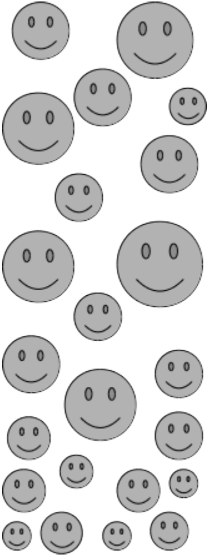
Quantitative genetics

- Natural selection relies on heritable variation
- Quantitative genetics focuses on **variation** in phenotypes
- Not looking at specific genes

Measuring heritable variation



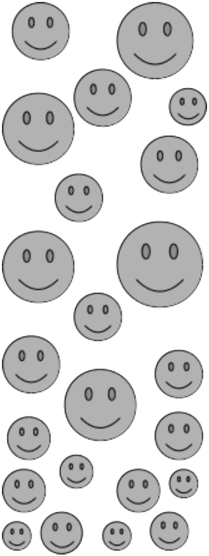
Components of phenotypic variation,

$$V_P = V_G + V_E.$$

- V_P = phenotypic variance
- V_G = genetic variance
- V_E = environmental variance

Total phenotypic variance is the sum of genetic variance and environmental variance.

Measuring heritable variation



Components of phenotypic variation,

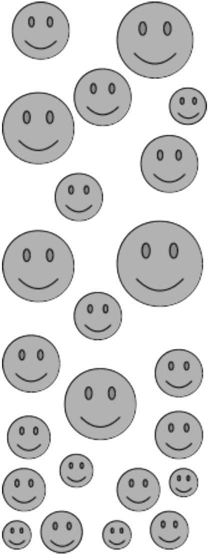
$$V_P = V_G + V_E.$$

We can break down V_G even further,

$$V_G = V_A + V_D + V_I.$$

- V_A = additive genetic variance
- V_G = dominance variance
- V_E = epistatic variance

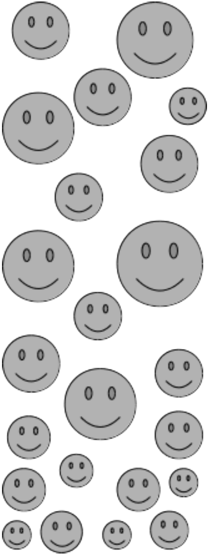
Additive genetic variation



Additive genetic variation (V_A) is the variation in phenotype attributable to the summed effects of individual alleles.

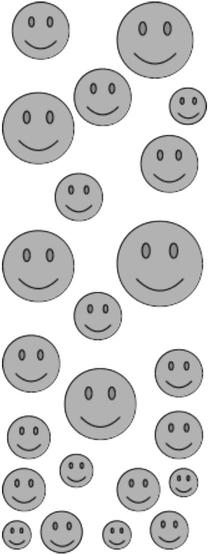
- Summed effects of individual alleles are independent of other alleles (hence ‘additive’).
- Natural selection can only see additive variation because dominance and epistasis break down from parent to offspring.

Heritability



The heritability of a phenotype determines the relative importance of heredity in determining the phenotypic value of a trait:
Heritability measures the proportion of the total phenotypic variation in a trait that is attributable to genetic as opposed to environmental effects.

Heritability



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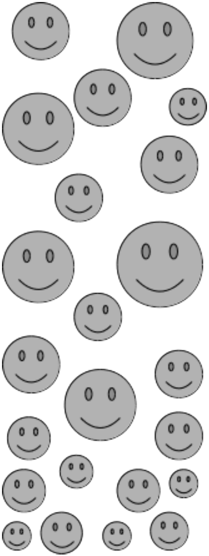
There are 2 types of heritability:

- Broad sense heritability: easier to measure, less informative
- Narrow sense heritability: harder to measure, more informative

Heritability

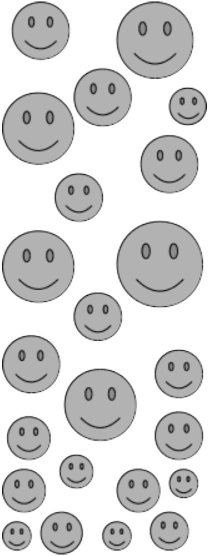


Broad sense heritability

$$H^2 = \frac{V_G}{V_P}$$

Total genetic variation divided by total phenotypic variation (must be between 0 and 1).

