Crossbreeding

Reasons for crossbreeding

1. Sire-Dam complementation
2. The averaging of breed effects
3. Grading up to a new breed
4. Step towards creation of synthetic/composite
5. To introduce a single gene
6. To exploit heterosis

An example of the value of selection between breeds：

- 25 *Bos Taurus* breeds - 71% of the variation in 72-week weight was due to breed effects (Thiessen et. al., 1984). Standard deviation within breeds was 33.5Kg and standard deviation between true breed means was 52.4Kg

- This gives the percentage variation that is due to breed:

$$100 \times \frac{52.4^2}{52.4^2 + 33.5^2} = 71\%$$

- Choose a breed just one standard deviation 'better' - 52.4 Kg improvement

- Same as moving from eg. the average breed (50% standing) up to the breed with 84% standing, on a 0% (worst breed) to 100% (best breed) scale.

An example of the value of selection within breeds :

Age at calving:	2	3	4	5	6
Bulls:	1	1			
Cows:	8	8	8	8	8

40 Cows x 0.8 gives 16 males + 16 females per year cohort.

$p_m = 1/16$ giving $i_m = 1.970$

$p_f = 8/16$ giving $i_f = 0.798$

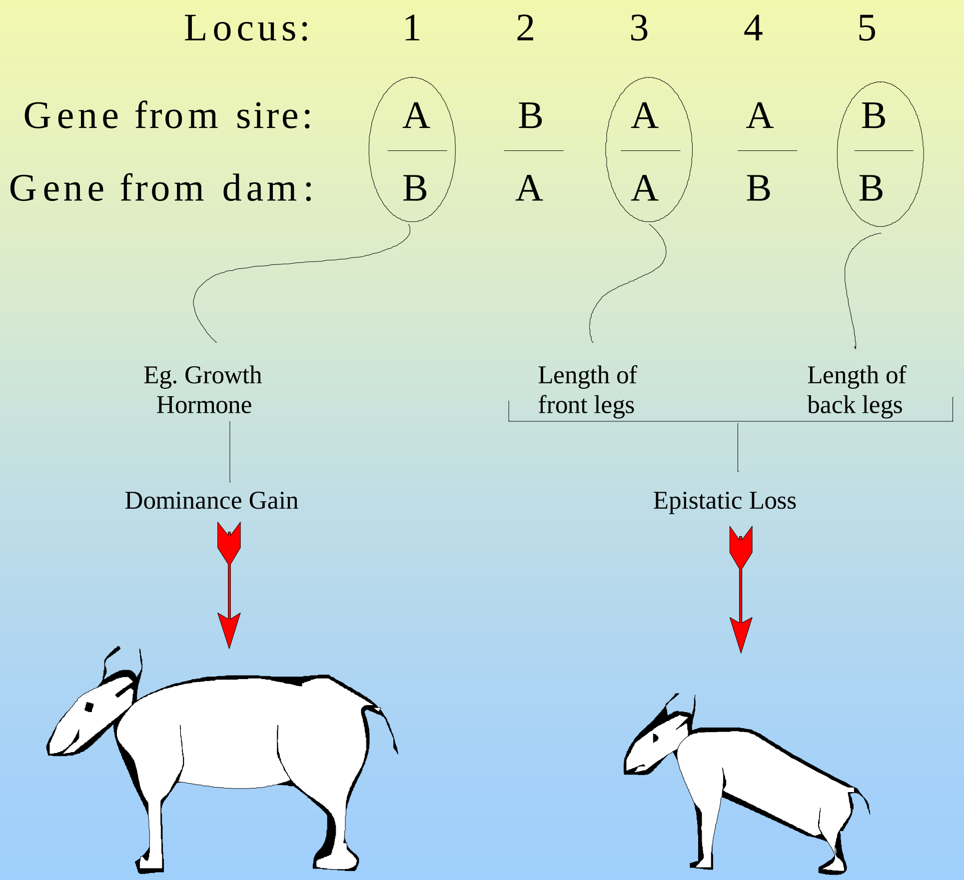
$L_m = 2.5$ and $L_f = 4$

$$R_{yr} = \frac{i_m + i_f}{L_m + L_f} h^2 \sigma_P = \frac{1.970 + 0.798}{2.5 + 4} \times 0.4 \times 33.5 = 5.7 Kg / yr$$

The comparison :

- Between breeds:52.4Kg
- Within breeds: 5.7Kg/yr
- Our selection between breeds is worth 9 years 2 months and 6 days selection work with breed!
- Selection between breeds is worth considering - depending on costs and opportunities.

