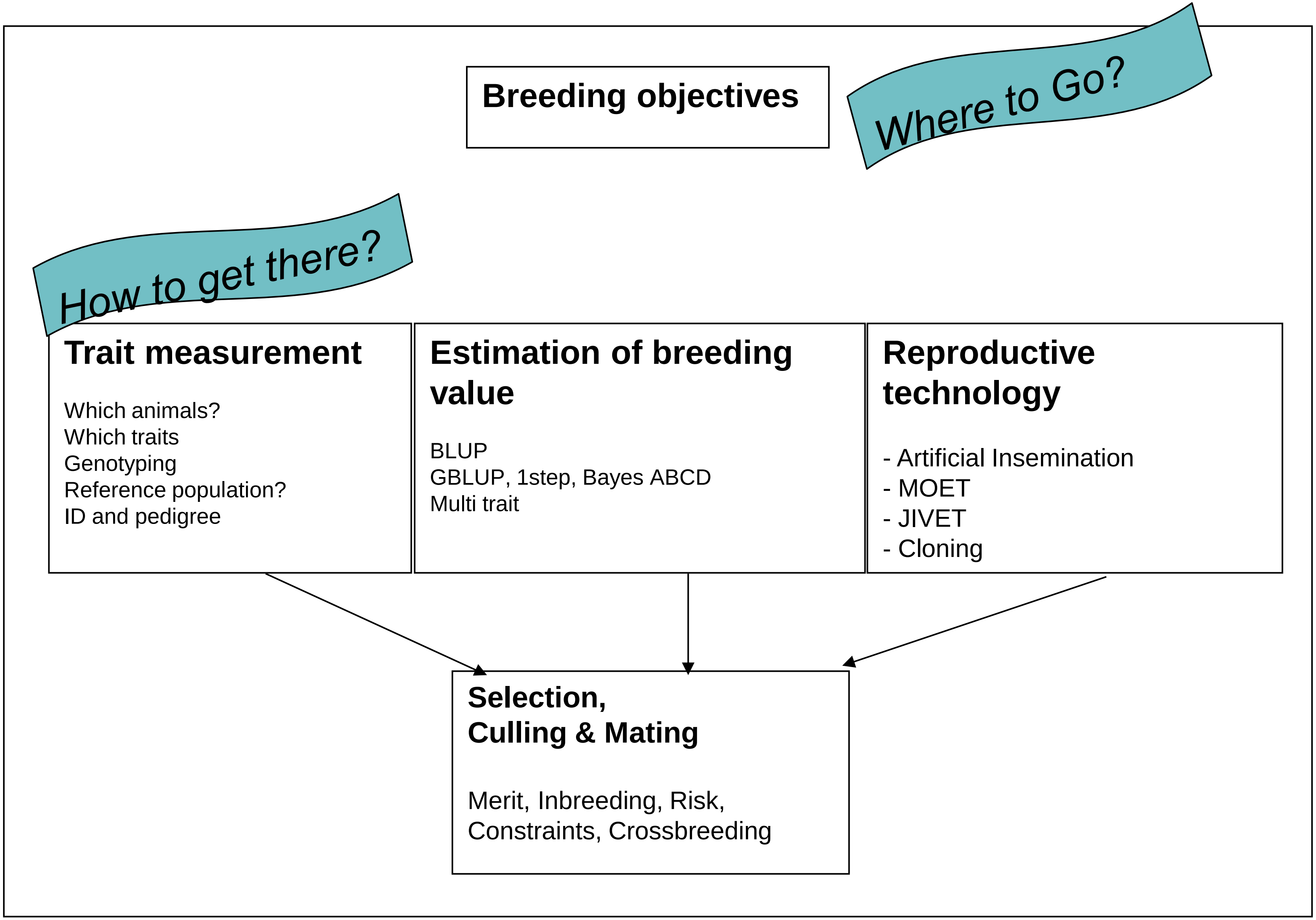
Design of Breeding Programs

Decisions in breeding programs

Where to go?	breeding objective (which traits)
Who and what to measure?	performance, DNA test genetic evaluation
Who to select and mate?	reproductive technol. gains vs inbreeding

Animal Breeding in a nutshell



Breeding objectives

Where to Go?

How to get there?

Trait measurement

Which animals?
Which traits
Genotyping
Reference population?
ID and pedigree

Estimation of breeding value

BLUP
GBLUP, 1step, Bayes ABCD
Multi trait

Reproductive technology

- Artificial Insemination
- MOET
- JIVET
- Cloning

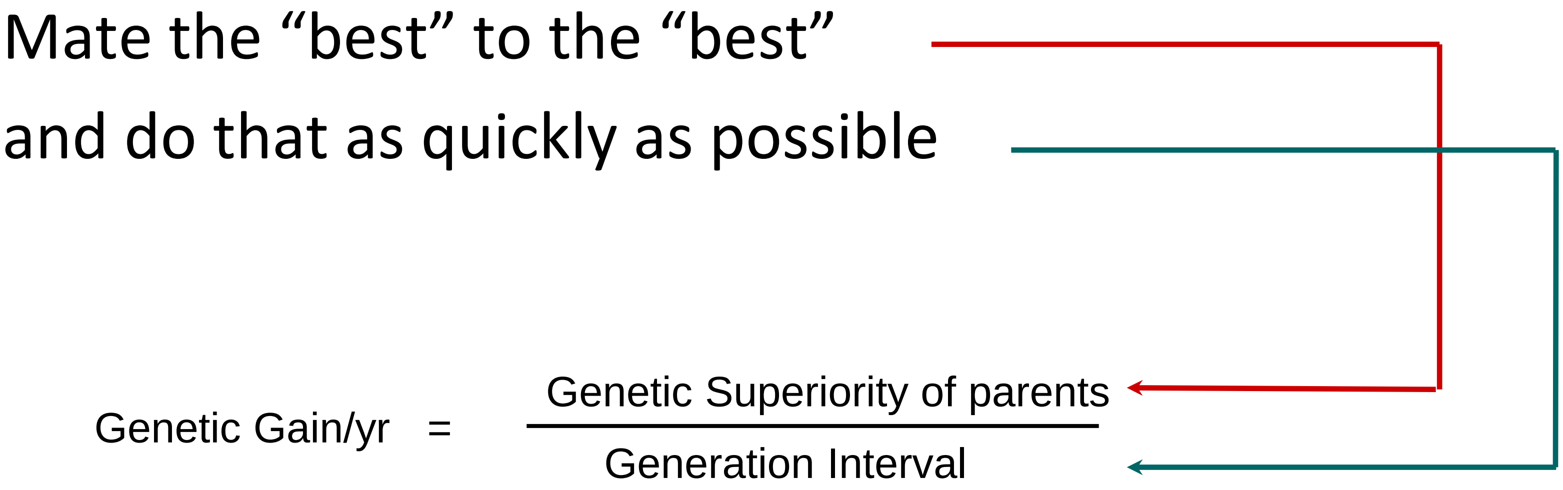
Selection,
Culling & Mating

Merit, Inbreeding, Risk,
Constraints, Crossbreeding

Why do we need a design?

- **Genetic Improvement:**
  - Which animals to measure?
  - Where to select them?
  - Mating strategy
  - Reproductive and Genomic Technologies?
- **Dissemination of Genetic Superiority**
- **Inbreeding**

Basic Principle of making genetic progress



Mate the “best” to the “best”

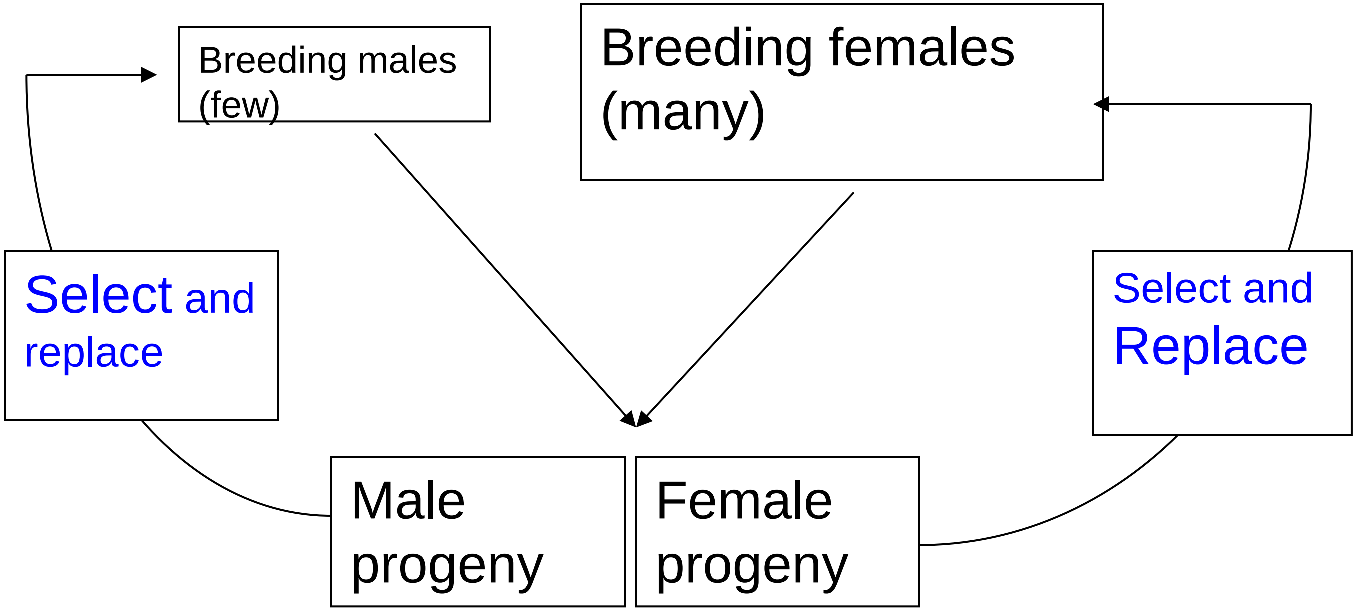
and do that as quickly as possible

$$\text{Genetic Gain/yr} = \frac{\text{Genetic Superiority of parents}}{\text{Generation Interval}}$$

$$\text{Genetic Gain/yr} = \frac{\text{Sel Intensity x Accuracy X Genetic SD}}{\text{Generation Interval}}$$

Design Examples

- One-tier breeding program



Breeding males (few)

Breeding females (many)

