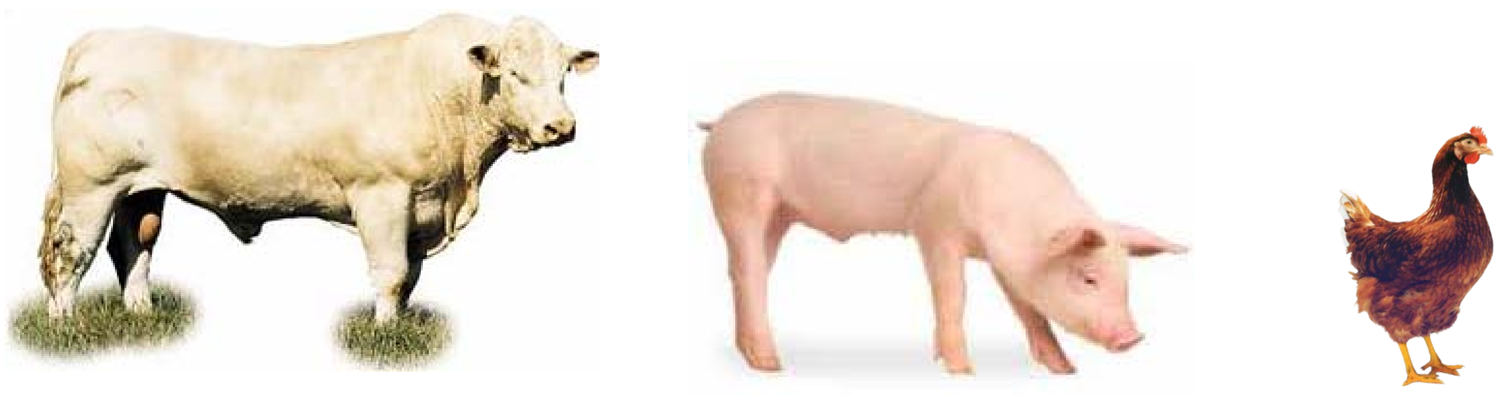
Challenges for closing the phenomic gap in farm animals



Hocquette, J.F., De La Torre, A., Meunier, B., Le Bail, P.-Y., Chavatte-Palmer, P., Le Roy, P., Mormède, P.

Outline

- New challenges for livestock breeding
- Scientific challenges
- High-throughput phenotyping: definitions and methodologies
- The need for standardisation
- Towards a new organisation?

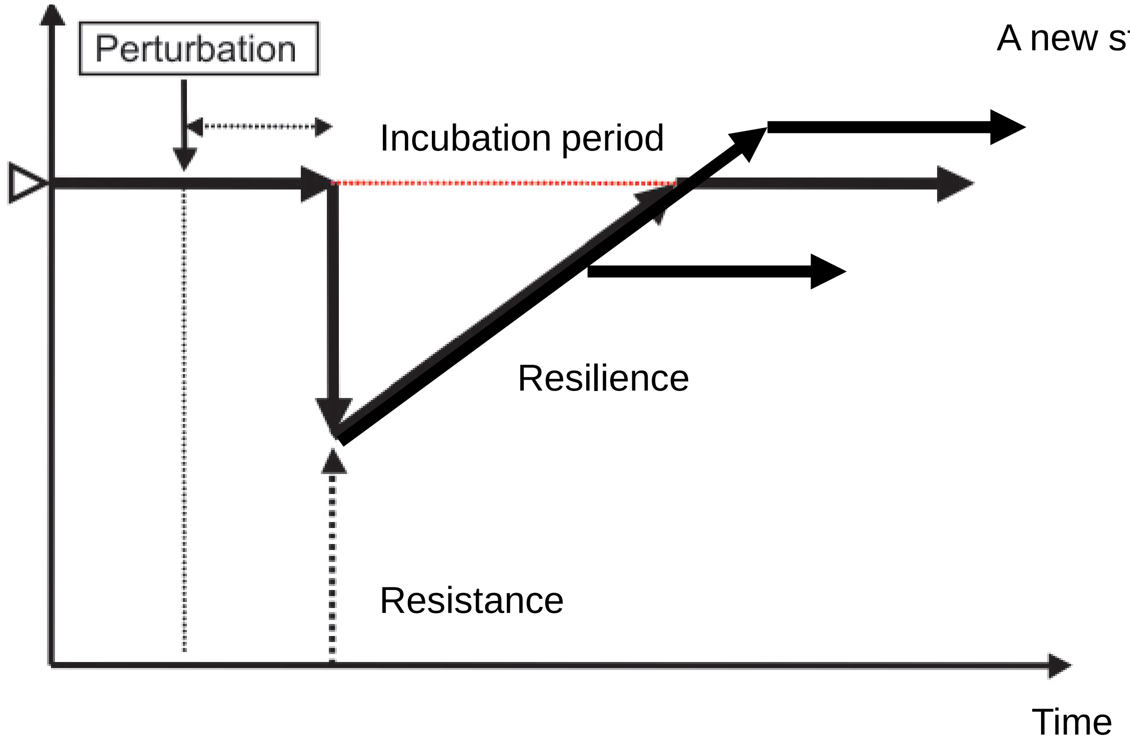
New challenges for livestock breeding

Animal husbandry research is focusing on the selection of animals that should be:

- **Efficient** in terms of the processing of food resources to limit their use at the maximum and to reduce emissions to the environment,
- **Robust and adaptable** towards climate change and towards a wide range of livestock breeding systems and
- Able to generate **a high yield of quality products** to meet consumers' needs in taste, health and nutrition and citizens' expectations concerning for instance animal welfare.

