74th Annual Meeting of the European Federation of Animal Science – Lyon, France – 28/09/2023

Session 19 - "Advances in nutritional modelling and feeding systems (in memory of Daniel Sauvant)"

Systemic modelling of nutrient partitioning: from the seed sown by D. Sauvant to future prospects

Puillet L.

UMR MoSAR, Paris

INRAE science for people, life & earth

UMR MoSAR

AgroParisTech | université PARIS-SACLAY

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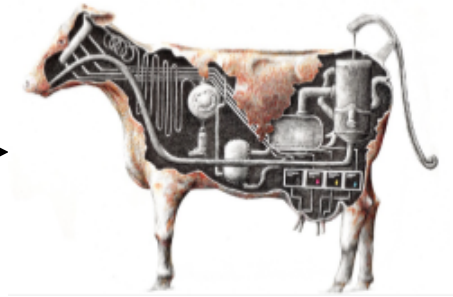
Nutrient partitioning: feeding systems

Diet →  → Products

Set of rules
Based on animal's need
BW gain|loss as buffer

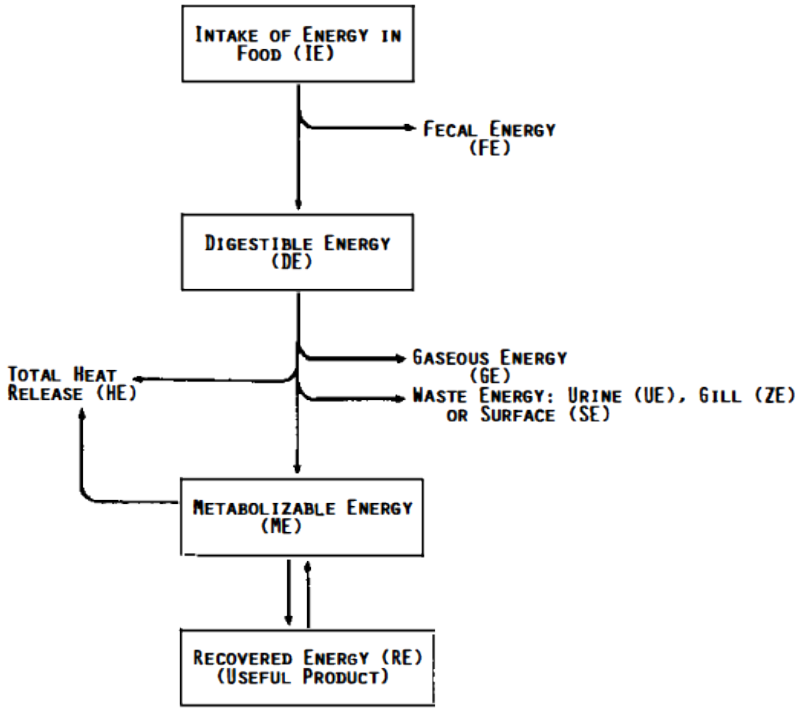


Figure 1. Partition of energy in animals. Adapted from NRC (45).

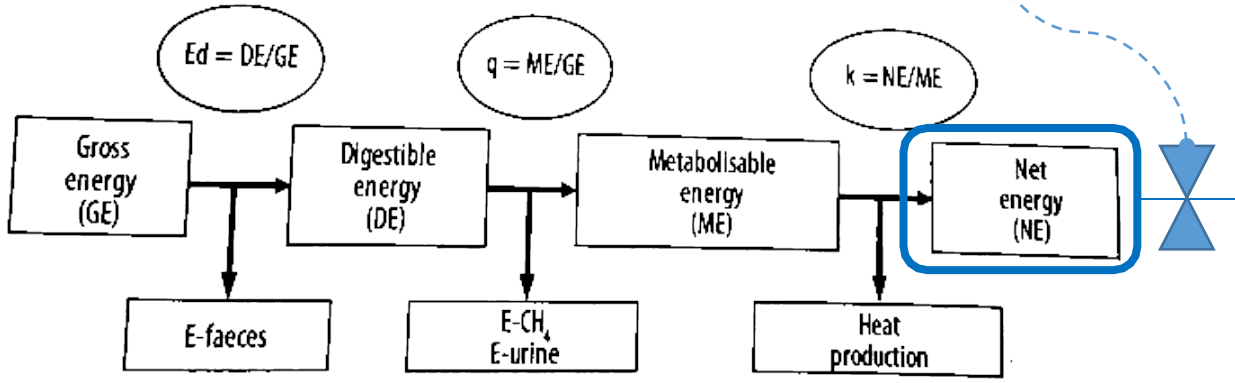


Figure 6.1. The major steps in the utilisation of energy of feed resources by ruminants.

NE_{growth}

$NE_{maintenance}$

$NE_{lactation}$

$NE_{[...]}$

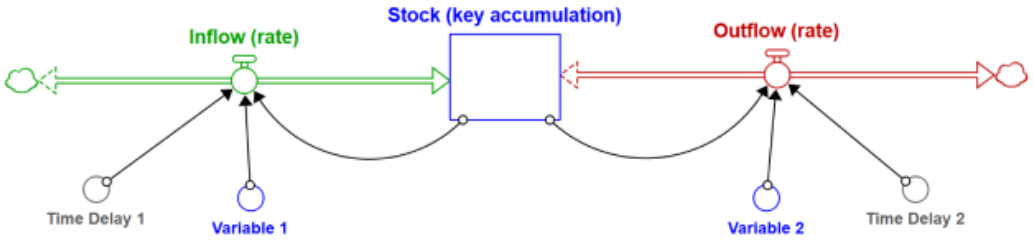
Baldwin and Bywater, 1984

INRAE, 2018

Nutrient partitioning: dynamics of feed utilization

- Development of mechanistic models
  - Accumulated experimental knowledge
  - Computing capacities
  - Systems thinking

See Tedeschi, 2019



- Incorporating regulations
  - Inherent to dynamic models
    - Metabolic capacity | rate, hormonal signal
  - Properties of living systems
    - Homeostasis (HS) and homeorhesis (HR)
    - Short-term vs long-term
    - Targeted trajectory

HOMEORHESIS – Orchestrated changes for the priorities of a physiological state, *i.e.* coordination of metabolism in various tissues to support a physiological state.

Figure 2. Types of regulation in partitioning of nutrients to various body tissues.

Bauman and Currie, 1980

Nutrient partitioning: Daniel's view on regulations

Modelling homeostatic and homeorhetic regulations in lactating animals

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4

D. Sauvant

Laboratoire de Nutrition et Alimentation (INRA-INAPG), Institut National Agronomique Paris-Grignon, 16 rue Claude Bernard 75231 Paris, France

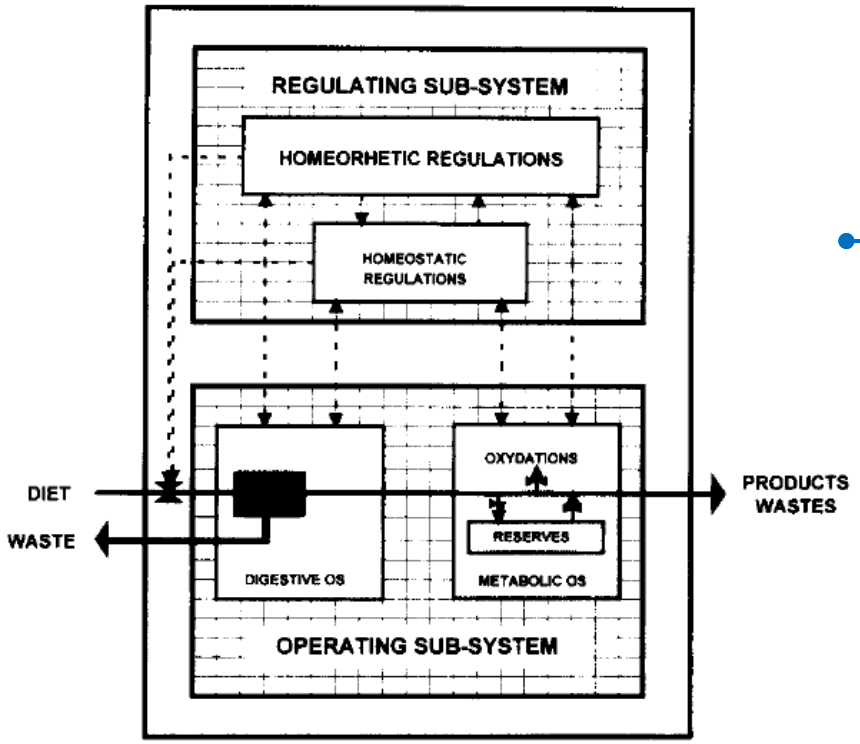
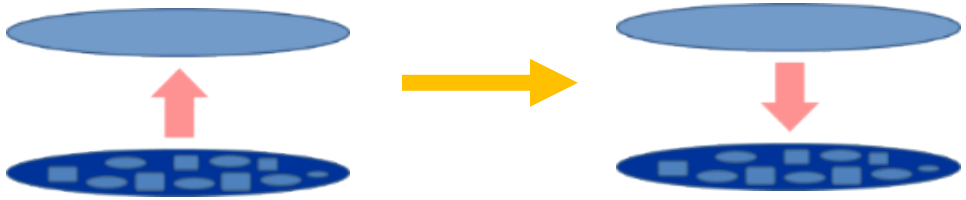


Fig. 1. The live organism as a regulated system.

Conceptual proposal

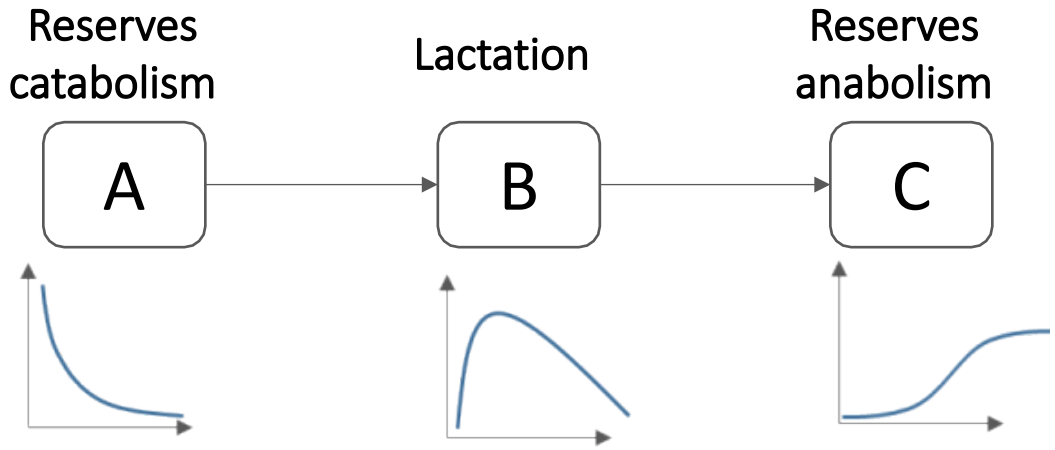
Bottom-up *Top-down*



See Friggens et al., 2011

Concrete proposal

Explicit model of priorities = network of state variables
↔ meta-hormones, used as control variables