Select and replace

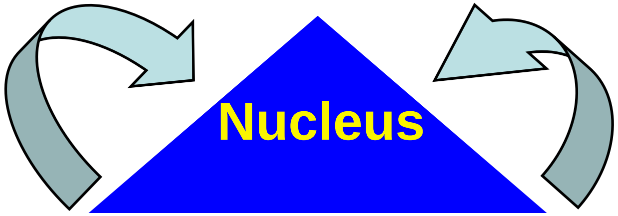
Select and Replace

Male progeny

Female progeny

Design Examples

One-tier breeding program

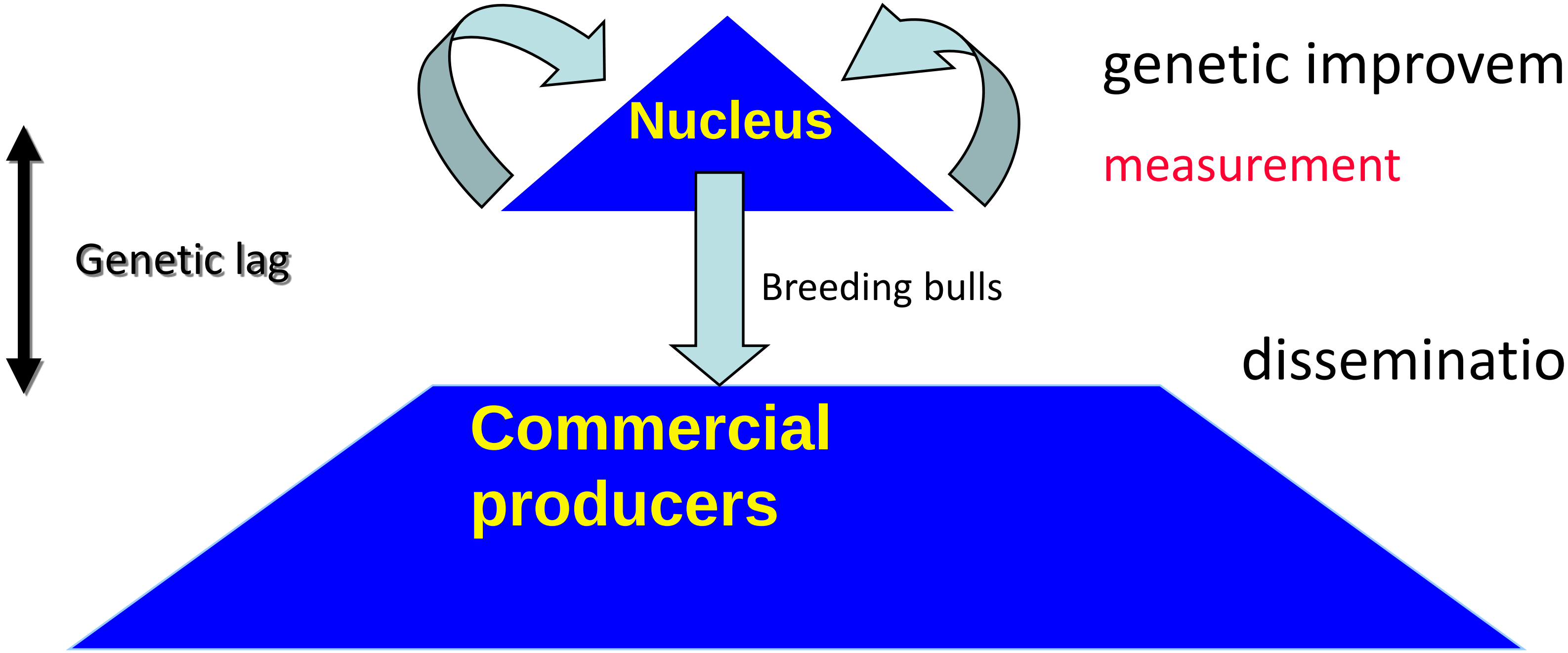


genetic improvement

measurement

Design Examples

Two-tier breeding program



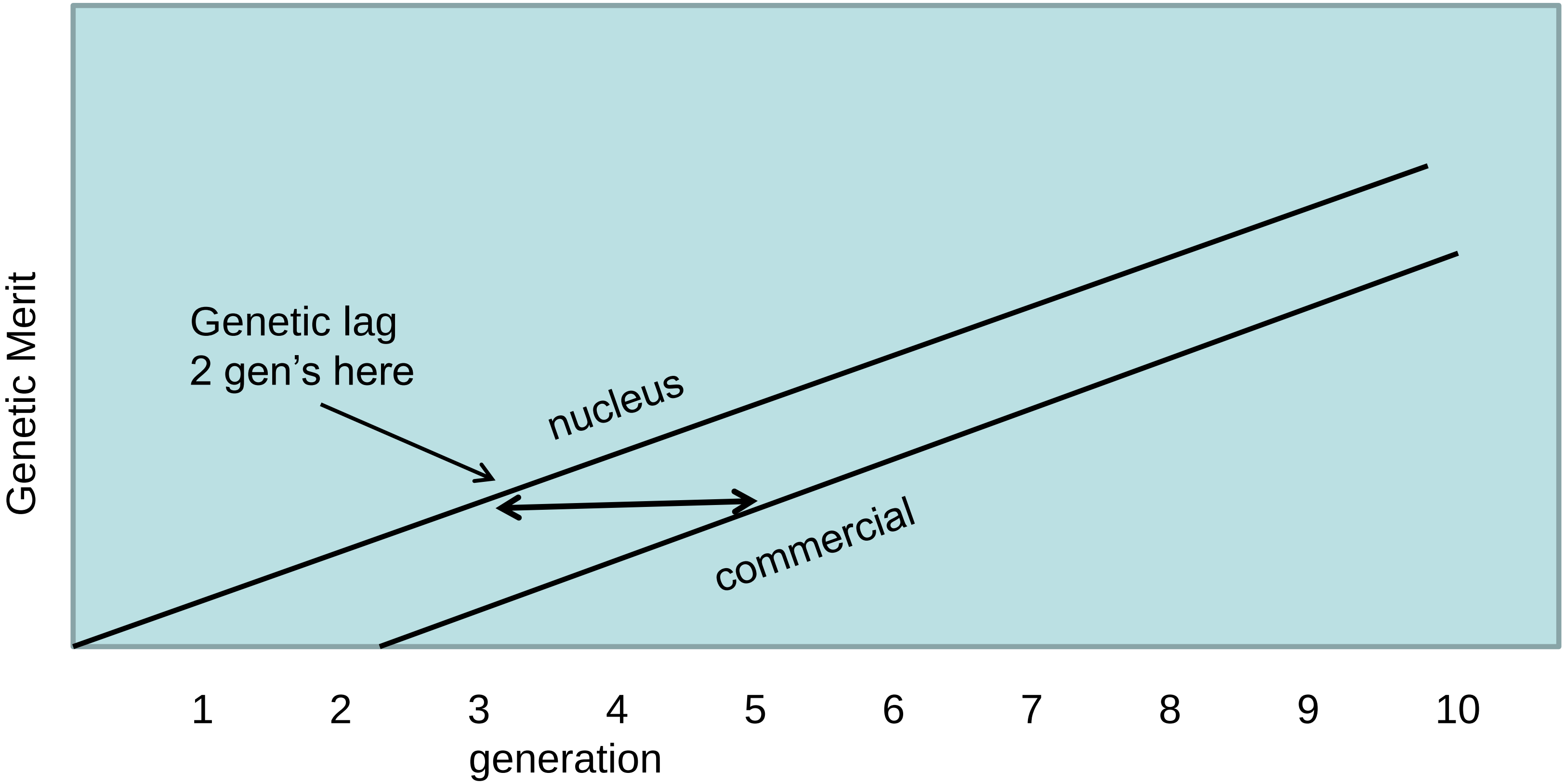
genetic improvement

measurement

dissemination

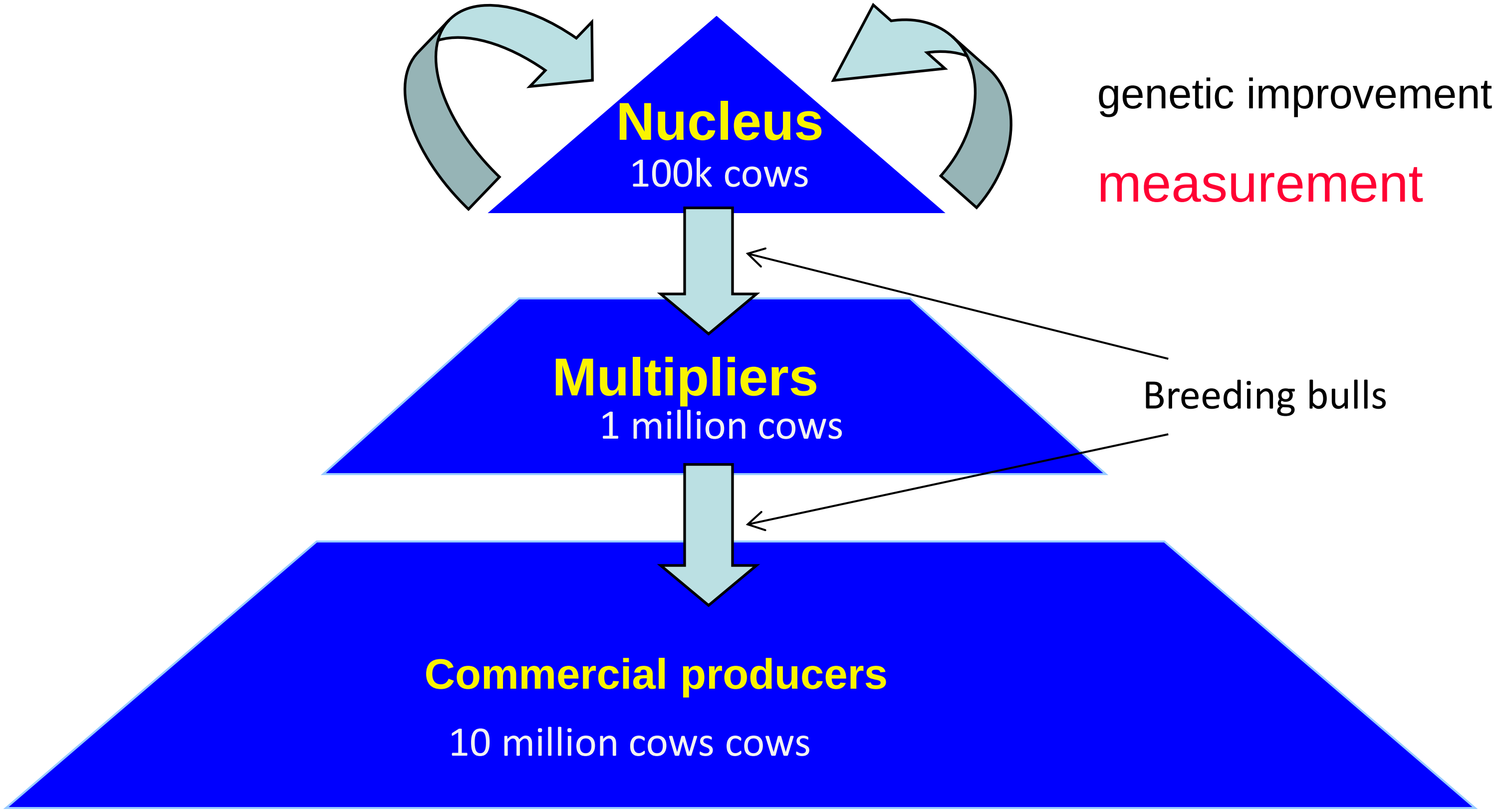
Genetic merit of Nucleus versus Commercial