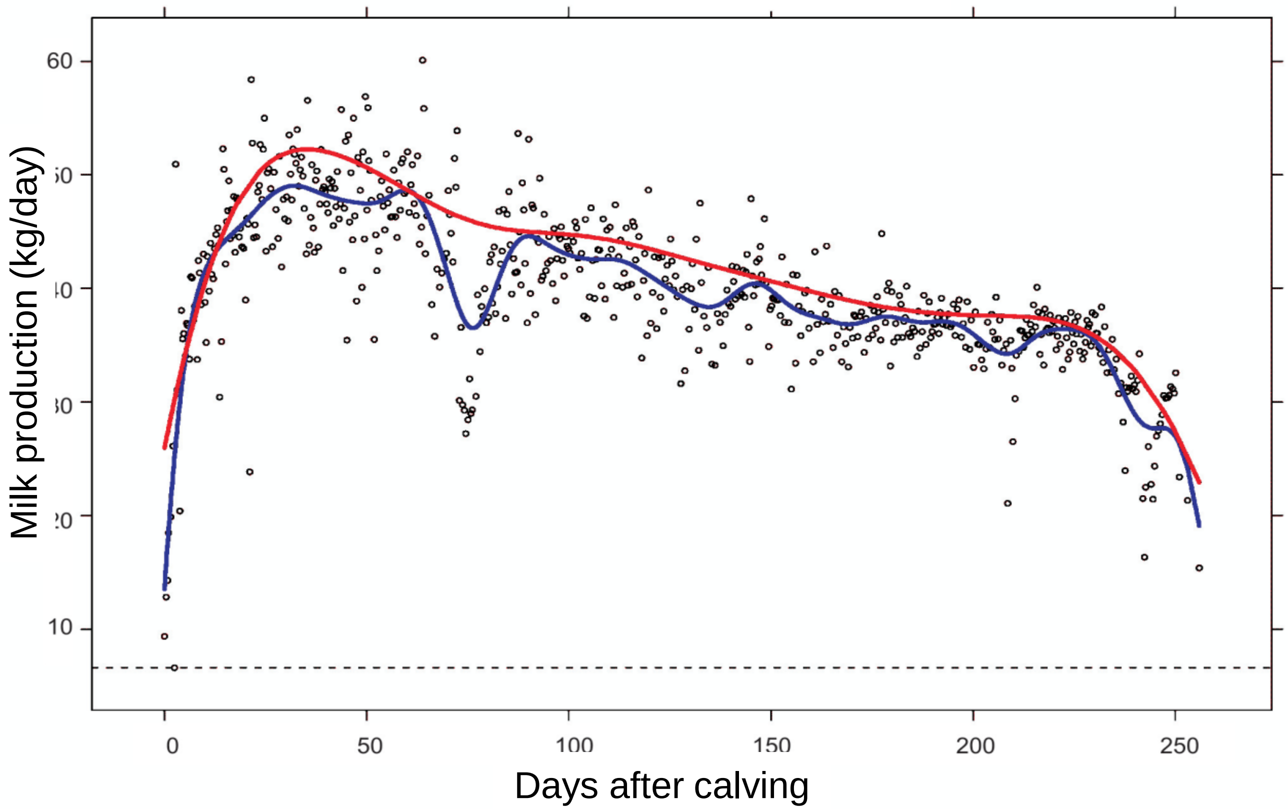
Robustness

Robustness is the property that enables an animal to produce normally but to adapt to or withstand changes in its environment, in particular, climate changes that are becoming increasingly frequent with higher amplitude *(Sauvant & Martin, 2010, Inra Prod Anim 23:5-10).*



Robustness, dynamic aspects

An animal's performance response to environmental variations (and therefore the assessment of its robustness) requires **high-frequency measurement** of specific traits, hence the importance of **high-throughput phenotyping** *(Friggens, Sauvant, Martin, 2010, Inra Prod Anim 23:43-52).*



Robustness: a new target

- **Robustness assessments**

  → based on a **set of physiological functions** of interest

  → involve the **measurement of diverse characteristics**

  animal health, reproduction, behavior and life span, ability to withstand stress and grow normally *(Mormède et al. 2011, Animal 5, 651–657)*

- **To better assess robustness**

  →**Recording of (new) traits** which are **sensitive** to the **environment** (and not only direct productive traits): vitality, longevity, fertility, disease resistance, feed efficiency, carbon footprint, social and feeding behaviour, etc

Sources: Boichard & Brochard (Animal 2010, 6:4, 544-550) for dairy cattle; Merks et al. (Animal 2012, 6:4, 535-543) for pigs and Amer 2012 (Turning science on robust cattle into improved genetic selection decisions).

Potential economic gains

- The value of animal production at farm level in the European Union-25 (EU25) is €132 billion, amounting to 40% of the value of agricultural production (2004).

- A conservative estimate of the economic gain achieved each year by animal breeding at farm level is €1.83 billion in Europe alone. Hence, the genetic gain achieved by breeders is carried over to producers as an economic gain reaching approximately **1.5% of the economic value of EU farm animal production**.

From FABRE Technology Platform, February 2006. Sustainable Animal Breeding and Reproduction – a Vision for 2025

Potential economic gains

- One Euro invested for genomic selection, three Euros earned (Fest'IA, 2012).
- A 1% improvement in feed efficiency in beef cattle has the same economic impact as a 3% increase in rate of gain (http://www.nbcec.org/FeedEfficiencyBeefCattleISU.pdf).
- Reducing calving interval by 63 days in a herd of 100 dairy cows saves 9500 Euros per year (Bovins Croissances 03, France).
- Worldwide the productivity of farm animals is 30–40% below their genetic potential because of suboptimal conditions and health status (Leo den Hartog, Nutreco Director R&D).

