How much have we advanced, current situation, and how far can we go with growth models?

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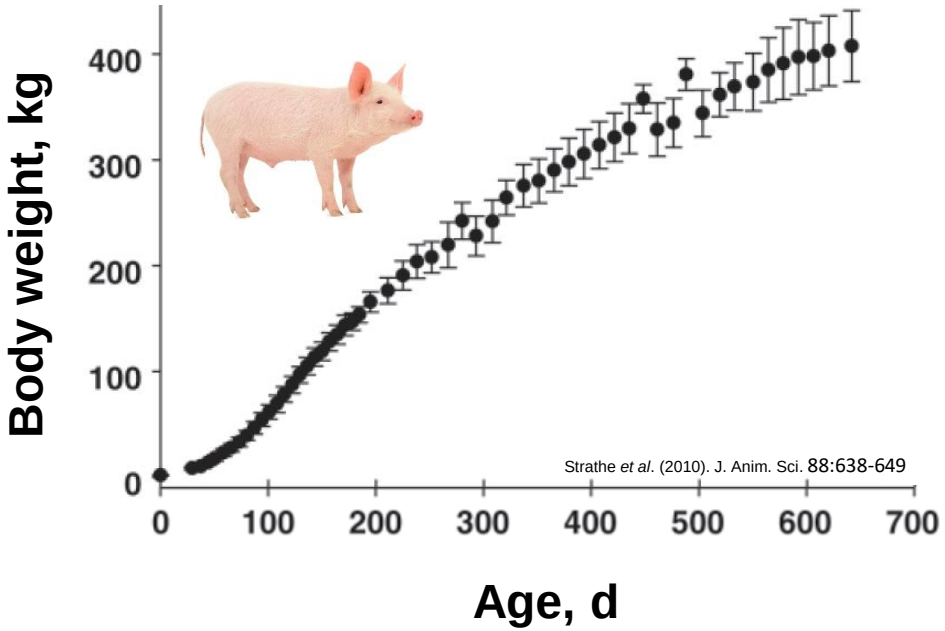
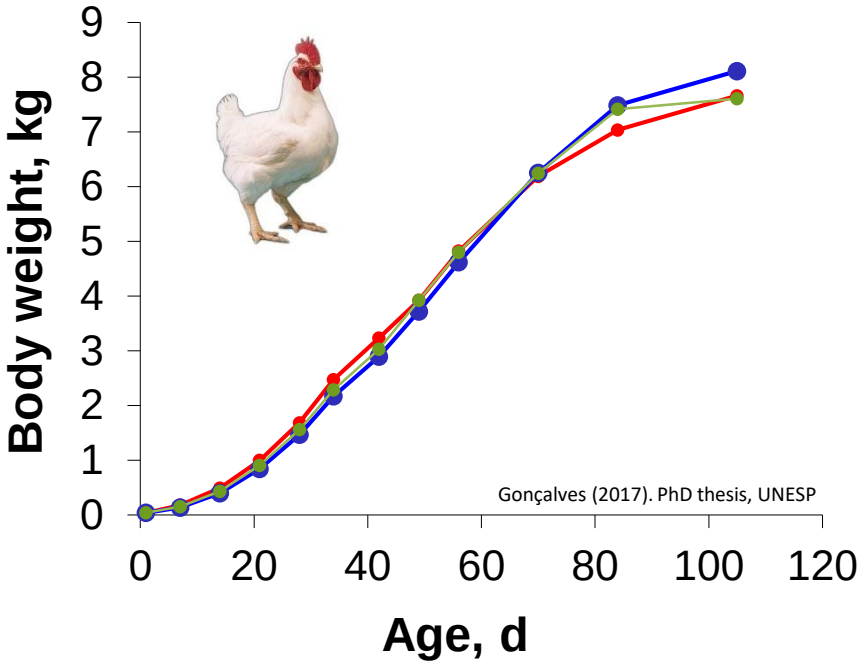
Preliminary remark