Dominance and epistasis cause heterosis



DOMINANCE - wider genetic base leads to better performance

EPISTASIS - breakdown of favourable interactions leads to loss of performance

Dominance model of heterosis

```
                              one gene pair
                                         |   another gene
pair
                                         |     |
Purebreed  "A"      Genes from sire:  A  A  A  A  A  A  A  A
                    Genes from dam :  A  A  A  A  A  A  A  A

                    Heterosis expression = 0%



F1  cross "A x B"   Genes from sire:  A  A  A  A  A  A  A  A
                    Genes from dam :  B  B  B  B  B  B  B  B

                    Heterosis expression = 100%
```

Dominance model of heterosis

3 breed cross	Genes from sire:	C	C	C	C	C	C	C	C
"C x (AxB)"	Genes from dam :	A	B	A	B	A	B	A	B

Heterosis expression = 100%

Backcross	Genes from sire:	A	A	A	A	A	A	A	A
"A x (AxB)"	Genes from dam :	A	B	A	B	A	B	A	B

Heterosis expression = 50%

F_2 cross	Genes from sire:	A	A	B	B	A	A	B	B
"(AxB) x (AxB)"	Genes from dam :	A	B	A	B	A	B	A	B

Heterosis expression = 50%

	How much heterosis?
Purebreds	0
F1	100%
F2	50%
Backcross	50%

Breed-of-origin heterozygosity
∝
allelic heterozygosity

Breed X

	$p_x=0.3$	$q_x=0.7$
$p_x=0.3$	.09 a	.21 d
$q_x=0.7$	d .21	-a .49

Breed X = -0.4a + 0.42d

Breed Y

	$p_y=0.9$	$q_y=0.1$
$p_y=0.9$	.81	.09
$q_y=0.1$	.09	.01

Breed Y = 0.8a + 0.18d

Parental Mean:

$\bar{P}$ = 0.2a + 0.3d

Breed-of-origin heterozygosity
∝
allelic heterozygosity

F1 Cross

	$p_x=0.3$	$q_x=07$
$p_y=0.9$	.27	.63
$q_y=0.1$	.03	.07

F1 Cross = 0.2a + 0.66d
Heterosis = .36d = $d(p_x - p_y)^2$

Breed-of-origin
Heterozygosity =1

F2 Cross

	0.6	0.4
$\frac{p_x+p_y}{2} = 0.6$	.36	.24
$\frac{q_x+q_y}{2} = 0.4$	.24	.16

F2 Cross = 0.2a + 0.48d
Heterosis =.18d = $\frac{1}{2}d\,(p_x - p_y)^2$

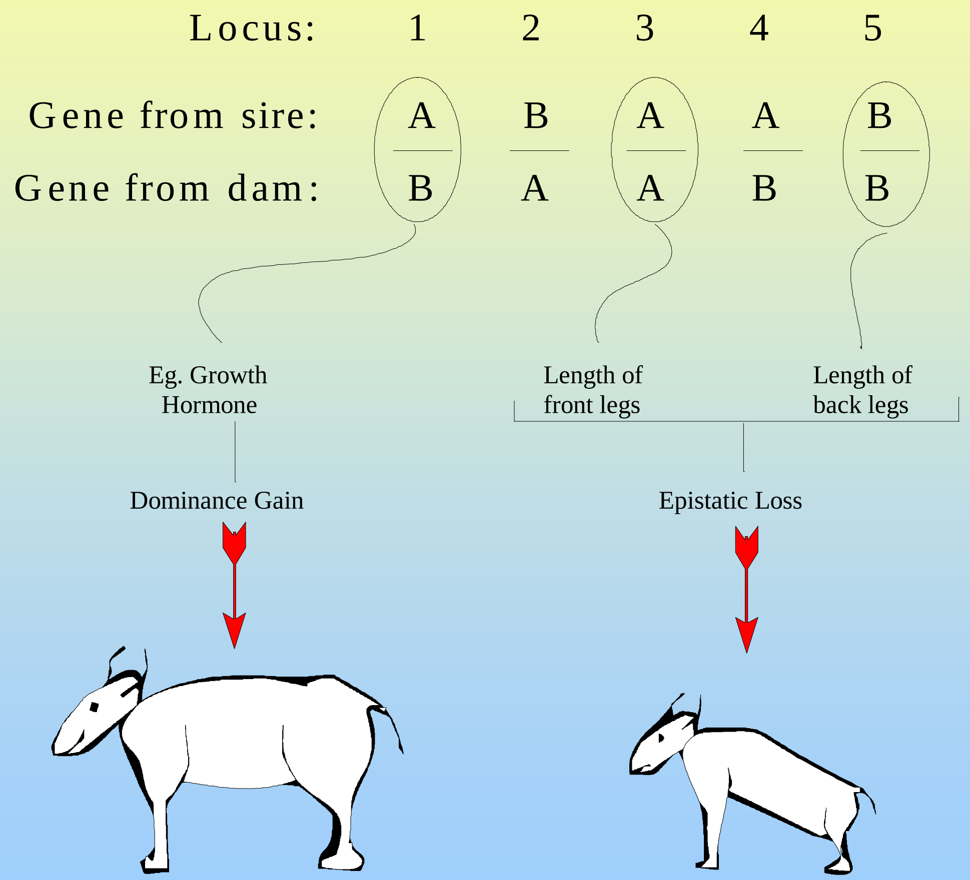
Breed-of-origin
Heterozygosity =½

Epistasis

Material in book is

For reference only !