Outline

Priorities among functions as drivers of nutrient partitioning

#1 Implementing priorities in animal simulation model

#2 Interpreting time-series data

#3 Implementing acquisition allocation framework

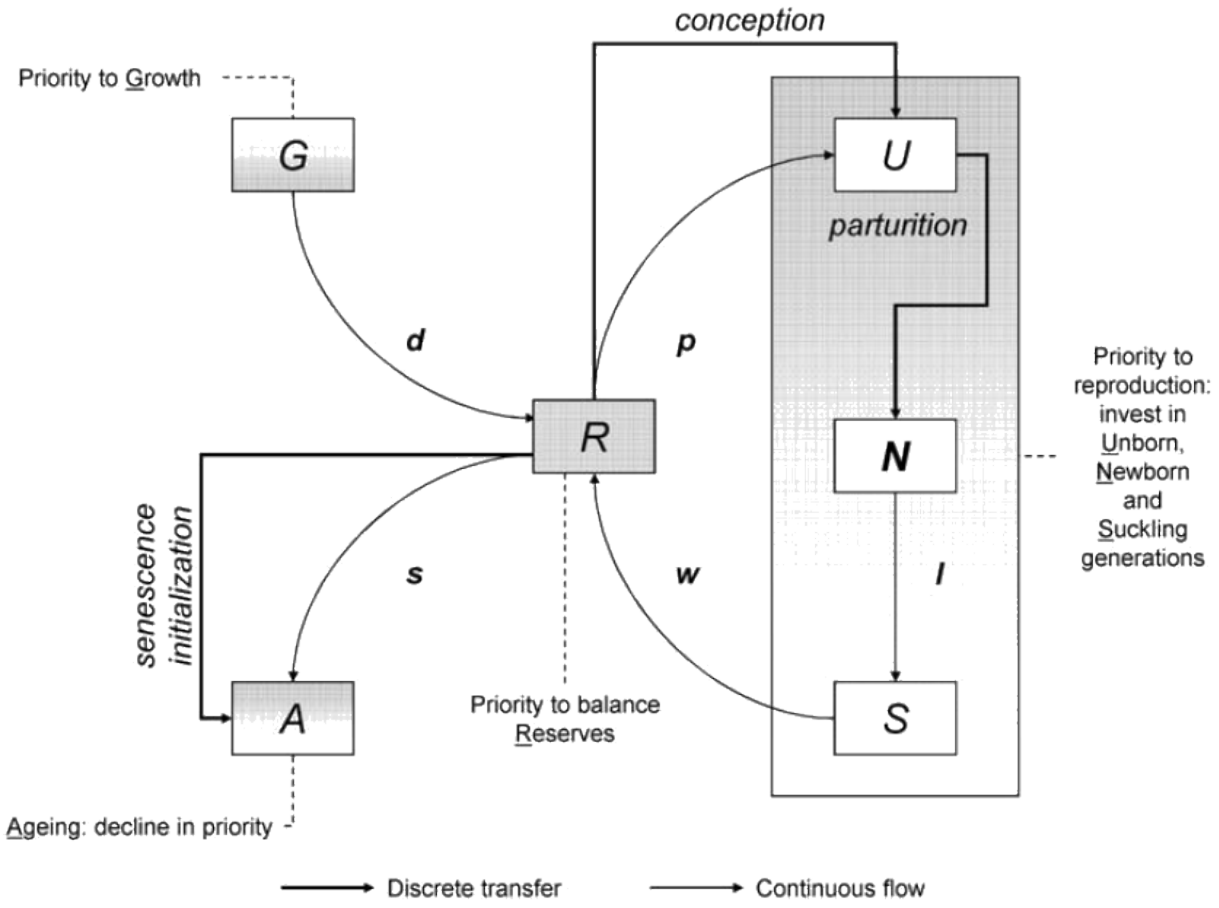
#1 Implementing animal's priorities

- Model of priorities : GARUNS (Martin and Sauvant, 2010)

A teleonomic model describing performance (body, milk and intake) during growth and over repeated reproductive cycles throughout the lifespan of dairy cattle. 1. Trajectories of life function priorities and genetic scaling

O. Martin† and D. Sauvant

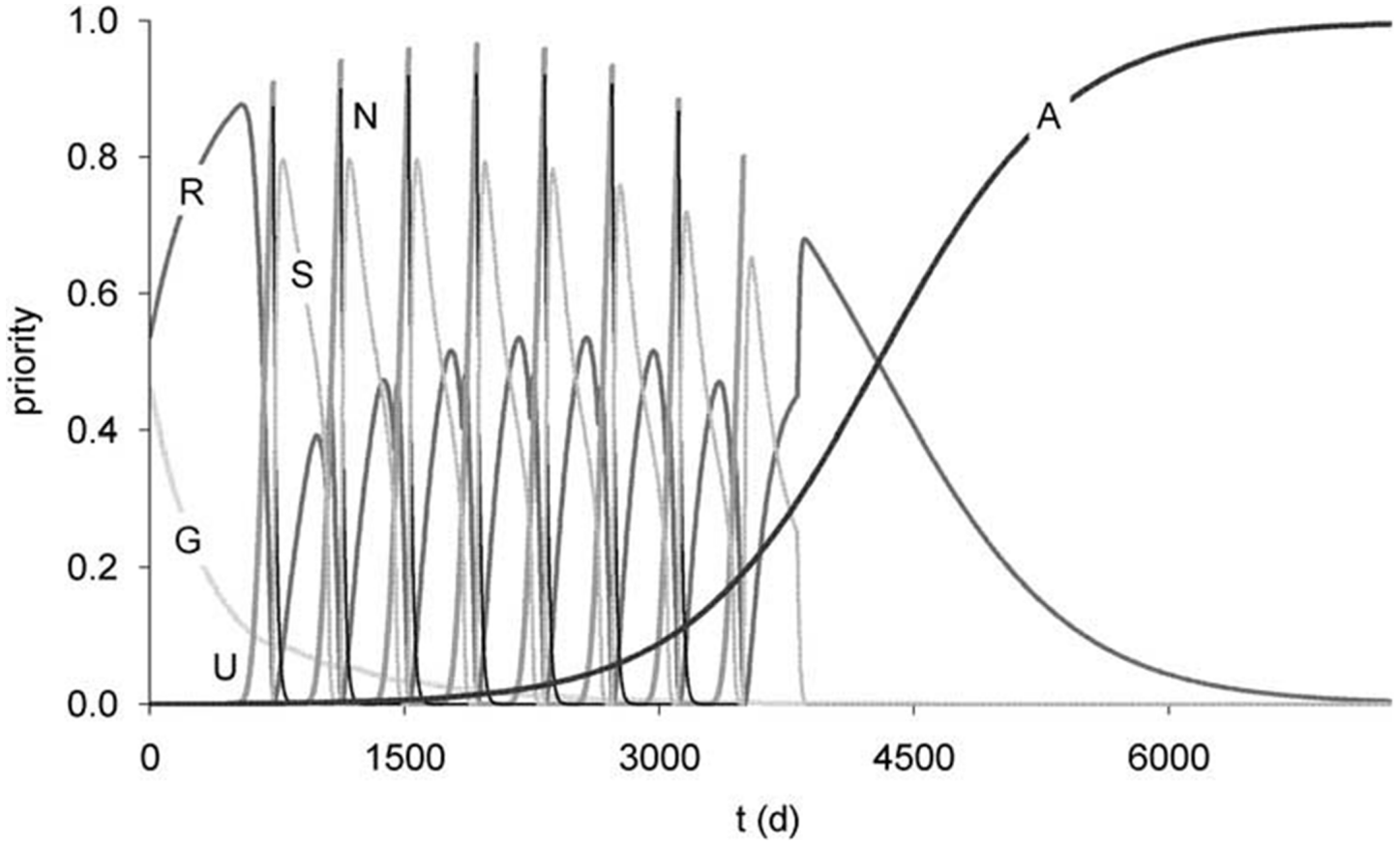
UMR Modélisation Systémique Appliquée aux Ruminants (MoSAR), INRA-AgroParisTech, 16, rue Claude Bernard, 75231 Paris cedex 05, France



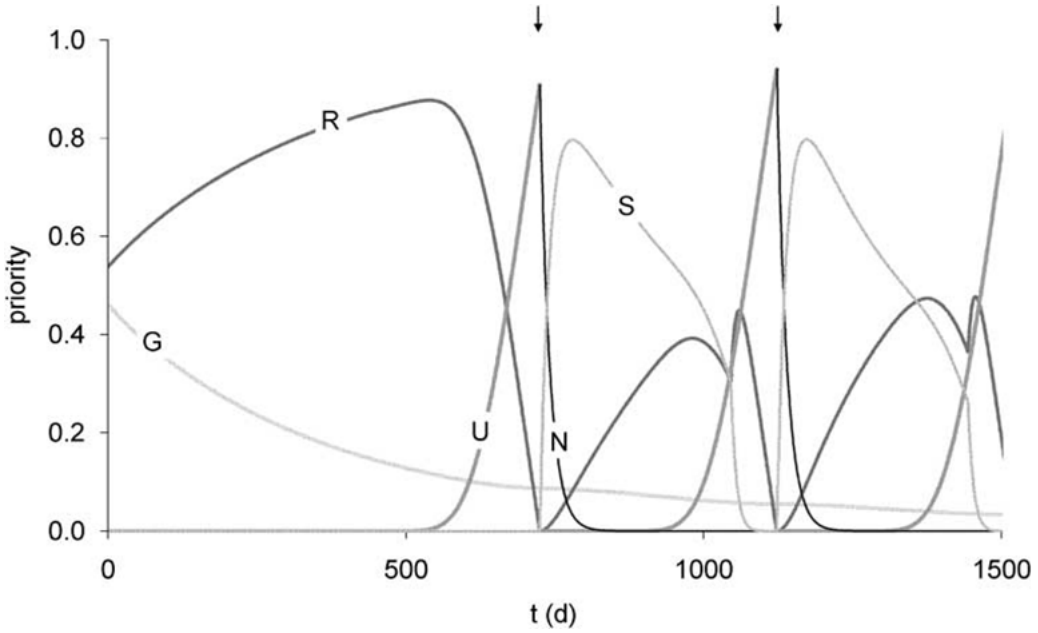
- System of priorities = virtual dimensionless quantity of 1 flowing in a network of compartments ~ biological functions
- Body reserves as a function
- Dynamics @ lifetime level

#1 Implementing animal's priorities

- Model of priorities : GARUNS (Martin and Sauvant, 2010)



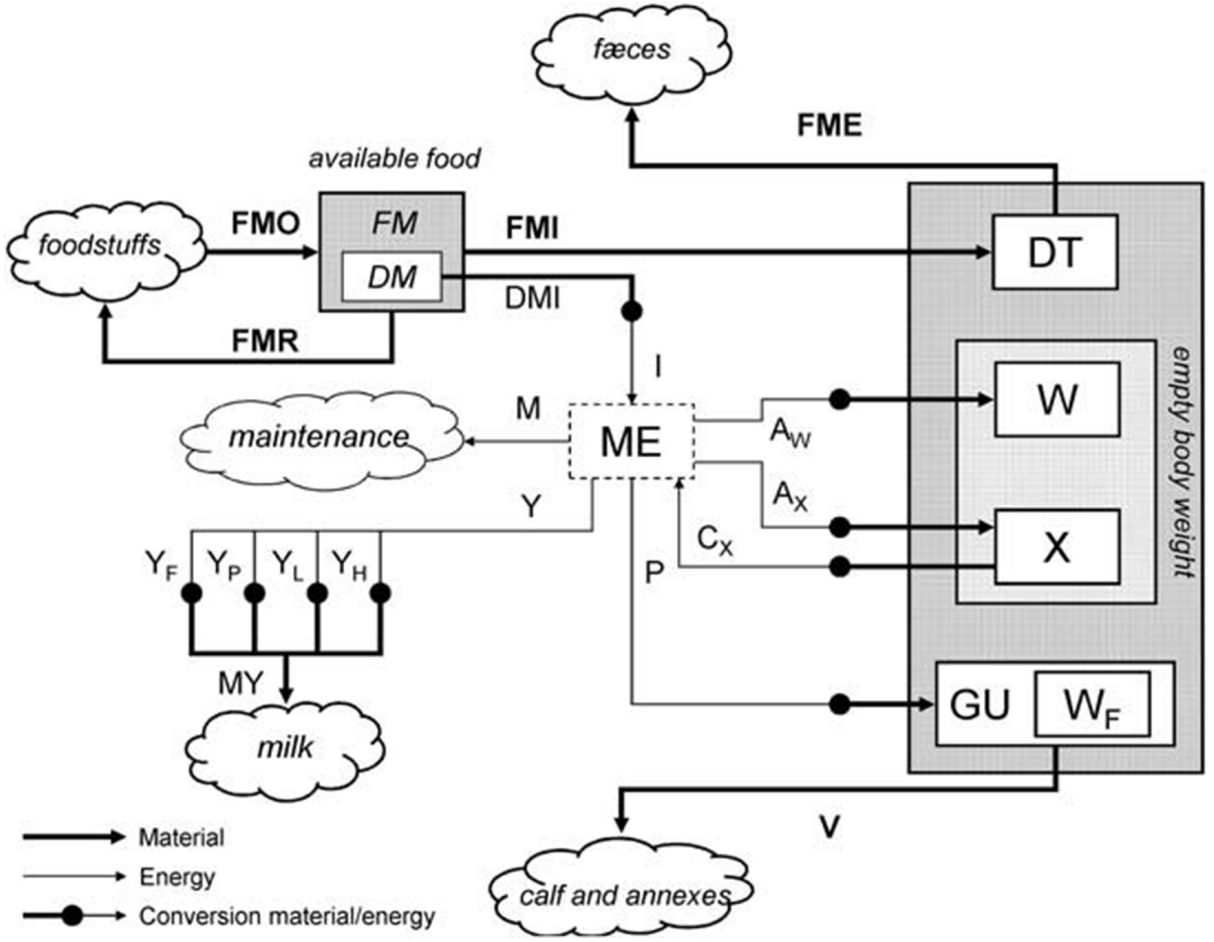
Coordinated changes @ lifetime level and across parities



#1 Implementing animal's priorities

- Transmission to a "classical" operational system

- Conversion energy | material based on existing nutritional knowledge
- Flow = $Flow_{GARUNS}$ + $Deviation_{Intake}$



