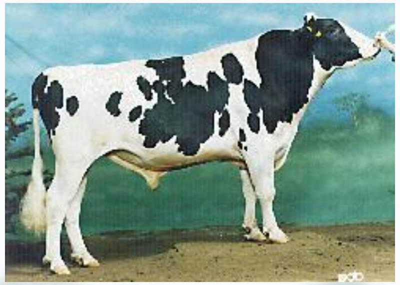
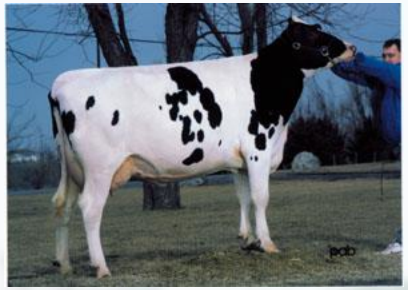
Colour *and* Horn Condition…

So, what happens when...





Black and White ***and*** Polled X Black and White ***and*** Polled

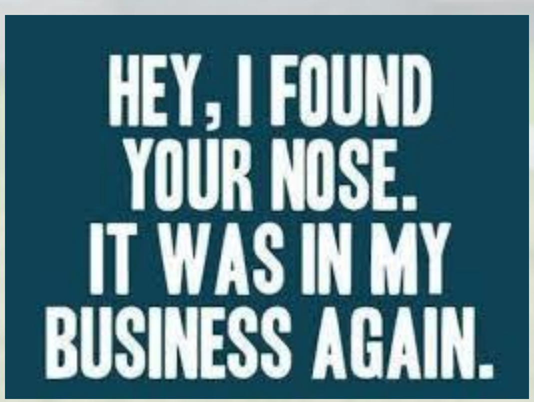
Genotypes?
Phenotypes?
Ratios?

Mendel's Second Law...

The Law of Independent Assortment

- Genes controlling separate traits segregate independently

- Segregation of genes at one locus does not influence segregation of genes at another locus



Punnett Square... again!

The “A” Gene and
The “B” Gene

	♂ AB	♂ Ab	♂ aB	♂ ab
♀ AB	AABB	AABb	AaBB	AaBb
♀ Ab	AABb	AAbb	AabB	Aabb
♀ aB	aABB	aABb	aaBB	aaBb
♀ ab	aAbB	aAbb	aaBb	aabb

Assume that A > a
and B > b

GENOTYPES?

1 : 2 : 1 : 2 : 4 : 2 : 1 : 2 : 1   RATIO

9 genotypes

	♂ AB	♂ Ab	♂ aB	♂ ab
♀ AB	AABB	AABb	AaBB	AaBb
♀ Ab	AABb	AAbb	AabB	Aabb
♀ aB	aABB	aABb	aaBB	aaBb
♀ ab	aAbB	aAbb	aaBb	aabb

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Assume that A > a
and B > b

PHENOTYPES?

9 : 3 : 3 : 1 RATIO

4 phenotypes

	♂ AB	♂ Ab	♂ aB	♂ ab
♀ AB	AABB	AABb	AaBB	AaBb
♀ Ab	AABb	AAbb	AabB	Aabb
♀ aB	aABB	aABb	aaBB	aaBb
♀ ab	aAbB	aAbb	aaBb	aabb

The Algebraic Method

For Genotypes…

AaBb X AaBb

1AA : 2Aa : 1aa

1BB : 2Bb : 1bb

1AABB : 2AaBB : 1aaBB : 2AABb : 4AaBb : 2aaBb : 1AAbb : 2Aabb : 1aabb

The Algebraic Method

For Phenotypes…

♀ AaBb X ♂ AaBb

3A? : 1aa
3B? : 1bb

9A?B? : 3aaB? : 3A?bb : 1aabb

Formulae for:

(assumes hybrid crossing, two alleles per locus and complete dominance)

	eg, Aa X Aa	eg, AaBb X AaBb	eg, AaBbCc X AaBbCc	eg, AaBbCcDd X AaBbCcDd		
Number of Traits / Number of Gene Pairs	**1**	**2**	**3**	**4**	**...**	***n***
Number of Gametes	2	4	8	16	...	2^n
Number of Combinations	4	16	64	256	...	$(2^n)^2$
Number of Genotypes	3	9	27	81	...	3^n
Number of Phenotypes	2	4	8	16	...	2^n

But even if those assumptions don't hold, Mendel's 2nd Law of *Independence of Events* will work

Shorthorn Cattle…

X

Monohybrid Cross

Rr

X

Rr

RR

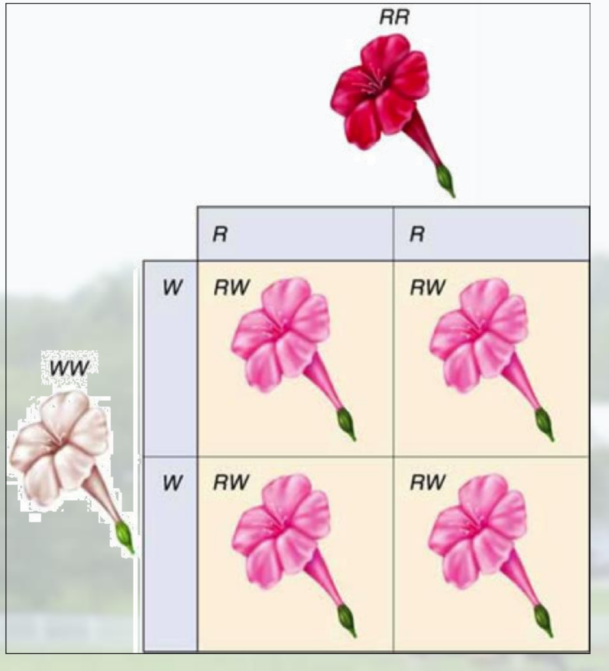
rr

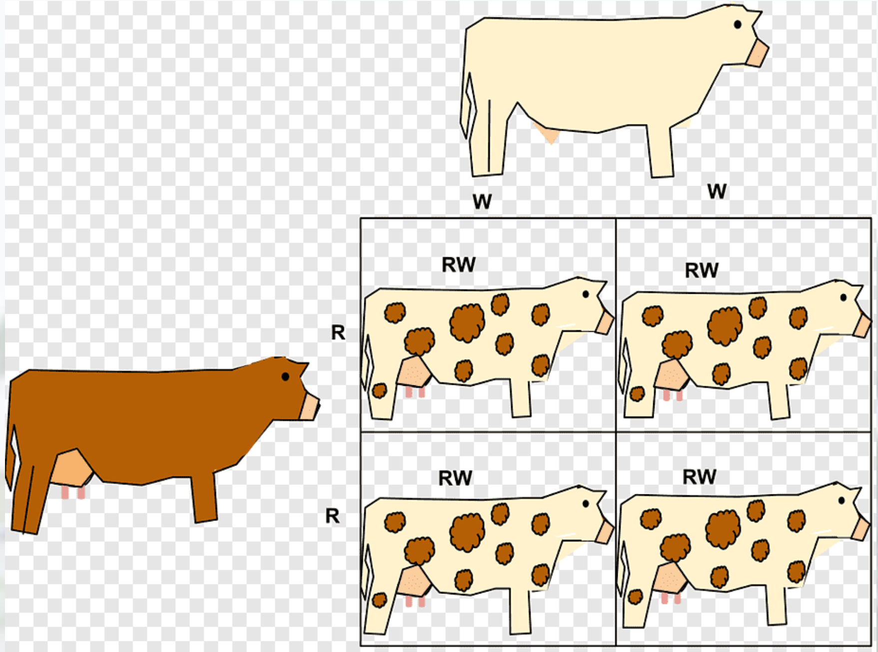
Coat Colour in Shorthorn Cattle…
an example of Codominance

And we use the notation of

R = r   or   R = W

Incomplete Dominance versus *Co*dominance

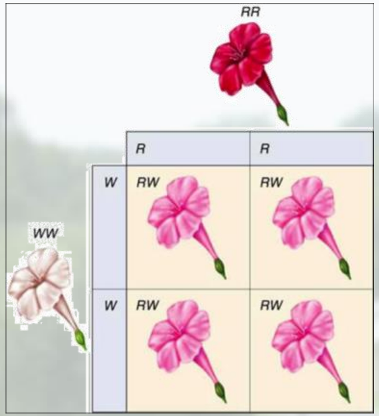


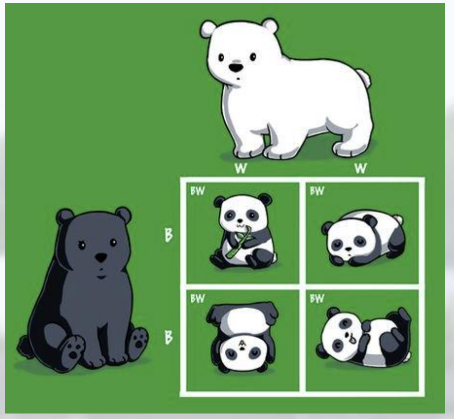


- With incomplete dominance, neither allele gets to express itself completely (e.g., there is *no* red and there is *no* white).
- Neither allele dominates

- With codominance, both alleles get to express themselves partially (e.g., some black *and* some white).
- Both alleles dominate