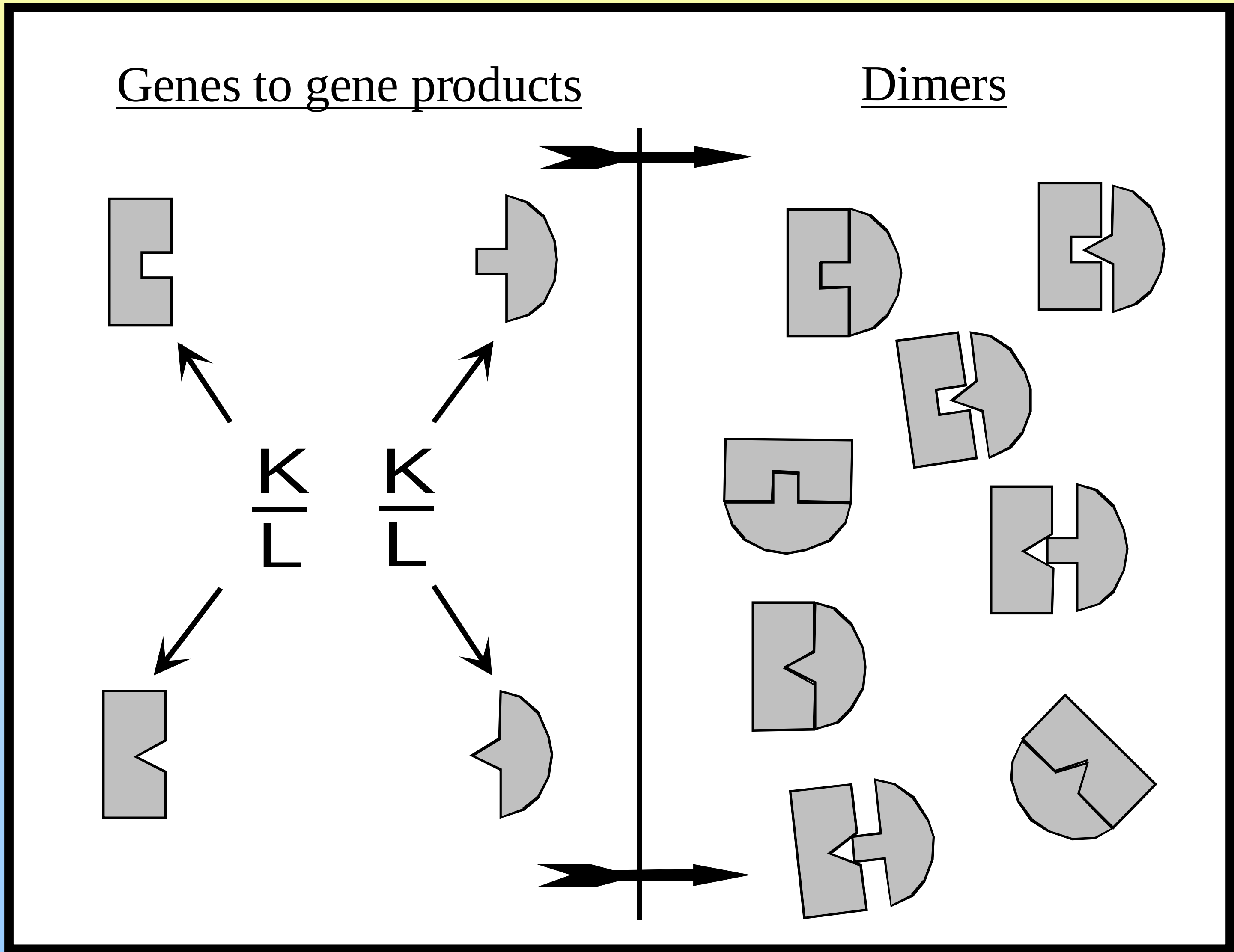
Dominance and epistasis cause heterosis



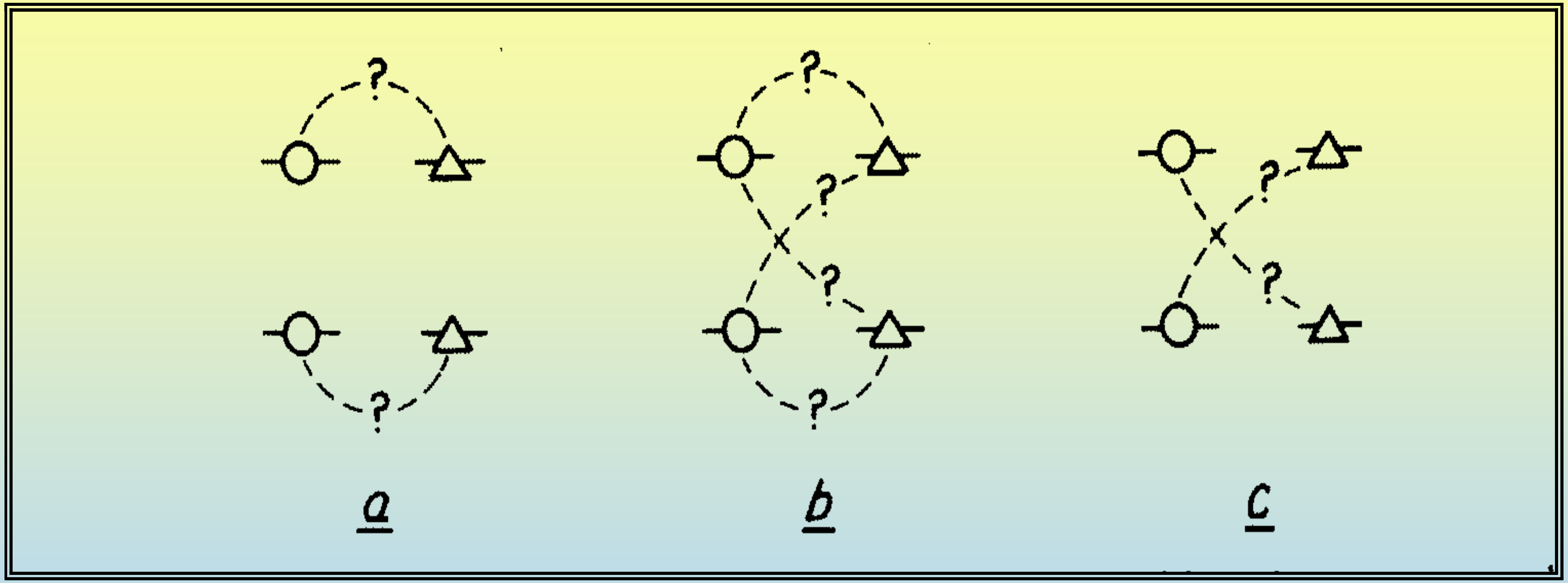
DOMINANCE - wider genetic base leads to better performance

EPISTASIS - breakdown of favourable interactions leads to loss of performance

Additive x additive model of heterosis



Where ‘recombination loss’ fits in



Recombination loss, r

Additive x additive epistasis, E_{aa}

The difference, equal to dominance, d

$$P(E_{aa}) = [p(r) + p(d)]/2$$

Crossbreeding parameters...

• ***Direct additive effects A_{d1}, A_{d2} and A_{d3}*** Additive effects of purebreeds. For yearling weight, they relate to the ability to grow quickly.