#1 Implementing animal's priorities

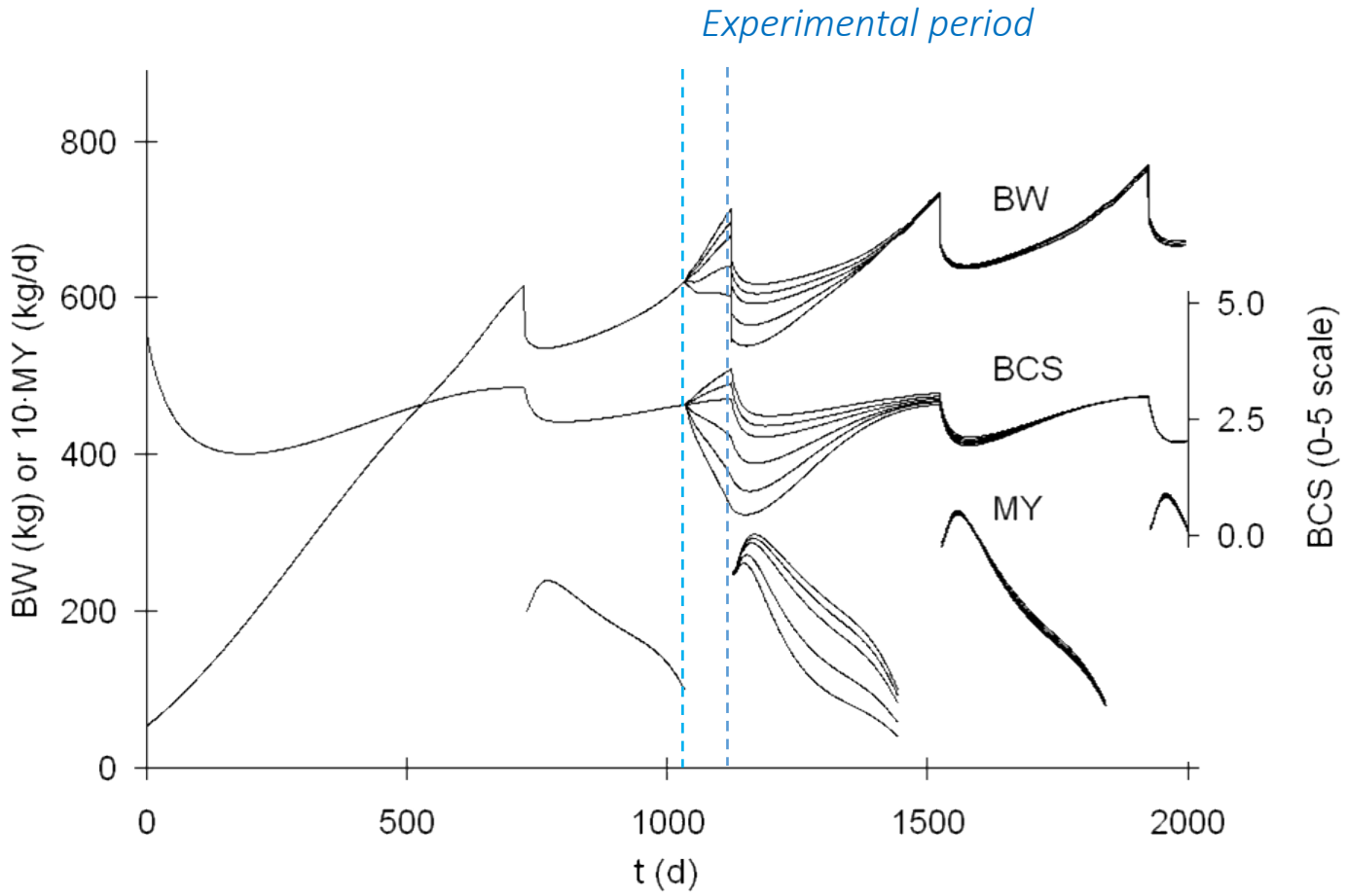
- Simulation = set of phenotypic trajectories

Simulated performance

$$P = P^* + \delta P$$

Performance defined by system of priorities

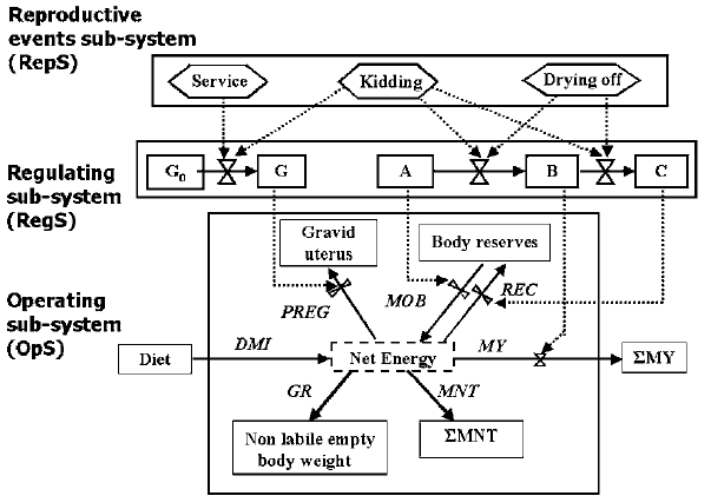
Performance deviation induced by diet



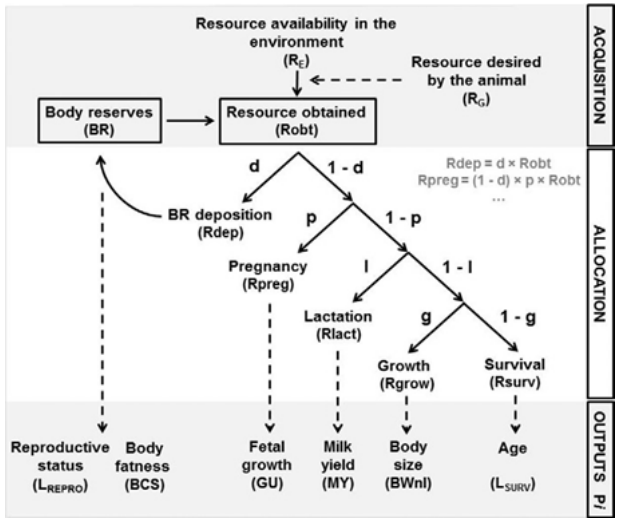
Virtual experiment based on Garnsworthy and Topps, 1992

#1 Implementing animal's priorities

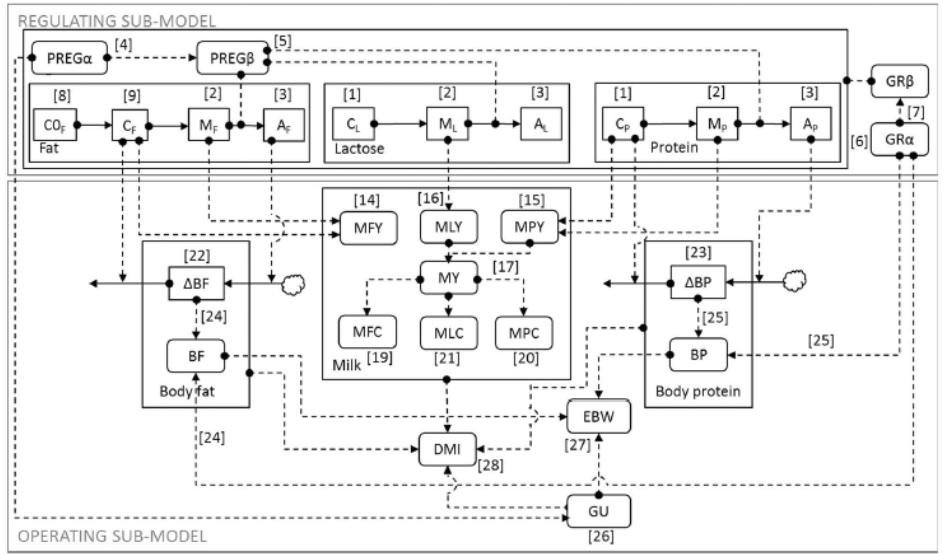
- Some "cousins" in the family



Puillet et al., 2008



Douhard et al., 2014



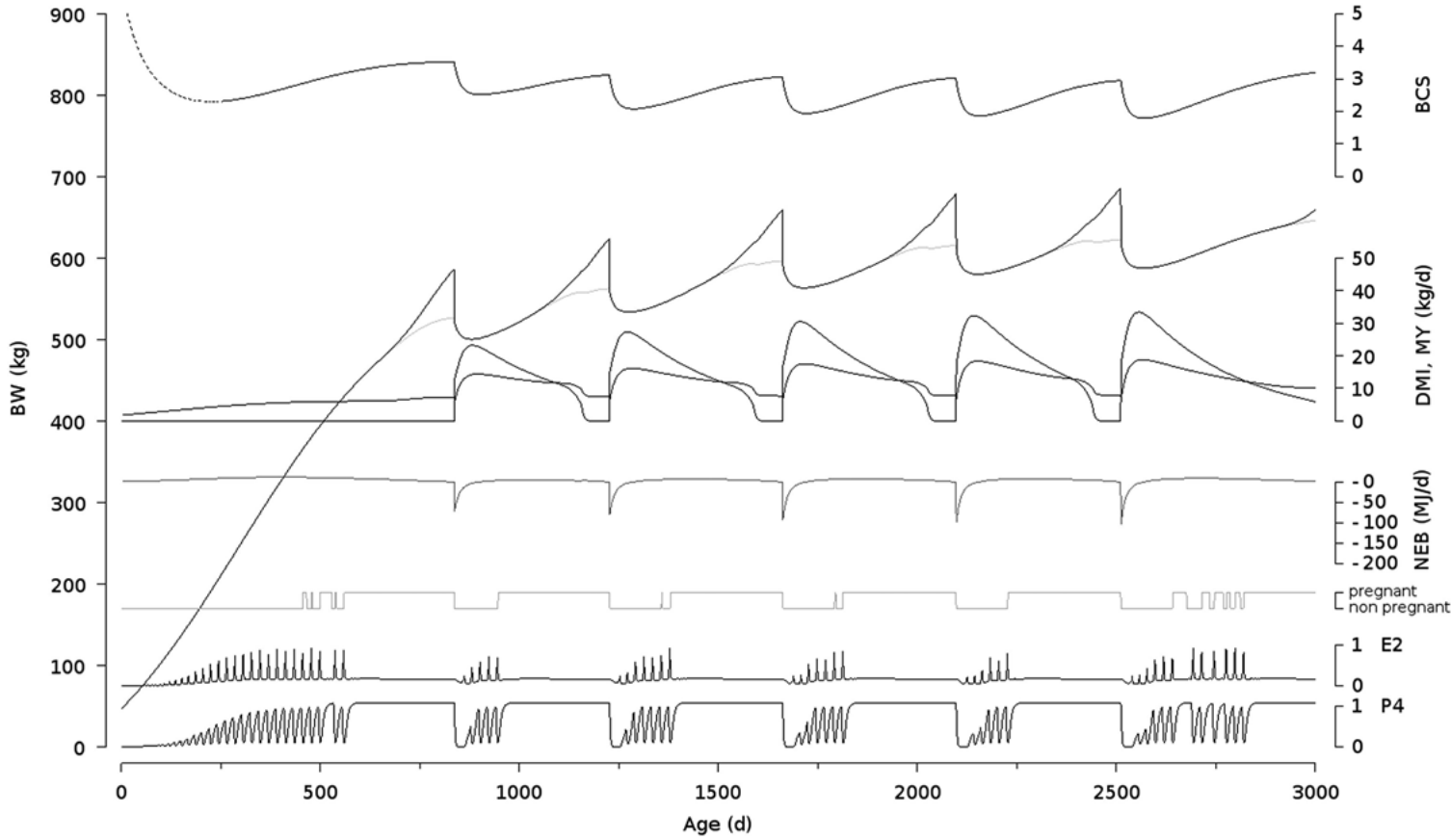
Daniel et al., 2018

#1 Implementing animal's priorities

- So what with GARUNS model?
  - Extending with reproduction (Martin *et al*., 2018)

Coupling a reproductive function model to a productive function model to simulate lifetime performance in dairy cows

O. Martin[1†], P. Blavy[1], M. Derks[1,2,3a], N.C. Friggens[1] and F. Blanc[2]



#1 Implementing animal's priorities

- Up-scaling @ n+1
  - [GARUNS x RFM] = virtual animal model
  - Building-block for herd level (IBM) → InSiliCow

Toward a digital twin of dairy cow herd

- Down-scaling @ n-1
  - Integrating metabolism | organs → HS regulations

[HR x HS] altering reference pattern

Dynamic model of the lactating dairy cow metabolism

O. Martin[†] and D. Sauvant

INRA, UMR Physiologie de la Nutrition et Alimentation, 16 rue Claude Bernard, 75231 Paris Cedex 05, France

FLiver: nutrient Fluxes across and within the Liver

A novel approach combining meta-analysis with mechanistic modeling to predict net hepatic nutrient fluxes in ruminants

L. Bahloul[*,§], D. Sauvant[#,⊥], C. Loncke[#], M. Chartoire[#], J. Vernet[*], H. Lapierre[‡], P. Nozière[*] and I. Ortigues-Marty[*]