Rate of gain is the same in all tiers



Design Examples

3-tier breeding program



Nucleus

100k cows

genetic improvement

measurement

Multipliers

1 million cows

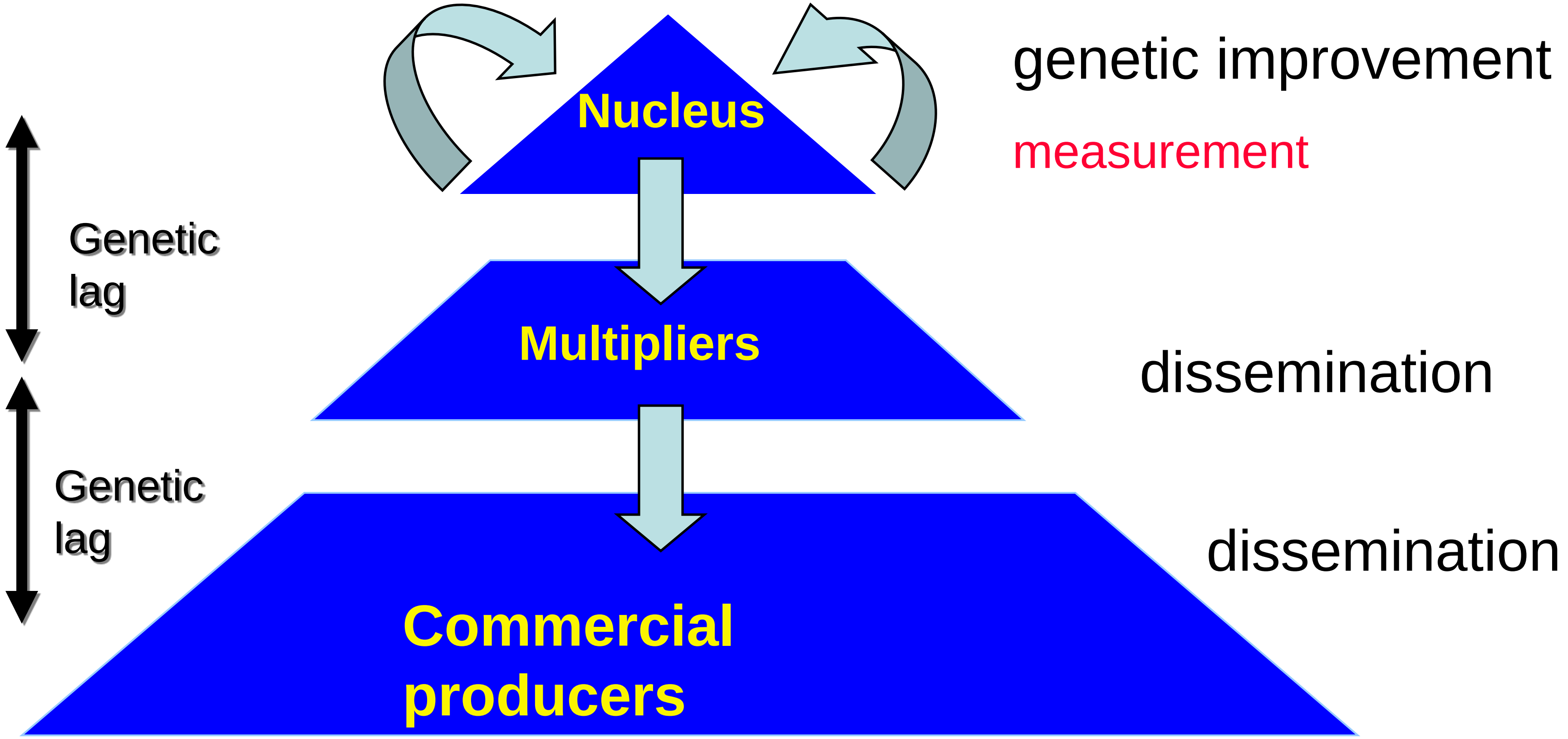
Breeding bulls

Commercial producers

10 million cows cows

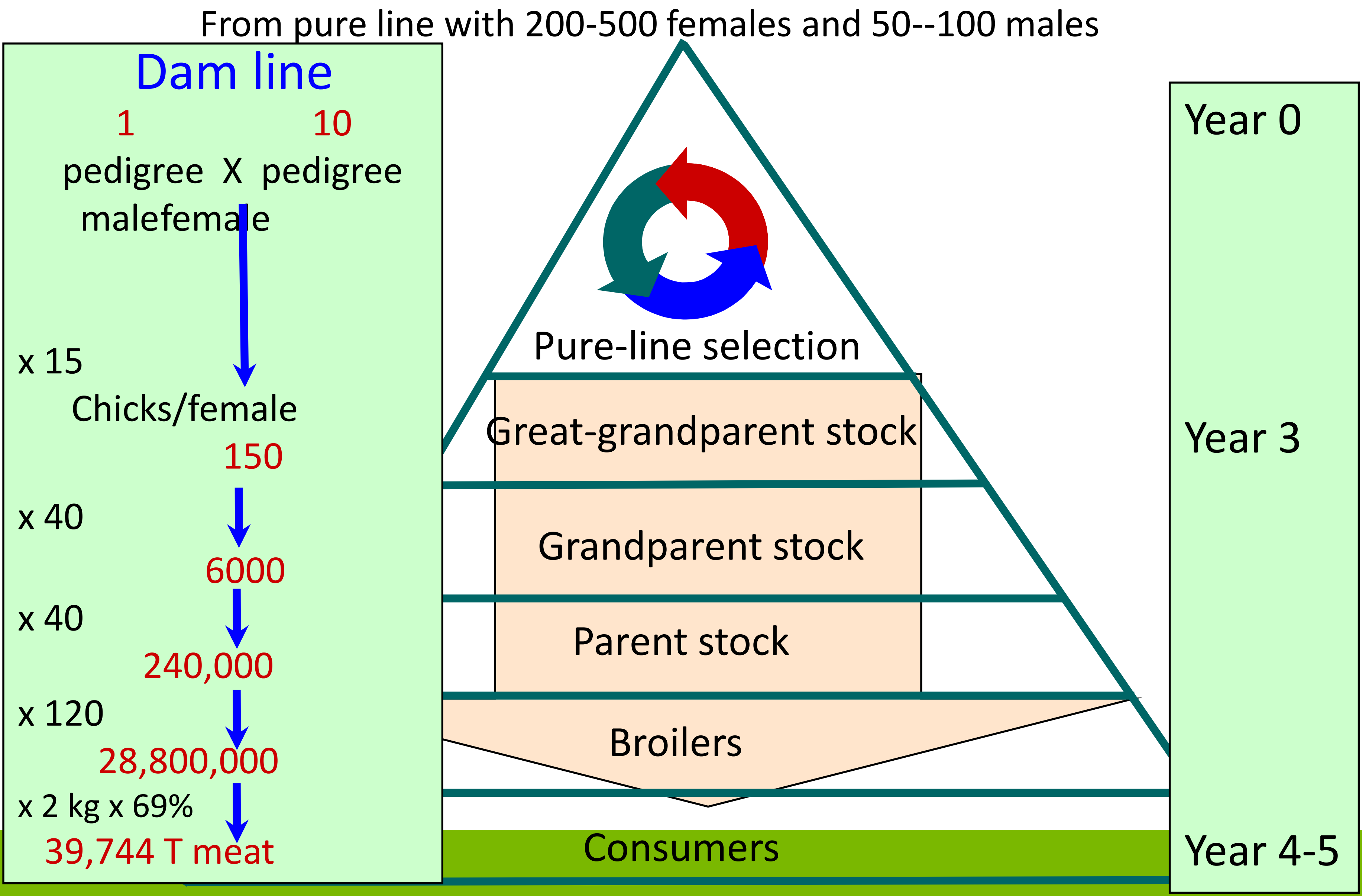
Design Examples

3-tier breeding program



Multiplication in Broiler Breeding Programs

Adapted from: Poultry Breeding and Genetics, Crawford (ed). Elsevier, 1990



From pure line with 200-500 females and 50--100 males

Dam line

1 10

pedigree X pedigree

malefemale

x 15

Chicks/female

150

x 40

6000

x 40

240,000

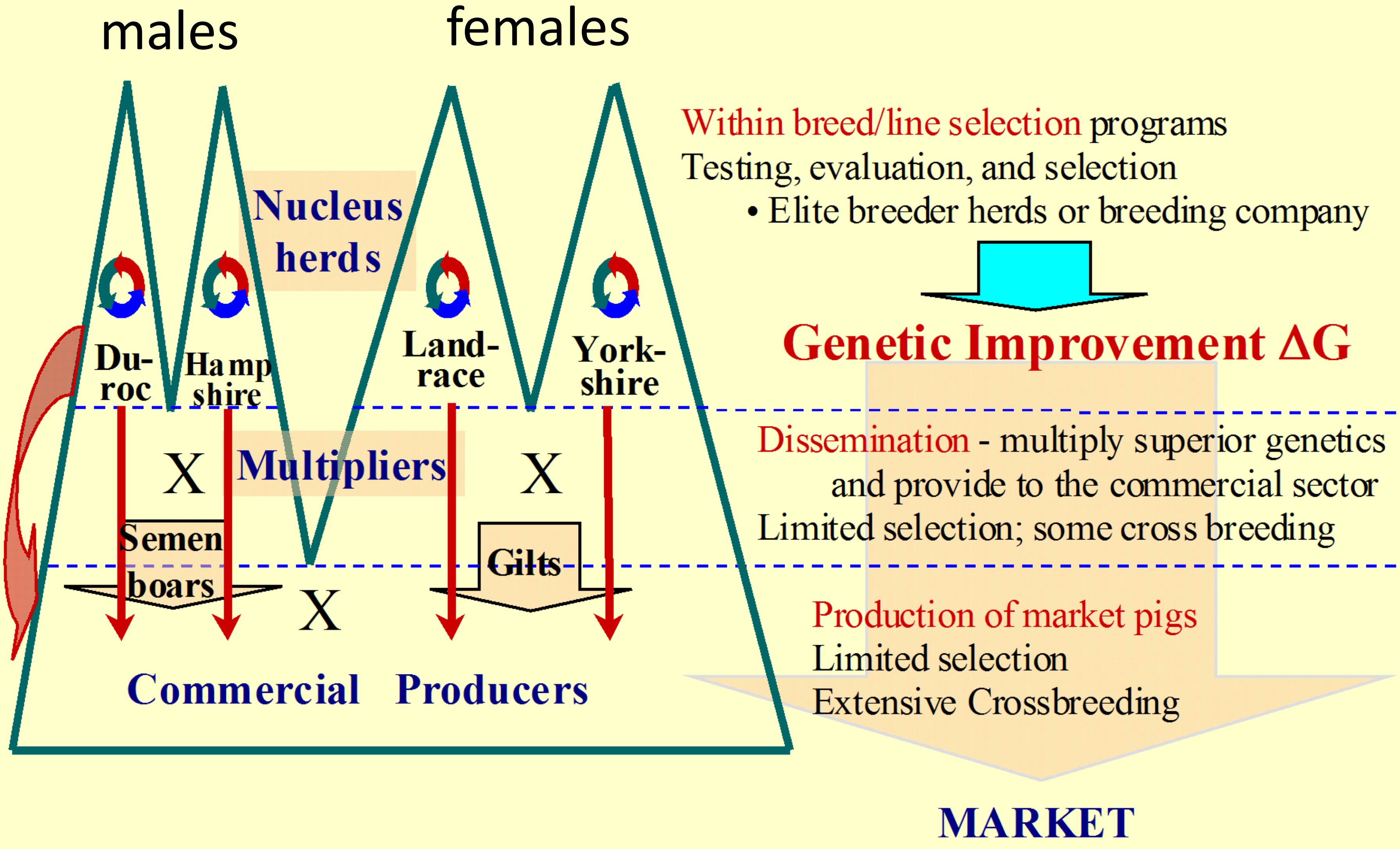
x 120

28,800,000

x 2 kg x 69%

39,744 T meat

Structure of Swine (Poultry) Breeding Programs



Within breed/line selection programs
Testing, evaluation, and selection
- Elite breeder herds or breeding company

Genetic Improvement ΔG

Dissemination - multiply superior genetics and provide to the commercial sector
Limited selection; some cross breeding

Production of market pigs
Limited selection
Extensive Crossbreeding

MARKET

Design Examples

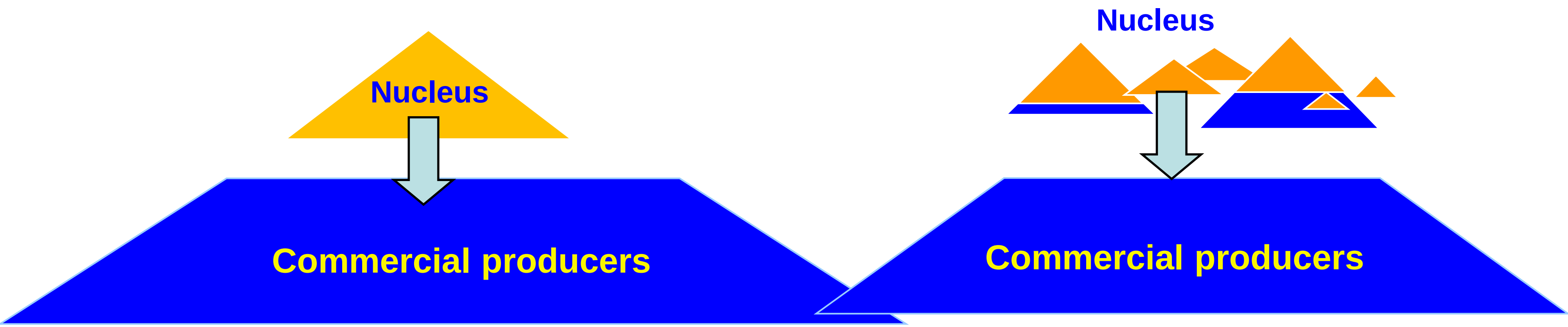
Two-tier breeding program

Central Nucleus

(pigs, poultry, some dairy)

or Dispersed

(sheep, cattle)



Nucleus

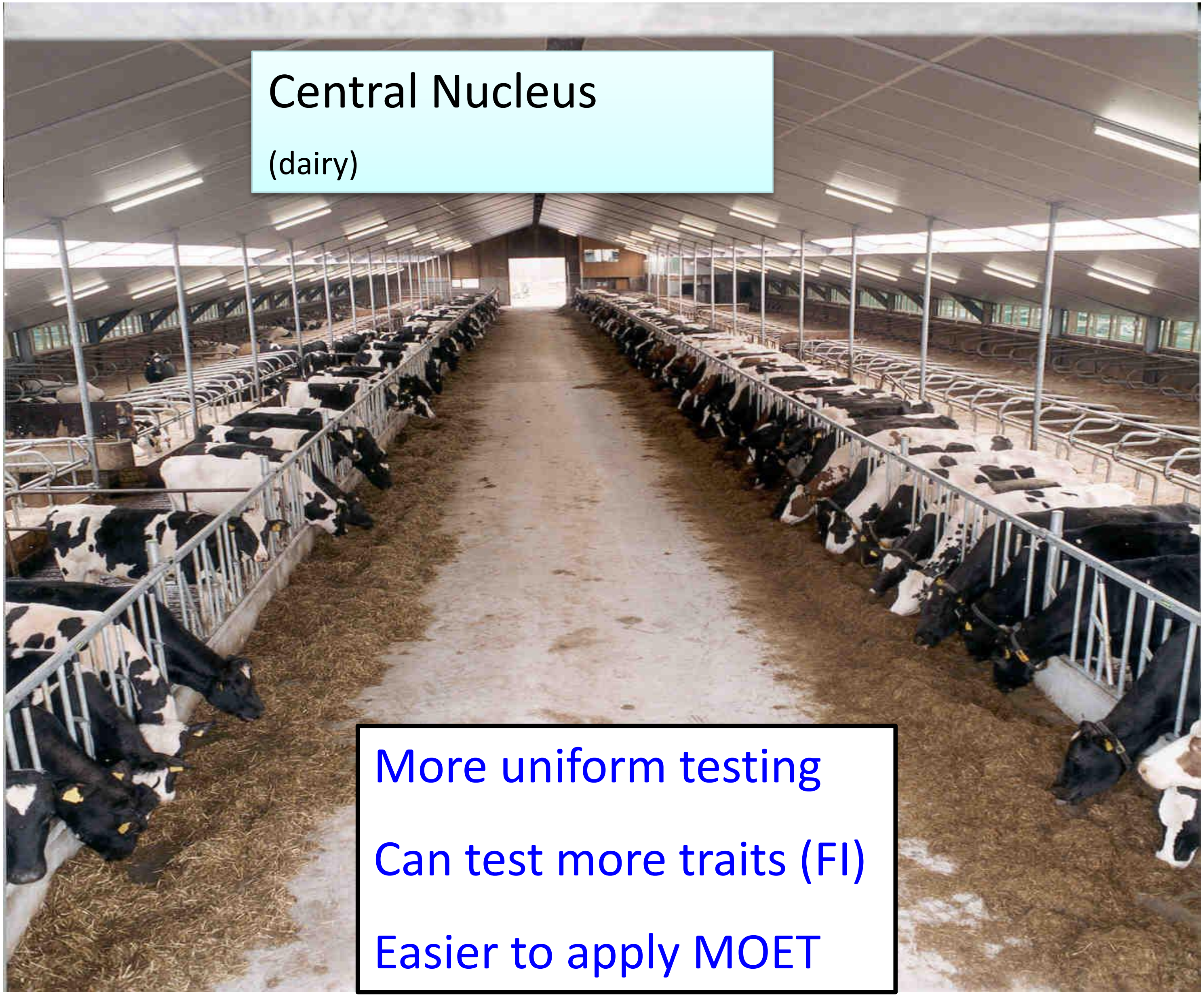
Commercial producers

Nucleus

Commercial producers

Central Nucleus

(dairy)



More uniform testing

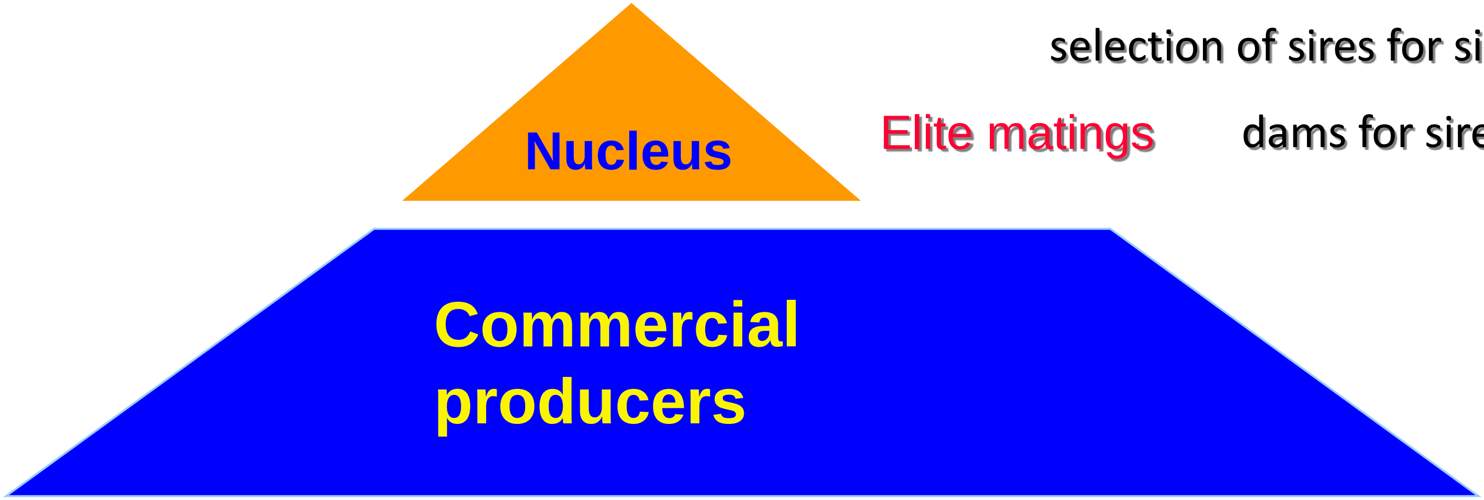
Can test more traits (FI)

Easier to apply MOET

What defines the nucleus?

