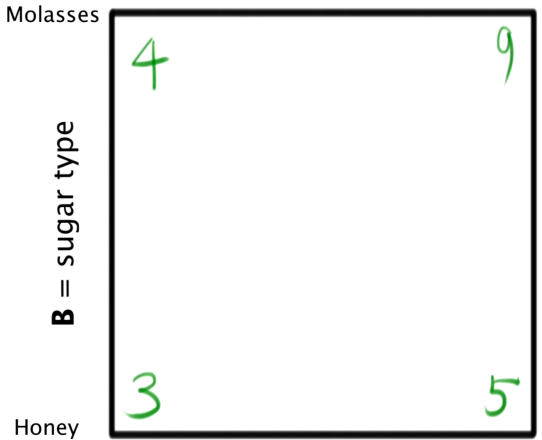
$$y = \text{baseline} + 1.75x_A + 1.25x_B + 0.75x_Bx_A$$

Taste results prediction model



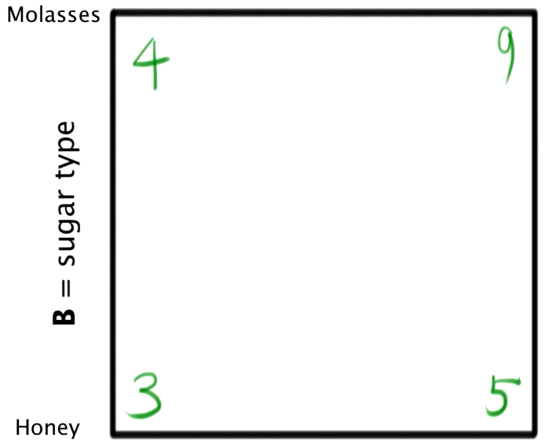
$$\textbf{baseline} = \frac{3+5+4+9}{4} = 5.25$$

Taste results prediction model



$$y = 5.25 + 1.75x_{\mathrm{A}} + 1.25x_{\mathrm{B}} + 0.75x_{\mathrm{A}}x_{\mathrm{B}}$$

Taste results prediction model



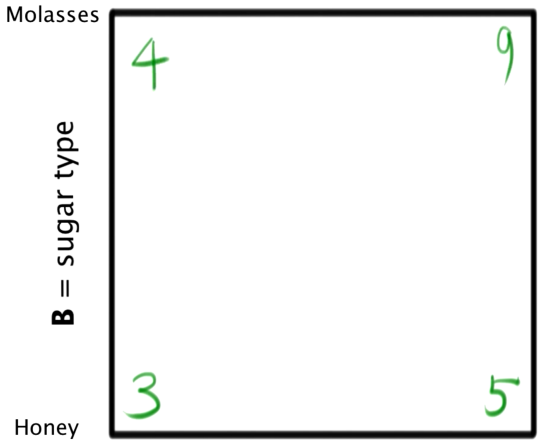
Taste prediction for **molasses**, and baking for **8 minutes**

$$y = 5.25 + 1.75x_A + 1.25x_B + 0.75x_Ax_B$$

What is the coding?

$x_A =$ _____ and $x_B =$ _____

Taste results prediction model



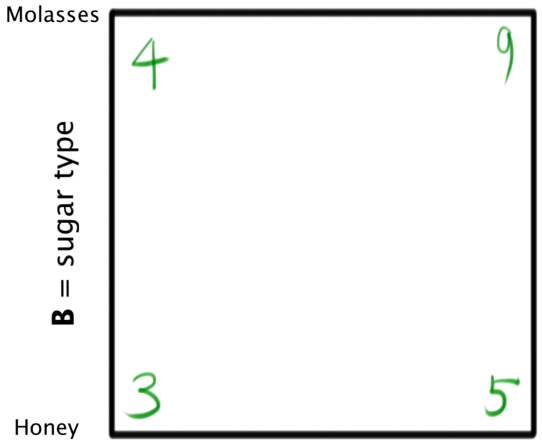
Taste prediction for **molasses**, and baking for **8 minutes**