In revision

Outline

Priorities among functions as drivers of nutrient partitioning

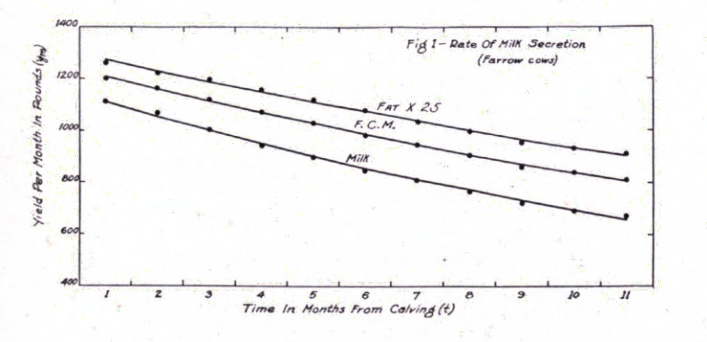
#1 Implementing priorities in animal simulation model

#2 Interpreting time-series data

#3 Implementing acquisition allocation framework

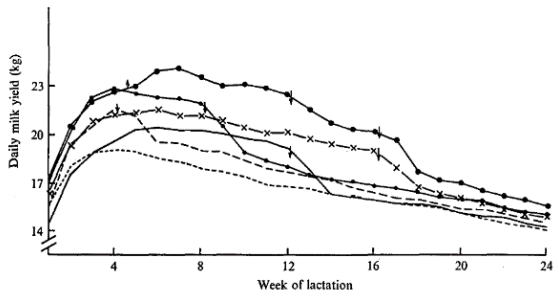
#2 Interpreting time-series data

- From “small” to “big” data



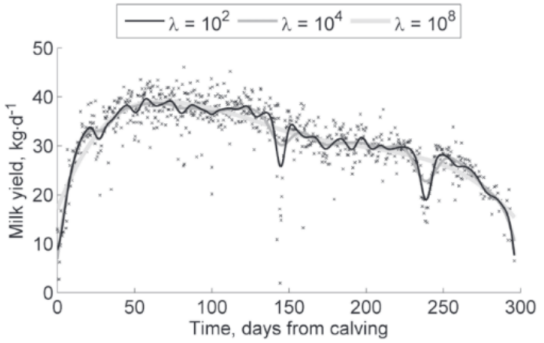
MONTHLY

Gaines and Davidson, 1926



WEEKLY

Broster et al., 1975



DAILY

Codrea et al., 2011

- More frequent
- Longer period
- More animals

- Need phenotyping tool : raw information → indicators
  - A playground for statistical tools (smoothing, …)
  - Interpretation can be difficult (lack of biological meaning)
  - Especially @ lifetime level

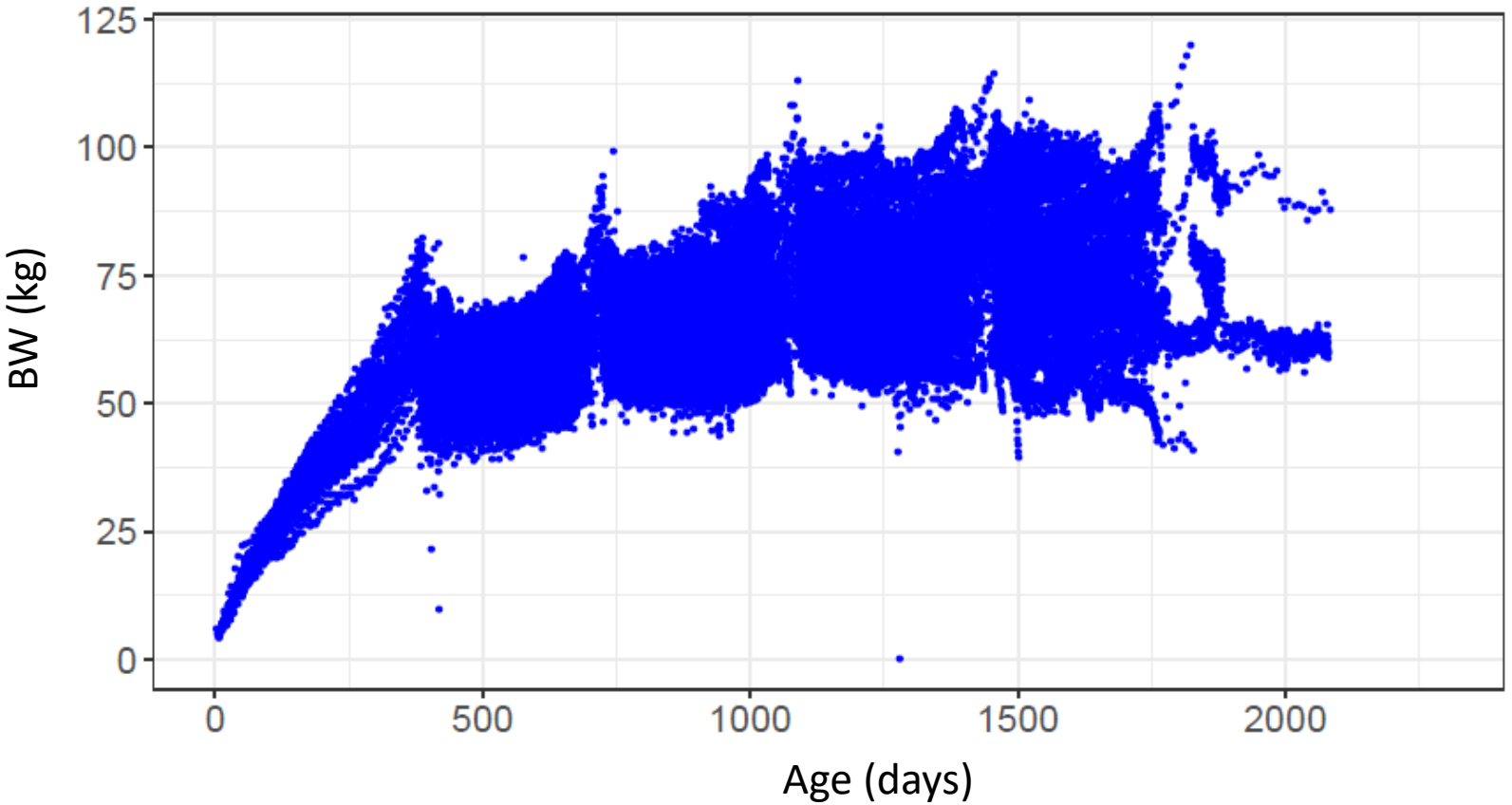
#2 Interpreting time-series data

- GRUM model
  - A tool for body weight data

A dynamic model as a tool to describe the variability of lifetime body weight trajectories in livestock females[1]

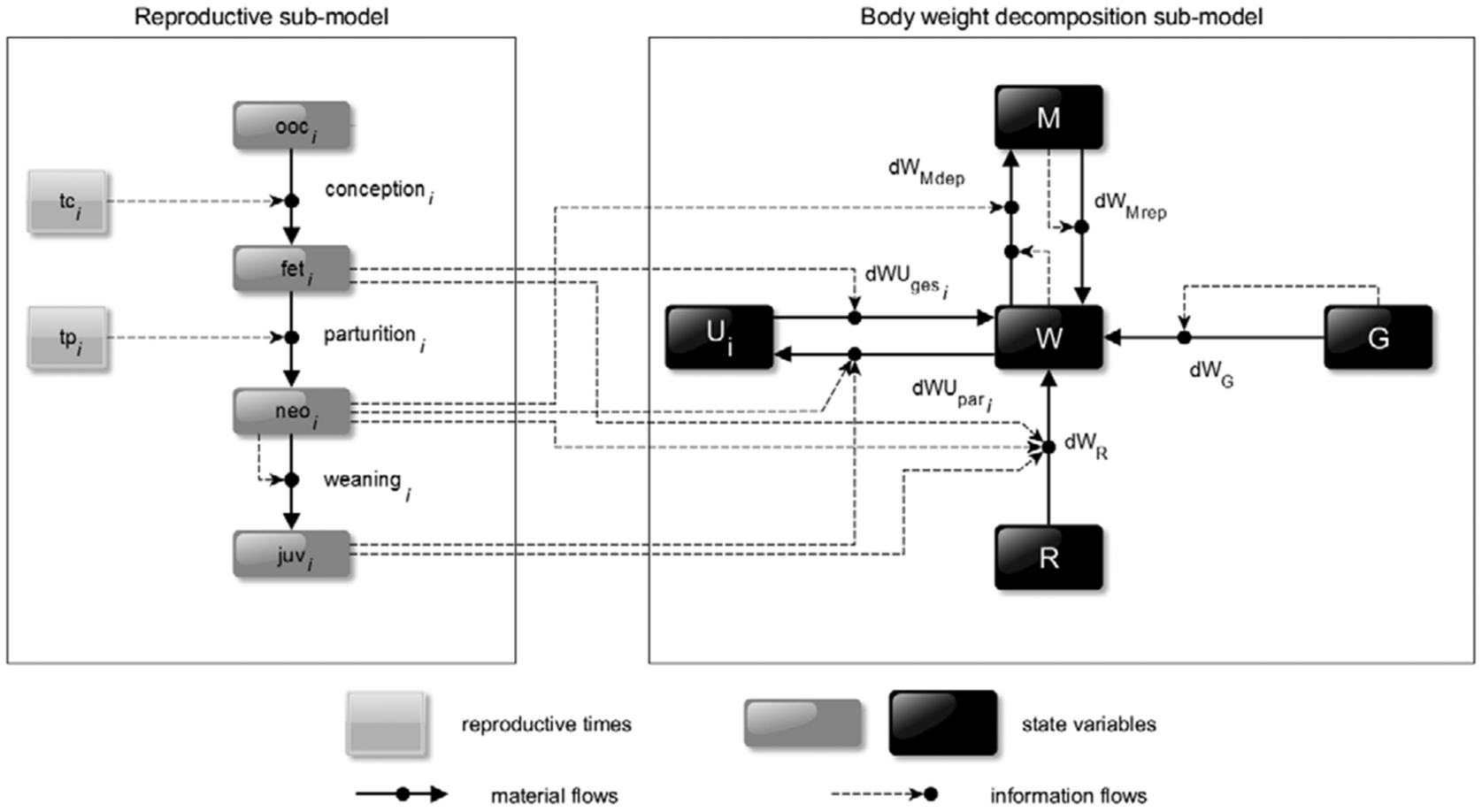
L. Puillet[2] and O. Martin

UMR Modélisation Systémique Appliquée aux Ruminants, INRA, AgroParisTech, Université Paris-Saclay, 75005, Paris, France



#2 Interpreting time-series data

- H_0: BW changes reflect changes in female's priorities



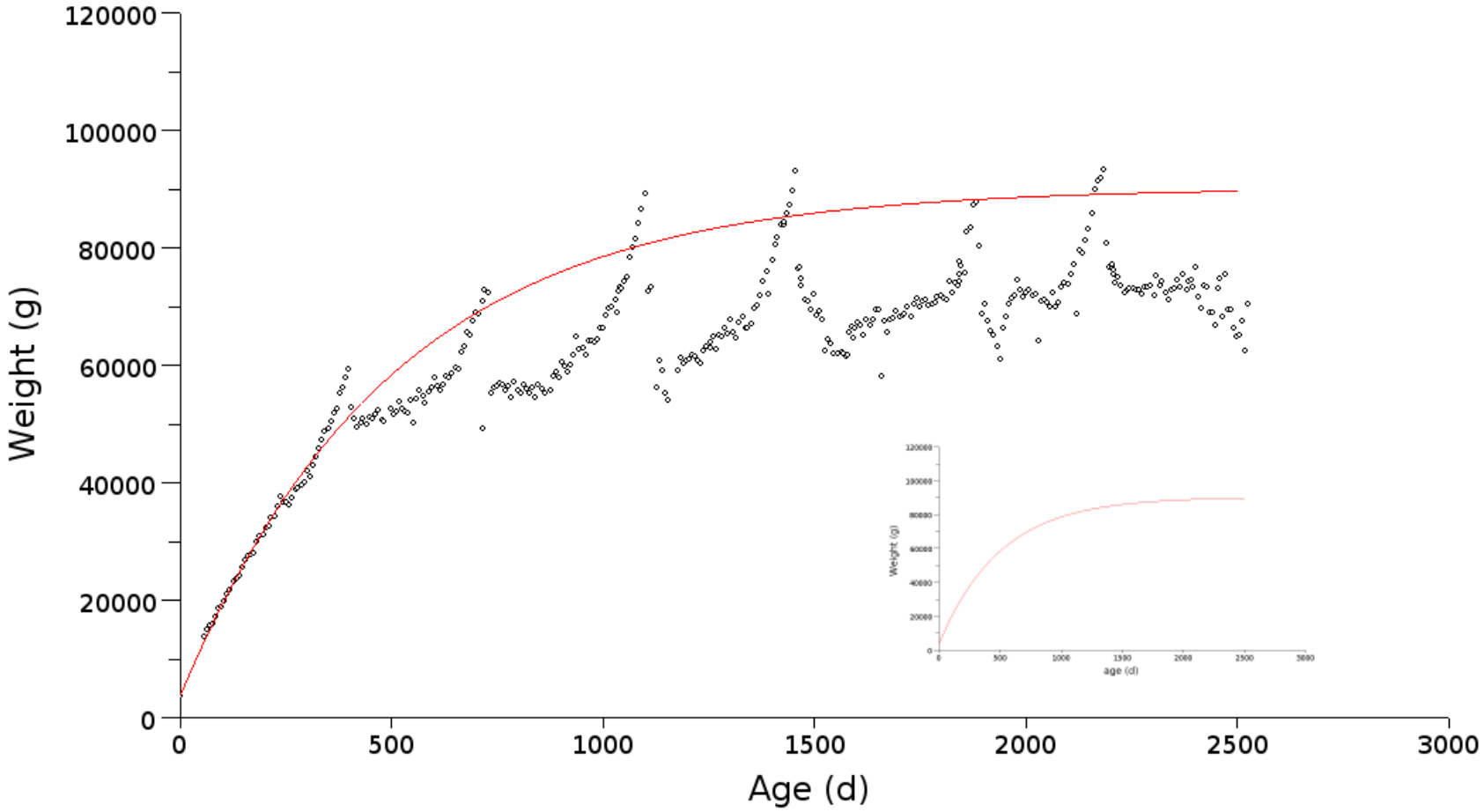
- Elementary variations of BW ~ priorities
- Compartmental model
- Adjusted on individual data (1 fitting/animal)