Heritability



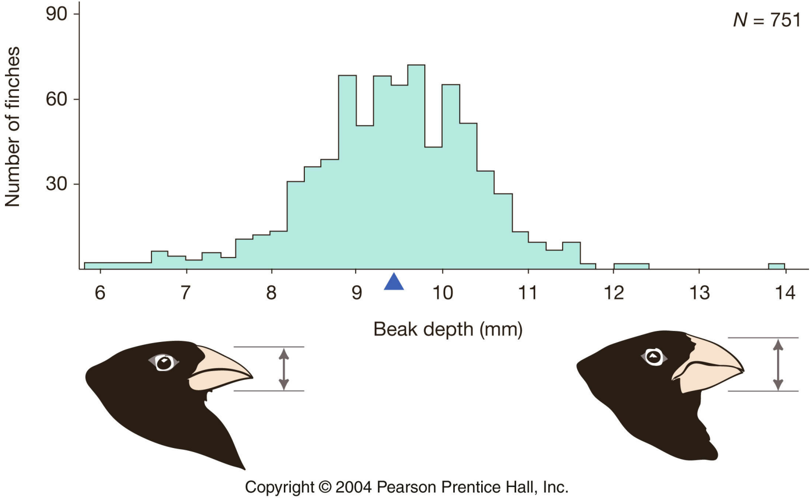
Narrow sense heritability

$$h^2 = \frac{V_A}{V_P}$$

Estimated 2 ways:

- Resemblance between relatives
- Response of a population to selection

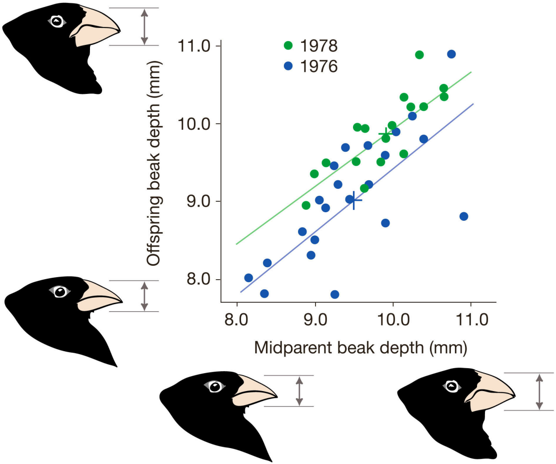
Postulate 1: Individual variation in beak depth



[1] Image: Freeman, S., & Herron, J. C. (2007). Evolutionary analysis (Vol. 834). Upper Saddle River, NJ: Pearson Prentice Hall. Page 82.

Postulate 2: Beak depth is heritable

Parents with deeper beaks tend to have offspring with deeper beaks, and vice versa.



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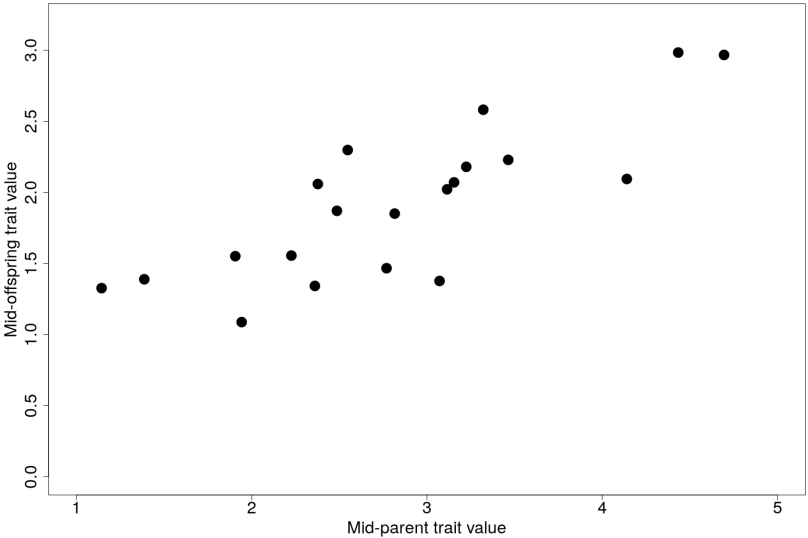
Estimating h^2 from parent and offspring resemblance