• ***Maternal additive effects A_{m1}, A_{m2} and A_{m3}*** Additive effects of purebreeds as expressed by the dams of the crossbred individuals under consideration. They probably relate to milk production and rearing ability. Note that these effects add to zero - they describe the relative maternal performance of each pure breed.

• ***Direct dominance effect D_d*** The effect of heterosis in crossbred individuals, when fully expressed, as in an F1 cross.

• ***Maternal dominance effect D_m*** The effect of heterosis due to crossbreeding in the dam, when fully expressed, as in an F1 dam.

Estimating crossbreeding parameters...

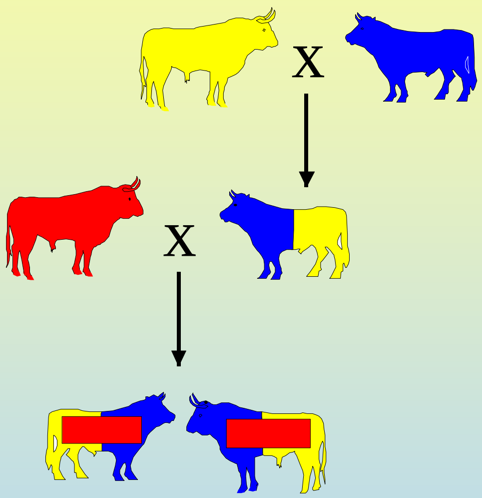
Cross Table (Yearling weight)