$$dW/dt = dW_G + dW_R + dW_{U_i} + dW_M$$

Growth
Reserve balance
Uterine load
Maternal investment

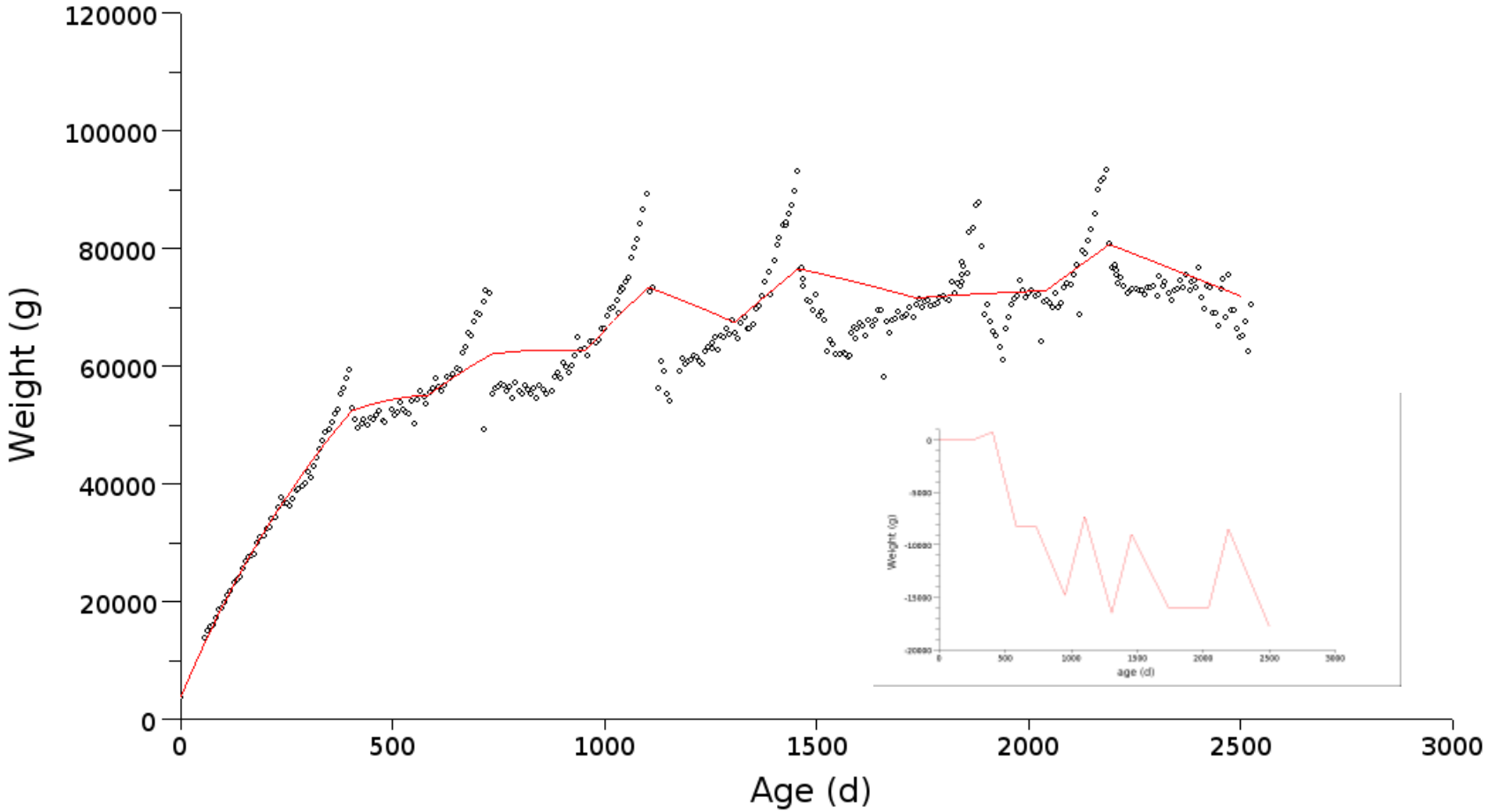
#2 Interpreting time-series data

- Sequential fitting: G



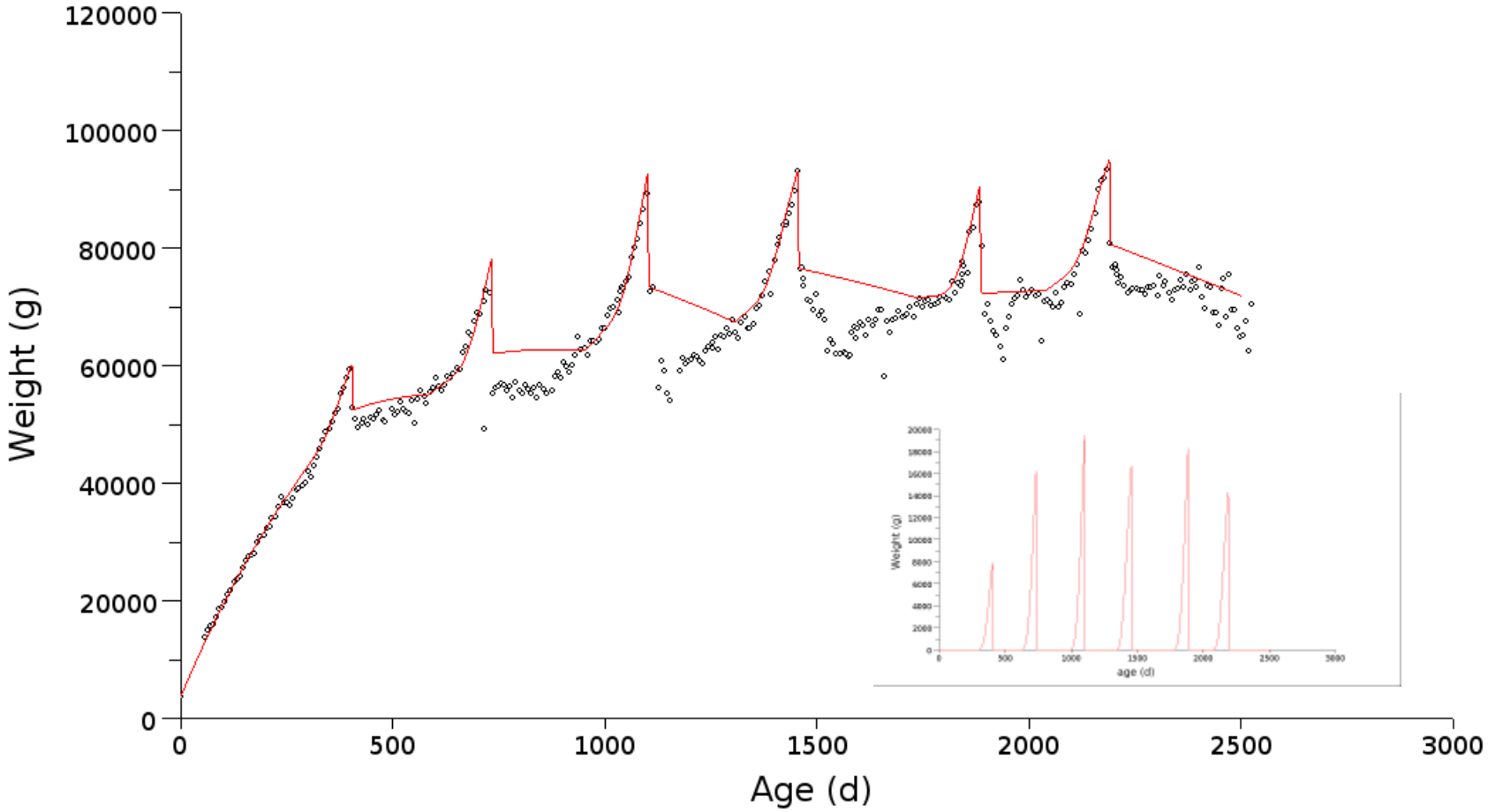
#2 Interpreting time-series data

- Sequential fitting: GR



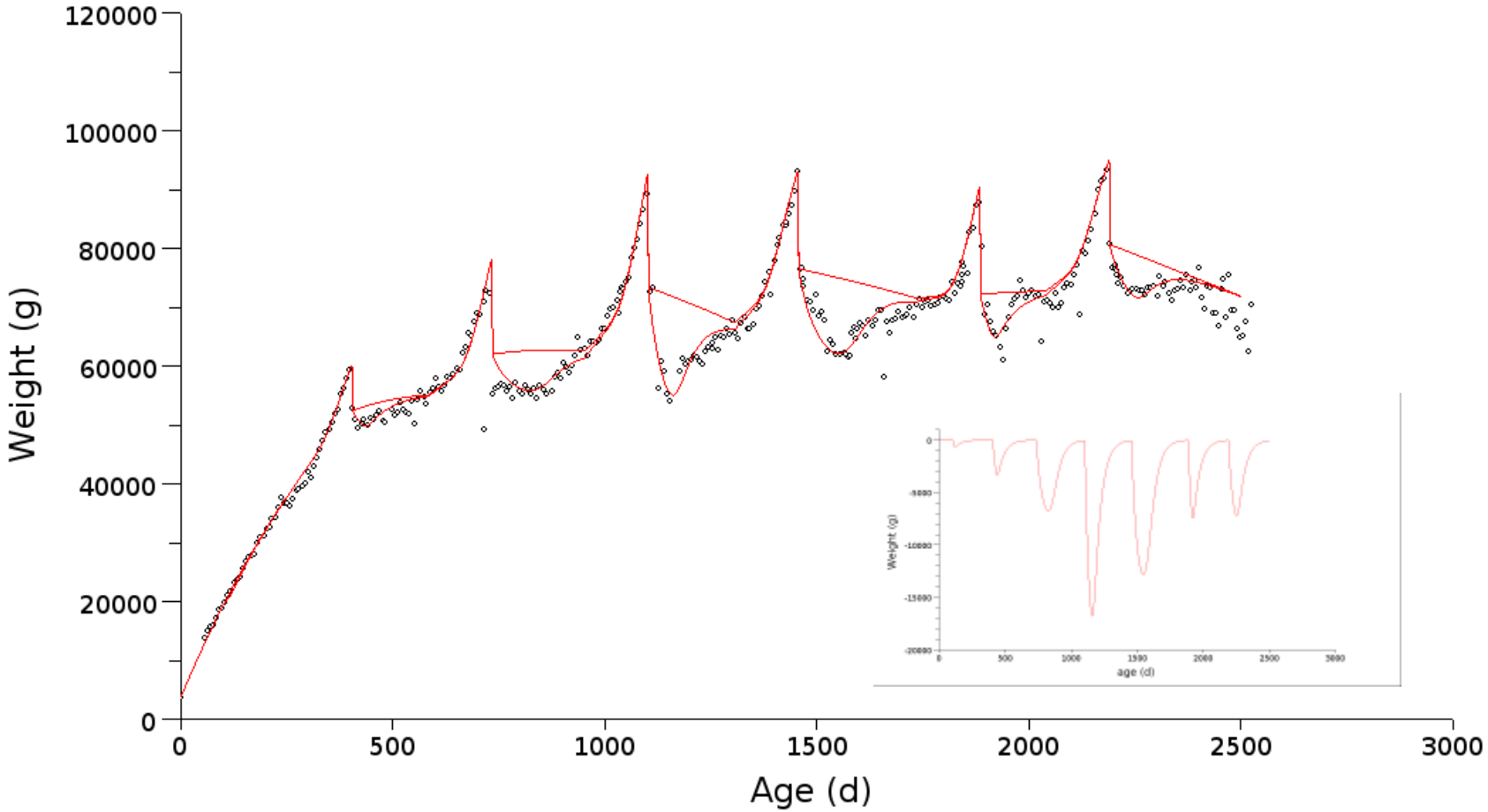
#2 Interpreting time-series data

- Sequential fitting: GRU



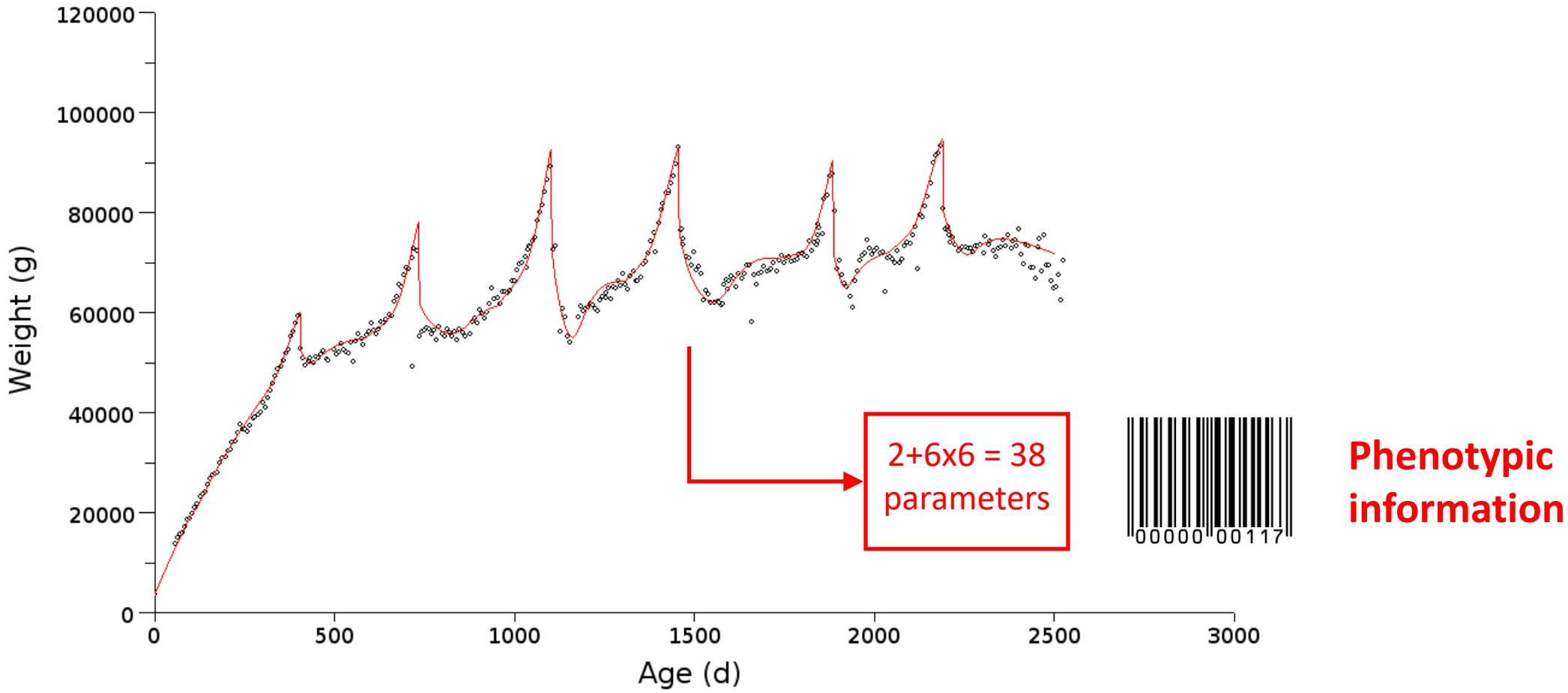
#2 Interpreting time-series data

- Sequential fitting: GRUM



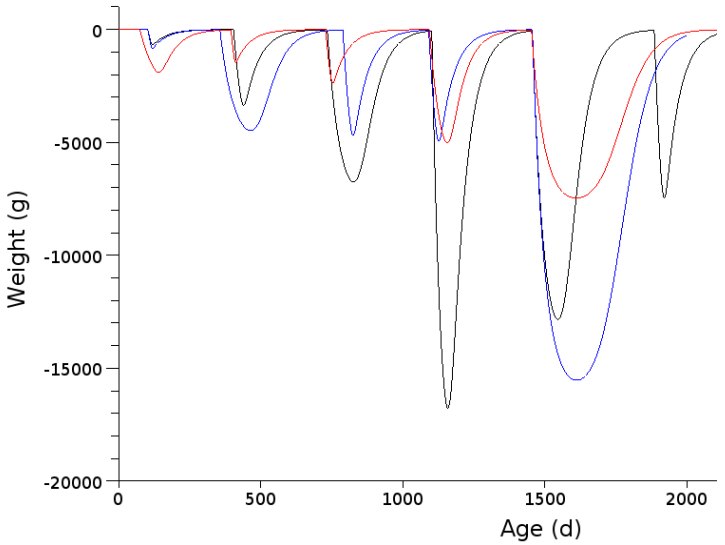
#2 Interpreting time-series data

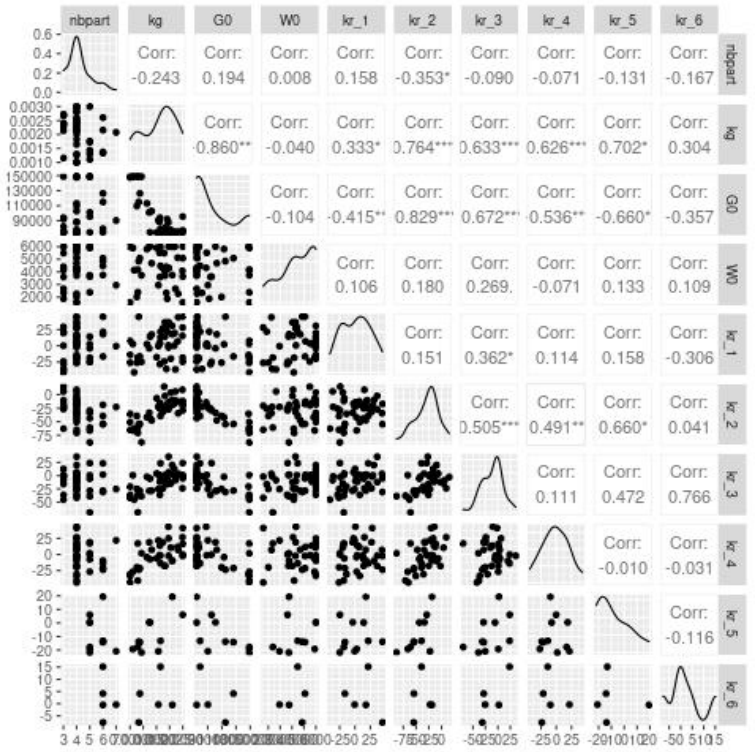
- Sequential fitting: GRUM

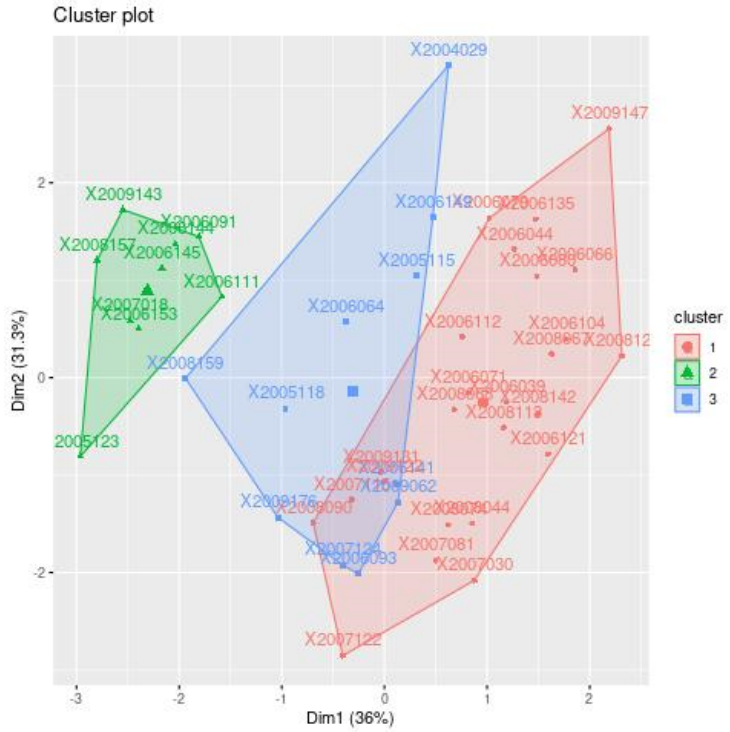


#2 Interpreting time-series data

- Work with GRUM fitted parameters
  - Comparing individuals, parities
  - Combining with other traits







Generic tool for mammal, under development in a GALAXY pipeline

Outline