Nucleus: could be defined as

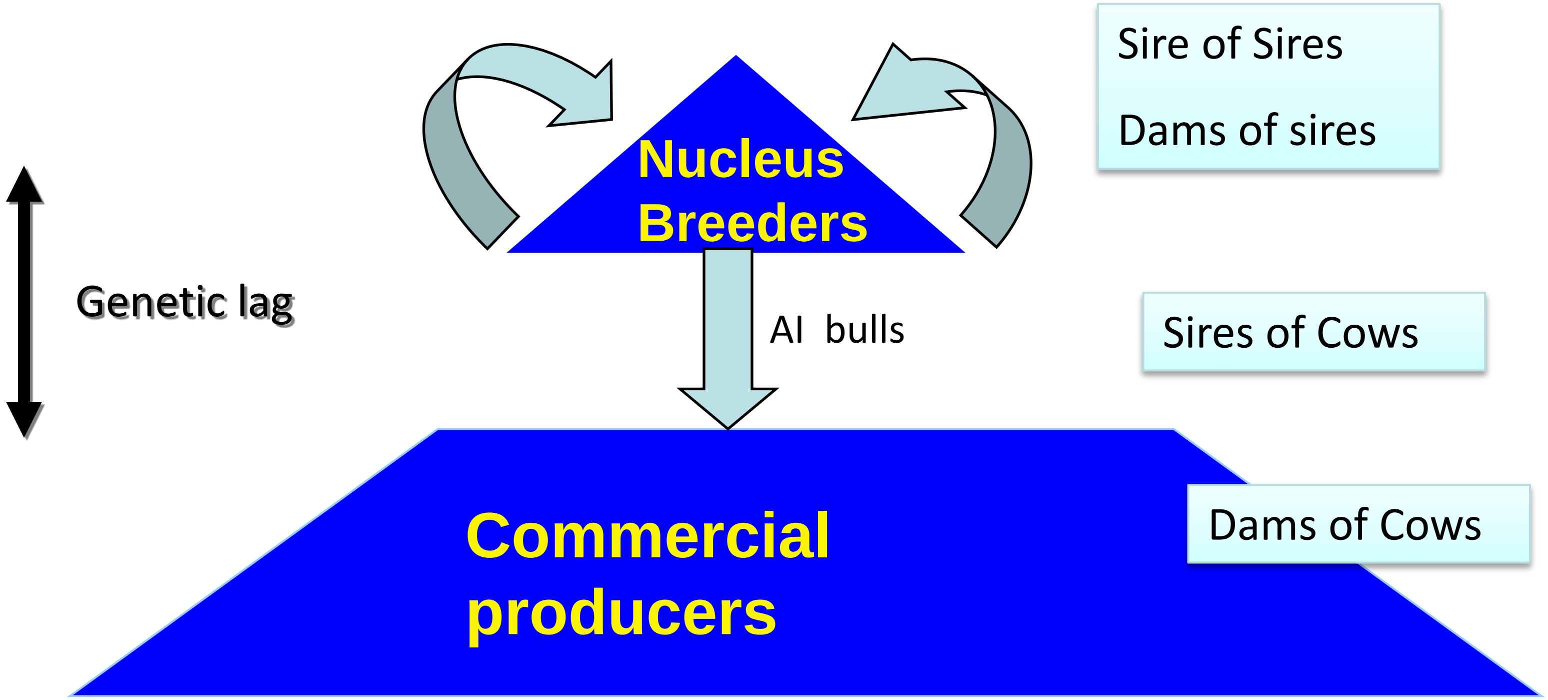
”the mothers and fathers of the future bulls”



	4 pathways:	dairy
	selection of sires for sires	top AI sires
Elite matings	dams for sires	bull dams
Normal matings	sires for cows	average AI sires
	dams for cows	normal cows

Design Examples

Two-tier breeding program (can compare with 4 pathways)



Sire of Sires

Dams of sires

Nucleus Breeders

Genetic lag

AI bulls

Sires of Cows

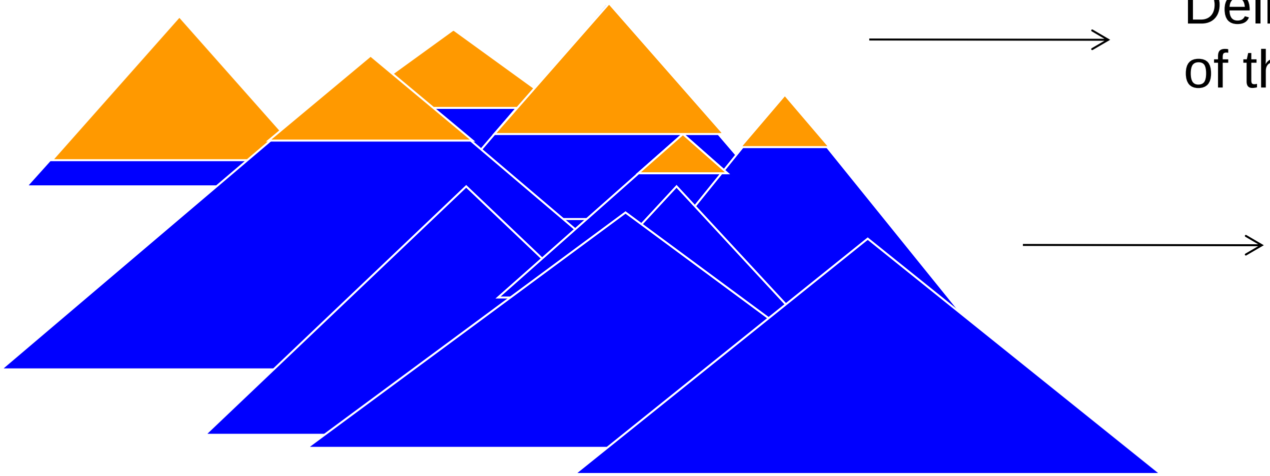
Commercial producers

Dams of Cows

Dispersed Nucleus

Nucleus: could be defined as

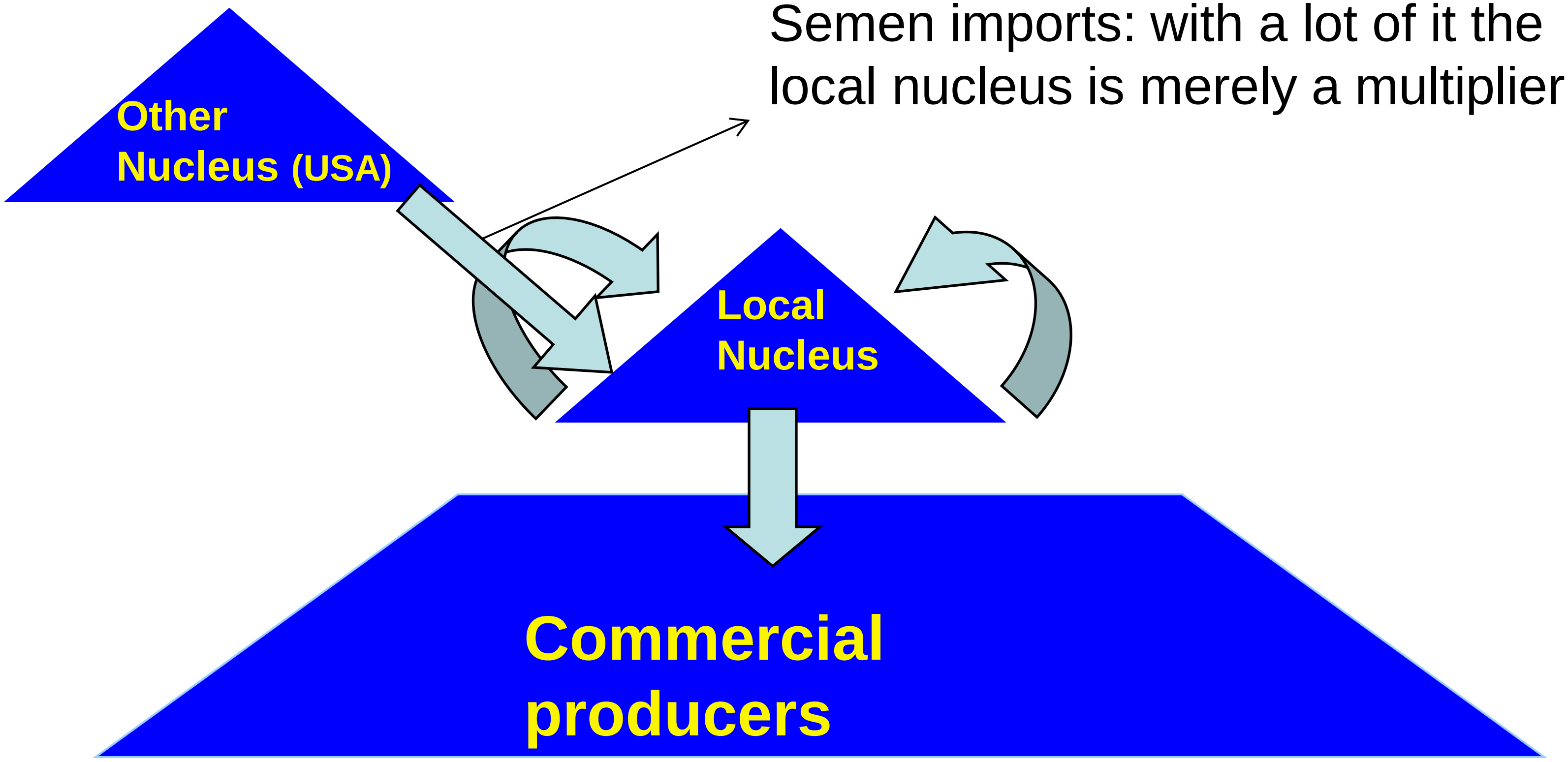
”the mothers and fathers of the future bulls”



Top studs
Delivering the genetics of the future bulls

Other studs
Acquire their genetic from top studs
Themselves being merely multipliers

Local ‘nucleus’ can in fact be multiplier



Other
Nucleus (USA)

Semen imports: with a lot of it the local nucleus is merely a multiplier

Local
Nucleus

Commercial
producers

Examples:	Angus Australia breeding program Holstein Australia Breeding program

Nucleus Breeding Schemes

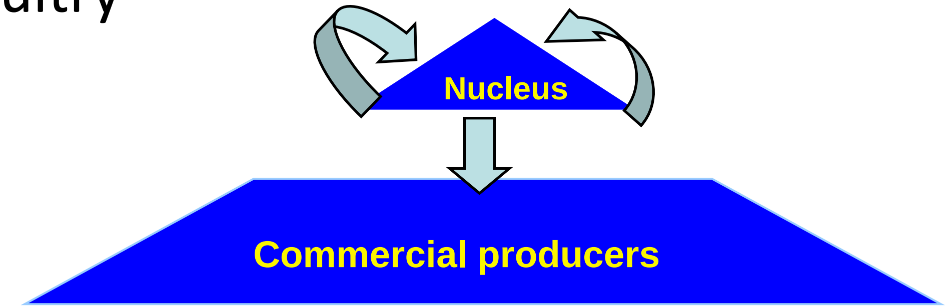
Closed Nucleus

Replacement animals for nucleus only from nucleus

Selection only permanently effective in nucleus.

Nucleus objectives impact on whole scheme.