Outline

- Nutritional modeling of growth
  - Empirical models of growth
  - Concepts used in nutritional models
  - From models to tools
- Towards more mechanistic models?
- Future directions

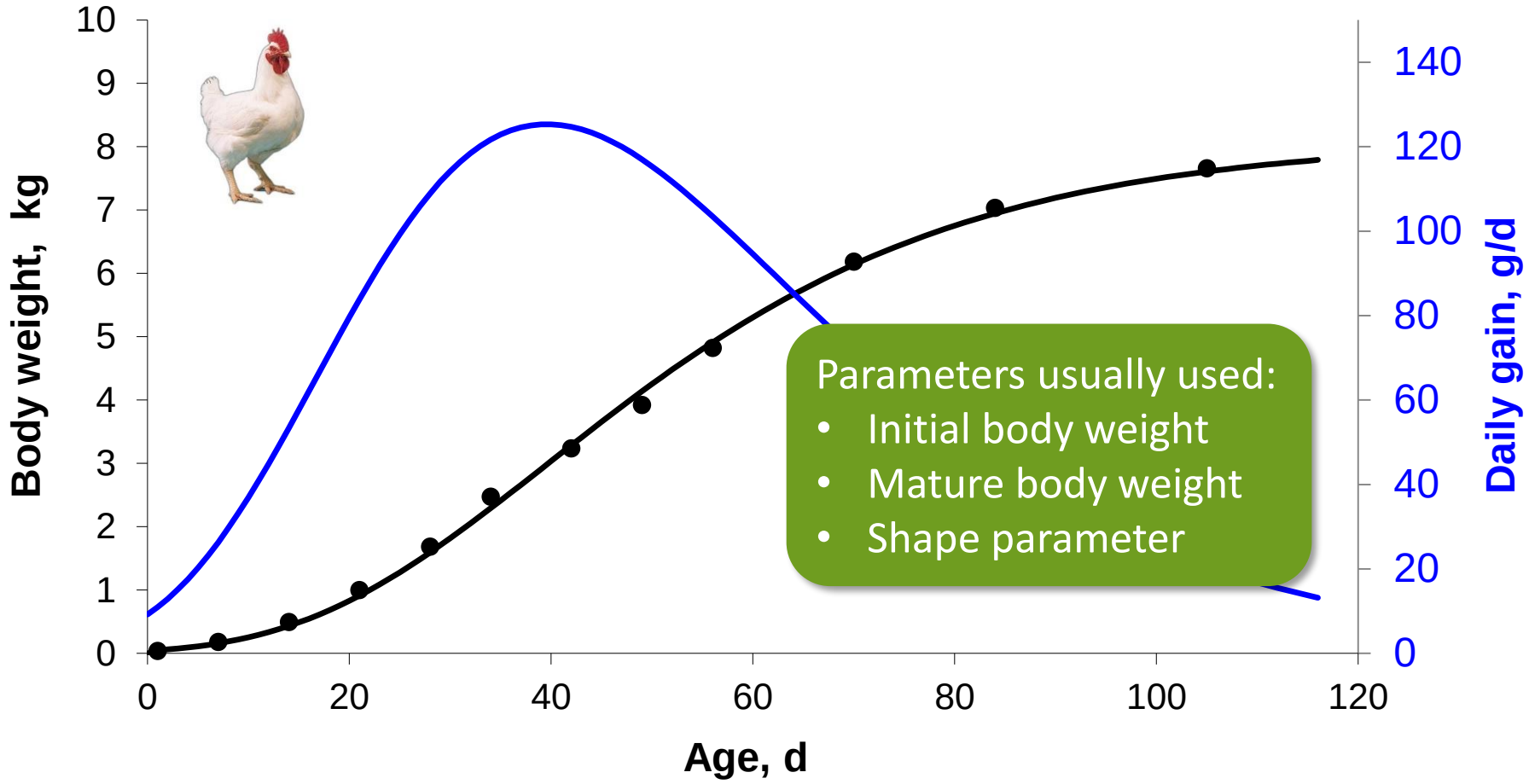
Empirical modeling of growth





Age (or time) as a driving force for growth

Growth can be described by a Gompertz function



Gonçalves (2017). PhD thesis, UNESP

Growth can be described by a Gompertz function

In commercial settings, we rarely have data that allow to accurately estimate the mature body weight