3 Breeds | New Row | Reset Table | Breed / Trait | Update | Defaults | Close | Calculate

		Ad1	Ad2	Ad3	Am1	Am2	Am3	Dd	Dm	Merit	
Effects: **Value (Kg)**		300	280	260	-6	-1	7	20	10		
1	1 x 1	1	0	0	1	0	0	0	0	294	☑
2	2 x 2	0	1	0	0	1	0	0	0	279	☑
3	3 x 3	0	0	1	0	0	1	0	0	267	☑
4	1 x 2	0.5	0.5	0	0	1	0	1	0	309	☑
5	1 x 23	0.5	0.25	0.25	0	0.5	0.5	1	1	**318**	☑
6	1 x 12	0.75	0.25	0	0.5	0.5	0	0.5	1	311.5	☑
7	2 Br Bal Comp	.5	.5	0	.5	.5	0	.5	.5	301.5	☑
8	3 Br Bal Comp	.3333	.3333	.3333	.3333	.3333	.3333	.667	.667	299.982	☐
9	2 Br Opt Comp	.63	.37	0	.63	.37	0	.47	.47	302.55	☐
10	3 Br Opt Comp	.57	.31	.12	.57	.31	.12	.56	.56	302.91	☐
11	2 Br Rotation	.5	.5	0	.5	.5	0	.667	.667	306.51	☐
12	3 Br Rotation	.3333	.3333	.3333	.3333	.3333	.3333	.86	.86	305.772	☐

Crossbreeding:
More ‘structure’ gives more merit ...

In general ...



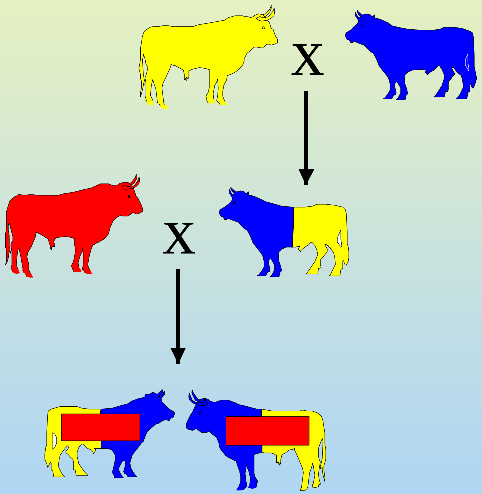
The shorter the breed pedigree back to purebred parents:

- the more heterosis can be expressed.
- the more sire-dam complimentarity can be expressed

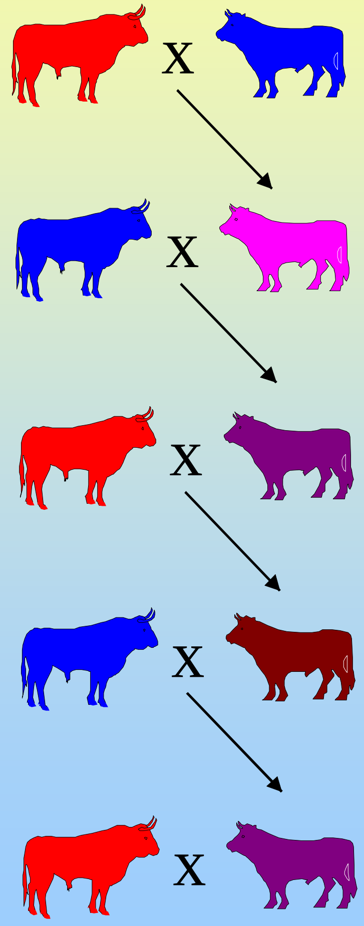
BUT: The more expensive the operation is to run

Loss of heterosis and complimentarity ...

3-Breed Cross

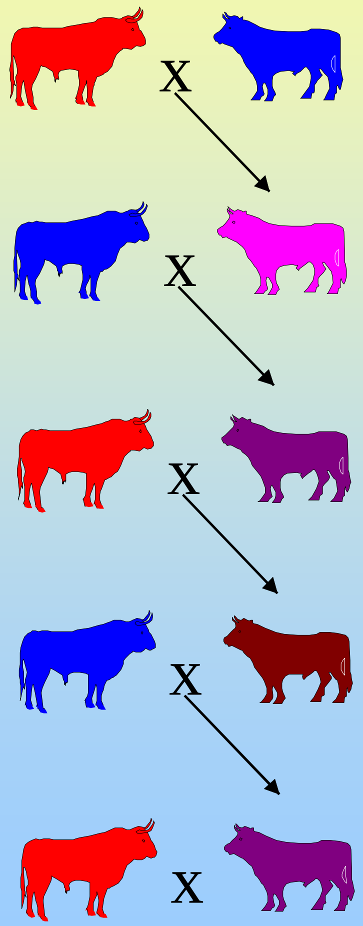


Rotational Cross



Loss of heterosis and complimentarity ...

Rotational Cross



A x B

B x AB

A x $\frac{1}{4}$ A $\frac{3}{4}$ B

B x $\frac{5}{8}$ A $\frac{3}{8}$ B

A x $\frac{5}{16}$ A $\frac{11}{16}$ B

A x $\frac{1}{3}$ A $\frac{2}{3}$ B ... giving $\frac{2}{3}$ heterosis

B x $\frac{2}{3}$ A $\frac{1}{3}$ B ... giving $\frac{2}{3}$ heterosis

Which crossing system to adopt?