Common in pigs and poultry



Nucleus Breeding Schemes

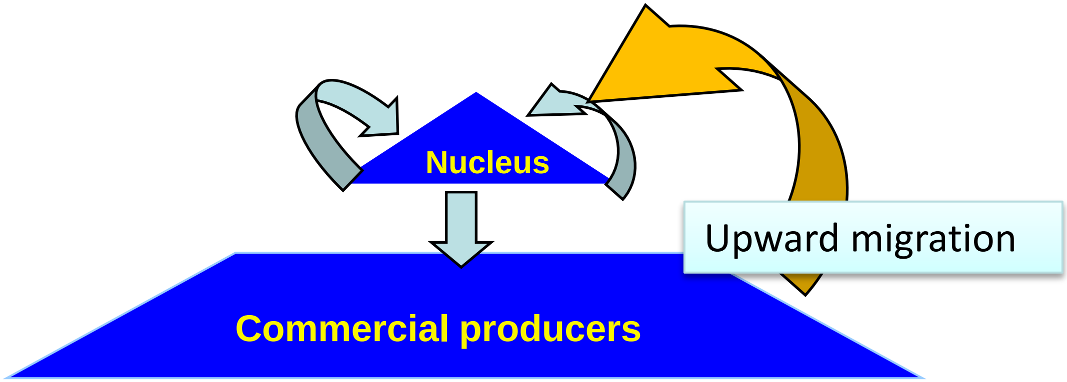
Open Nucleus

Replacement animals for nucleus but also some from base

Selecting from base requires measurement in base

More genetic improvement than closed scheme (~15%)

Common in dairy

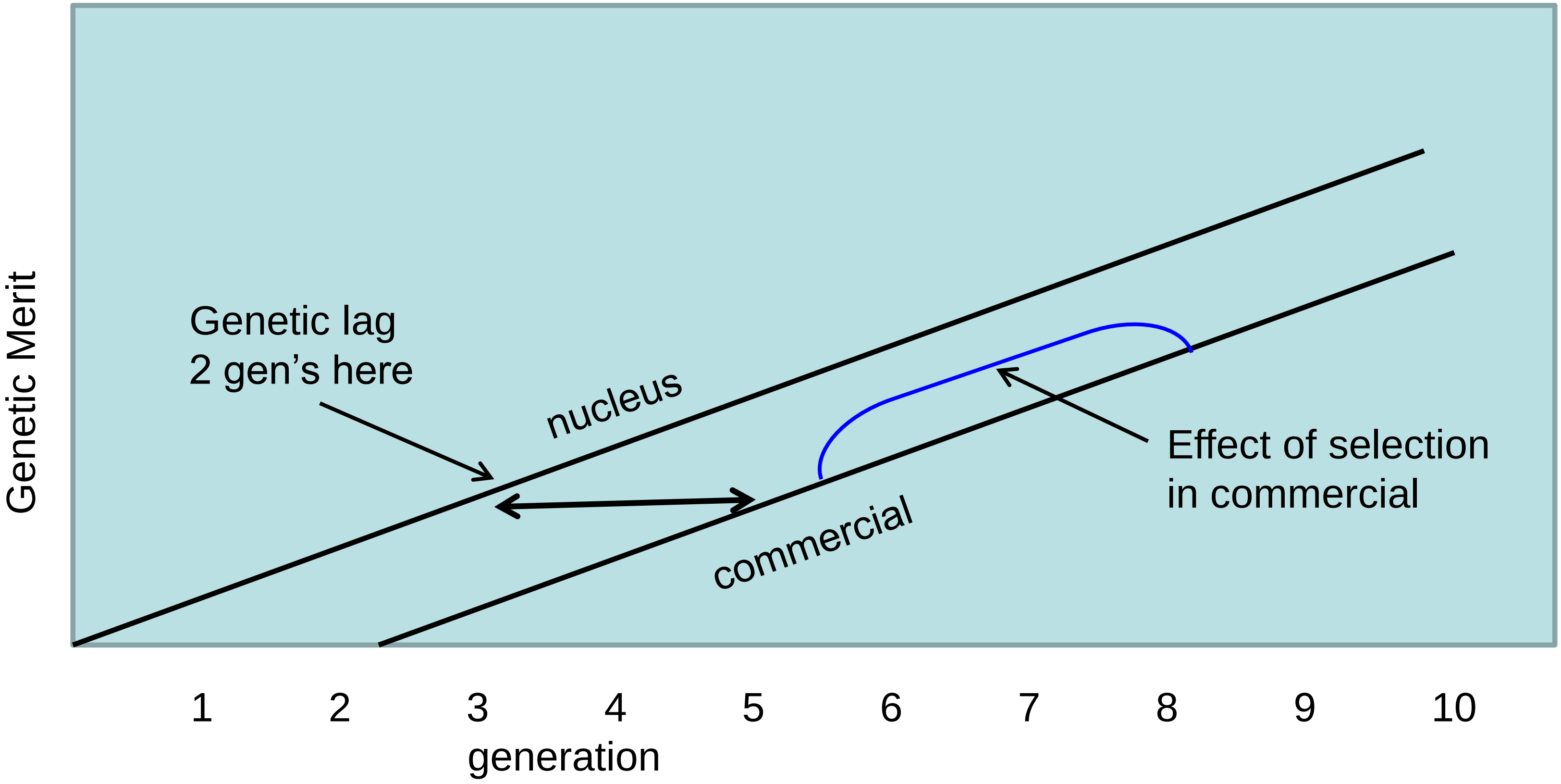


Nucleus

Commercial producers

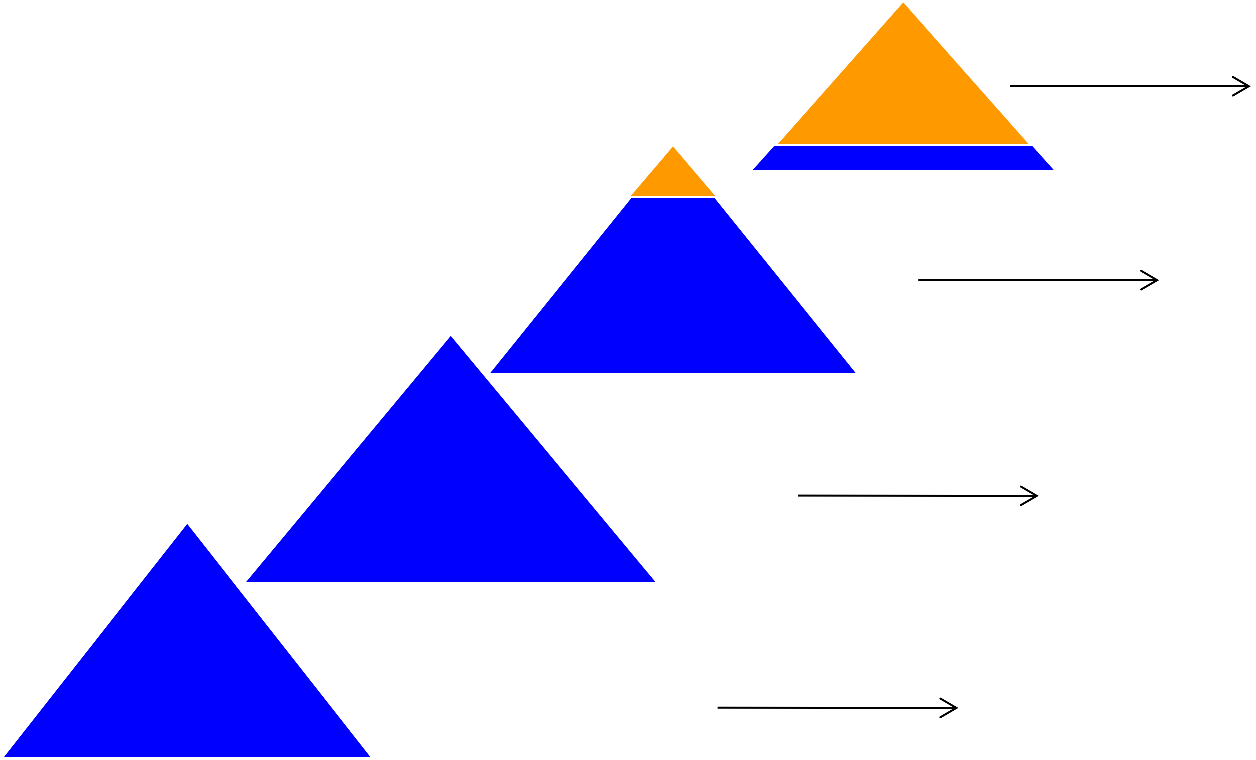
Upward migration

Genetic merit of Nucleus versus Commercial



In reality, tiers might be quite blurry

in beef, sheep (dairy)



Top studs
‘nucleus

Other studs
Buying bulls, select a bit

Commercial herds
Buying best bulls

Commercial herds
‘Buying average bulls

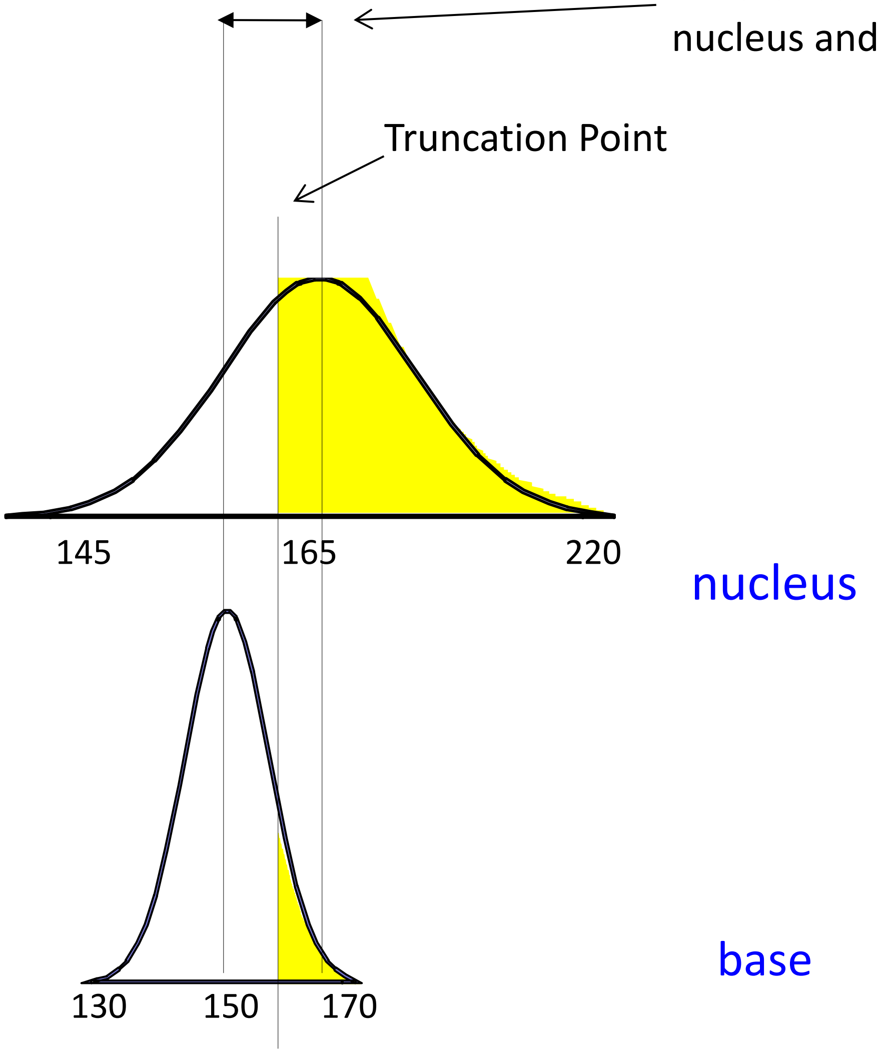
Open nucleus systems

- Select the best animals from lower tiers to compete for being nucleus parents

- degree of ‘openness depends on
  - difference between nucleus and commercial
  - spread of their breeding values

- Open to nuclei

Open Nucleus

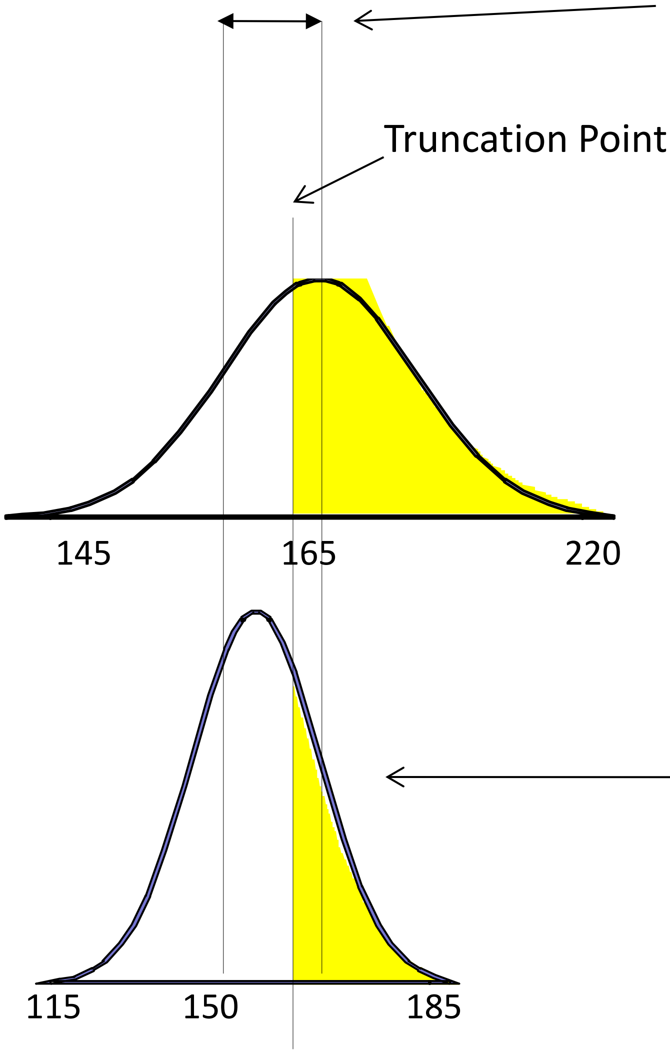


Difference in genetic mean between nucleus and base (~ 2 generations)

Truncation Point

Selection of females for elite matings (e.g.
80% from nucleus
20% from base

Open Nucleus: *effect of more information in base*



Difference in genetic mean between nucleus and base (~ 2 generations)

Truncation Point

Selection of females for elite matings (e.g.
70% from nucleus
30% from base

nucleus

More measurement in base, more spread of EBV, more selected from base

base

Contributions of pathways

$$R = \frac{\boxed{i_m r_m} + \boxed{i_f r_f}}{L_m + L_f}\sigma_A$$

2 pathways

	sel.int	sel.accur
• Selection of sires	2	.5-.8
• Selection of dams	0.5-1	.5-.6

- → S_{sires} : S_{dams} at least varies from 2:1 to 5:1
- Sire selection contribute more than 70%-90% to dG

Contributions of pathways

4 pathways in dairy

	contribution to dG
Selection of sires for sires	39%
Selection of sires for cows	38%
Selection of dams for sires	22%
Selection of dams for dams	1%

Why need a design?