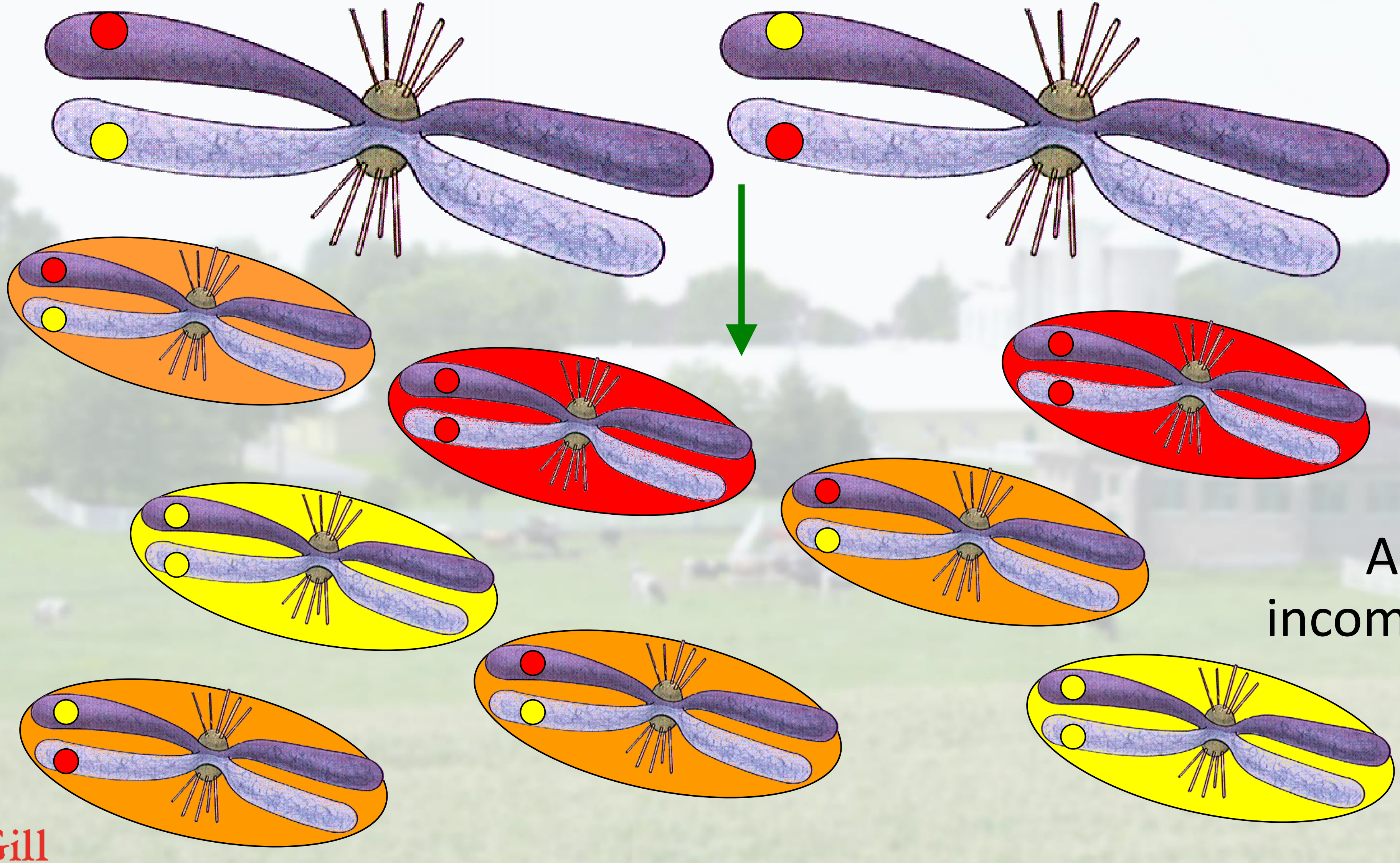
Incomplete Dominance versus *Codominance*





In <u>both</u> cases, the genotype is heterozygous.

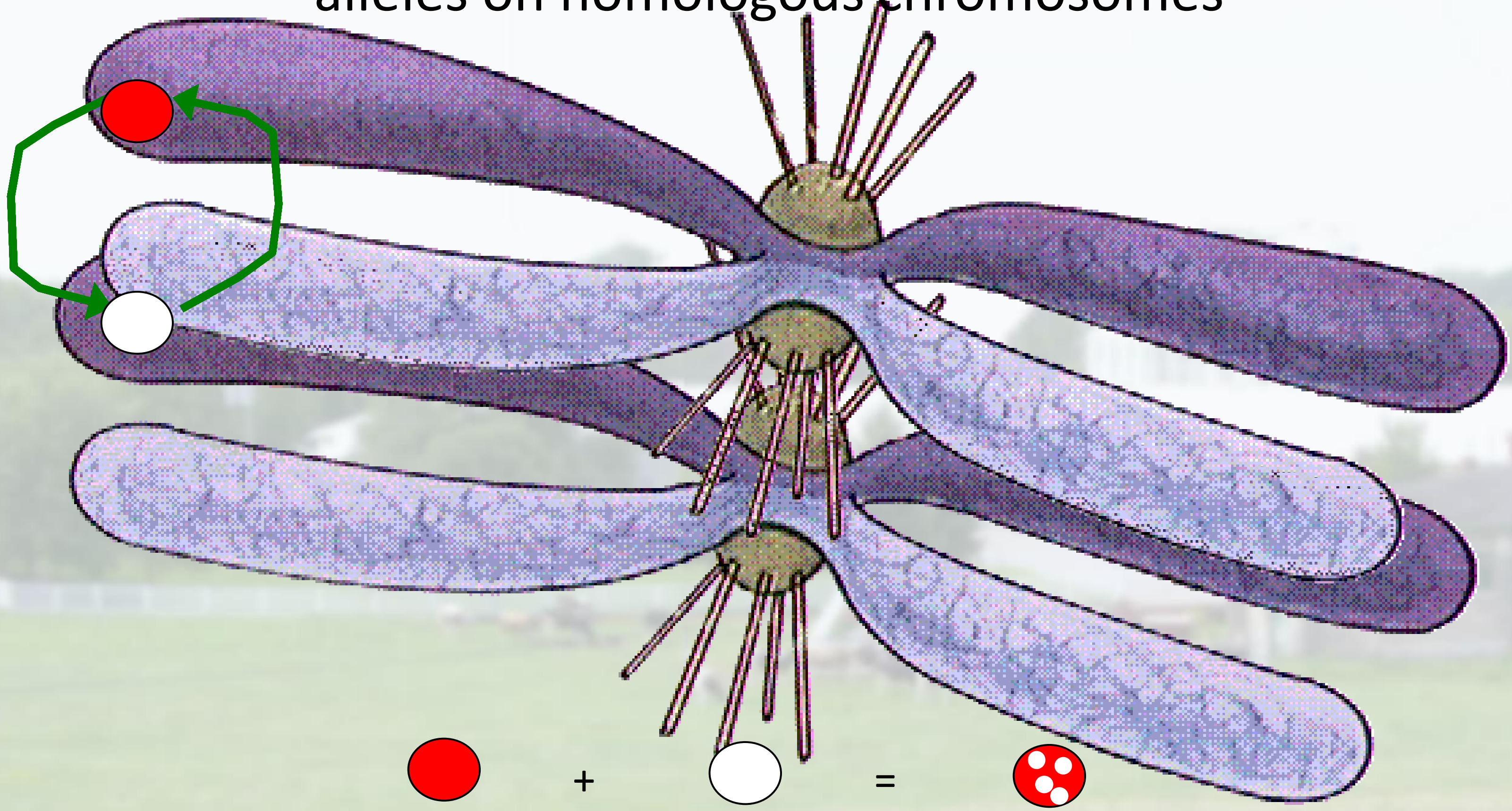
The Monohybrid Cross… again (but 🔴 = 🟡)



An example of
incomplete dominance

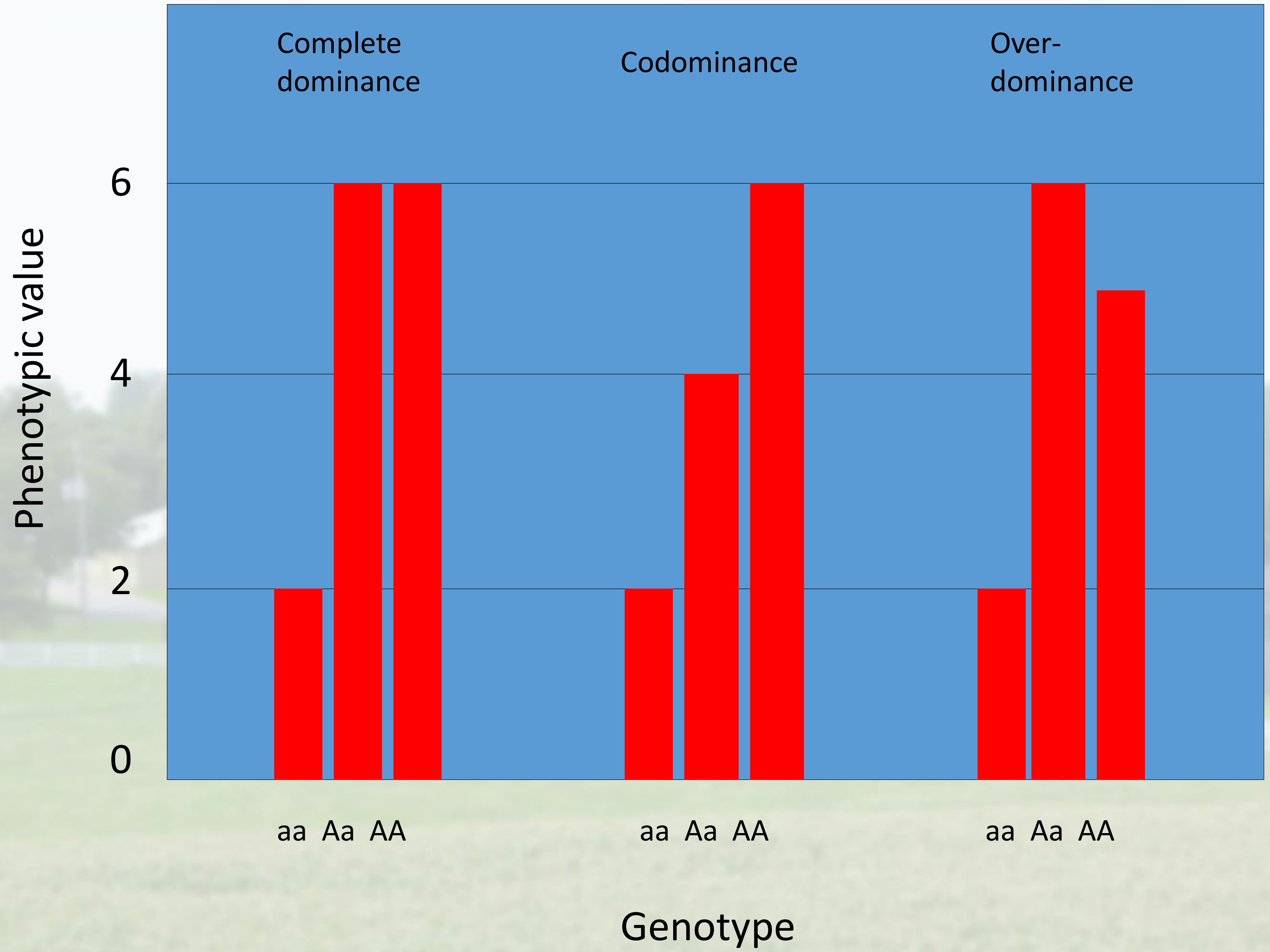
Allelic Interaction

Interactions between corresponding alleles on homologous chromosomes

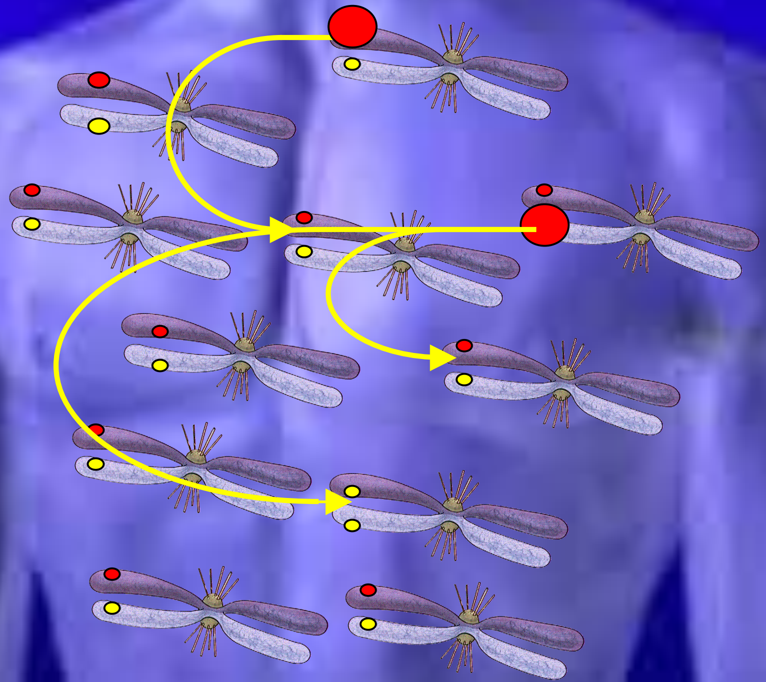


An example of codominance

Red (R) + White (r) = Roan (Rr)


Complete dominance
Codominance
Over-dominance
Phenotypic value
6
4
2
0
aa Aa AA
aa Aa AA
aa Aa AA
Genotype

EPISTATIC Interaction



Genes/Alleles at *one* locus modify the expression of genes at *another* locus.