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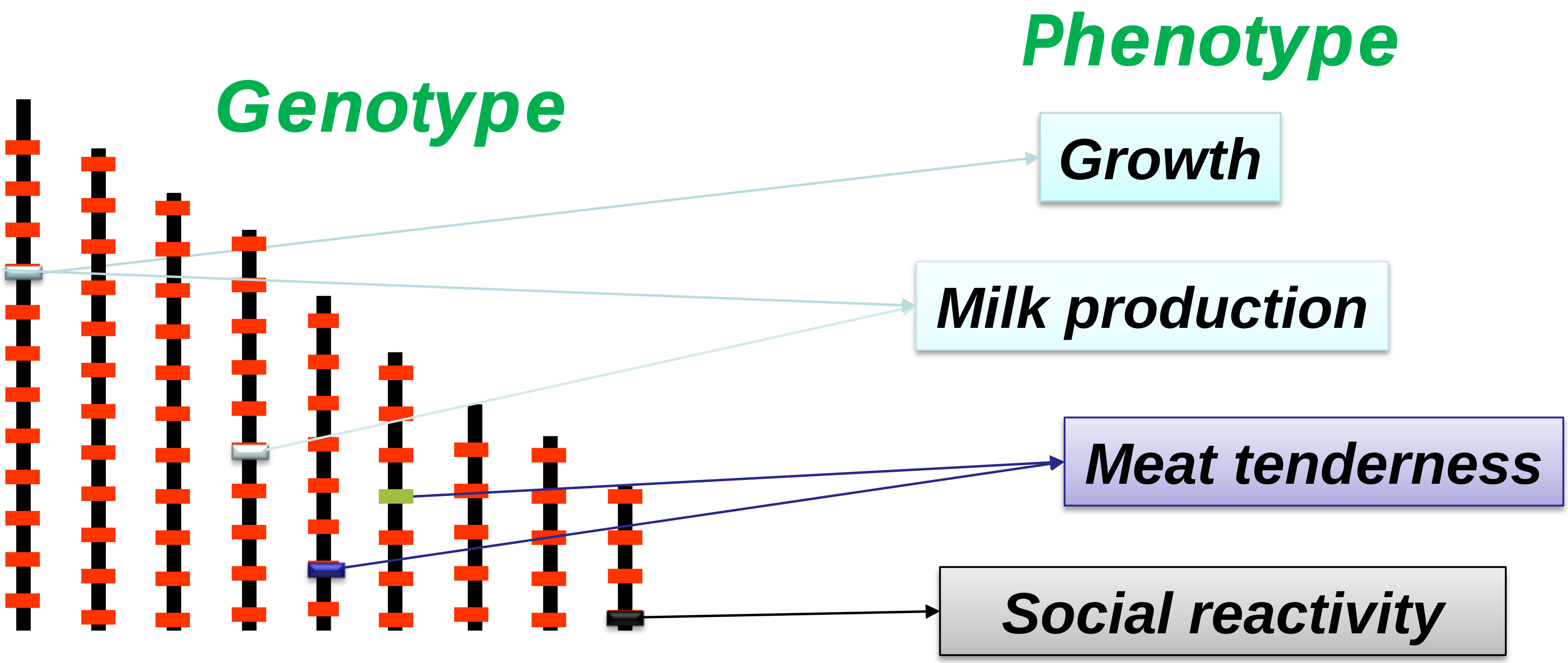
A first challenge: genomic selection

The key objective is to establish ever more fine-grained functional relationships between animal genotypes and their phenotypes



Currently animal breeding programs can only improve measurable traits or traits genetically related to measurable traits.

The genomic selection is also an opportunity to consider new and complex phenotypes (e.g. adaptation, robustness) if we are able to measure them !

Challenges

- Genotyping is performed in a standardized and automated way using robots.

  → **It should be the same for phenotyping**

- For traits with low measurement repeatability (r < 0.95), 2 or 3 independent measurements of the same trait should be obtained on the same samples.
- Individuals should be genotyped solely for strongly correlated traits for independent measurements *(Barendse 2011).*

  → **In a few words: standardization, automation, high repeatibility.**

- **'In the age of the genotype, phenotype is king'** *(Coffey 2011, ICAR Meeting).*

A second challenge: predictive biology

Animal identification and movement
Feeding data collection
Fertlity recording
Health recording
etc

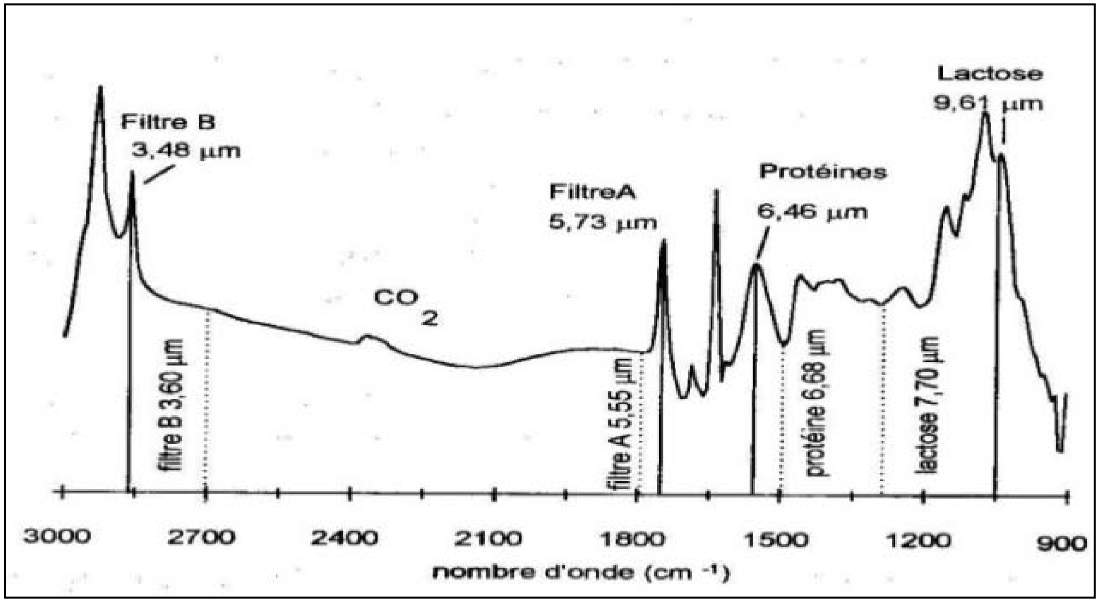
+ Milk spectra MIR data = Pooled Database

↓

New performance indicators based on MIR

↓

Pregnancy diagnosis
Evaluation of energy balance
Early detection of masticis
Estimation of methane production



Dehareng F. 2011. Optimir new tool for a more sustainable dairy sector, General Assembly and annual workshop of ICAR 2011 'New technologies and new challenges for breeding and herd management'. Bourg-en-Bresse, France, June 22nd to 24th, 2011. http://www.icar.org/Documents/Bourg-en-Bresse2011/Presentations/session%204%20-%2023%20am/1%20Frederic%20Dehareng.pdf

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Prediction of beef quality in Australia