Body weight, kg

Daily gain, g/d

Age, d

Gonçalves (2017). PhD thesis, UNESP

Potential protein deposition can be described by a Gompertz function

Potential protein deposition can be described by a Gompertz function

Precocity

Mean protein deposition
(∝ average daily gain)

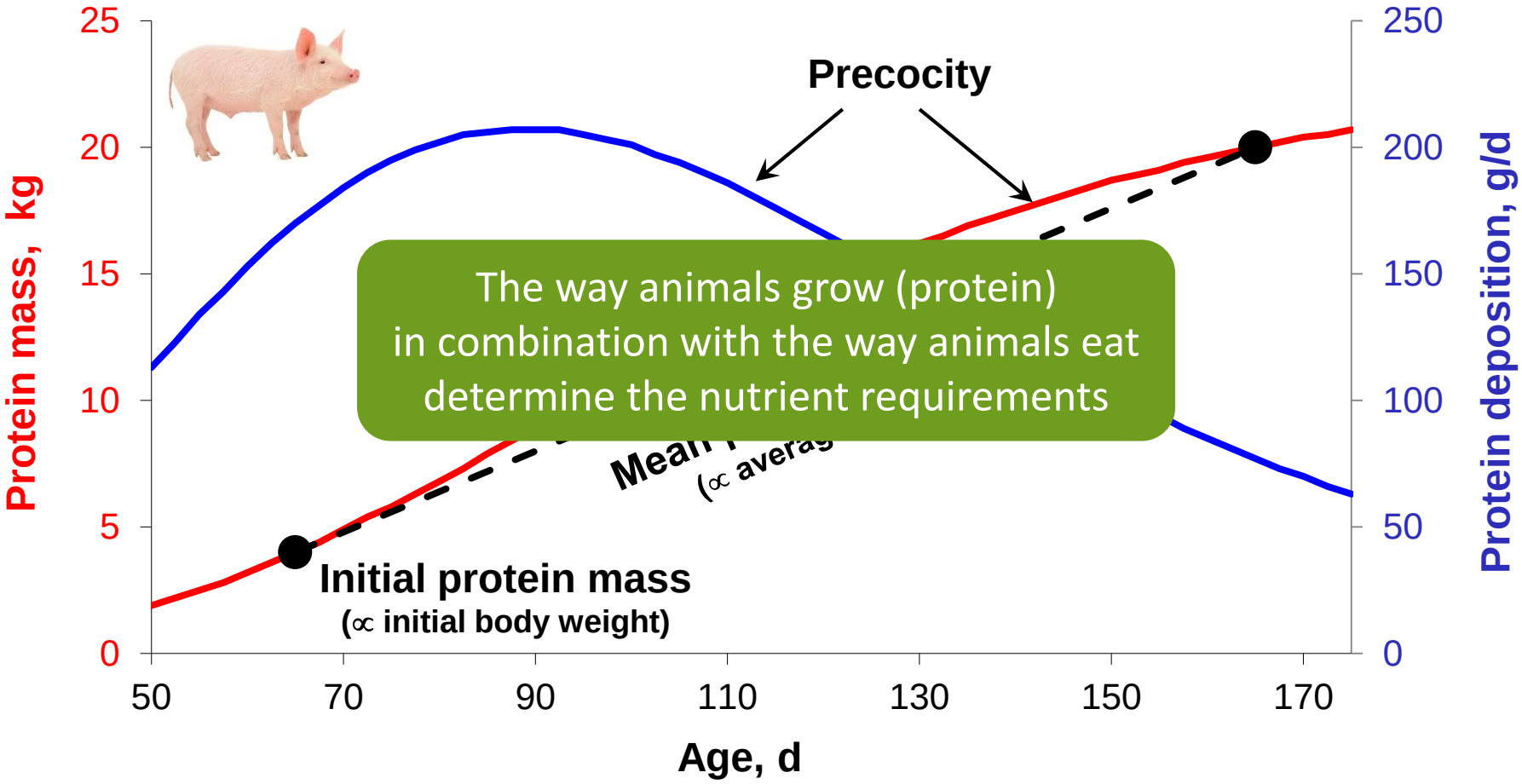
Initial protein mass
(∝ initial body weight)