PUREBREED	when no cross is better.
F_1 CROSS	when direct heterosis is important.
3 BREED CROSS	when both direct and maternal heterosis are important.
4 BREED CROSS	when paternal heterosis is important as well.
BACKCROSS	when only 2 good parental breeds are available and/or when direct heterosis is not important.
ROTATIONAL CROSSES	when females are too expensive to either buy in or to produce in the same enterprise.
OPEN OR CLOSED COMPOSITE	when both males and females are too expensive. A few initial well judged importations establish the synthetic (or 'composite'), and it can then either be closed (which helps to establish a breed 'type'), or left open to occasional well judged importations.

Patterns of use of crossbreeding

Industry	Fecundity	Typical crossing systems
Poultry	highest	4-breedcrosses
Pigs	↓	3-breed crosses;back crosses
Meat sheep		3-breedcrosses
Wool Sheep		purebred*
Dairy		purebred*
Temperate Beef		rotations;composites
Tropical Beef	lowest	composites

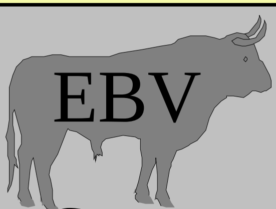
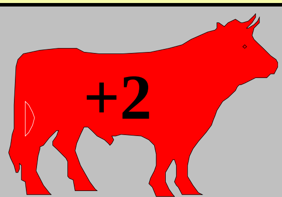
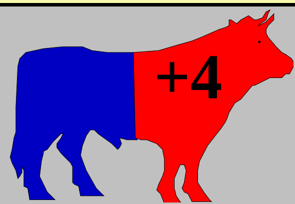
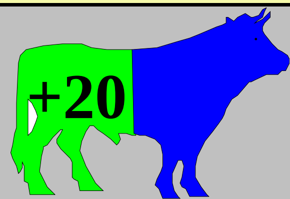
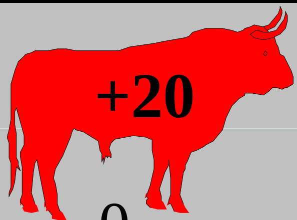
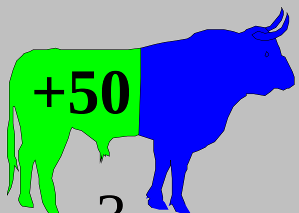
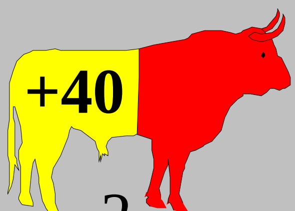
***Wool sheep and dairy industries are exceptions due to availability of an outstanding pure breed in each.**

Exploiting both between and within breed variation

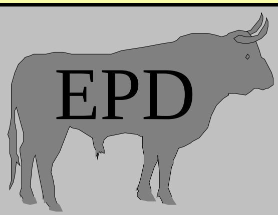
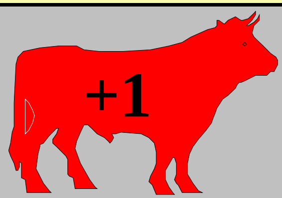
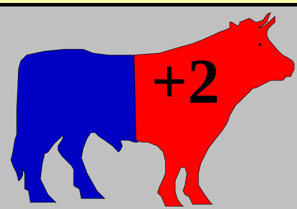
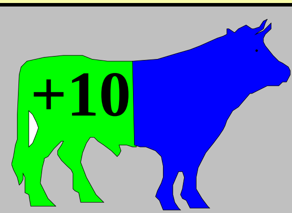
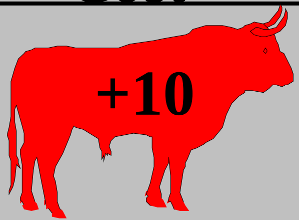
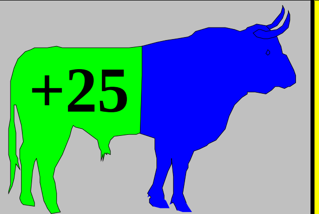
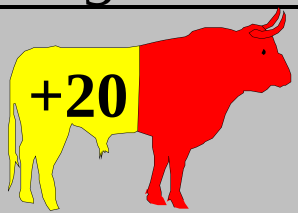
- Designing crossbreeding systems based on breed means

- Actually selecting animals based on within breed EBVs
  - E.g. mate merinos with the best BL ram
  - Use the best Angus bulls for rotational crossing
  - Etc.
- Could also use across breed EBV (not always) but that does not exploit heterosis

‘Automatic design’ through mate selection.