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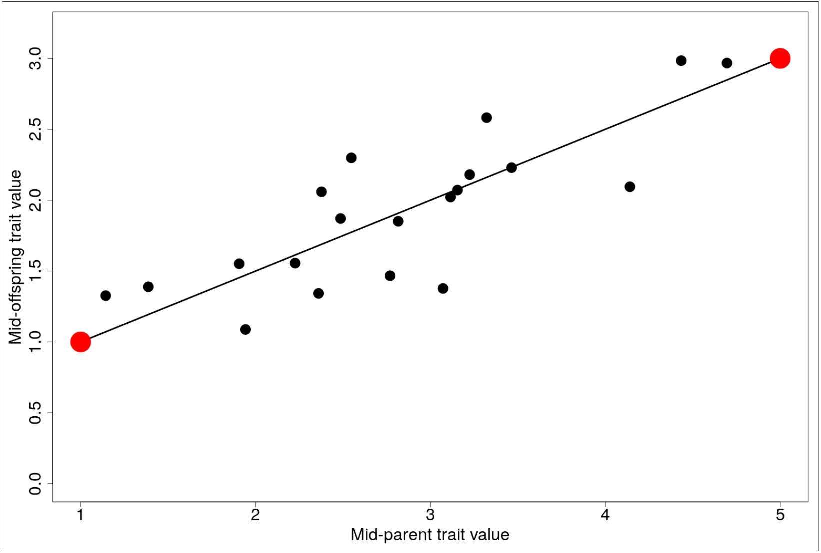

Estimating h^2 from parent and offspring resemblance

Narrow sense heritability can be estimated from the slope of the mid-parent to offspring regression line,

$$h^2 = \frac{rise}{run} = \frac{y_2 - y_1}{x_2 - x_1}.$$

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For the previous example,

$$h^2 = \frac{rise}{run} = \frac{3 - 1}{5 - 1} = \frac{2}{4} = 0.5.$$

Remember $h^2 = V_A/V_P$, so we can also find,
$V_A = h^2 \times V_P$.

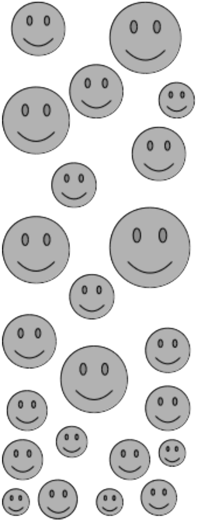
Heritability and the response to selection

Phenotypic response (R) of a trait to selection (S) in a generation depends on h^2,

$$h^2 \times S = R.$$

Given $h^2 = 0.5$, if we select for an increase of 2 in mean parent trait, we will get an actual change of 1 in offspring.

Heritability and the response to selection



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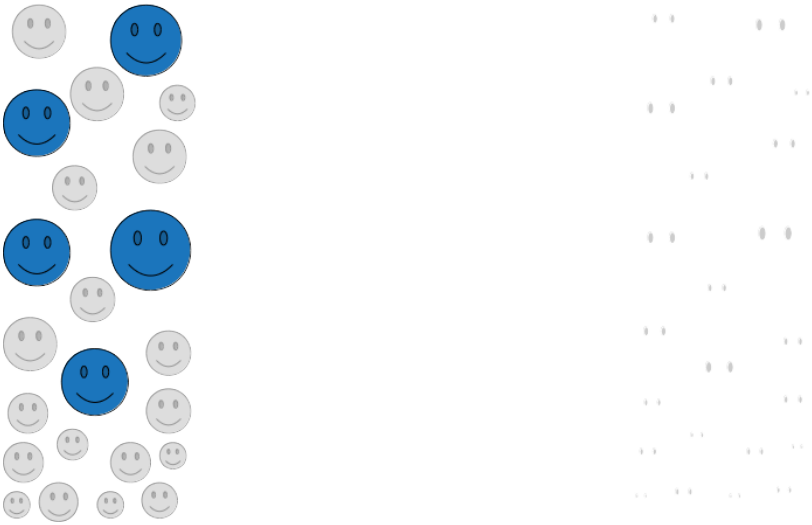