- Genetic improvement

Need decisions on

  - which animals to measure or genotype *nucleus* *males (females)*
  - where to select them *nucleus/base*
  - mating strategy *best to best* → elite matings

- Dissemination of genetic superiority
  - Often a challenge when setting up a new program, esp in developing countries.
  - How to sell/give improved seedstock to local farmers

- Inbreeding

Crossbreeding

<u>Reasons</u>

1. Sire-Dam complementation
   - Paternal: large, fast growth, good carcass
   - Maternal: small mature size, good fertility

   ……….to increase the efficiency of the whole production system

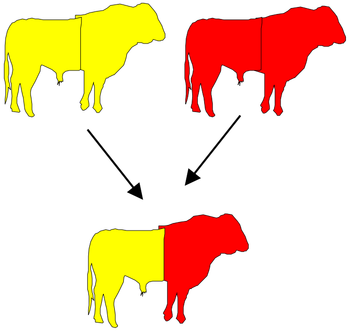
2. Heterosis
   - Direct heterosis
   - Maternal heterosis

3. Averaging of breed effects, Use of widest possible resources

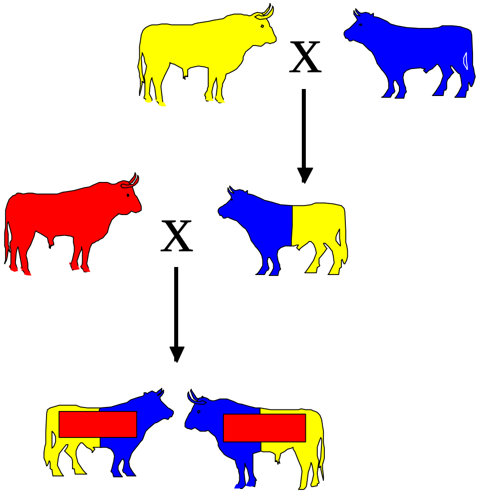
4. Other

Crossbreeding Examples

2-Breed Cross

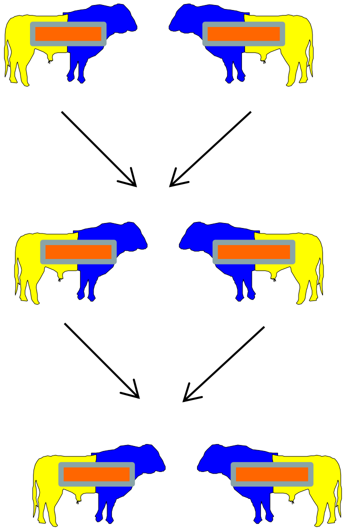


3-Breed Cross

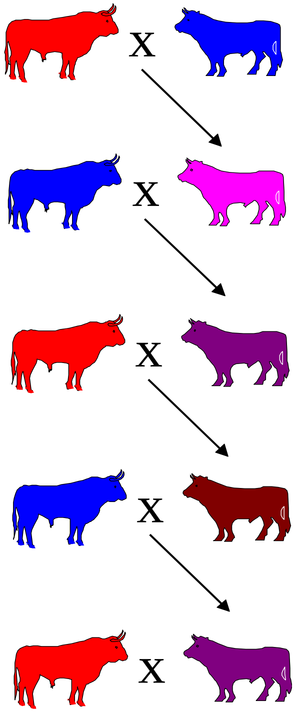


Terminal crosses

Composite/
hybrid



Rotational Cross



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.**

Crossbreeding:

Specialized lines and crossbreeding or dual purpose breeds?

		relative performance	
	price	meat breed	wool breed
wool	0.7	60	100
meat	1	100	60

Income from each system

		rel nr.	meat breed	wool breed	X-ing system	dual purpose
wool income	females	1	42	70	70	56
meat income	males	0.5	100	60	80	80
		profit	92	100	110	96

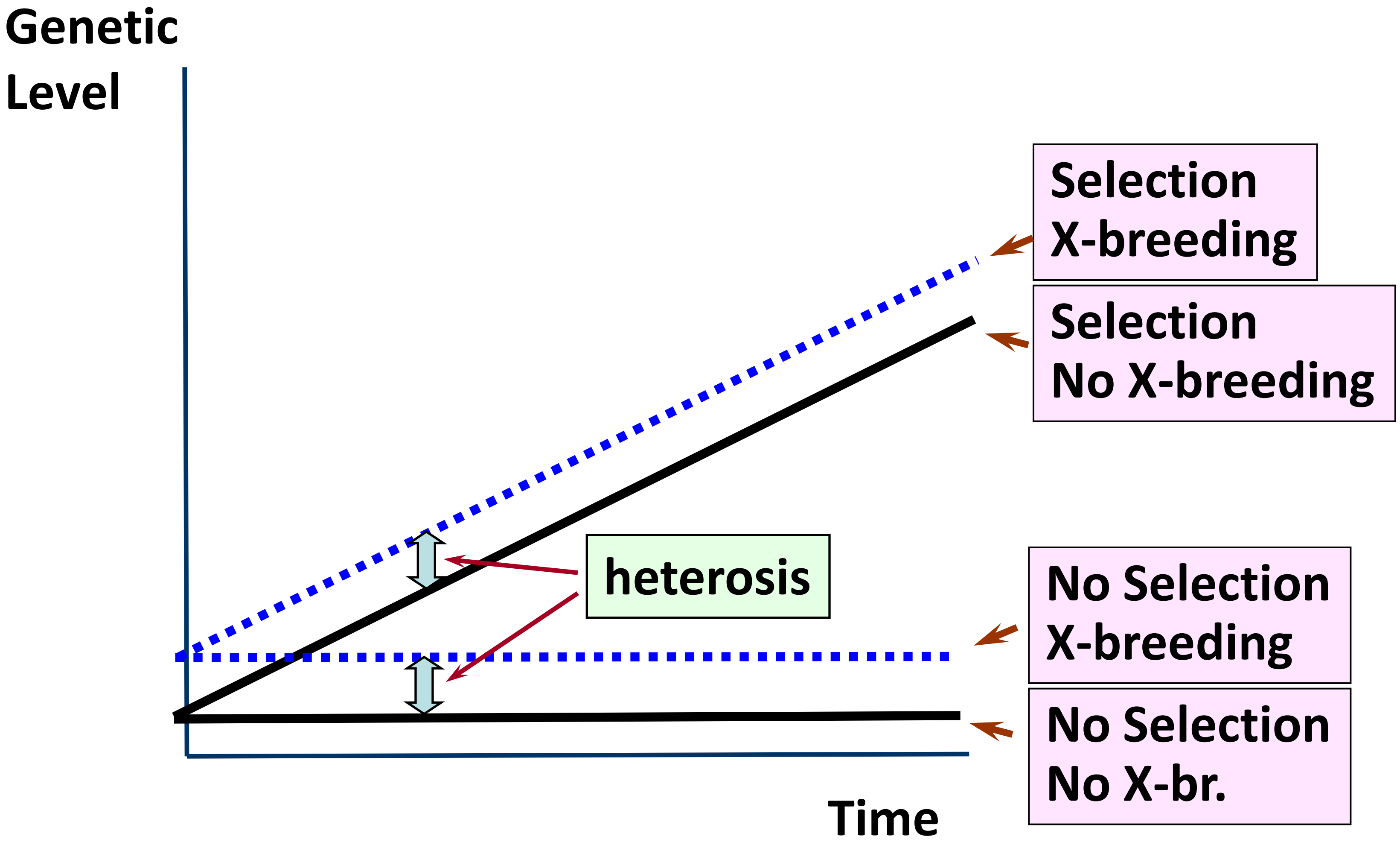
A crossbreeding system is more profitable,
it exploits sire-line and dam-line complementation

Predicting Crossbred Performance

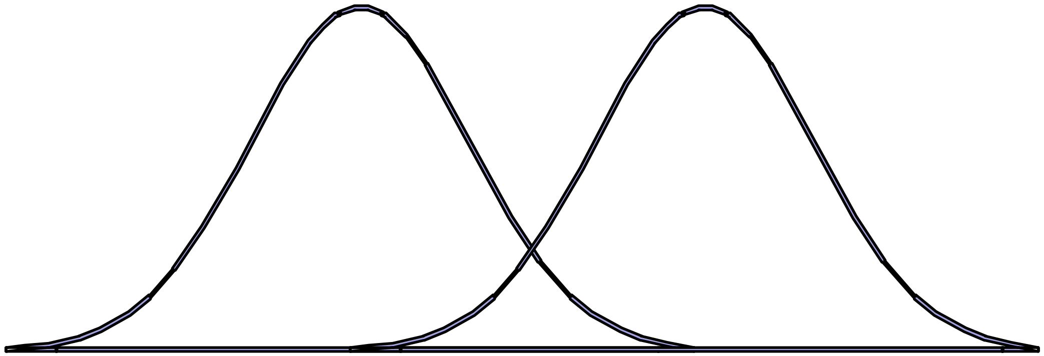
- Additive direct breed effects
- Additive maternal breed effects
    - Proportional to breed proportion of animal / dam

- Direct heterosis
- Maternal heterosis
    - Proportional to heterozygosity of animal / dam

Importance of Selection vs. Mating/Crossbreeding



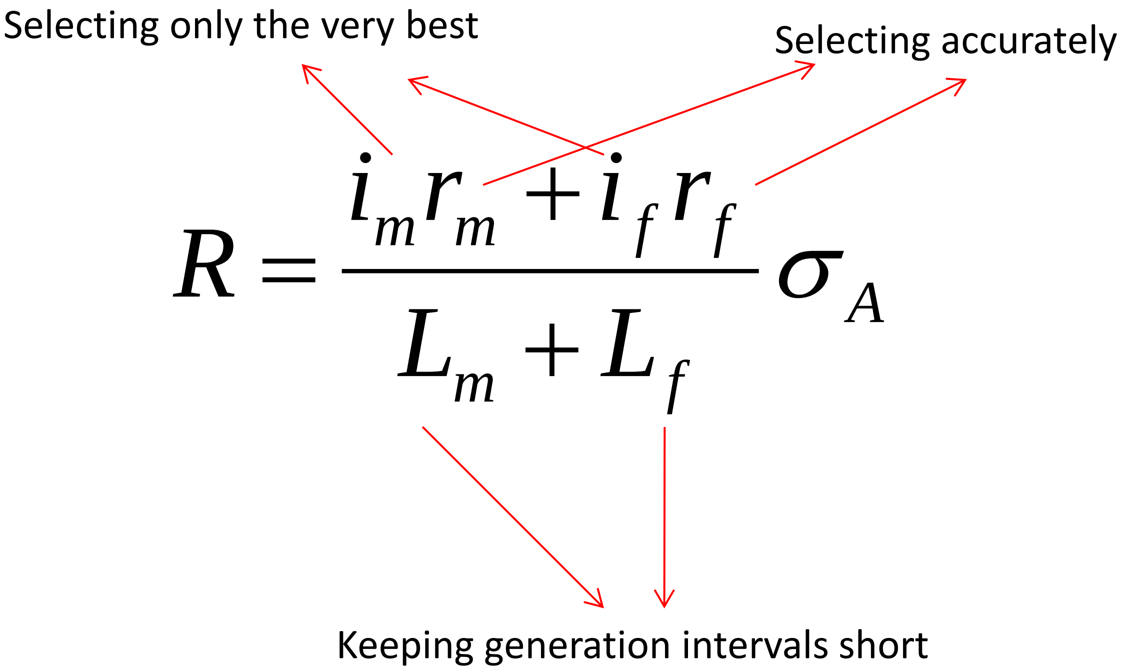
Importance of selection vs using between breed variation



Reproductive technologies

- Reproductive boosting
  - Artificial insemination, AI
  - Multiple Ovulation and Embryo Transfer, MOET
  - Oocyte Pickup
  - Juvenile In Vitro Embryo Transfer, JIVET
- Sexing of semen and embryos
- Cloning
- Whizzy Genetics - breeding in a test-tube

Making genetic progress is about



Selecting only the very best

Selecting accurately

$$R = \frac{i_m r_m + i_f r_f}{L_m + L_f} \sigma_A$$

Keeping generation intervals short

Reproductive rates affect all of the above!