They are called "modifier" genes.

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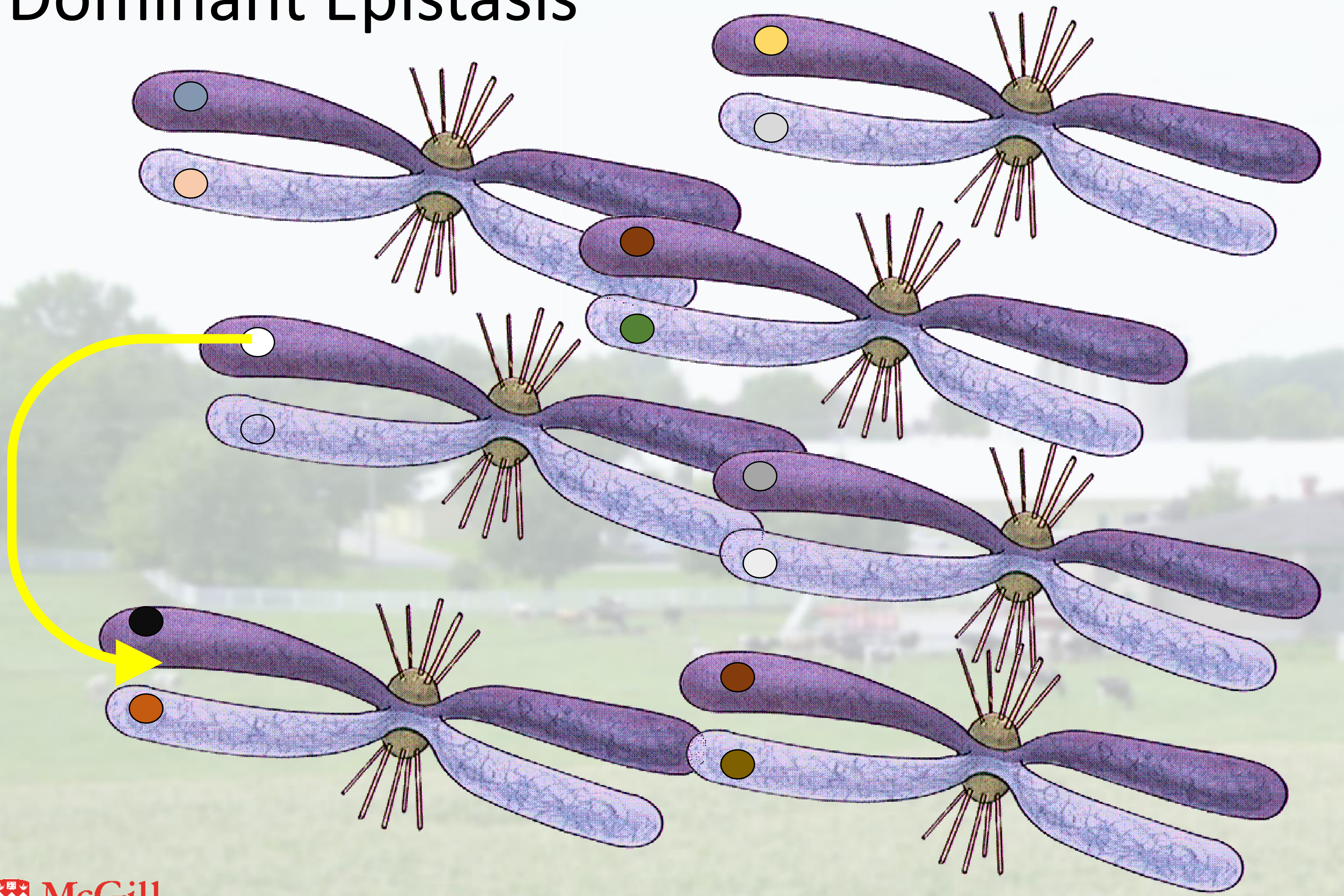
Dominant Epistasis



A ***dominant*** allele at *one* locus modifies the expression of genes at *another* locus

Bb Ww X Bb Ww

B_	W_	9	12 white
bb	W_	3	
B_	ww	3	3 black
bb	ww	1	1 brown

Assume that B > b
and W > w

PHENOTYPES

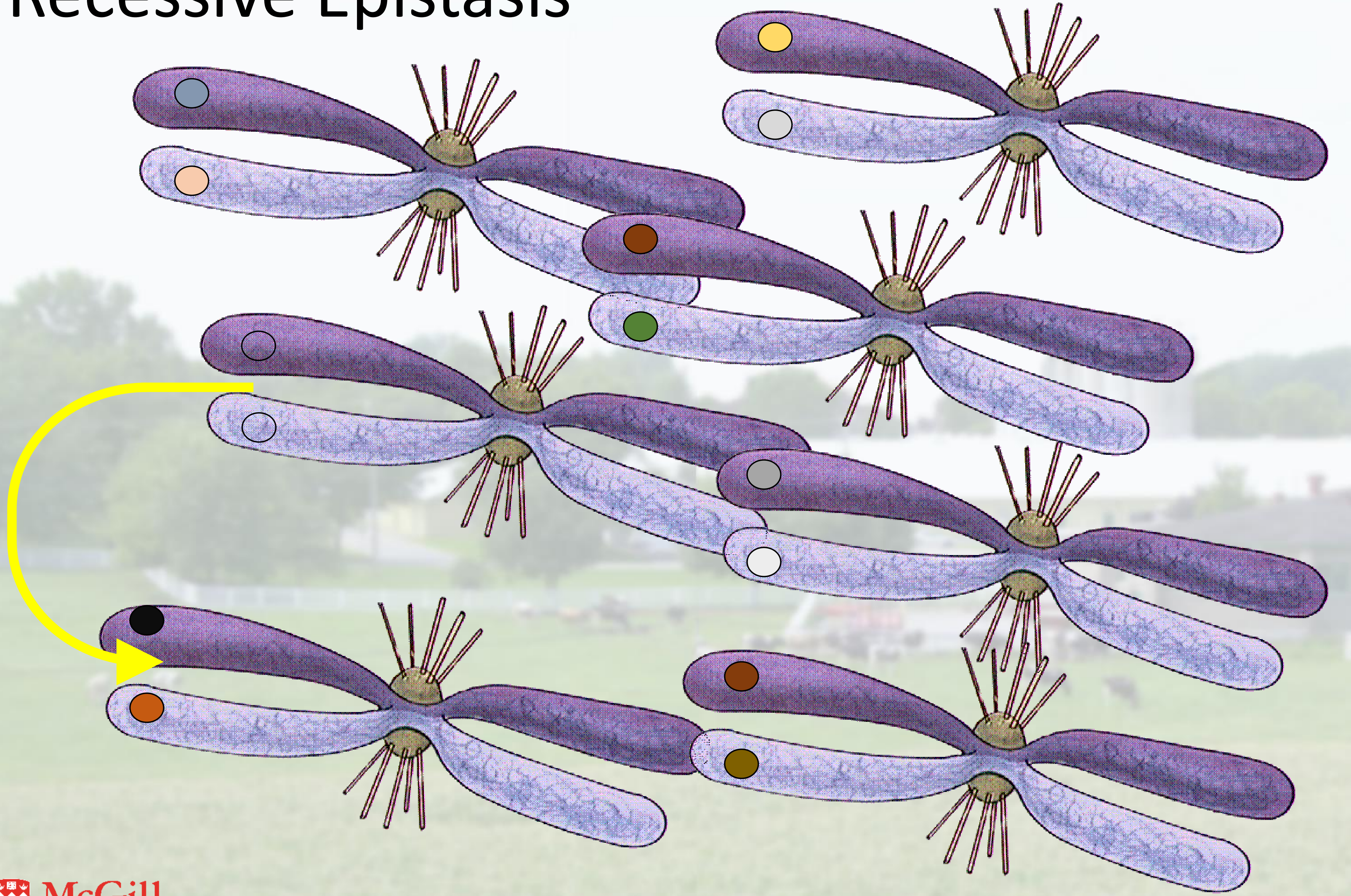
~~9 : 3 : 3 : 1~~

12 : 3 : 1

Because...
W_ dominates
all forms of
the B genotype

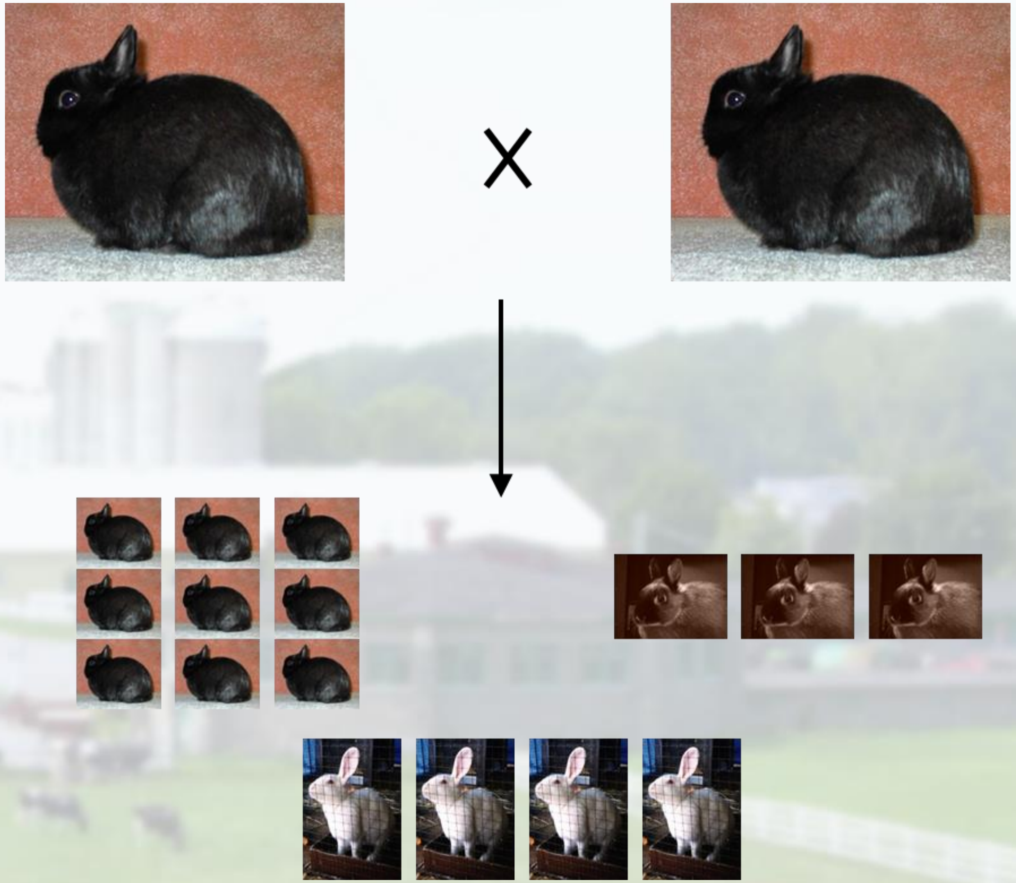
	♂ BW	♂ Bw	♂ bW	♂ bw
♀ BW	BBWW	BBWw	BbWW	BbWw
♀ Bw	BBwW	BBww	BbwW	Bbww
♀ bW	bBWW	bBWw	bbWW	bbWw
♀ bw	bBwW	bBww	bbwW	bbww