 EBV Cost	 +2 0	 +4 10	 +20 10
 +20 0	Crossing: 300 EBV: 11 Cost: 0 ***Total: 311***	Crossing: 310 EBV: 12 Cost: -10 ***Total: 312***	Crossing: 325 EBV: 20 Cost: -10 ***Total: 335***
 +50 3	Crossing: 318 EBV: 26 Cost: -3 ***Total: 341***	Crossing: 308 EBV: 27 Cost: -13 ***Total: 322***	Crossing: 300 EBV: 35 Cost: -13 ***Total: 322***
 +40 2	Crossing: 290 EBV: 21 Cost: -2 ***Total: 309***	Crossing: 320 EBV: 22 Cost: -12 ***Total: 330***	Crossing: 327 EBV: 30 Cost: -12 ***Total: 345***

Mate allocations ...

 EPD / Cost	 +1 / 0	 +2 / 10	 +10 / 10
 +10 / 0	311	312	335
 +25 / 3	341	322	322
 +20 / 2	309	330	345

Linear Programming approach

Jansen and Wilton (1985)

Bull→ Cow↓	1	2	3	**Dummy bull**
1	311	312	335	999
2	341	322	322	999
3	309	330	345	999
Dummy Cow	999	999	999	999

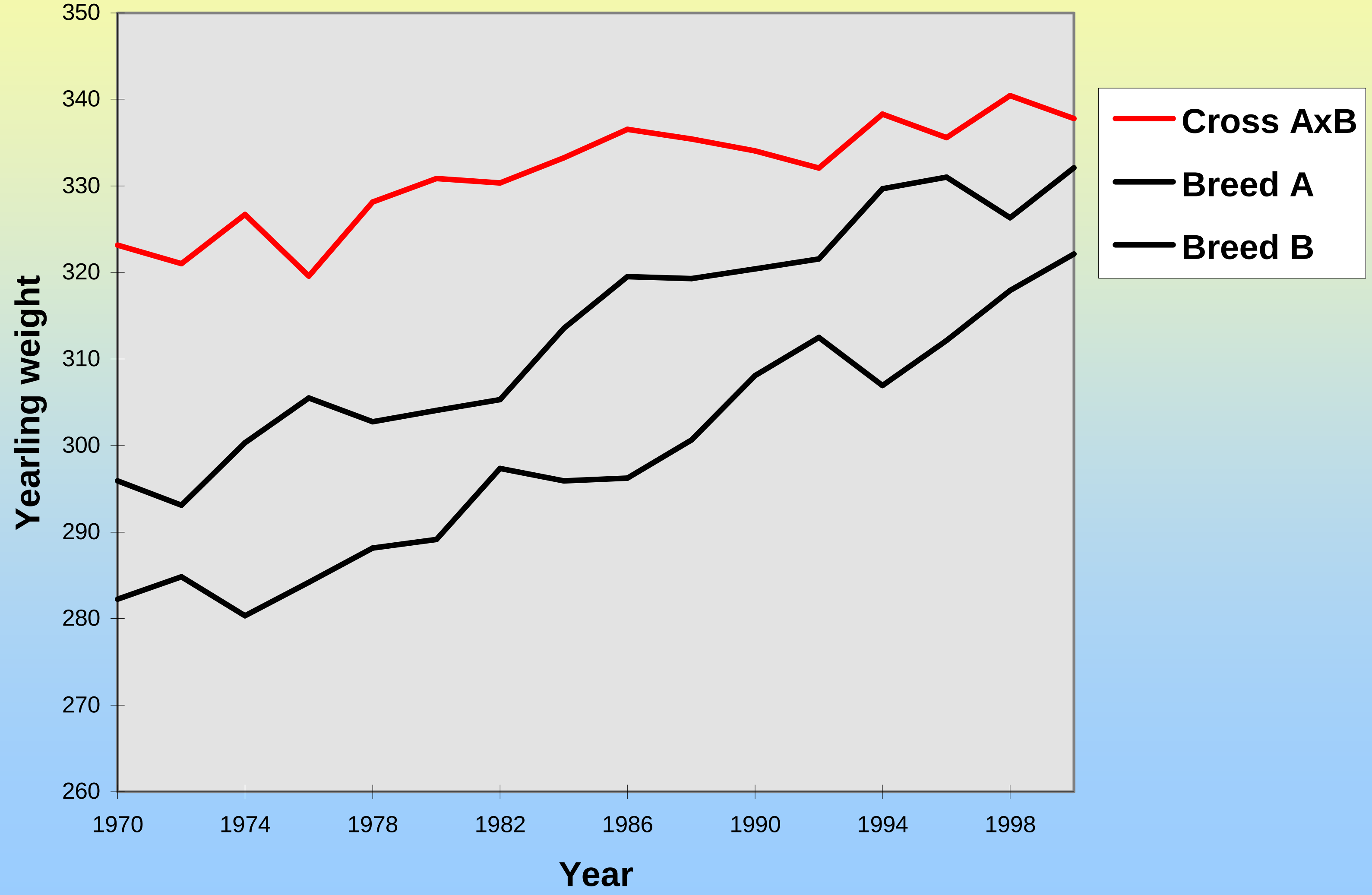
Maximise sum of merit of chosen cells, with constraints such as:

- Max. one mating per cell
- Max. one mating per female
- Max. ***d*** matings per male

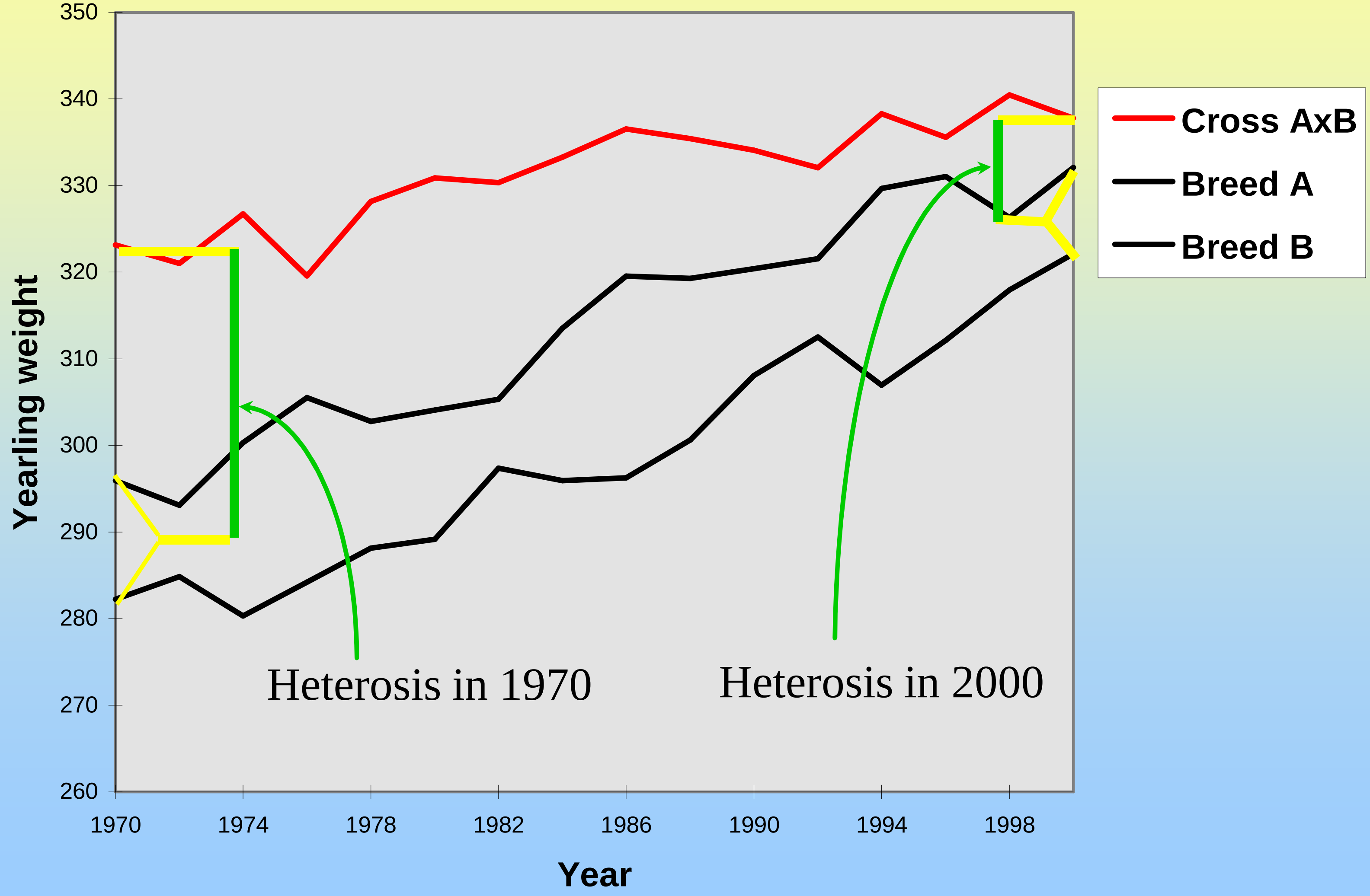
Does bull ranking depend on mate breed?

EPD's	Angus Bull No. 1	Angus Bull No. 2	Angus Bull No. 3
Angus cows	+++	++	+
Hereford cows	+	++	+++
Brahman cows	-	++	+

If “Pure-Cross correlation” were less than 100% …



If “Pure-Cross correlation” were less than 100% …



Conclusion about crossbreeding

- Design optimal structure based on breed parameters (averages)
- Operationally: select and mate based on EBVs and predicted heterosis
- Non-additive effects not important for selection within lines or breeds