Prediction

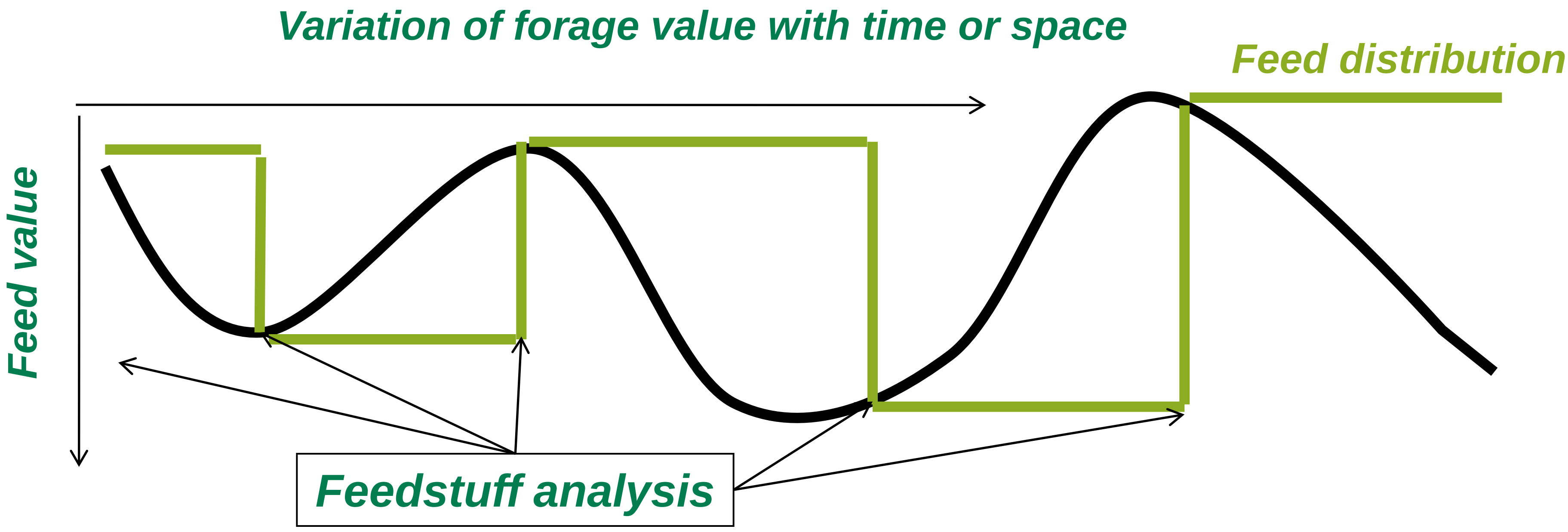
MSA2000model®

Hang (AT/TC/TS/TX)	AT
Sex (M, F)	m
Est.% Bos Indicus	0
Hump Height cms	0
Hot Std Carc Weight	200
USDA Ossification	100
Milk Fed Vealer Y/N	N
USDA Marbling	130
Days Aged (min 5)	5
Quarter Point Ribfat	5
Ultimate pH	5.40
AUSMEAT Meat Col.	2
Saleyard? (Y, N)	n
Wght/App.Maturity	1.32

Cut Description	Muscle Reference	Days Aged	Grilled Steak	Roast Beef	Stir Fry	Thin Slice	Cass-erole	Corned Beef
Tenderloin	TDR062		5	4	5			
Cube Roll	CUB045		3	3	3	4		
Striploin	STR045		3	3	3	3		
Oyster Blade	OYS036		4	3	4	4		
Bolar Blade	BLD096		3	3	3	3	3	
Chuck Tender	CTR085			3	3	3	3	
Rump	RMP131		3	3	3	3		
Point End Rump	RMP231		3	3	3	4		
Knuckle	KNU099		x	3	3	3	3	
Outside Flat	OUT005			x	x	3	3	3
Eye Round	EYE075		x	3	3	3	3	x
Topside	TOP073		x	3	x	3	3	
Chuck	CHK078			3	3	3	3	
Thin Flank	TFL051				3		3	
Rib Blade	RIB041				3			
Brisket	BRI056				x	3	3	x
Shin	FQshin						3	

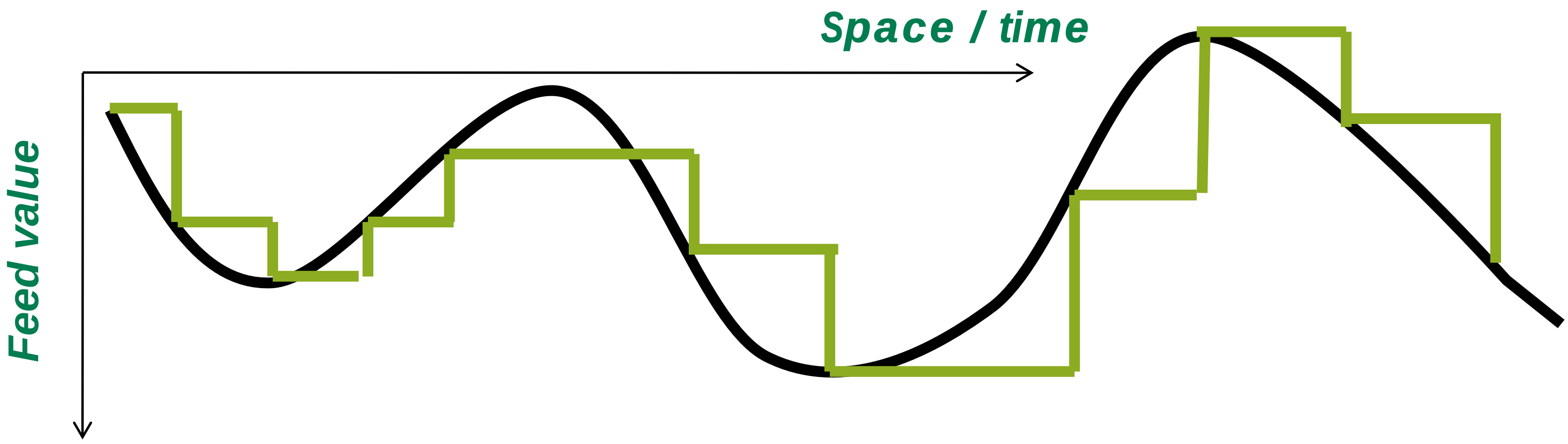
A third challenge: Precision Farming

Example: Feed efficiency



Feedstuff analysis are done to formulate rations.
Feed distribution may be slightly over or under real animal needs.
Therefore, rations do include safety margins with the intent of covering at least animal needs. This has a cost !