Reproductive technologies

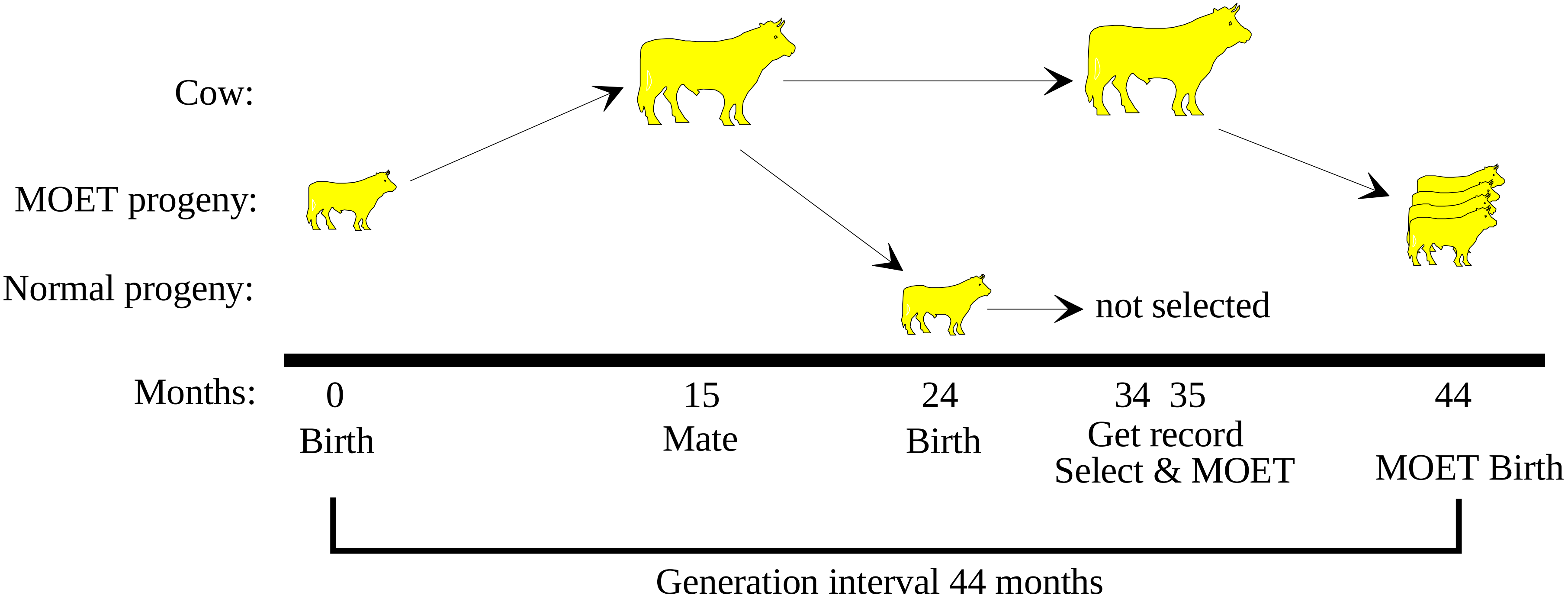
- Increases selection intensities

- Increases accuracy of EBVs

- Decreases generation intervals

- Increases inbreeding

Adult dairy MOET scheme (1983)



Cow:

MOET progeny:

Normal progeny:

not selected

Months: 0 Birth

15 Mate

24 Birth

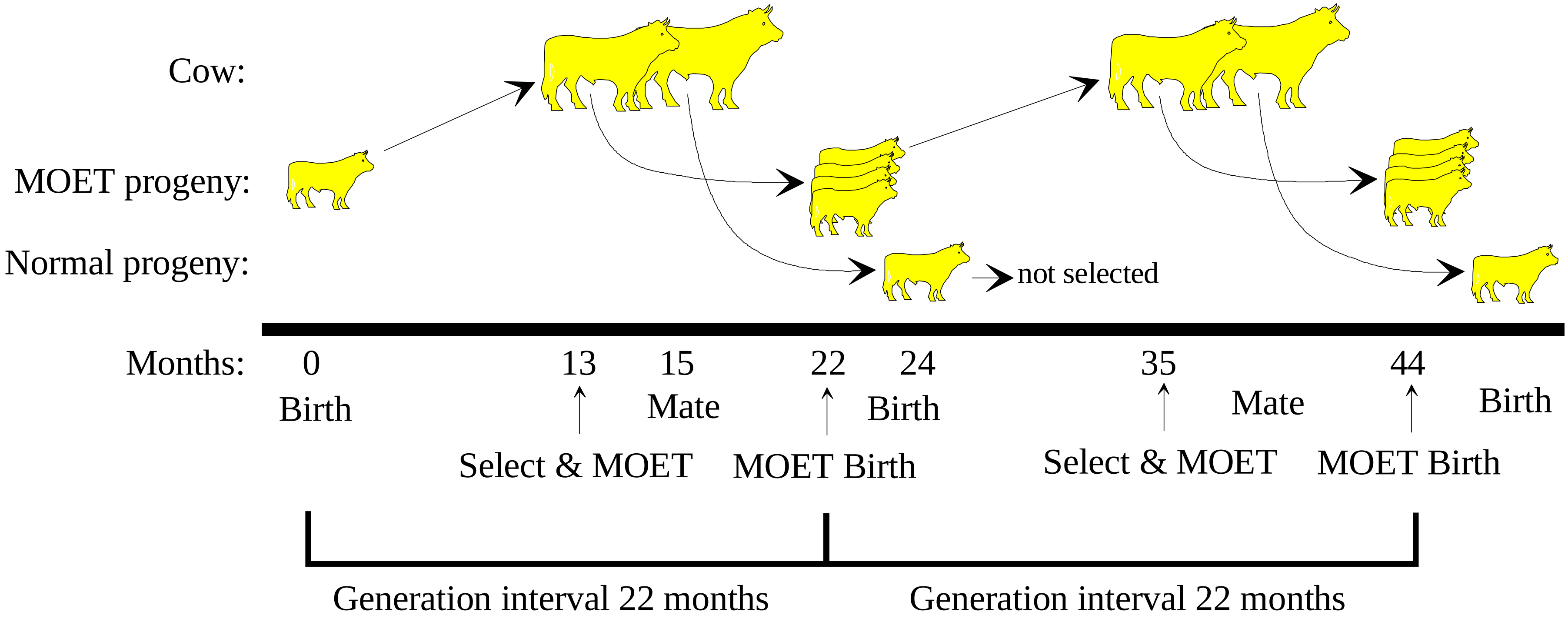
34 35 Get record Select & MOET

44 MOET Birth

Generation interval 44 months

More offspring of top cow *after* testing it

Juvenile dairy MOET scheme (1984)



Cow:

MOET progeny:

Normal progeny:

not selected

Months: 0 13 15 22 24 35 44

Birth

Mate

Birth

Mate

Birth

Select & MOET

MOET Birth

Select & MOET

MOET Birth

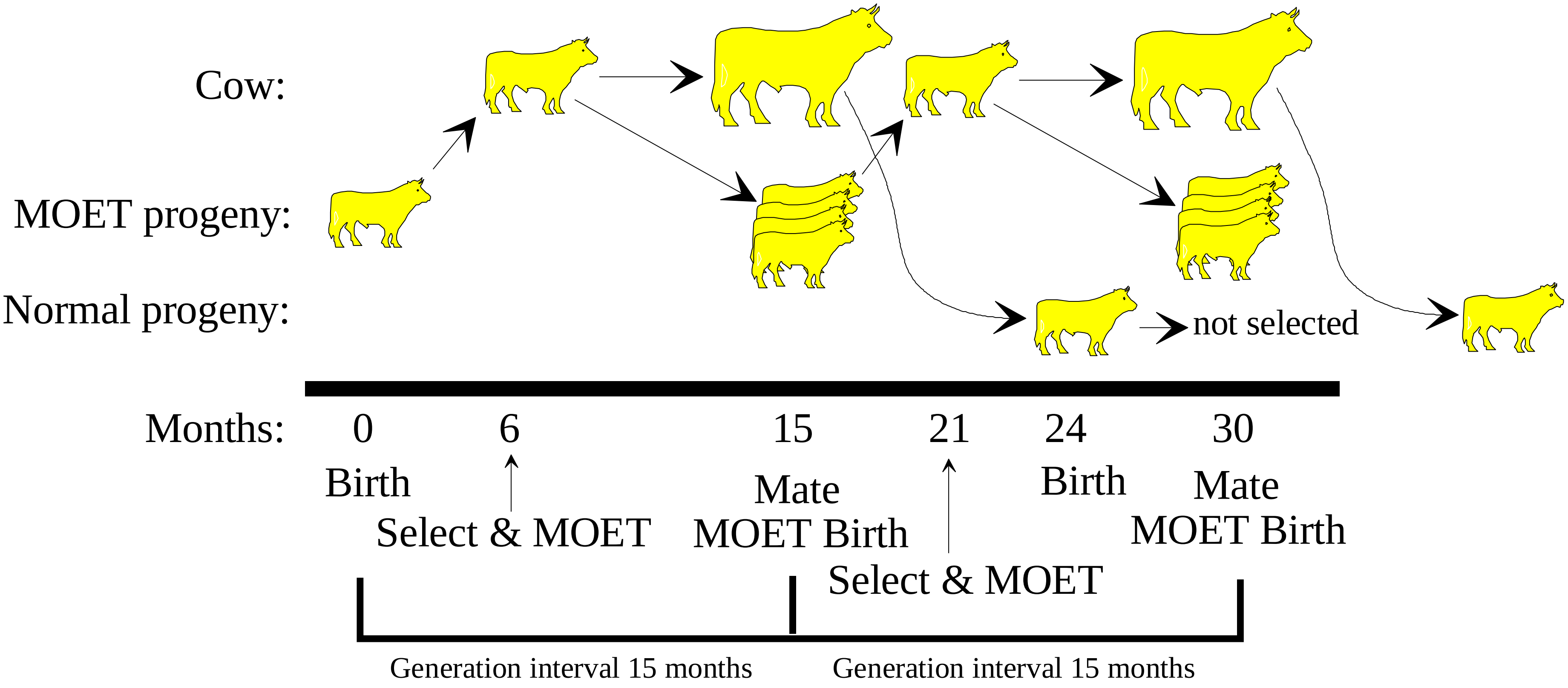
Generation interval 22 months

Generation interval 22 months

More offspring of top cow *before* testing it

Select base on parent average

Even more juvenile dairy MOET...



Cow:

MOET progeny:

Normal progeny:

not selected

Months: 0 6 15 21 24 30

Birth

Select & MOET

Mate

MOET Birth

Select & MOET

Birth

Mate

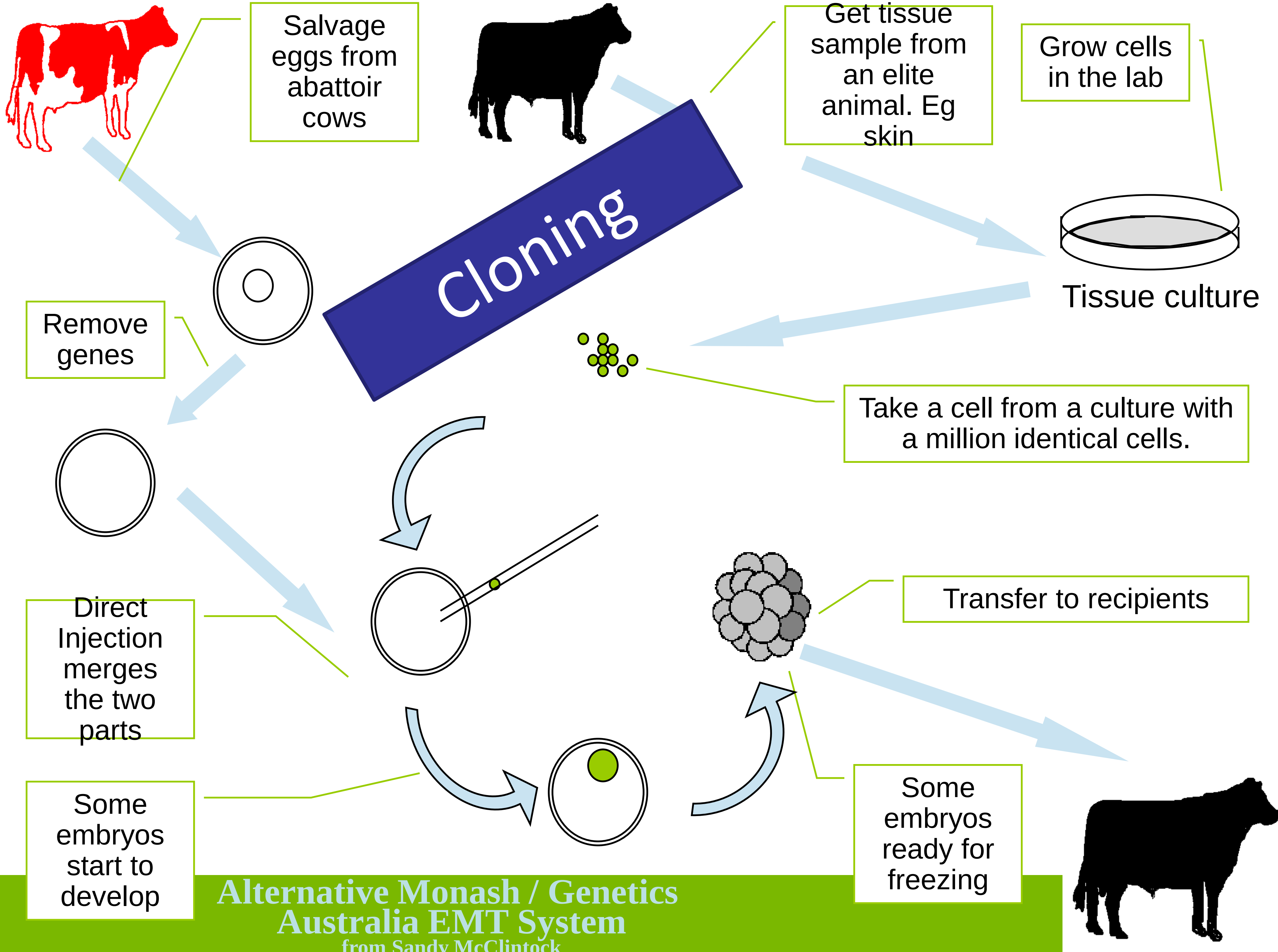
MOET Birth

Generation interval 15 months

Generation interval 15 months

1998: Note that this is a bad design - EBV from grandparents!

2015: Maybe it isn't when we use genomics selection!



Cloning

Salvage eggs from abattoir cows

Get tissue sample from an elite animal. Eg skin

Grow cells in the lab

Tissue culture

Remove genes

Take a cell from a culture with a million identical cells.

Direct Injection merges the two parts

Transfer to recipients

Some embryos start to develop

Some embryos ready for freezing

Alternative Monash / Genetics Australia EMT System

from Sandy McClintock

Cloning in animals

- Cloning from embryos, adults and cell lines.
  - Cell lines → easy genetic manipulation.
- Evaluate individuals via their clones ...
  - evaluations can be biased
  - fewer genetic individuals as candidates.
- Clone elite individuals for use in industry
  - eg. beef bulls for natural mating.