$$y = 5.25 + 1.75x_A + 1.25x_B + 0.75x_Ax_B$$

$$\hat{y} = 5.25 + 1.75(-1) + 1.25(+1) + 0.75(-1)(+1)$$

$$\hat{y} = 5.25$$

Taste results prediction model



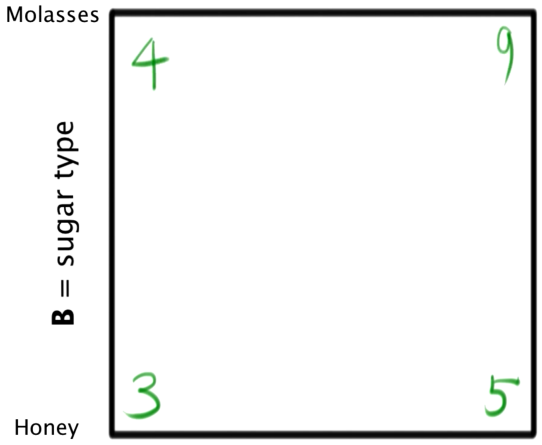
Taste prediction for **molasses**, and baking for **8 minutes**

$$y = 5.25 + 1.75x_A + 1.25x_B + 0.75x_Ax_B$$

$$\hat{y} = 5.25 + 1.75(-1) + 1.25(+1) + 0.75(-1)(+1)$$

$$\hat{y} = 5.25 \underbrace{-1.75}_{\text{baking time's contribution}}$$

Taste results prediction model



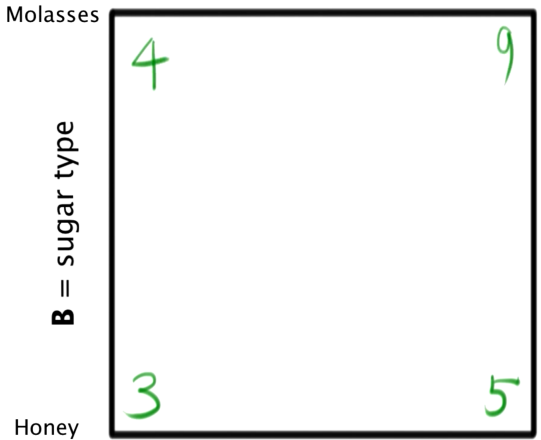
Taste prediction for **molass s**, and baking for **8 minutes**

$$y = 5.25 + 1.75x_A + 1.25x_B + 0.75x_Ax_B$$

$$\hat{y} = 5.25 + 1.75(-1) + 1.25(+1) + 0.75(-1)(+1)$$

$$\hat{y} = 5.25 - 1.75 \underbrace{+1.25}_{\text{sugar type's contribution}}$$

Taste results prediction model



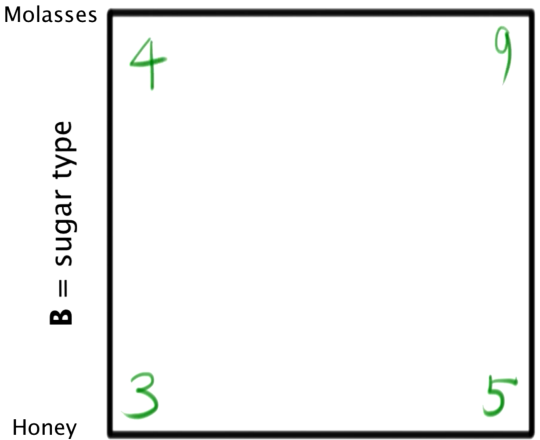
Taste prediction for **molasses**, and baking for **8 minutes**

$$y = 5.25 + 1.75x_A + 1.25x_B + 0.75x_Ax_B$$

$$\hat{y} = 5.25 + 1.75(-1) + 1.25(+1) + 0.75(-1)(+1)$$

$$\hat{y} = 5.25 - 1.75 + 1.25 \underbrace{-0.75}_{\text{interaction's contribution}}$$