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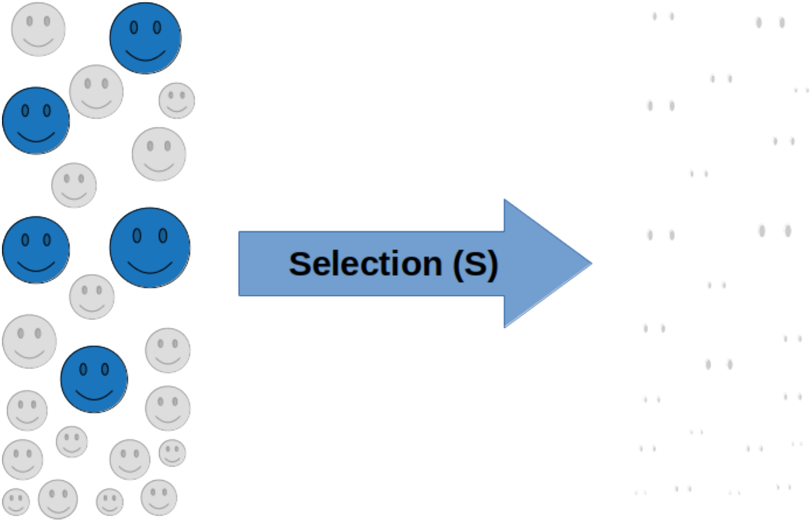

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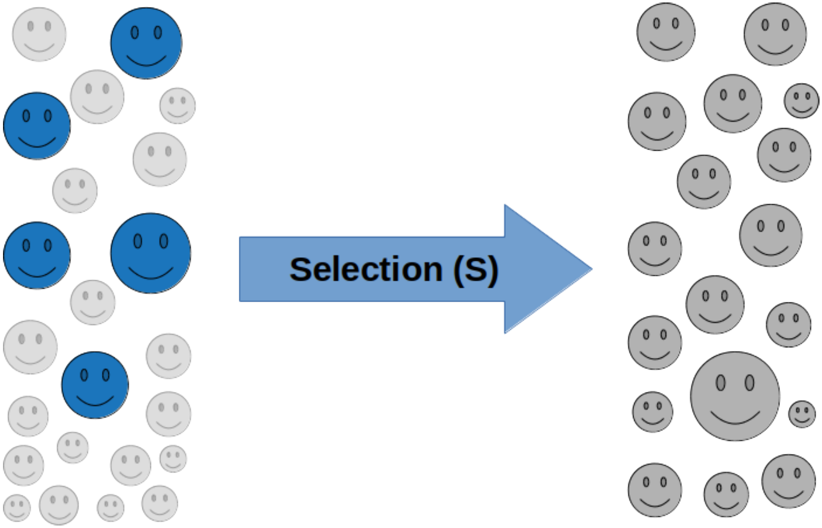

Heritability and the response to selection

Before selection

- $\bar{P}$: Mean phenotype of population
- P^*: Mean phenotype of selected parents
- $S = P^* - \bar{P}$: Selection differential

After selection

- $\bar{O}$: Mean phenotype for offspring of all population
- O^*: Mean phenotype for offspring of selected parents
- $R = O^* - \bar{O}$: Selection differential

$$h^2 = \frac{R}{S} = \frac{O^* - \bar{O}}{P^* - \bar{P}}$$

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Rearrange the above to get the Breeder's equation:

$$R = h^2 S$$

Example of heritability in response to selection

Suppose you are a plant breeder attempting to increase flower width in a horticultural species.

- Measure mean corolla width of population to be 2 cm
- Select parents with a mean corolla width of 2.8 cm
- Next generation, find mean corolla width is 2.2 cm

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Note that we can assume $\bar{O} = \bar{P}$.

Predicting evolutionary change

- Can also look at multiple traits simultaneously (multivariate)
- Breeder's equation is foundational for food security
  - Increasing crop[1] & agricultural[2] yield
  - Increasing crop drought resistance[3]
- Sustainable Development Goal (SDG) 2.

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[1]Cobb, J. N., et al. (2019). Enhancing the rate of genetic gain in public-sector plant breeding programs: lessons from the breeder's equation. *Theoretical and applied genetics* 132:627-645.

[2]Hill, W. G., & Kirkpatrick, M. (2010). What animal breeding has taught us about evolution. Annual review of ecology, evolution, and systematics, 41:1-19.

[3]Cooper, M., & Messina, C. D. (2023). Breeding crops for drought-affected environments and improved climate resilience. *The Plant Cell*, 35:162-186.