How to increase feed efficiency and to save money



Forage variability cannot be removed but it can be managed thanks to frequent sampling and analysis (Feedstuff NIR analysis is accurate, fast and cheap)

http://www.icar.org/Documents/Bourg-en-Bresse2011/Presentations/session%205%20-%2023%20pm/04b%20Barbi.pdf

Precision Farming

- Precision Farming is the use of **technologies** to measure physiological, behavioral, and production indicators on individual animals to improve management strategies and farm performance.

- Real time data used for **monitoring animals** may be incorporated into **decision support systems** designed to facilitate decision making for issues that require compilation of **multiple sources of data**.

Jeffrey Bewley,, 2010

Precision Farming

- The main objectives of Precision Farming are **maximizing individual animal potential**, **early detection of disease**, and **minimizing the use of medication** through preventive health measures.

- **Perceived benefits** of Precision Farming technologies include increased efficiency, reduced costs, improved product quality, minimized adverse environmental impacts, and improved animal health and well-being (Jeffrey Bewley, 2010).

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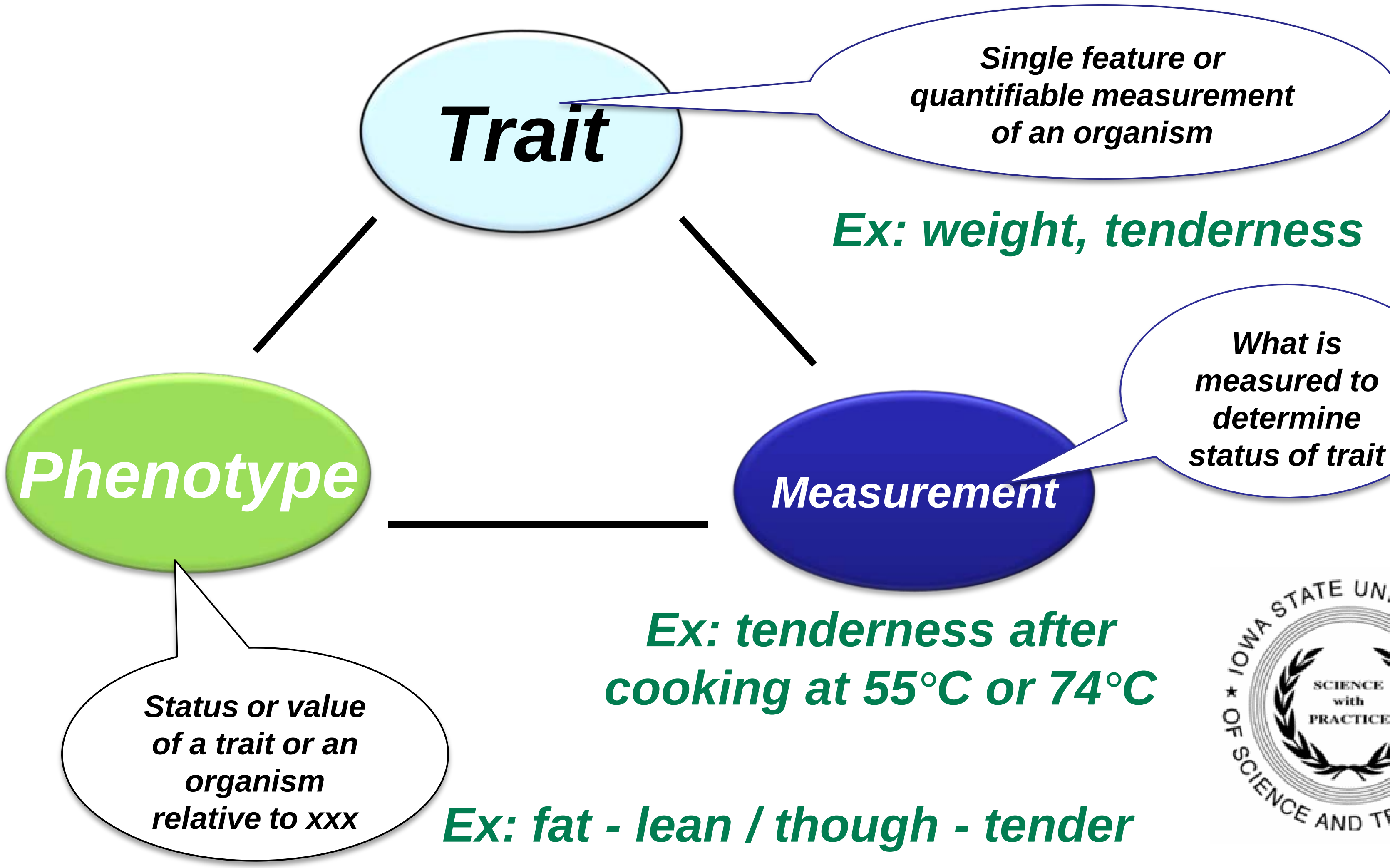
Definitions : trait, phenotype, mesurement « Animal trait Ontology »