Taste results prediction model



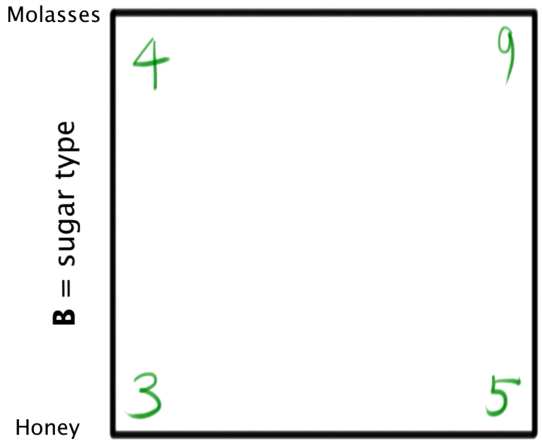
Taste prediction for **molasses**, and baking for **8 minutes**

$$y = 5.25 + 1.75x_A + 1.25x_B + 0.75x_Ax_B$$

$$\hat{y} = 5.25 + 1.75(-1) + 1.25(+1) + 0.75(-1)(+1)$$

$$\hat{y} = 5.25 - 1.75 + 1.25 - 0.75 = \mathbf{4}$$

Taste results prediction model



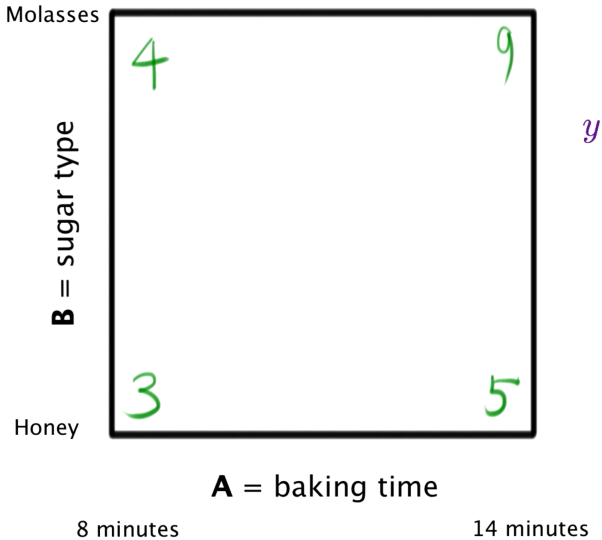
Taste prediction for **molasses**, and baking for **14 minutes**

$$y = 5.25 + 1.75x_A + 1.25x_B + 0.75x_Ax_B$$

$$\hat{y} = 5.25 + 1.75(+1) + 1.25(+1) + 0.75(+1)(+1)$$

$$\hat{y} = 5.25 + 1.75 + 1.25 \underbrace{+0.75}_{\text{interaction's works with us!}} = \mathbf{9}$$

Taste results prediction model



$$y = 5.25 + 1.75x_{\mathrm{A}} + 1.25x_{\mathrm{B}} + 0.75x_{\mathrm{A}}x_{\mathrm{B}}$$

In the next class we will see a two factor interaction (2-fi) in a system that has 3 factors.