Protein mass, kg

Protein deposition, g/d

Age, d

Potential protein deposition can be described by a Gompertz function



The way animals grow (protein) in combination with the way animals eat determine the nutrient requirements

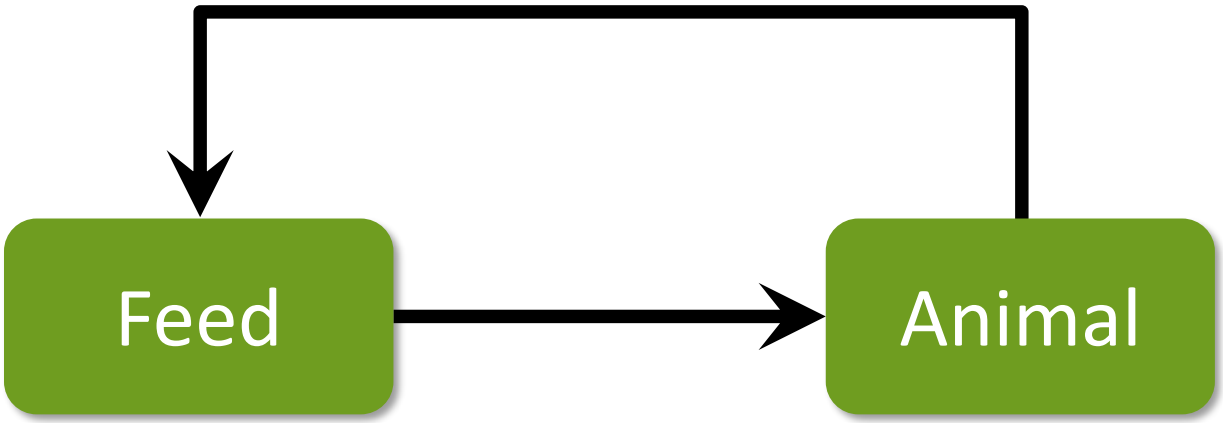
Empirical modeling of growth

Feed intake as a driving force for growth

Schulin-Zeuthen *et al.* (2008). Anim. Feed Sci. Technol. 143:314-327

Ad libitum feed intake: push or pull?

(the chicken-or-egg question, even for pigs)



Push: the animal eats and thus it grows
Pull: the animal eats because it wants to grow