Genetic evaluation using clones

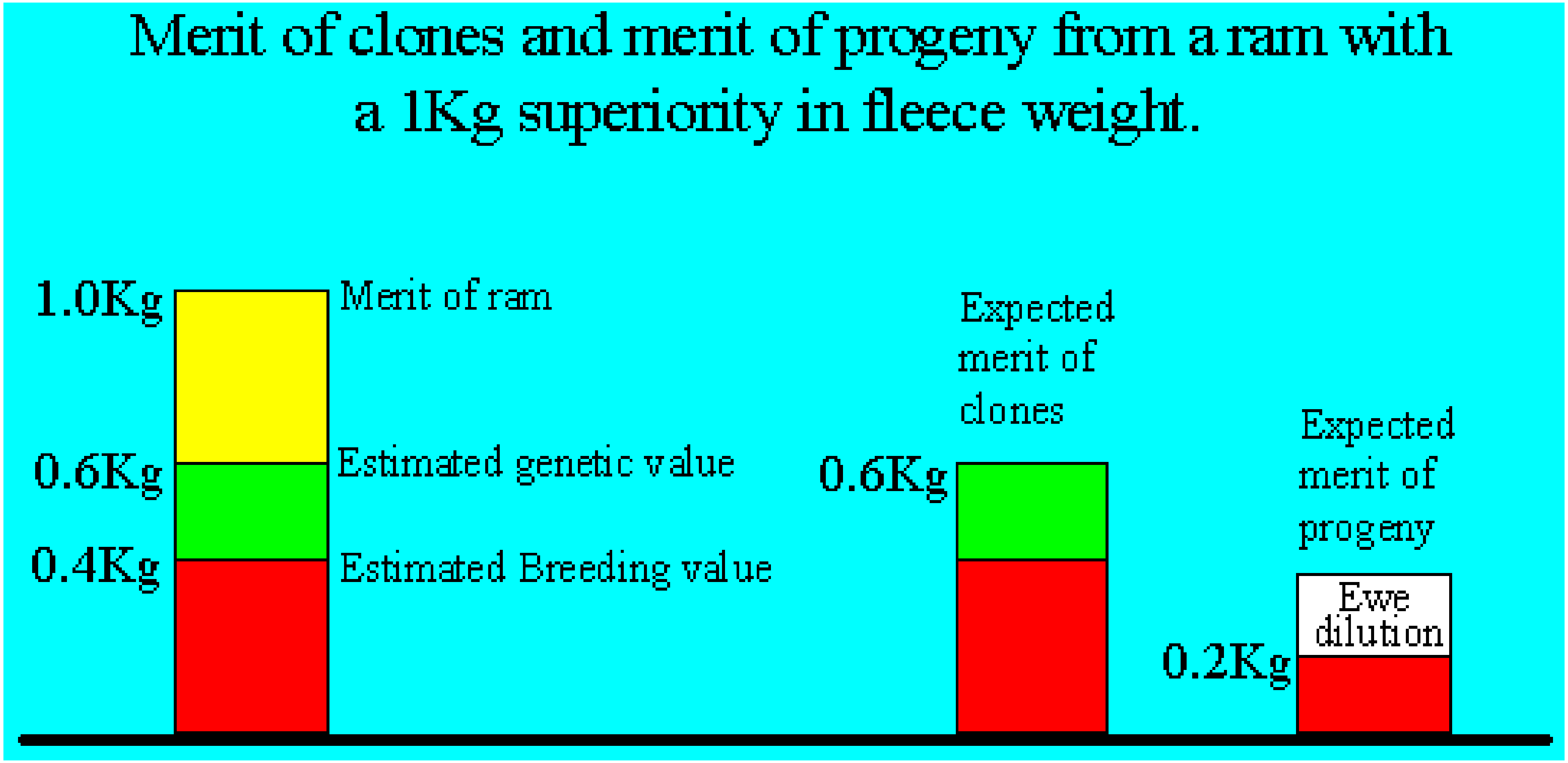
Breeding value.

This is ***the value of an animal's genes to its progeny***. For when we want to make judgements about breeding animals for generating progeny.

Genetic value, or Genotypic value.

This is ***the value of an animal's genes to itself***. For when we want to select animals to make clones of themselves to generate product to be harvested

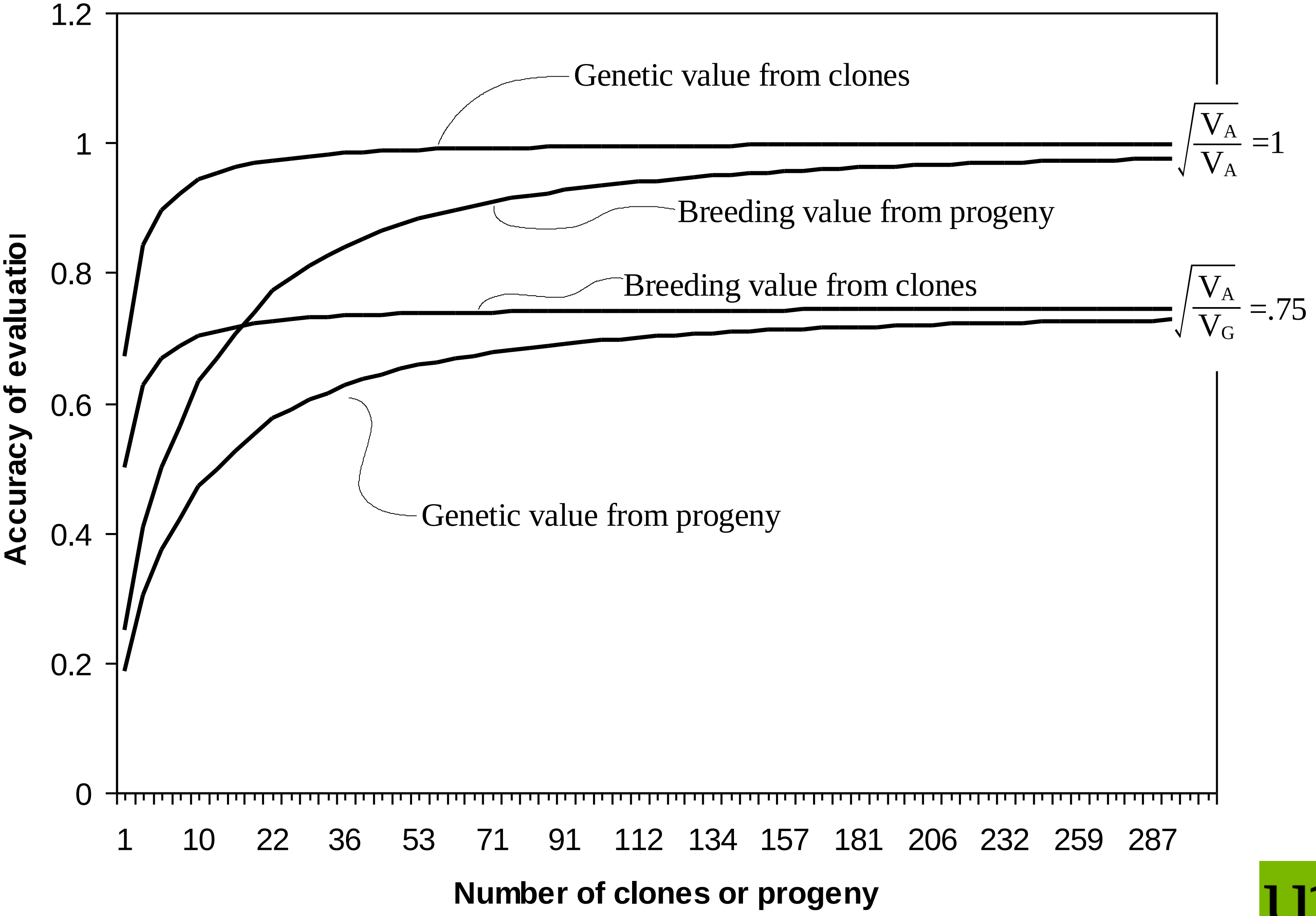
Clones versus progeny for direct use



Genetic evaluation using clones

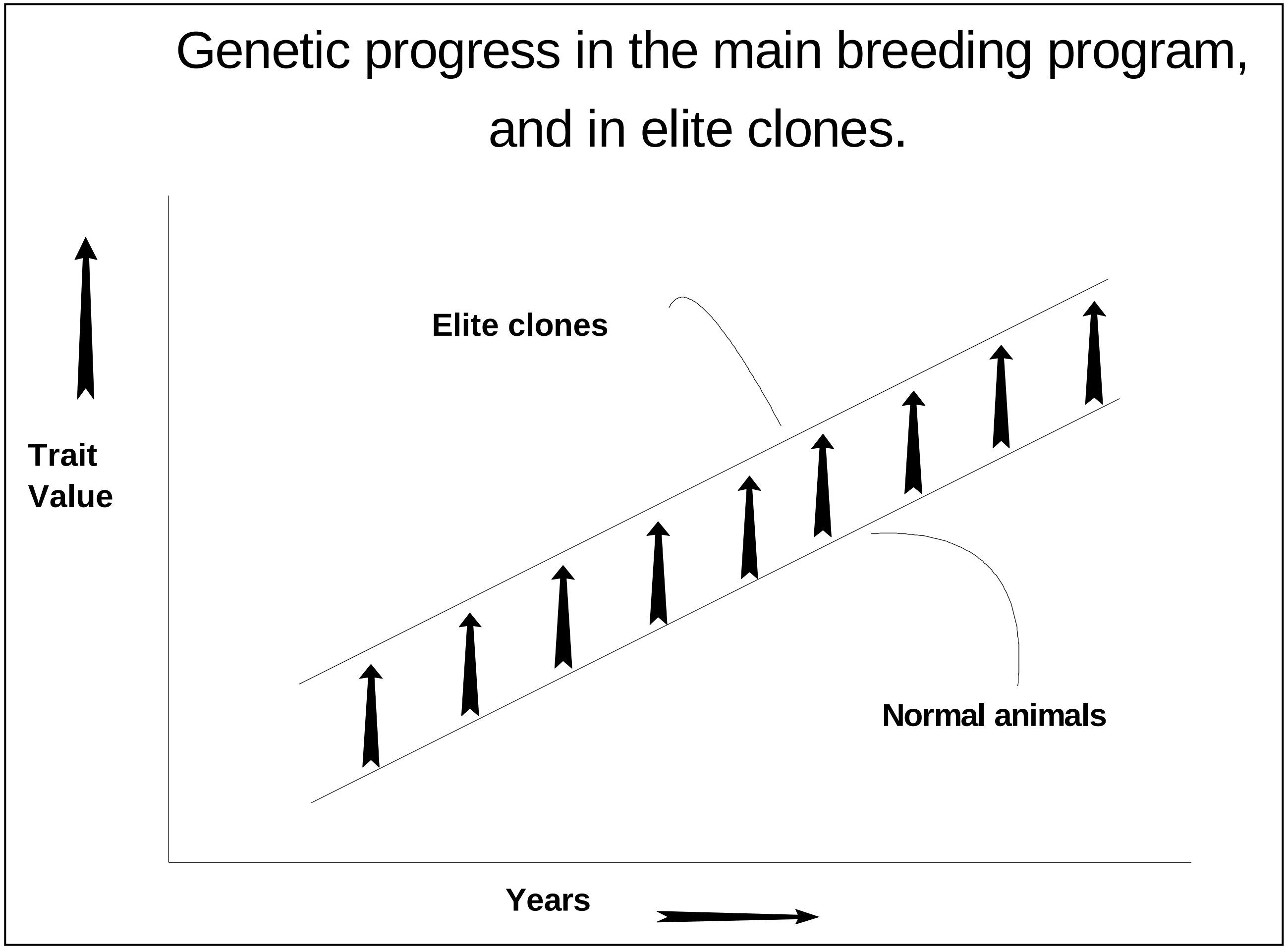
Data source	Accuracy of breeding value	Accuracy of genetic value
n progeny of each candidate	$\sqrt{\dfrac{¼V_A}{¼V_A + \dfrac{V_P - ¼V_A}{n}}}$	$\sqrt{\dfrac{¼V_A}{¼V_A + \dfrac{V_P - ¼V_A}{n}}} \times \sqrt{\dfrac{V_A}{V_G}}$
n clones of each candidate	$\sqrt{\dfrac{V_A}{V_G + \dfrac{V_P - V_G}{n}}}$	$\sqrt{\dfrac{V_G}{V_G + \dfrac{V_P - V_G}{n}}}$

Genetic evaluation using clones



Cloning

Impact on commercial production levels



Normal breeding program:

$i = 1.4$
$h^2 = 0.4$
L = 3.25 yrs.

Clone selection:

$i = 3$
$H^2 = 0.6$

Result: Today's elite clones are expected to be as good as normal animals born in just over 10 years' time.

Clones can give a more uniform product

Predicted range of expression within a cohort for a trait with $V_A/V_P = 0.25$ and $V_G/V_P = 0.45$ relative to unrelated animals = 100%.

Cohort type	Predicted range of trait expression
Unrelated animals	100%
A sire family	96.8%
A full-sib family	90.8%
A clone family	74.2%

Development of Breeding Strategies Summary

- Integration of the components of a breeding program into a structured system for genetic improvement, with the aim to maximize an overall objective (genetic gain, market share).

- Evaluate opportunities for improving upon current strategies.

- Evaluate the potential of new technologies.
    - How can they best be incorporated into current strategies?
    - Can their benefits best be capitalized on in a redesigned breeding structure?

Breeding Strategies - Summary

What tools are necessary to develop optimal strategies?

- Quantitative genetics theory
  - Predicting response to selection, selection index, inbreeding, etc.
- Systems analysis
  - Predicting and optimizing response in overall objective
- Common sense
- An open mind