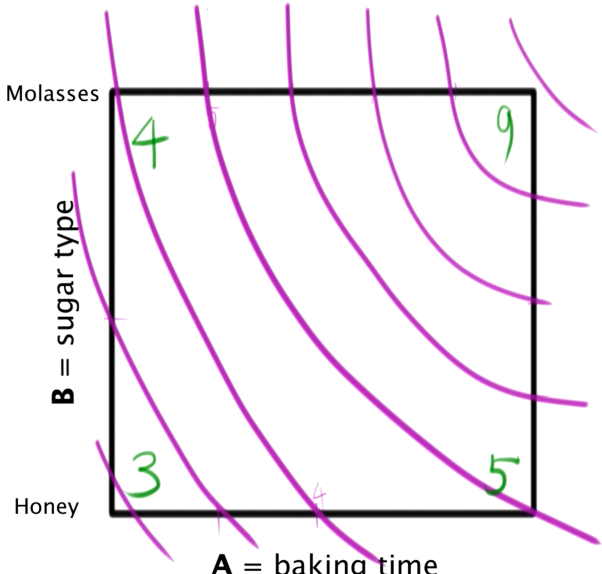
Always interpret your results

Critically think about your results by asking:

- what did I learn?
- what next experiments should I be doing?

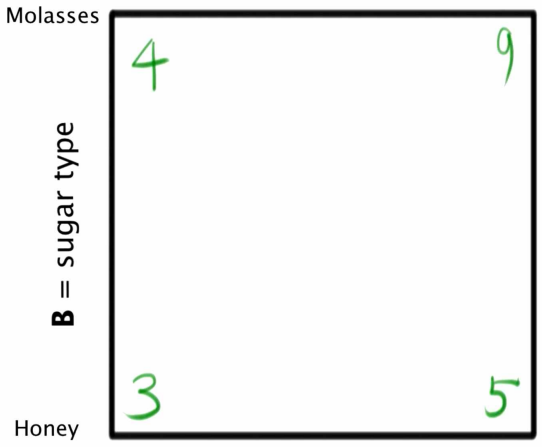
Experiments are expensive to repeat!

Taste results



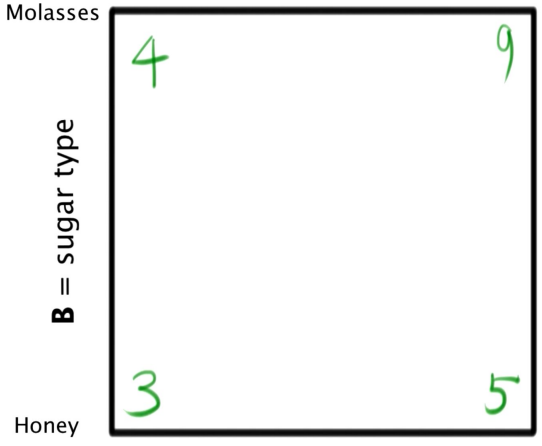
1 = bad

10 = exceptional



Kinds of Molasses First and second molasses have been used in foods for many years, and for a long time were the only form of sugar available to slaves and the poor of the rural South, usually bleached with sulfur dioxide and strongly sulfurous to the taste. Today, most molasses available to consumers are actually blends of molasses and syrups from various stages throughout the sugar-making process. They range from mild to pungent and bitter, from golden brown to brown-black. The darker the molasses, the more its sugars have been transformed by caramelization and browning reactions, and so the less sweet and more bitter it is. Light molasses may be 35% sucrose and 35% invert sugars, and 2% minerals; blackstrap molasses may be 35% sucrose, 20% invert sugars, and 10% minerals.

Molasses in Cooking The flavor of cane molasses is complex, with woody and green notes as well as sweet, caramel, buttery ones. Its complexity has made it a popular background flavor in many foods; popcorn



AND CONFECTIONERY

balls, gingerbread, licorice, barbeque sauces, and baked beans are examples. Cane molasses is usually but unpredictably acidic; its pH varies between 5 and neutral 7, so it can sometimes react with baking soda and produce leavening carbon dioxide in baked goods. Thanks to its invert sugars, it helps retain moisture in foods. And a variety of components contribute to a general antioxidant capacity, which helps slow the development of off-flavors.

Cane and Sorghum Syrups Cane syrups may be produced directly from cane juice at sugar factories, or from raw sugar at refineries. They generally contain a combination of sucrose (25–30%) and invert sugars (50%), are golden to medium brown in color, and have a mild flavor with caramel,