Recessive Epistasis



A ***homozygous recessive*** pair of alleles at *one* locus modifies the expression of genes at *a second* locus

Bb	Cc	X	Bb Cc
B_	C_	9	9 black
bb	C_	3	3 brown
B_	cc	3	4 albino
bb	cc	1	



Assume that B > b
and C > c

PHENOTYPES

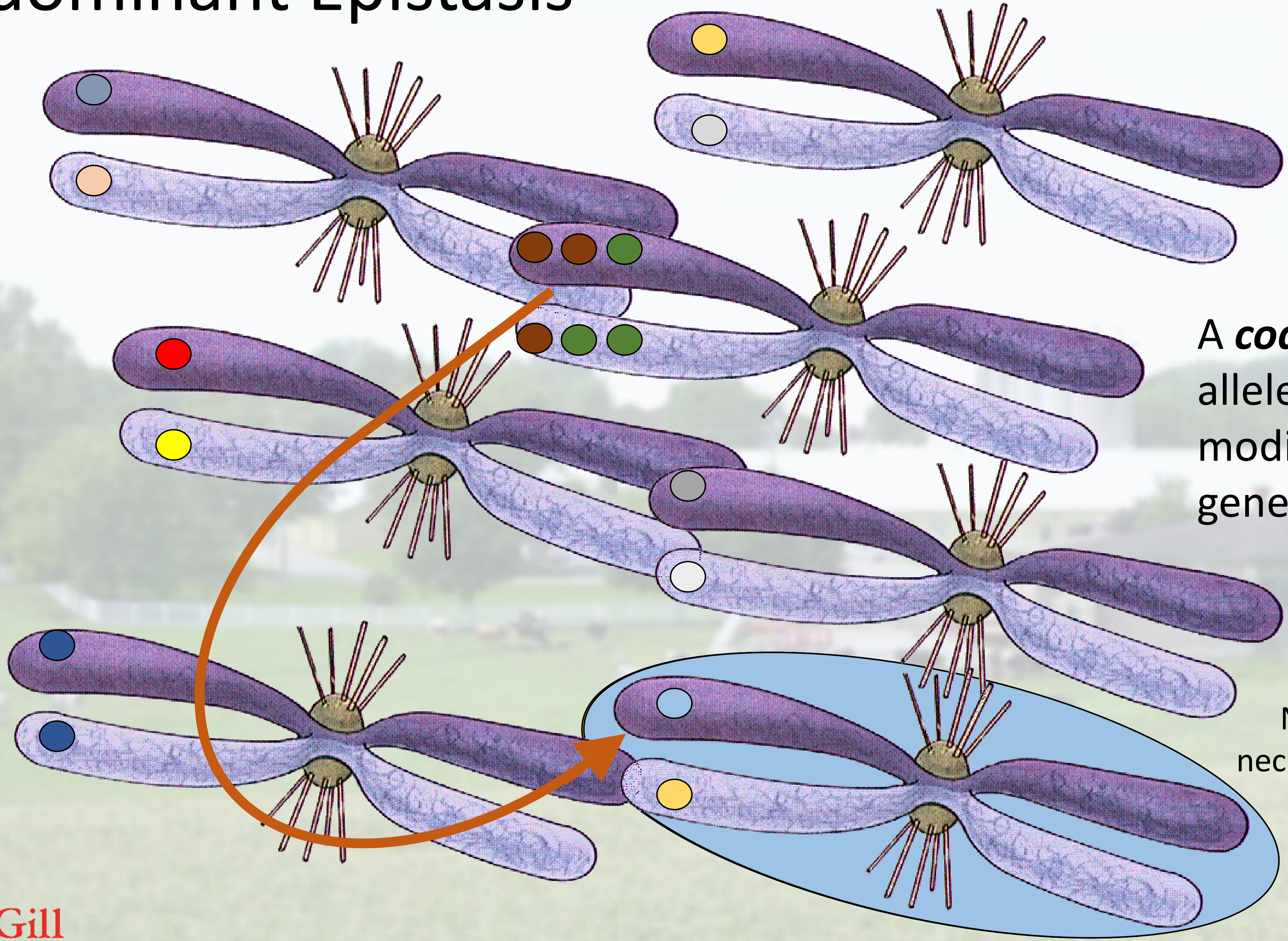
~~9 : 3 : 3 : 1~~

9 : 3 : 4

Because...
cc “dominates”
all forms of
the B genotype

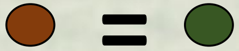
	♂ BC	♂ Bc	♂ bC	♂ bc
♀ BC	BBCC	BBCc	BbCC	BbCc
♀ Bc	BBcC	BBcc	BbcC	Bbcc
♀ bC	bBCC	bBCc	bbCC	bbCc
♀ bc	bBcC	bBcc	bbcC	bbcc

Codominant Epistasis



A ***codominant*** pair of alleles at *one* locus modifies the expression of genes at *a second* locus

Note: "codominant" does not necessarily mean that the alleles are in a "heterozygous" state



X

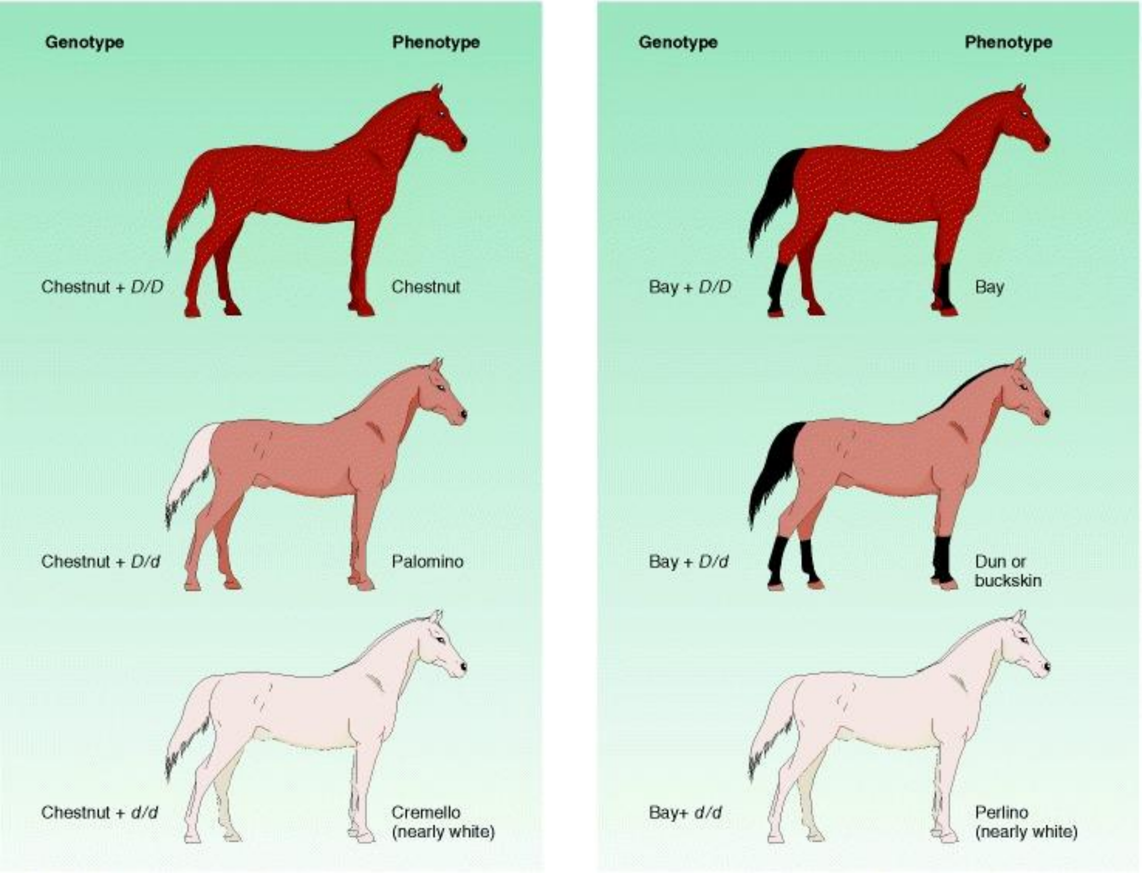
R_	DD	3	3
R_	Dd	6	6
R_	dd	3	4
rr	dd	1	
rr	Dd	2	2
rr	DD	1	1

Normally, Bay is dominant to Chestnut

Ee Cc X Ee Cc

(Buckskin) (Buckskin)

E_	CC	3	3 bay
E_	Cc	6	6 buckskin
E_	cc	3	4 off-white (Probably 3 Perlino and 1 Cremelo)
ee	cc	1	
ee	Cc	2	2 palomino
ee	CC	1	1 chestnut



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Creeper Condition in Poultry: Ratios don’t add up!

Cc

X

Cc

???

~~CC~~ : 2Cc : cc

Lethal Alleles…

Coat Colour in Mice

Creeper Condition in Chickens

Manx Cats (no tail)

Comprest Dwarfism in Cattle

A "lethal" condition arises when some allelic combination (e.g., mm) leads to an embryonic death, and so the resulting offspring (and its associated phenotype) is never observed, leading to an "unexpected" ratio (i.e., numbers don't add up to 4 or 16 or…).