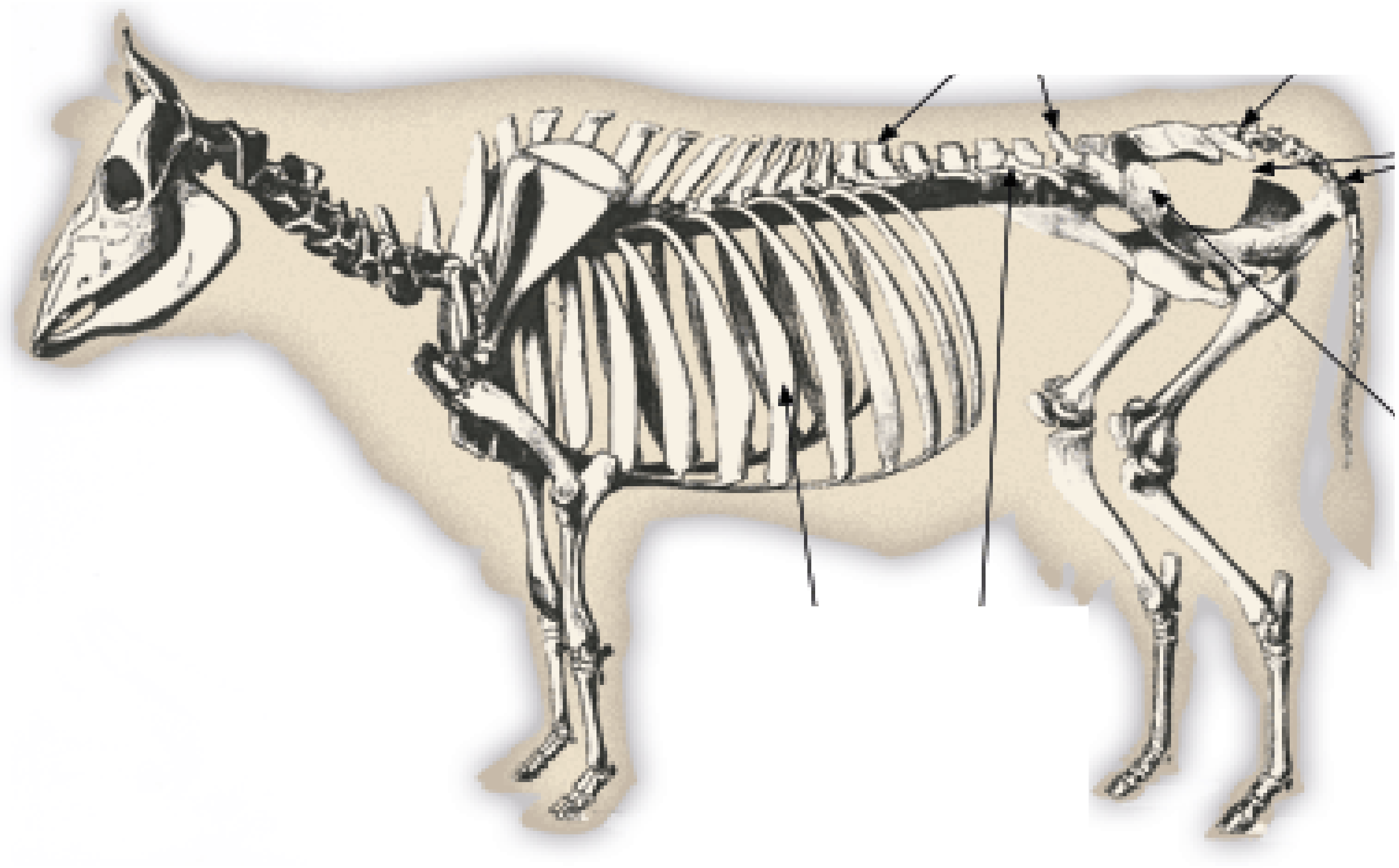
High-throughput phenotyping

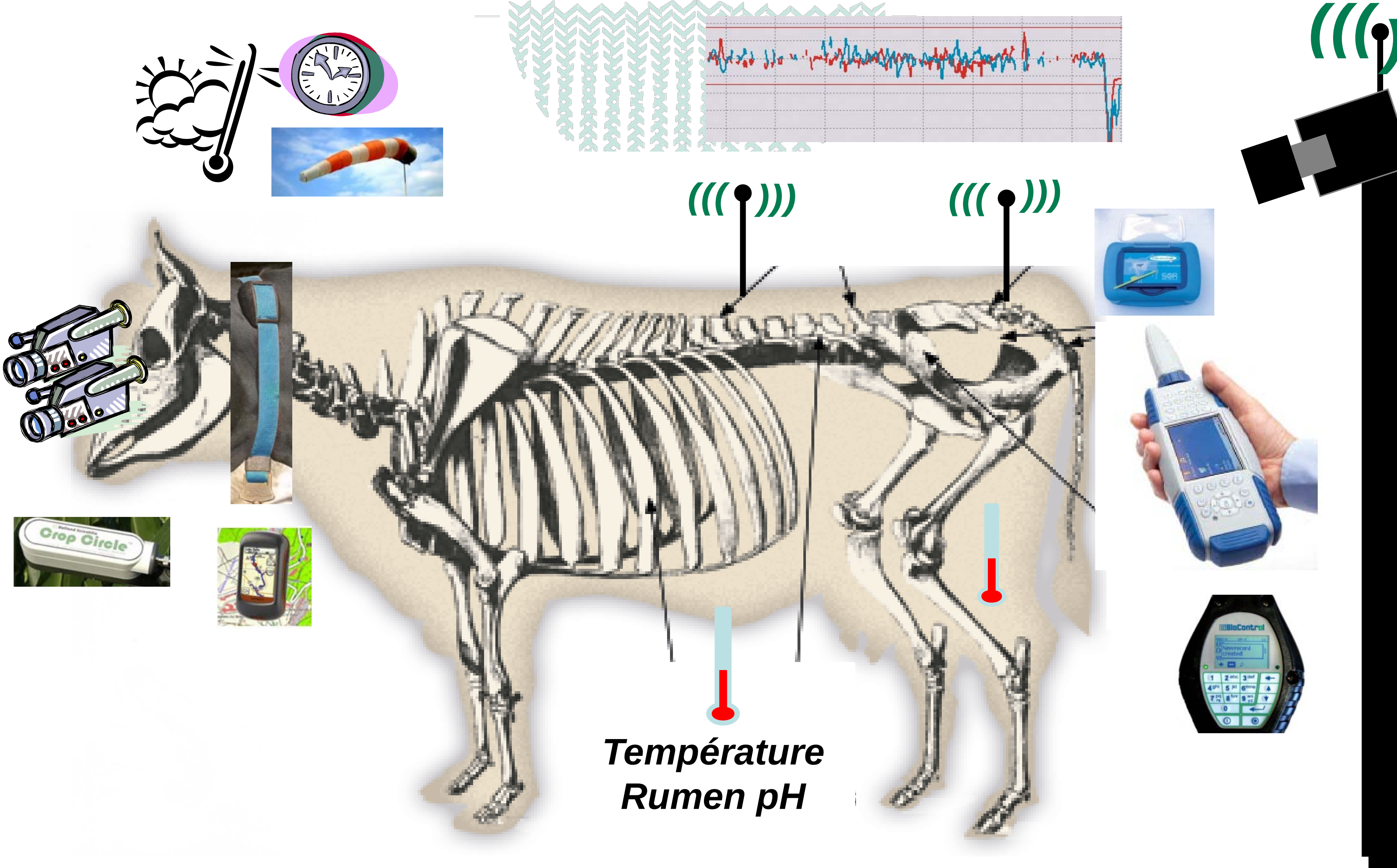
- ✓ Phenomics means the measurement of animal phenotypes.