Priorities among functions as drivers of nutrient partitioning

#1 Implementing priorities in animal simulation model

#2 Interpreting time-series data

#3 Implementing acquisition allocation framework

#3 Implementing acquisition-allocation framework

- Breeding for feed efficiency in a sustainable way
  - No detrimental impacts on other functions and resilience
  - Adaptation to various (limiting) environments

- Dealing with complex traits
  - Difficult to measure
  - Made of sub-traits
  - Time dependant
  - Trade-offs

A more agro-ecological view animal

(MoSAR) nutritional models as good "phenotypic" candidates

Simulation approach

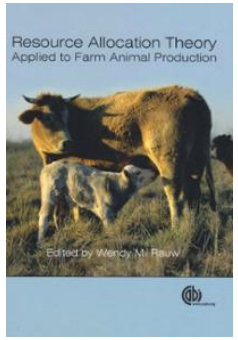
Feed conversion mechanisms

Lifetime trajectory

Nutrient partitioning

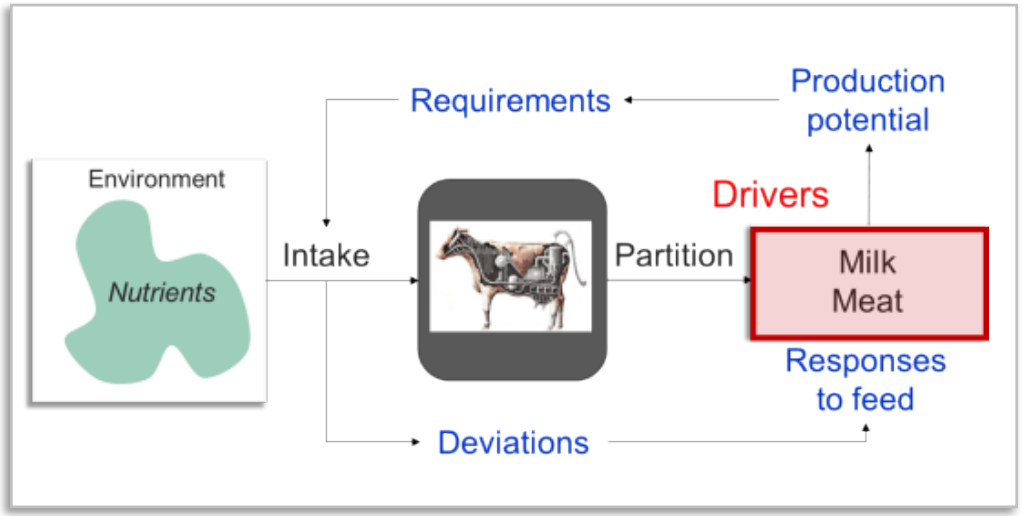
#3 Implementing acquisition-allocation framework

- How do we affect intake and partition?
- Does it generate trade-offs?