Multiple alleles

(refers to 3+ alleles available at any one locus)

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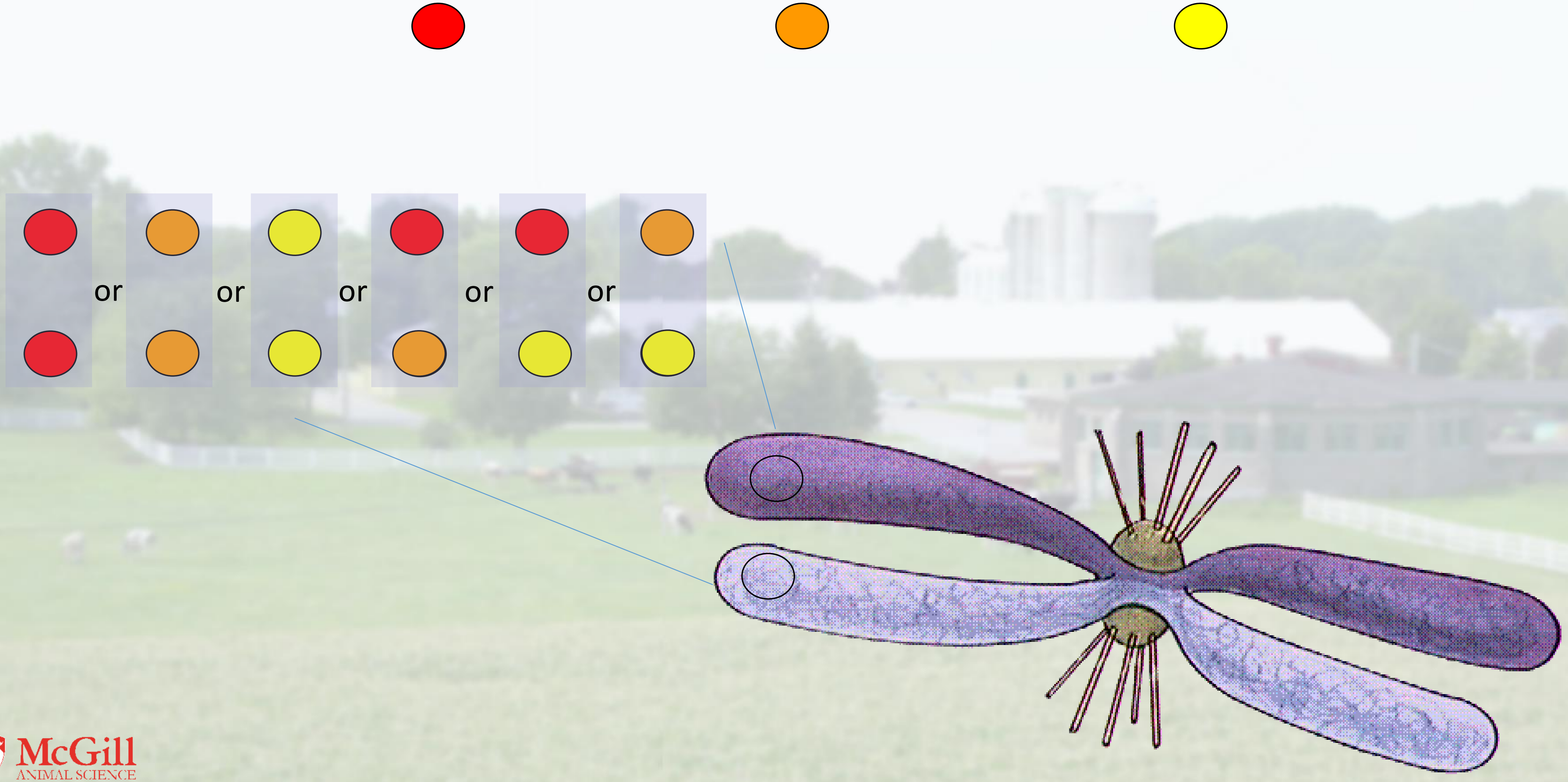
BUT there are still always ***only two loci*** !

Multiple alleles



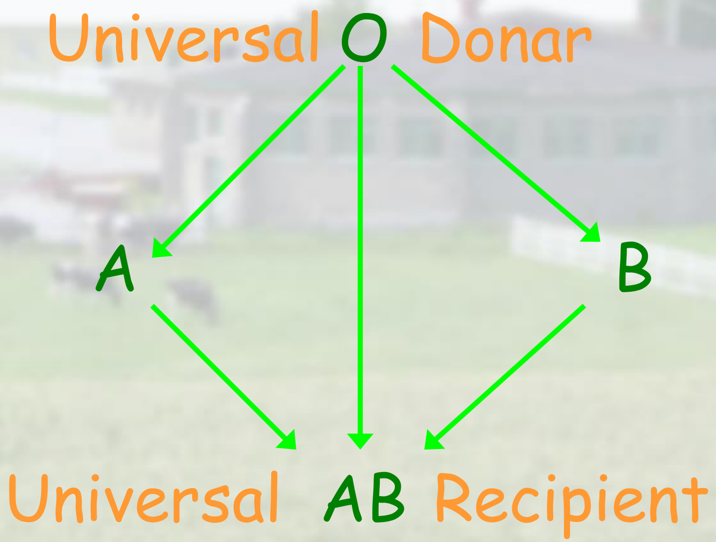
Multiple Alleles - Blood Groups in Humans

3 alleles (A, B and a)

$$A = B > a$$

i.e., $A = B$
$A > a$
$B > a$

Genotype	Blood Group
aa	O
AA, Aa	A
BB, Ba	B
AB	AB



Coat Colour in Holstein Cattle… a closer look!

The Red-Black Factor
The "Telstar" Factor

3 alleles (B, β and b)

$$B > \beta > b$$

BB or Bβ or Bb = "True" Black & White
ββ or βb = Red-Black Factor
bb = Red & White

Bb

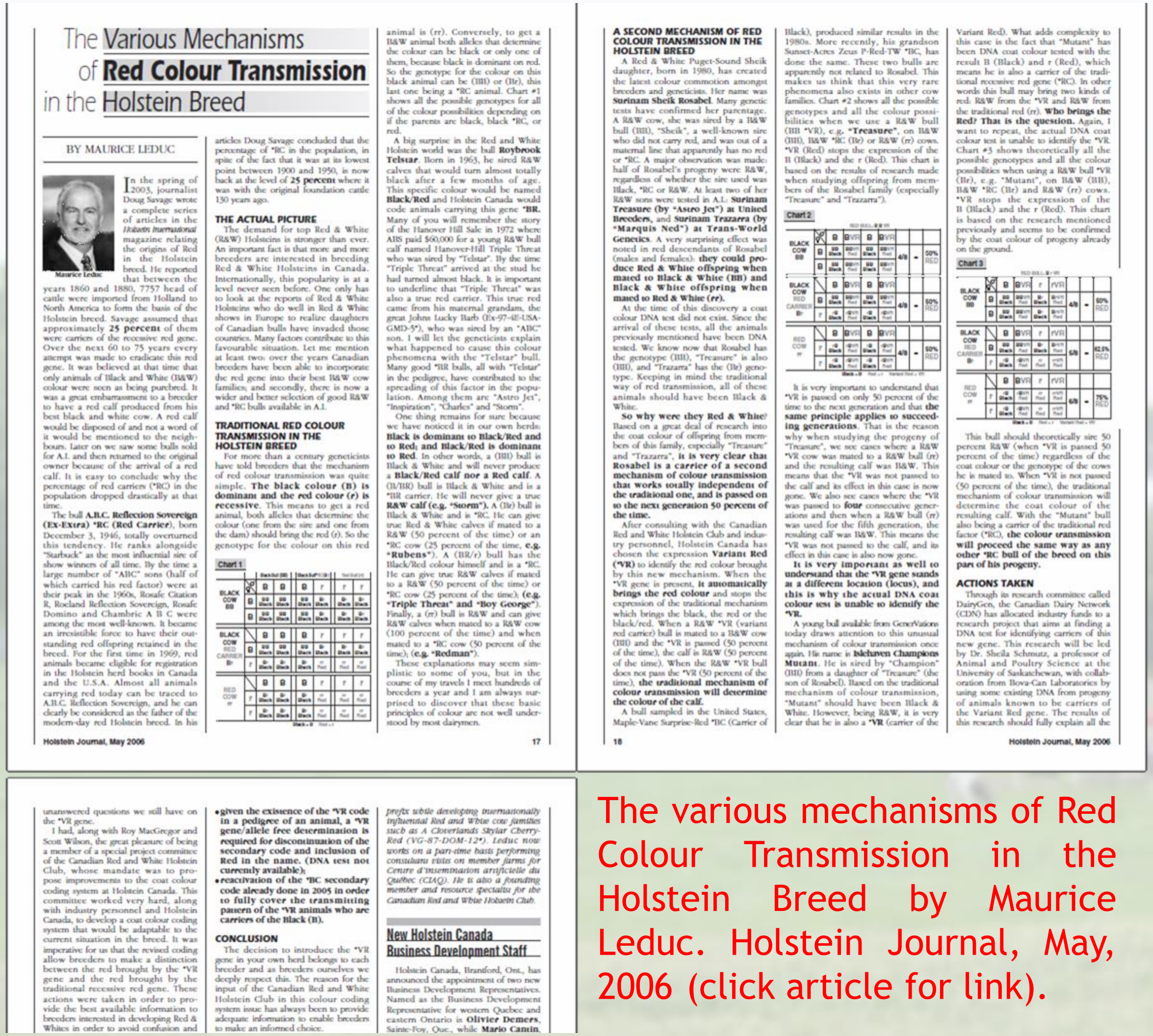
βb

Is there a cross that
can give all 3 <u>phenotypes</u>?

Why is this *not* a case of codominance?