- ✓ Measurement of phenotypes using rapid and repeatable methods that can be automated so that the process generates a large number of data

- ✓ **Two components**:
  - **systematic** phenotyping (a few variables on many animals)
  - **targeted** or deep phenotyping (more variables for a trait family on a small number of animals)

High-throughput phenotyping





Here is an animal with a multi-sensor onboard system that, in addition to the ID process (RFID chips), would also reproduce the animal's perceptions and monitor physiological parameters (temperature, ruminal pH, cardiac and respiratory rate, etc.) and behavioral parameters (travel, lameness, estrus, interactions with other animals, etc.) without disturbing either the animal's behavior or welfare.

The monitoring approach

The classic strategy

ANIMAL : « Tissue of interest » → Sample → (Lab assay) → Mesurement → Data analysis

Animal science, Biology, Biochemistry… (ANIMAL to Mesurement)

Maths, stats, modelling… (Data analysis)

Animal science, Biology, Biochemistry… ← ? ← *Maths, stats, modelling…*

The monitoring strategy (Multi-disciplinarity & Innovation)

Automatisable:

ANIMAL : *Sensor (physical measurement)* → *Signal* → *Scanner* → *Informatic treatment* → Mesurement

→ Data analysis

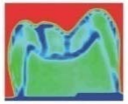
- *Animal Science, Biology, Biochemistry…* / Physics / Electronic Biophysics (Sensor)
- Electronic (Signal to Informatic treatment)
- Informatics (Mesurement)
- Maths., stats, Modelling (Data analysis)

Different physical characteristics we can record


Sound Waves
← 20Hz-10kHz


AM radio
600kHz-1.6MHz

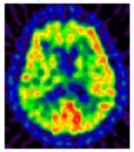

Mobile Phones
900MHz-2.4GHz


Bio imaging
1-10 THz


Fiber telecom
0.7-1.4 µ


Visible Light
425-750THz
700-400nm


Medical X-rays
10-0.1 Å


PET imaging
0.1-0.01 Å

10^0 **FREQUENCY** (Hz) → wavelength λ=c/F (m) 10^{22}

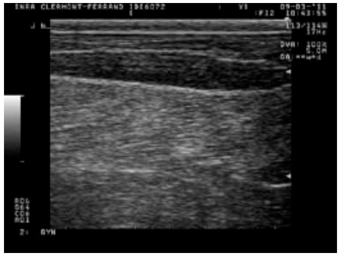
Low frequency | *Medium frequency* | *High-frequency* | *Infrared* | *Visible* | *UV, X, γ*

Acoustic

Vibration
►ECG

Sounds
►vocalization

Ultrasounds



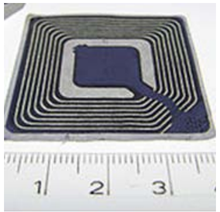
Echography
► internal morphology, internal fluxes

Telemetry
►external morphology

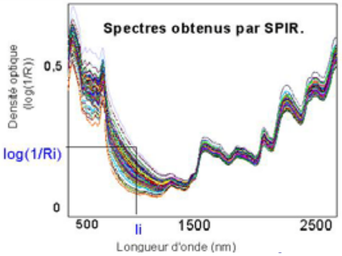
Communication

Telemetry
► transmission of measurements (eg: bolus)

RFID
►identification

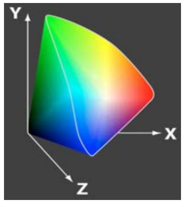


Spectrometry thermography



Visual perception

Colorimetry
►color



Videometry
►behaviour

Laser telemetry (1,2 ou 3D)
►morphology

Radiation

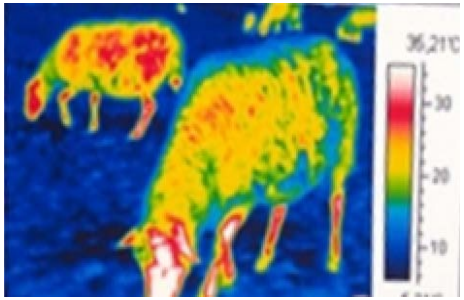
Our strategy

Data acquisition and phenotype recording

A known and interesting phenotype → **A trait easy to measure (ex: weight)** → **Phenotyping infrastructures to be developed**

A trait NOT easy to measure → **High-throughput method to be developed**

An unknown but interesting phenotype → **Basic research to develop first: ontology, measurement, etc**



All laboratory techniques have the potential to be upgraded in order to perform high-throughput procedures

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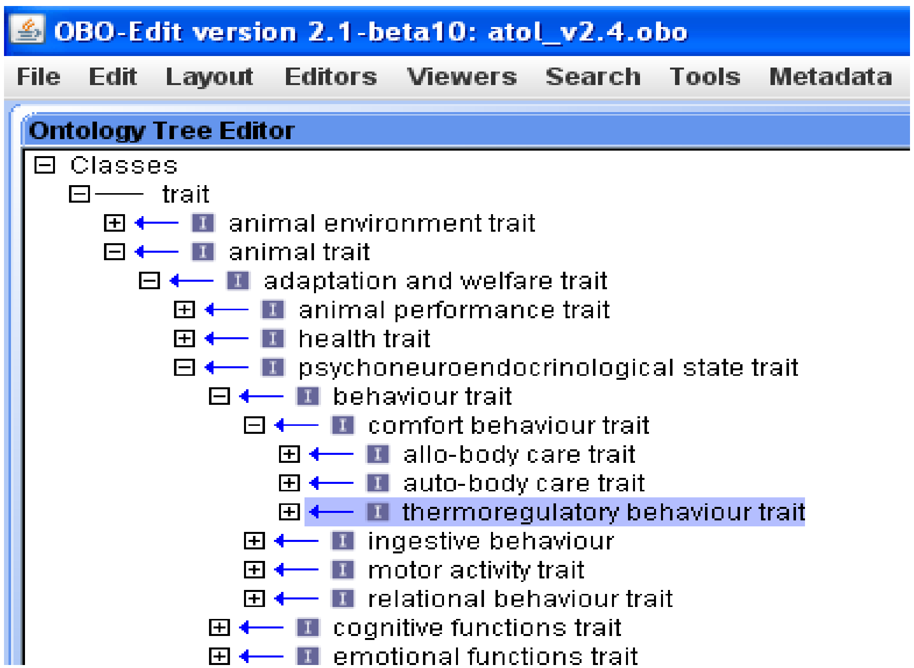
A prerequisite: ontologies