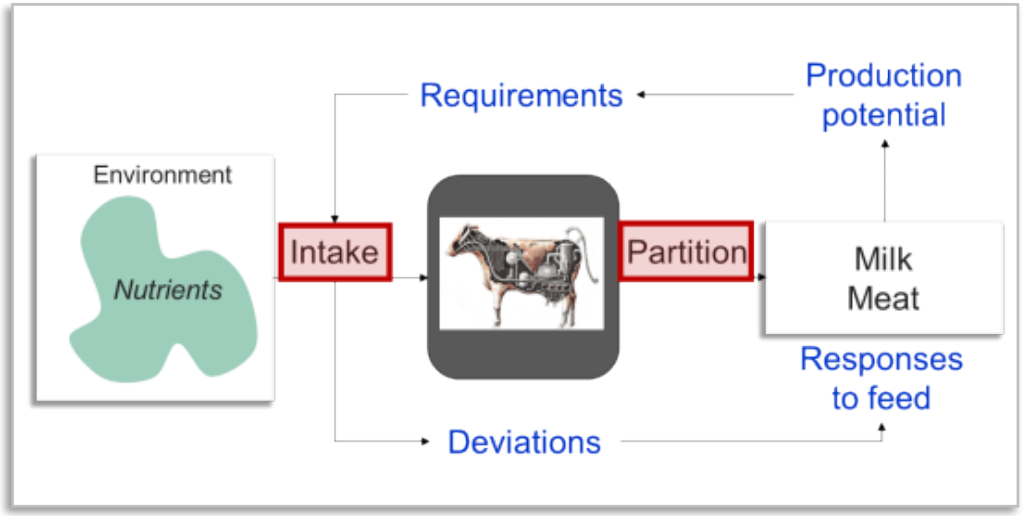


Rauw et al., 2009

From a phenotypic potential



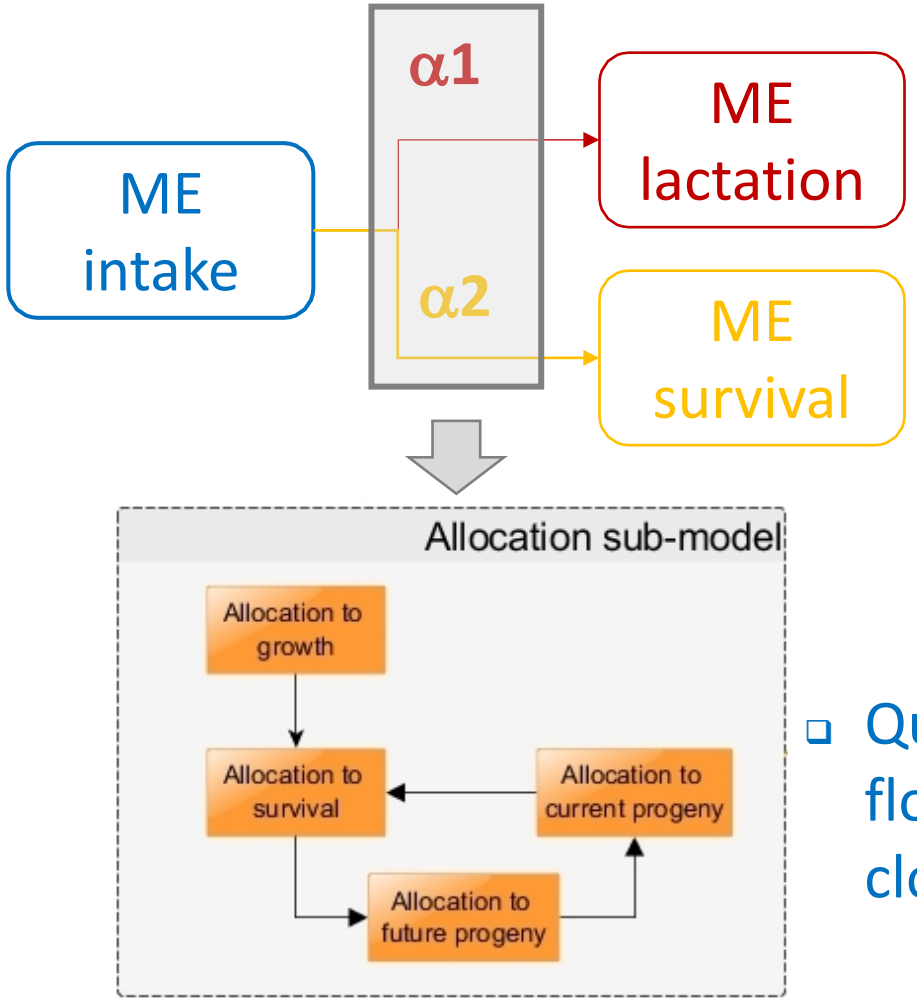
To an acquisition|allocation potential



- Changing the way to generate different animals (genotypes)

#3 Implementing acquisition-allocation framework

- AQAL model (Puillet et al., 2016)

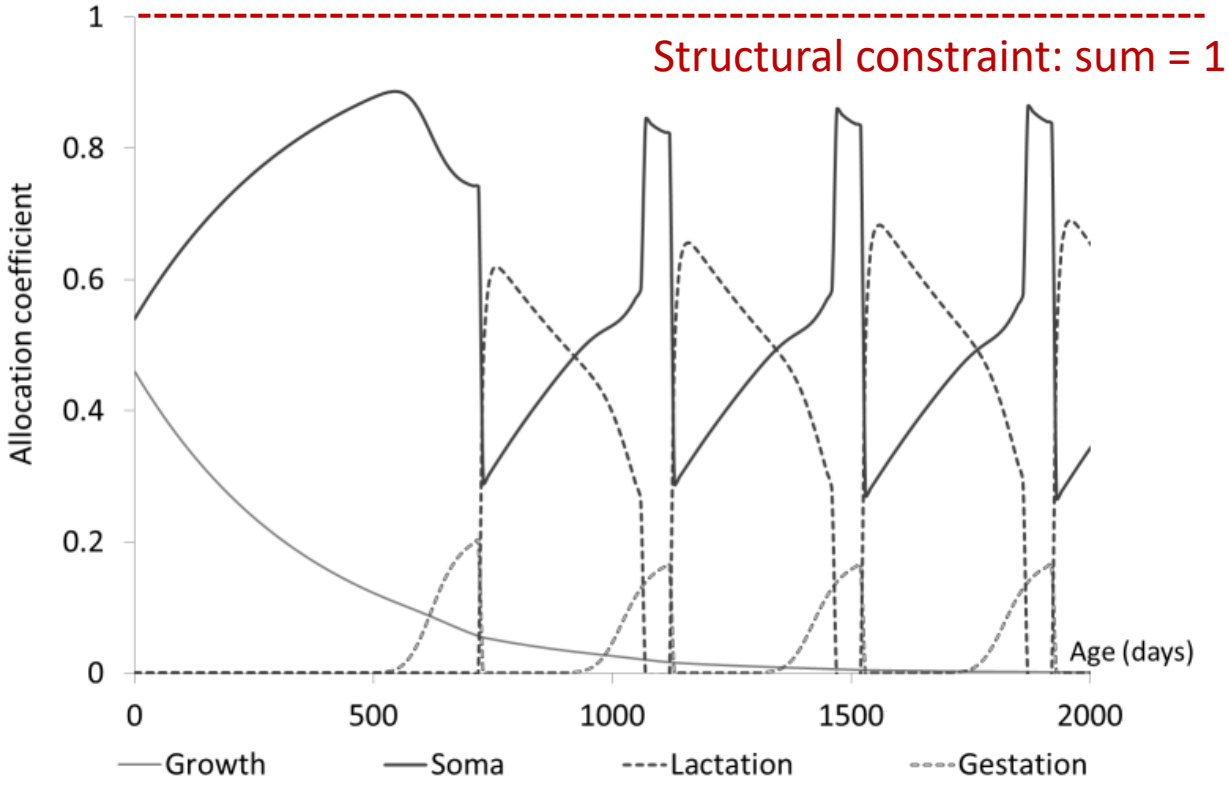


- Quantity of 1 flowing in a closed system

RESEARCH ARTICLE Open Access

Disentangling the relative roles of resource acquisition and allocation on animal feed efficiency: insights from a dairy cow model

Laurence Puillet[1*], Denis Réale[2] and Nicolas C. Friggens[1]



#3 Implementing acquisition-allocation framework

How many feed resource can get the cow ?

What is the cow strategy to distribute energy among functions?

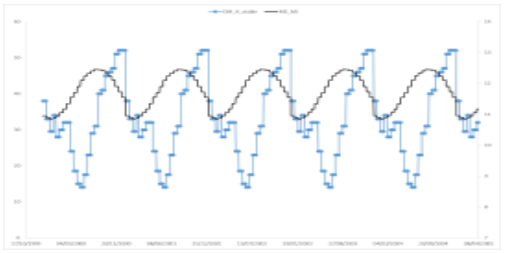
2 parameters of acquisition

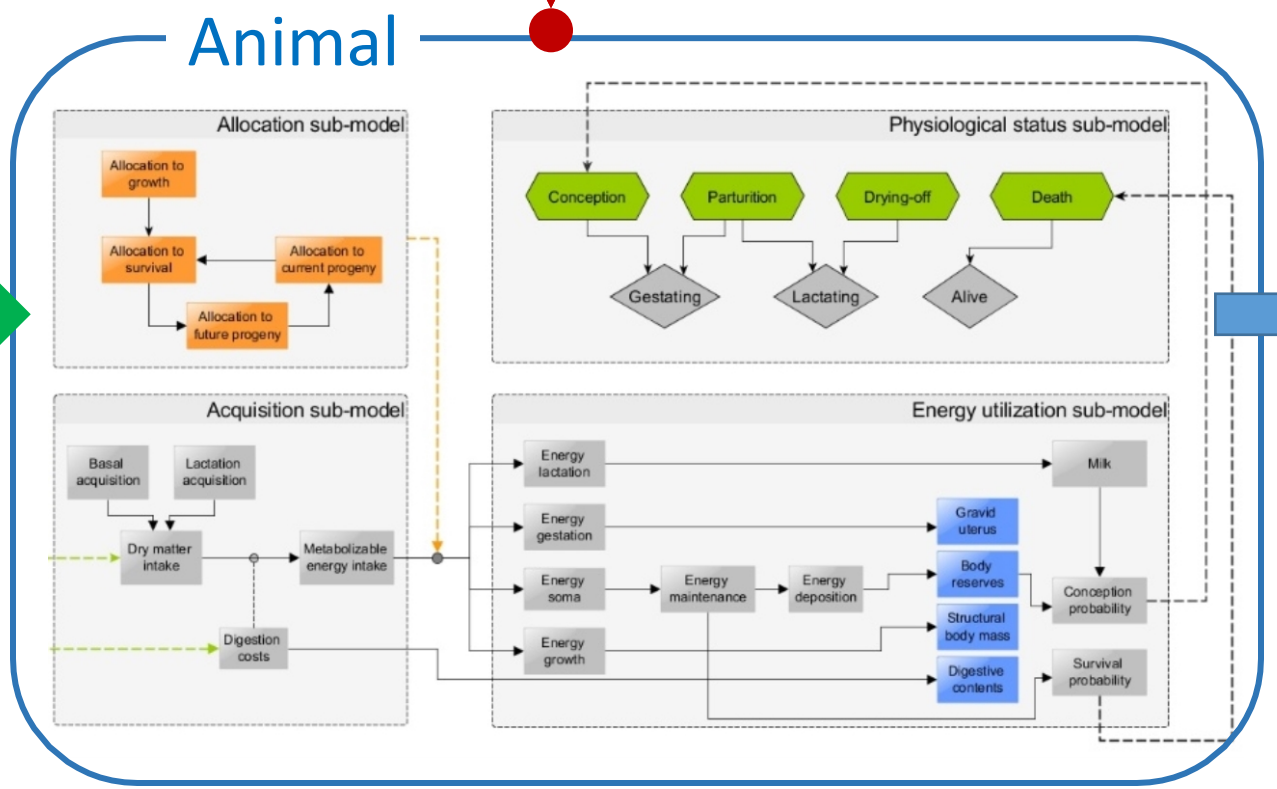
Dynamic drivers

2 parameters of allocation

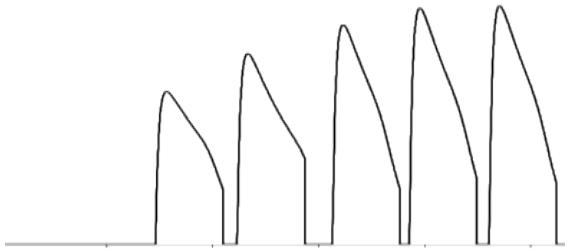
Dry matter offer (kg/d)

Energy content (ME/kg DM)