2 Black & White 1 Red-Black & White 1 Red & White

For more information (*not for the exam!!*)

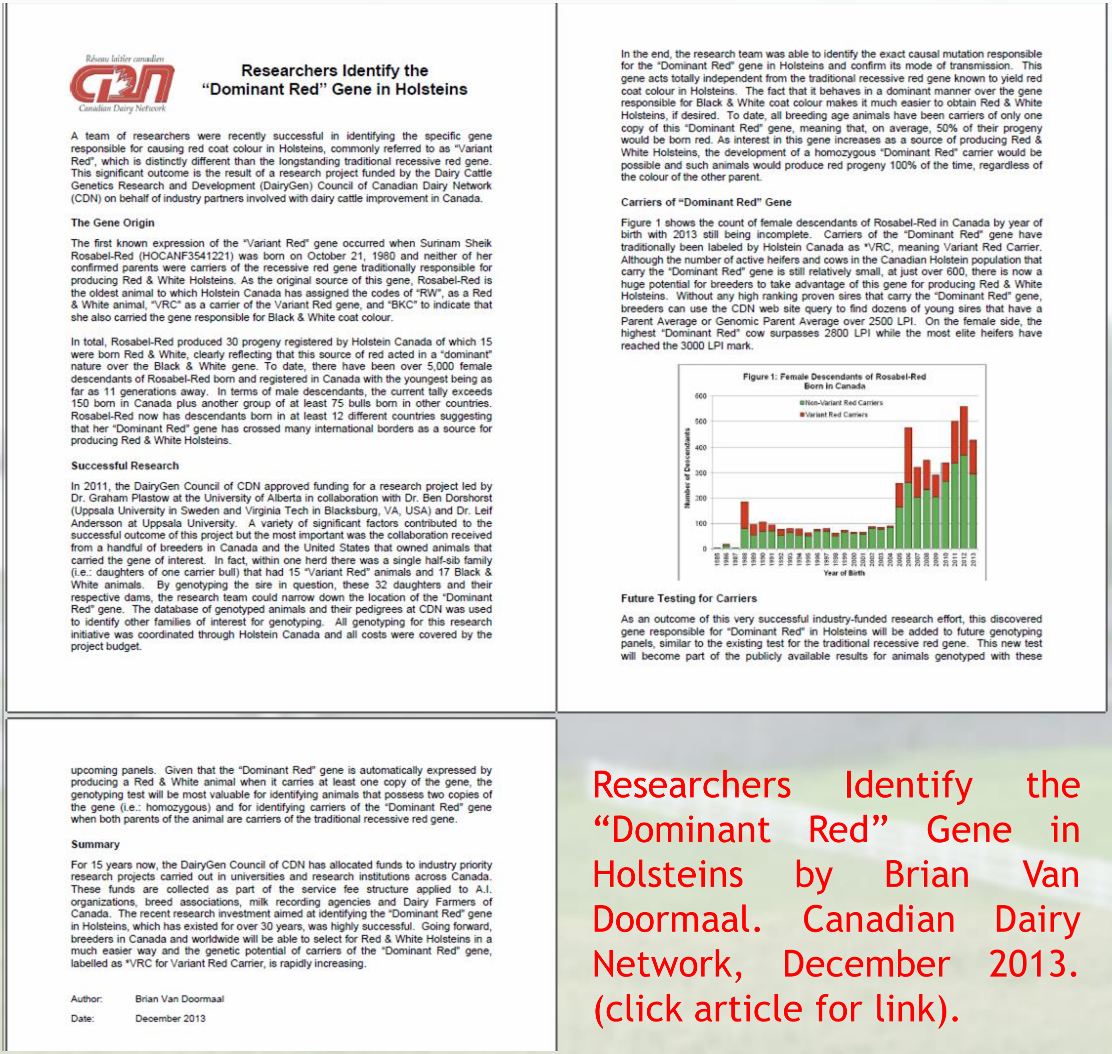


The Various Mechanisms of Red Colour Transmission in the Holstein Breed

BY MAURICE LEDUC

The various mechanisms of Red Colour Transmission in the Holstein Breed by Maurice Leduc. Holstein Journal, May, 2006 (click article for link).

*http://www.genefix.it/docs/**Red**_Color_Transmission_eng.pdf*



Researchers Identify the "Dominant Red" Gene in Holsteins

Researchers Identify the "Dominant Red" Gene in Holsteins by Brian Van Doormaal. Canadian Dairy Network, December 2013. (click article for link).

https://www.cdn.ca/document.php?id=339

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Formulae for numbers of...

(assumes hybrid crossing, two alleles per locus and complete dominance)

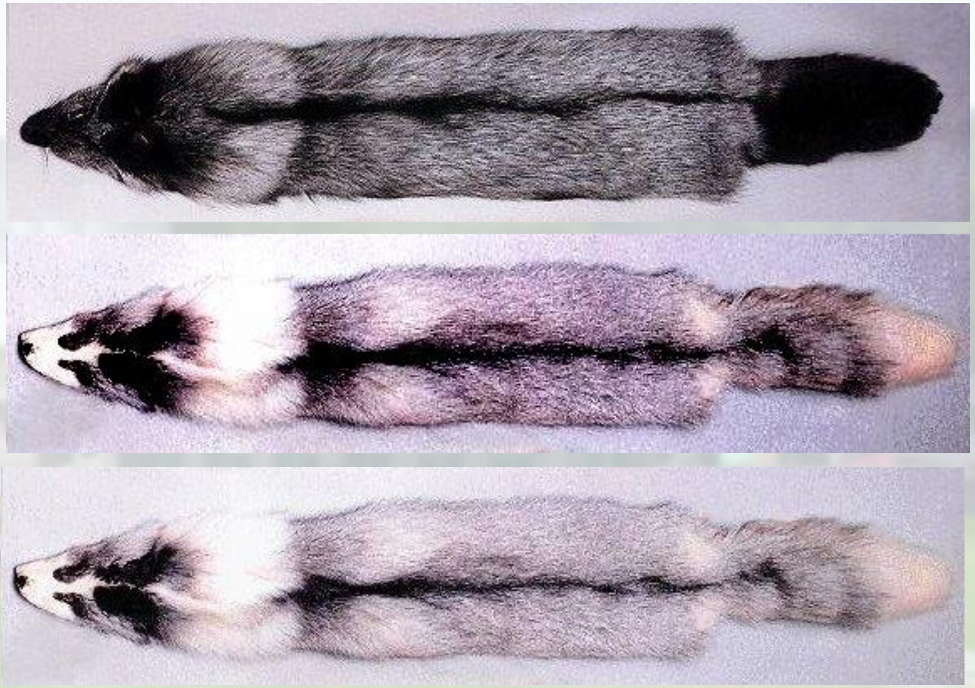
Number of Traits / Number of Gene Pairs	1	2	3	4	...	n
Number of Gametes	2	4	8	16	...	2^n
Number of Combinations	4	16	64	256	...	$(2^n)^2$
Number of Genotypes	3	9	27	81	...	3^n
Number of Phenotypes	2	4	8	16	...	2^n

Coat Colour in Foxes

(Simplified)

3 alleles: S, s, and p   How many combinations?

(S = s and S = p)



SS = Silver

Ss = Platinum-Silver

Sp = Platinum

ss
sp
pp
} Lethal

Platinum-Silver		Platinum
Ss	x	Sp

↓

SS	Sp	Ss	sp
Silver	Platinum	Platinum-Silver	X

Remember…
PEA comb is dominant to SINGLE comb

Rose comb

X

Pea comb

1 : 1 : 1 : 1

Walnut Rose Pea Single

X

Walnut comb

Walnut comb

9 : 3 : 3 : 1

Walnut Rose Pea Single

What is the mode of inheritance?

RrPp X RrPp

Phenotypes	Genotypes	Frequency
Walnut	R_P_	9/16
Pea	R_pp	3/16
Rose	rrP_	3/16
Single	rrpp	1/16

Double Recessive Epistasis!

Sex-*influenced* Inheritance

- Genes are found on the autosomal chromosomes
    - exactly like all the others so far
    - sex-influenced is <u>NOT</u> on the sex chromosomes

- The phenotype of the heterozygote is determined by the <u>sex</u> of the individual, mainly because of differences in the presence of certain hormones

AA	All ♂ and ♀ = Phenotype 1	
aa	All ♂ and ♀ = Phenotype 2	
Aa	♂ = Phenotype 1	♀ = Phenotype 2

Baldness in Humans – an example of a sex-influenced trait

Genotype	Female ♀	Male ♂
B^+B^+	Bald	Bald
B^+B^-	Full Hair	Bald
B^-B^-	Full Hair	Full Hair

So, in Females, Full Hair is dominant to Baldness but in Males, Baldness is dominant to Full Hair

Sex-influenced Traits…

- Examples in livestock…
- Horns are normally *dominant* in **male** sheep and *recessive* in **female** sheep
- The "beard" is normally dominant in male goats and recessive in female goats

Coat Colour in Ayrshire Cattle…

MM

Mahogany

mm

Red

Mm

♂ = Mahogany

♀ = Red

Note: This does *not* mean that all MM are males or all mm are females

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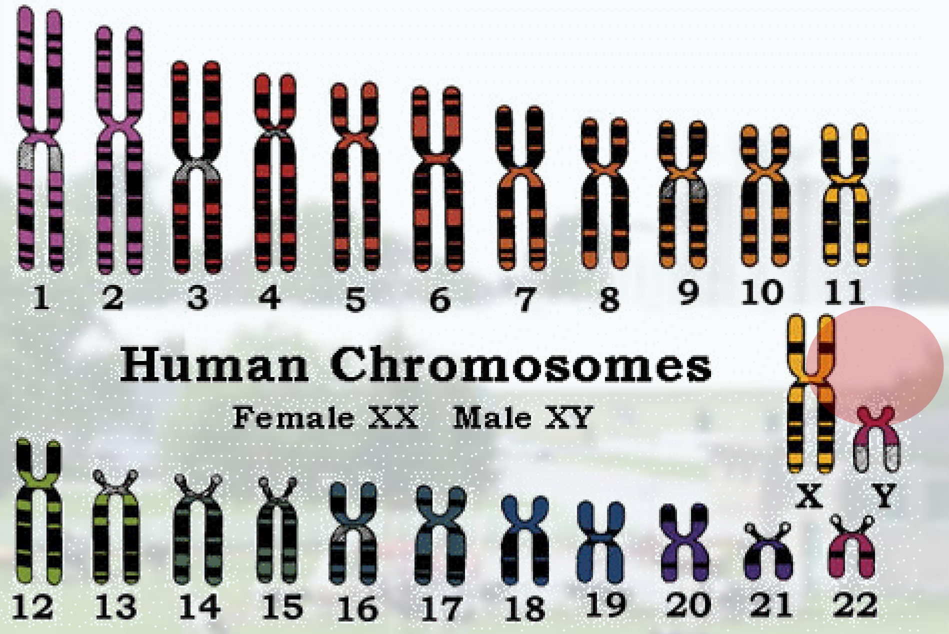
Sex Determination

	♀	♂
Mammals	XX	XY
Birds	XY	XX

The Sex Chromosomes are NON-homologous



Some traits have homologous counterparts and are expected to behave like traits on homologous chromosomes

Some traits do *not* have a counterpart

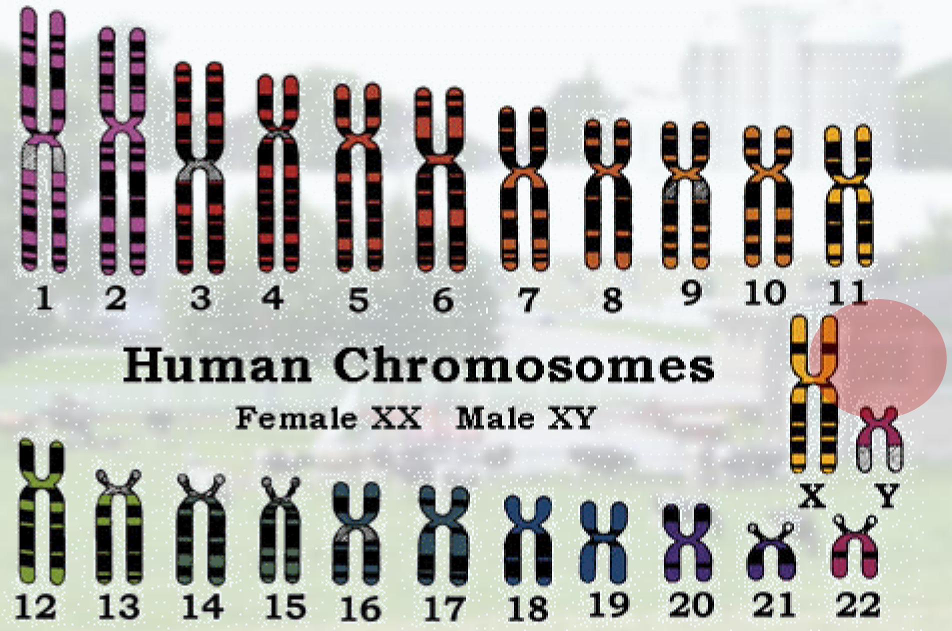
Notation change for sex-linked traits…

	♀	Mammals	♂
AA becomes	X_AX_A		X_AY
aa becomes	X_aX_a		X_aY
Aa becomes	X_AX_a		✗
	♂	Birds	♀