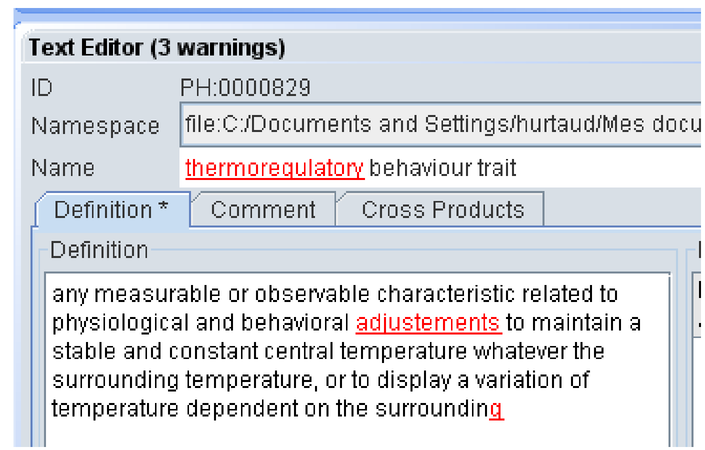
- An ontology is a formal, structured representation of a set of objects (in this case, animal traits or measurements), and of the relationships between these objects.
- Concepts are clearly defined with no ambiguity.
- The concepts are organized in a structured manner (often a hierarchical structure).
- The terms used must be machine readable (enabling automated measurements or data use).
- Ontologies are needed for animal traits, methods and environmental conditions under which the measurements are taken.

Ontology of farm animal traits

http://www.atol-ontology.com/

Over 1600 traits have been defined so far concerning animal adaptation and well-being (> 330), nutrition (> 470), growth and meat production (> 230), milk production (> 420) and reproduction (> 280)





Programme ATOL

Source: Hurtaud C., Bugeon J., Dameron O., Fatet A., Hue I., Meunier-Salaün M.C., Reichstadt M., Valancogne A., Vernet J., Reecy J., Park C., Le Bail P.Y. 2011. ATOL: a new ontology for livestock. General Assembly and annual workshop of ICAR 2011. Bourg-en-Bresse, France, June 22nd to 24th 2011.

Other standardization approaches

- MIAME for « Minimum information about a microarray experiment » (Brazma *et al.*, 2001).
- MIAPE for « minimum information about a proteomics experiment » (Taylor *et al.*, 2007).
- MIBBI for « minimum reporting requirements for biological and biomedical investigations » (Taylor, 2007).
- MIASE for « Minimum Information About a Simulation Experiment » (Waltemath *et al.*, 2011).

Need of new information systems

Why?

Current collection systems are obsolete or unsuitable

Volumes of recorded data are increasing

Multiplicity of information sources (farms, labs, slaughterhouses, etc.)

Limited human and financial resources (→ automatic methods)

How?

Information systems (IS) must be scalable and secure

Standardization and centralization of data: only one IS

Data fishing system from the web (semantic analysis) more efficient

Interoperability of databases

Custom-server software on workstations

Better numerical methods for analysis and modelling are needed to address a whole range of biological problems from the molecular to the ecosystem level.

We need to develop a central computational system between research organizations and private partners for data sharing and modeling purposes.

Today a person is subjected to more new information in a day than a person in the middle ages in his entire life!

http://www.st-andrews.ac.uk/staff/

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Towards international initiatives

- International Guidelines of ICAR
- International Guidelines of FAO within the « Global Plan of Action for Animal Genetic Resources»
- IMGC (International Milk Genomics Consortium)
- Canada: “Application of next generation genomic tools in Beef: Addressing the Phenomic Gap”. “The Poultry research centre”.
- USA : “Beef efficiency”.
- Germany: PHENOMICS. “Farm animal performance, health and welfare in cattle and pig”.
- Austria: “Health Monitoring Cattle”.

Infrastructures for phenotyping

- ANAEE – Infrastructure for Analysis and Experimentation on Ecosystems
- IPPN. International Plant Phenomics Network. http://www.plantphenomics.com/
- European Mouse disease clinic, www.eumodic.org
- International Mouse Phenotyping Consortium (IMPC)
- Infrafrontier – The European research infrastructure for phenotyping and archiving of model mammalian genomes

Conclusions

- Phenotyping: the poor partner in integrative biology and the rate-limiting step in genomic selection
- Unlike genomics (focused on DNA), phenomics is concerned by many targets and different methods.
- Some technological problems to solve before moving to high-throughput measurements
- A challenge: storage and analysis of data
- Even more difficult for new phenotypes: robustness
- Towards an European infrastructure between public and private organisations (large-scale organisations)?

Main source

Objectives and applications of phenotyping network set-up for livestock

Jean-François HOCQUETTE,[1,2] Carine CAPEL,[3] Valérie DAVID,[4] Daniel GUÉMENÉ,[5] Joël BIDANEL,[6] Claire PONSART,[7] Pierre-Louis GASTINEL,[8] Pierre-Yves Le BAIL,[9] Philippe MONGET,[10,11,12,13] Pierre MORMÈDE,[14,15] Maurice BARBEZANT,[16] Florian GUILLOU[10,11,12,13] and Jean-Louis PEYRAUD[17,18]

Animal Science Journal (2012) 83, 517–528