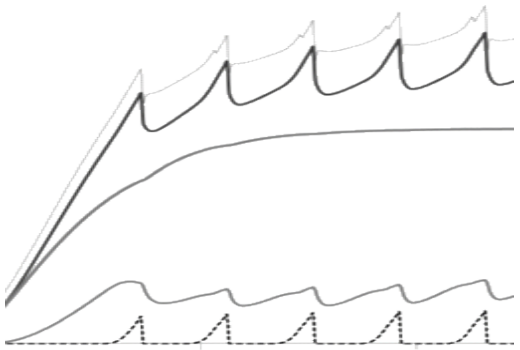




Milk production

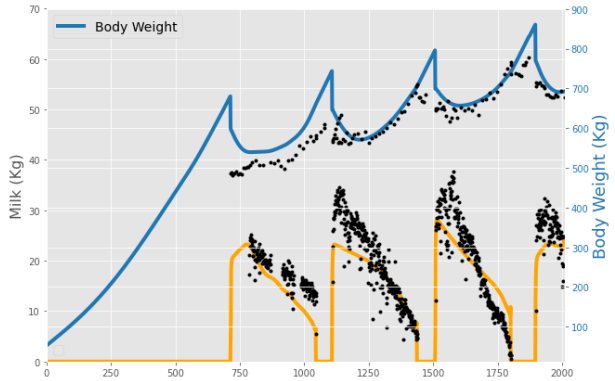


Body mass component

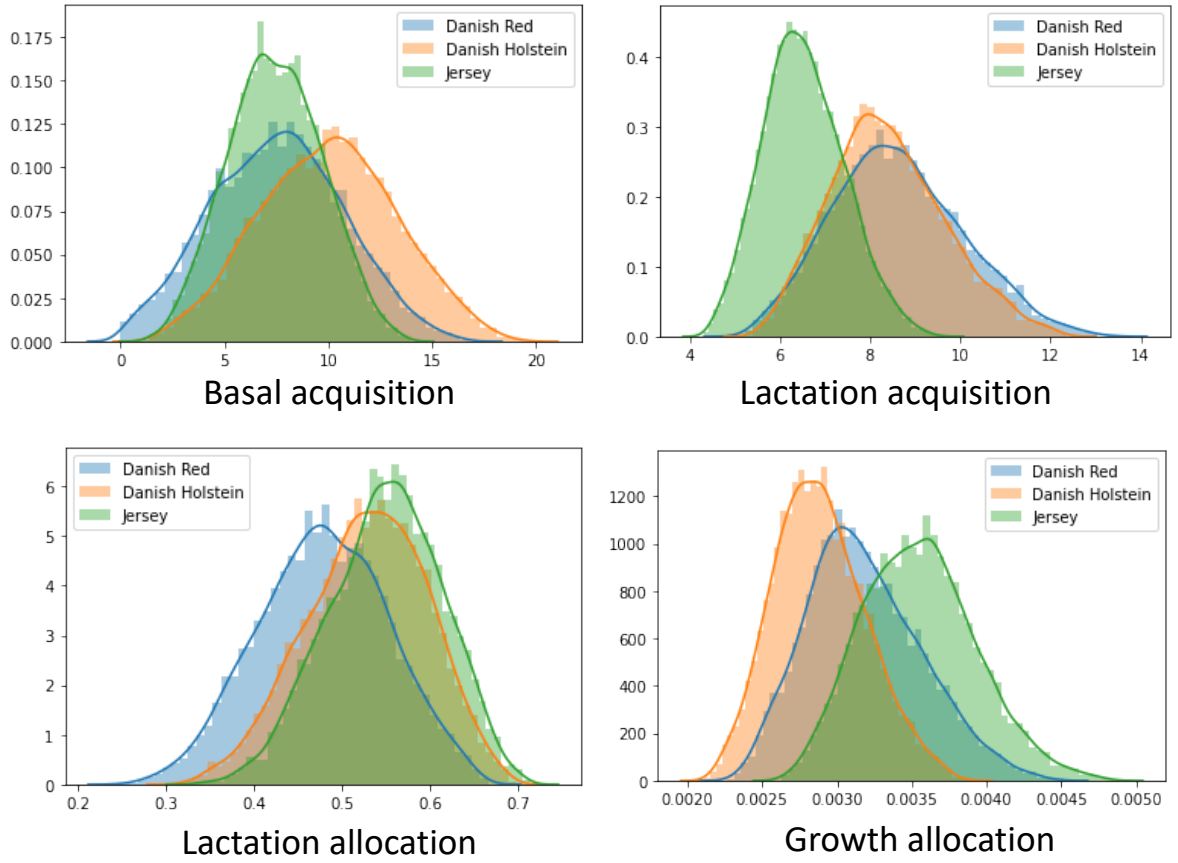


#3 Implementing acquisition-allocation framework

- Determining parameter values → finding out individual acquisition and allocation strategies



e.g. breed differences



#3 Implementing acquisition-allocation framework

- Looking at long-term effects of selection strategies

  - Genetic variation = sire population

  - Virtual experiment: same population in scenarios

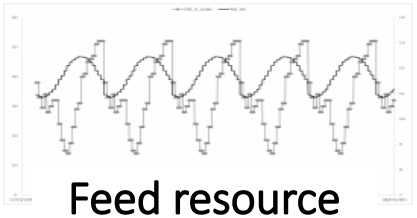
  - Comparing genetic parameters across environments → GxE

4 genetic-scaling parameters for acquisition | allocation

$$\begin{pmatrix} P_{acq1}, P_{acq2} \\ P_{alloc1}, P_{alloc2} \end{pmatrix}$$

Feed resource

Management rules



Feed resource

Management rules

Simulated traits in environment X

Cow	Sire	Efficiency	Longevity	MY	....	.....
1	1					
2	1	Genetic parameters				
3	1					

Simulated traits in environment Y

Cow	Sire	Efficiency	Longevity	MY	....	.....
1	1					
2	1	Genetic parameters				
3	1					

#3 Implementing acquisition-allocation framework

High and stable	2nd lactation production	2nd lactation efficiency	Lifetime efficiency	BW at 2nd calving	Body reserves at 2nd calving	Delay to 2nd conception
n	*17945*	*17945*	*17945*	*18171*	*18171*	*18171*
2nd lactation production	0.301					
2nd lactation efficiency	0.697	0.348				
Lifetime efficiency	0.708	0.854	0.123			
BW at 2nd calving	0.265	-0.425	-0.394	0.396		
Body reserves at 2nd calving	0.136	-0.225	0.184	0.366	0.307	
Delay to 2nd conception	0.126	0.432	0.080	-0.251	-0.473	0.008

Low and stable						
n	*13640*	*13640*	*13640*	*17019*	*17019*	*17019*
2nd lactation production	0.185					
2nd lactation efficiency	0.983	0.311				
Lifetime efficiency	0.526	0.477	0.211			
BW at 2nd calving	-0.528	-0.598	-0.768	0.390		
Body reserves at 2nd calving	0.011	-0.139	0.616	0.015	0.263	
Delay to 2nd conception	0.241	0.402	-0.314	-0.285	-0.862	0.011

When feed resource became limited (low-input pastoral system)

r_G between lactation and life efficiency decreased

r_G between life efficiency and body reserves increased

Importance of a balanced breeding goal

Where do we come from

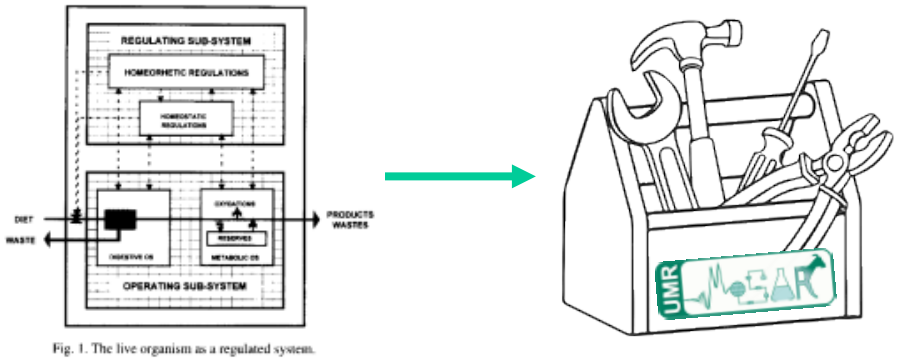


Fig. 1. The live organism as a regulated system.

InSiliCow

GRUM

AQAL

Interactions [feeding x reproduction] herd management

Phenotyping tool (PLF)

Population simulation within a genetic selection context

Responses to E_{nutri}

Lifetime level

Central role of reserves

Individual variability

Efficiency

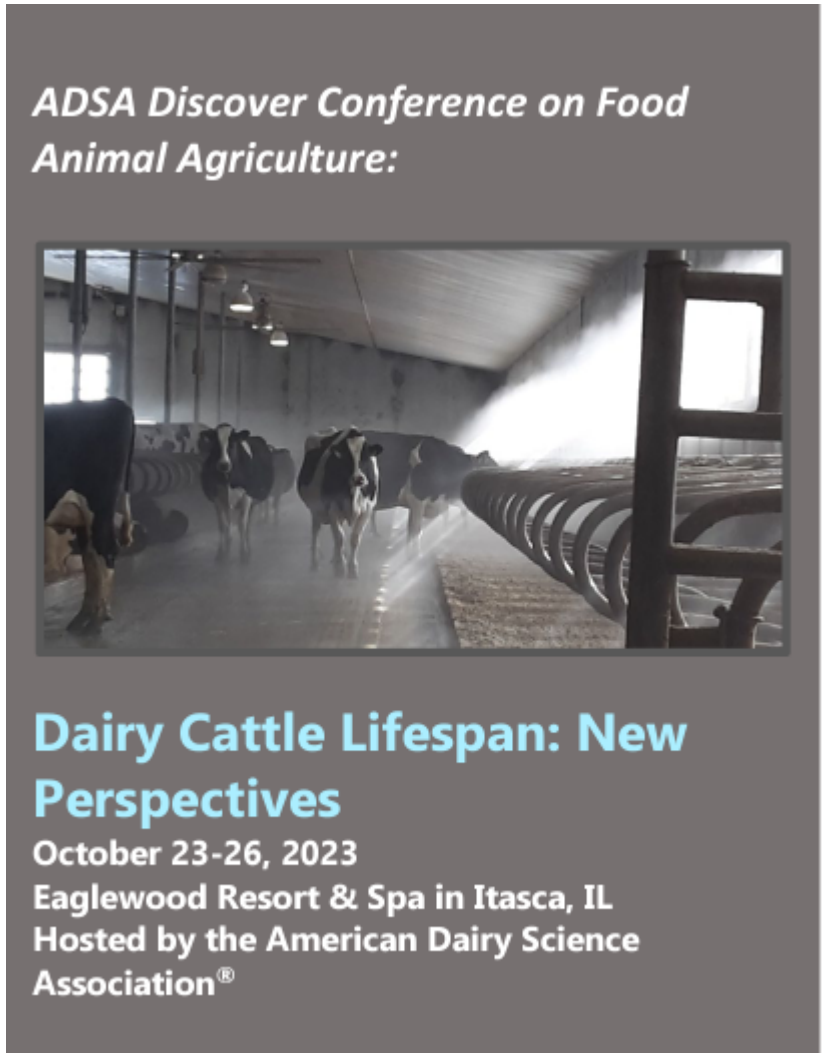
Resilience

Robustness

… and where are we going with nutrient partitioning

- Including other functions
  - Health, reproduction, thermoregulation, longevity
- Including other nutrients
  - Proteins, minerals
- Hybrid approaches
  - Concept and data-driven models
- Systemic modelling spirit, combining scales, increasing complexity

Advertising sequence…

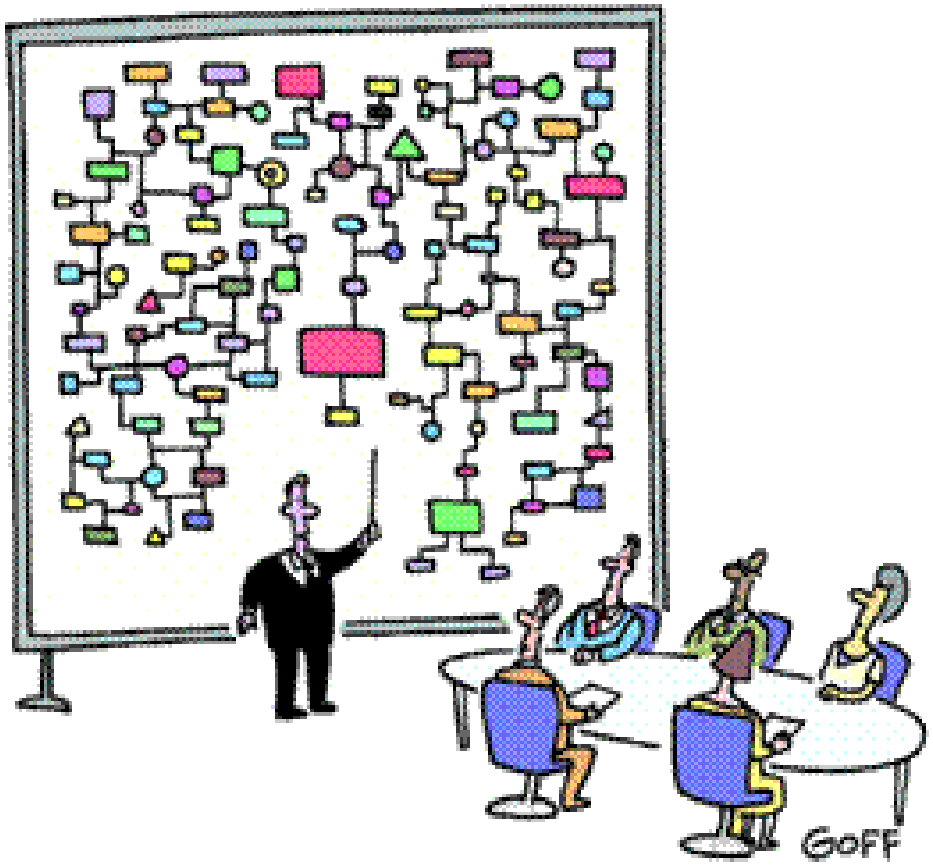


For complete conference information, including the latest program and registration materials, go to: https://www.adsa.org/Meetings/45th-Discover-Conference

Thanks to EAAP organizers for this session in memory to Daniel Sauvant

Thanks to Daniel for providing the sparks and the encouragement

Thanks for your attention



"And that's why we need a computer."