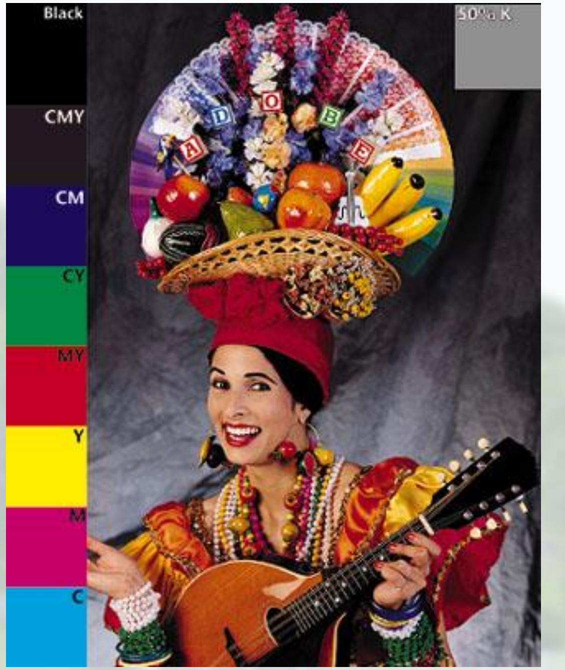
Sex-linked traits

Sex-linked Inheritance

(traits with *no* homologous counterpart
on the Y chromosome)



Colour-blindness in Humans



$$N > n$$

If the trait were inherited on homologous chromosomes...

$N\_$ = Normal Vision

nn = Colour-blind

But since the trait is sex-linked...

♀ $X_N X_\_$ = Normal Vision

$X_n X_n$ = Colour-blind

♂ $X_N Y$ = Normal Vision

$X_n Y$ = Colour-blind

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$X_N X_n$ $X_n Y$

$\frac{1}{2}$ daughters $X_N X_n$ $\frac{1}{2}$ sons $X_N Y$

$\frac{1}{2}$ daughters $X_n X_n$ $\frac{1}{2}$ sons $X_n Y$

So, $\frac{1}{2}$ the *children* are colour-blind and $\frac{1}{2}$ the *children* have "normal" vision

$X_n X_n$ $X_N Y$

All daughters $X_N X_n$

All sons $X_n Y$

Tortoiseshell coat pattern in Cats

An Example of Sex-linked Inheritance

Black

Tortoiseshell

Orange

B = b

$X_B X_B$ = Black

$X_b X_b$ = Orange

$X_B X_b$ = Tortoiseshell

$X_B Y$ = Black

$X_b Y$ = Orange

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$X_B X_B$ $\qquad$ $X_b Y$

All female kittens $X_B X_b$

All male kittens $X_B Y$

How to Determine Modes of Inheritance…

- Dominance/Recessiveness
- Codominance / Incomplete Dominance
  - 1:2:1 ratio
  - Both parents have the *__same__* phenotype and approximately 50% of the offspring have the same phenotype as the parents
- Multiple Alleles
  - Could *__also__* be 1:2:1 ratio __but__ parents will have *different* phenotypes
- Lethal
  - Ratios will *__not__* add up to the number of expected combinations – a 2:1 ratio is typical
- Epistatis
  - "Playing with the ratios" to get them to work!!
  - A "large" number of modified phenotypes → Dominant Epistasis; a "small" number of modified phenotypes → Recessive Epistasis
  - More than one "modification" → Codominant Epistasis
- Sex-influenced
  - You will have to be given numbers of males and females. The only case where one genotype can have 2 phenotypes.
  - Also, there ARE only two phenotypes!! IF there are 3 that means sex-linked
- Sex-linked
  - You will have to be given numbers of males and females
  - The heterogametic (XY) sex cannot express the heterozygous condition
  - The heterogametic (XY) sex is *__Male in Mammals__* and *__Female in Birds__*.

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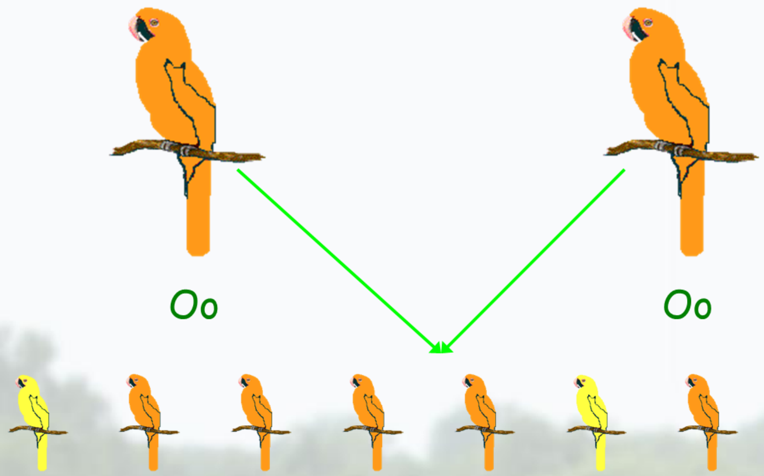
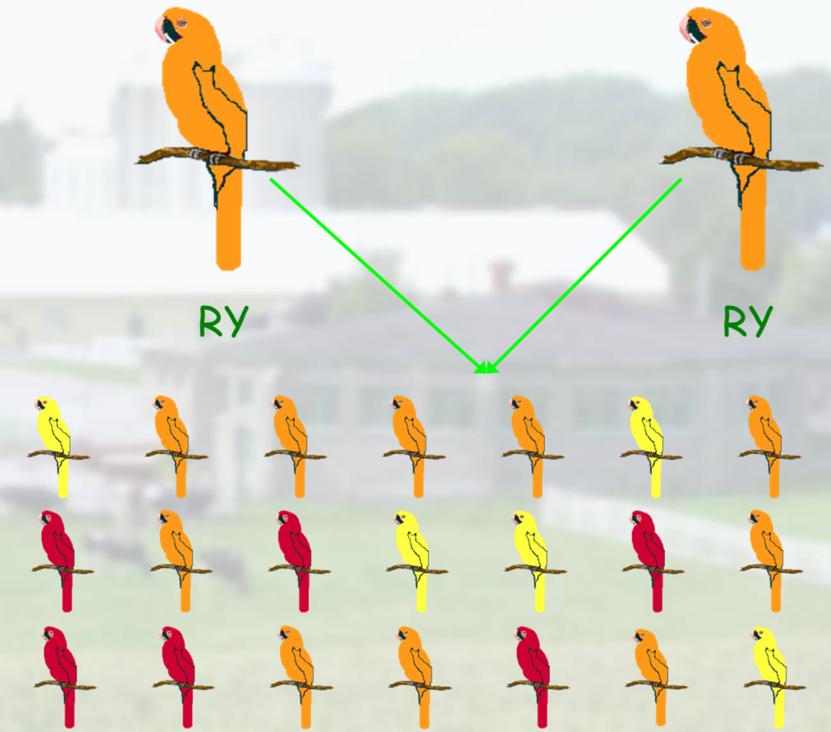


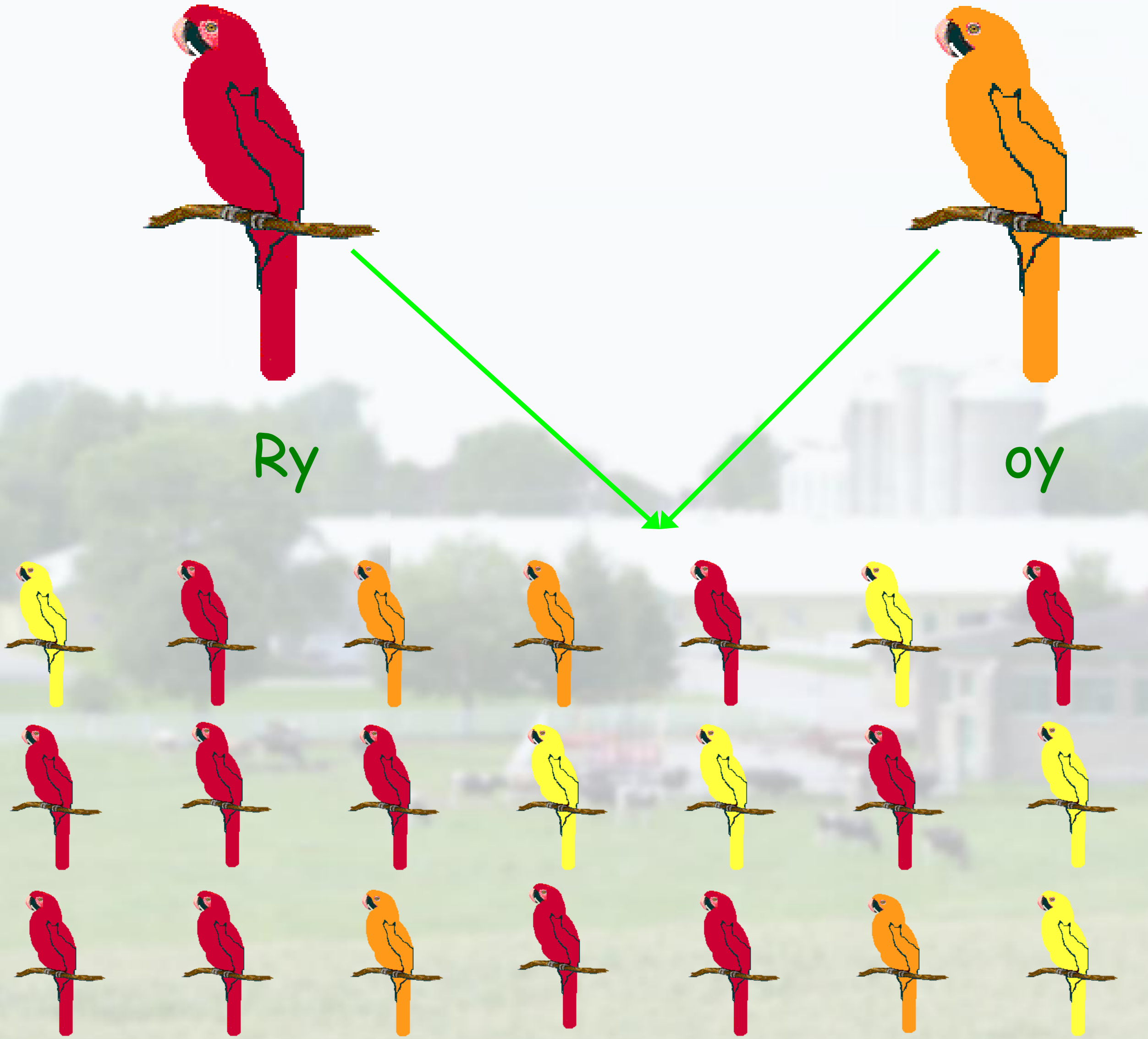
5 : 2

After 1 generation:
Simple Dominant-Recessive Trait
(or arguably a lethal with 2:1 ratio)



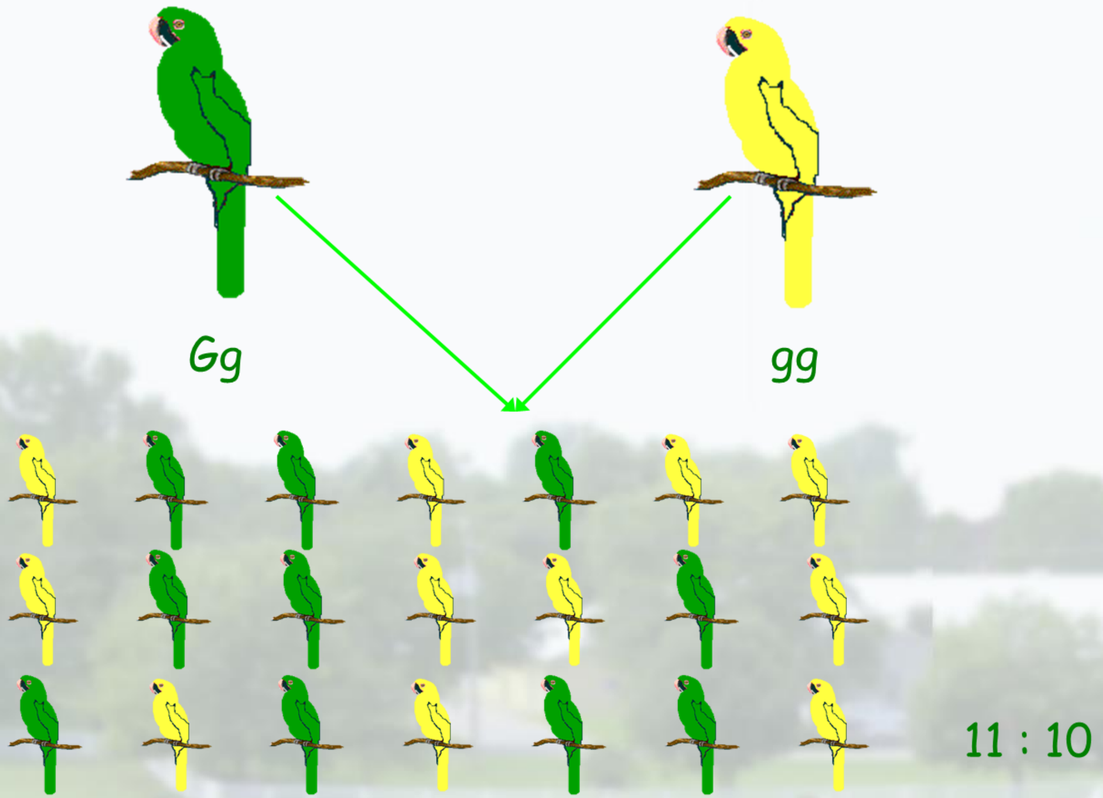
6 : 10 : 5

OVERALL: Incomplete Dominance / Codominant Trait

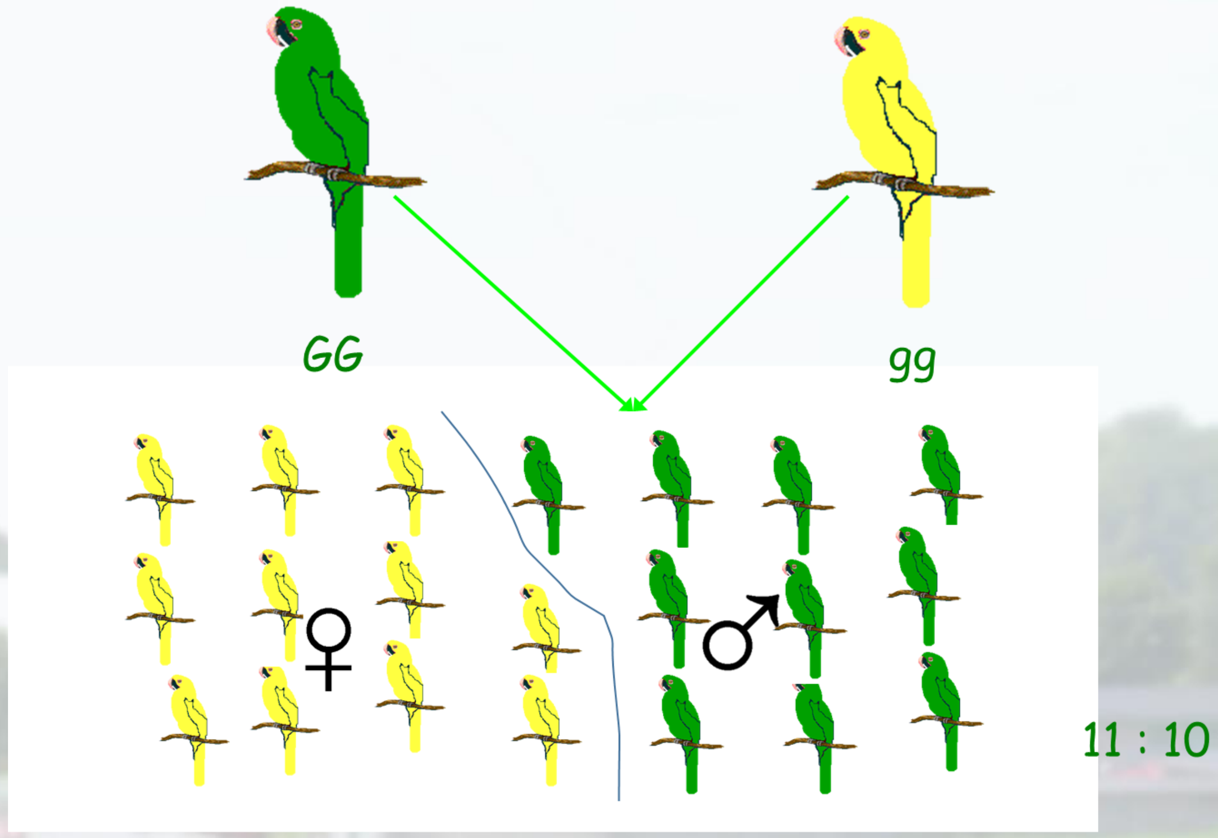


6 : 11 : 4

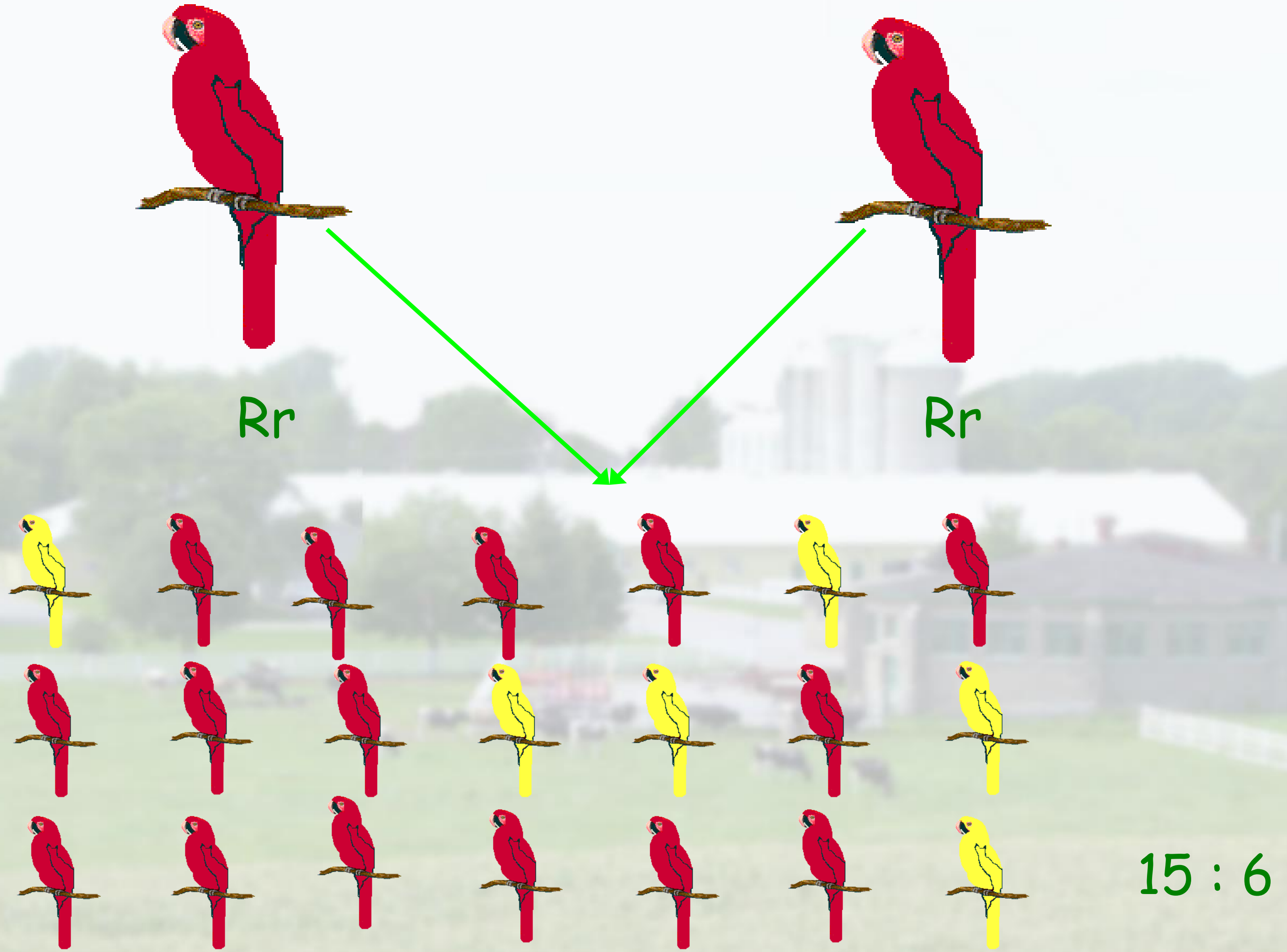
Multiple Alleles



Simple Dominant-Recessive Trait



Sex-influenced Trait



Simple Dominant-Recessive Trait