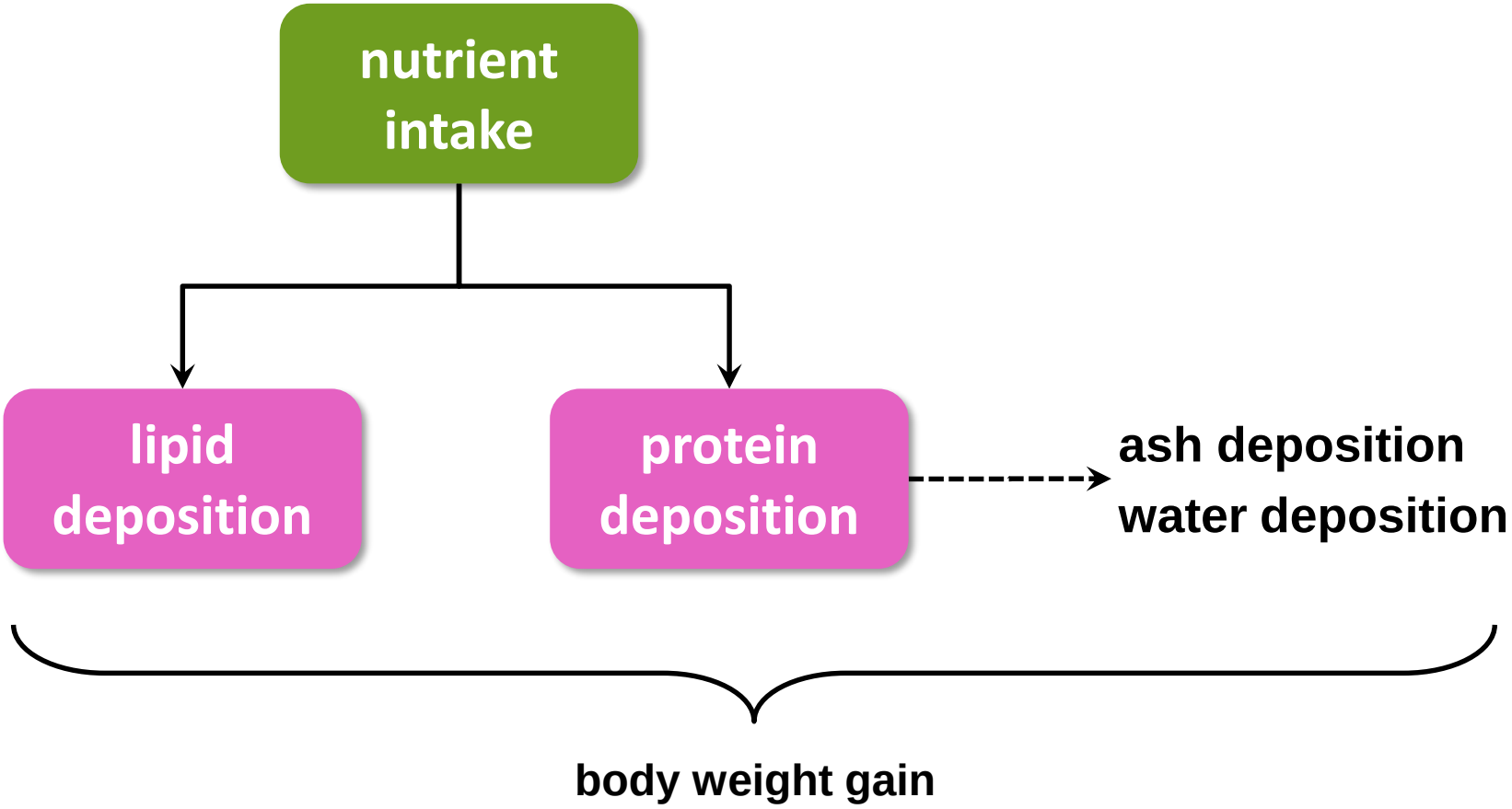
Ad libitum feed intake: push or pull?

(the chicken-or-egg question, even for pigs)

	Pull	Push
Explicit control function*	Potential lipid deposition	Feed intake
Additional issues and questions	Constraints can be imposed on feed intake (e.g., gut capacity, heat stress)	What controls ad libitum feed intake (DM, AME, NE)?
Consequence	The animal eats for net energy	Lipid deposition becomes an « energy sink »

*In addition to a function describing protein deposition

Concepts used in nutritional growth models



Whittemore and Fawcett (1974). Anim. Prod. 19:221-231

Concepts used in nutritional growth models

Feed intake (push)

DE_{CP} | DE_{starch} | DE_{sugars} | DE_{lipids} | $DE_{residue}$

$ME_{excess\ CP}$ | ME_{starch} | ME_{sugars} | ME_{lipids} | $ME_{residue}$

PD-free NE

endogenous losses
amino acid balance
phenotypic potential

protein deposition

lipid deposition | maintenance & physical activity | cost of protein deposition

body protein | body lipid

body weight
lean meat %
backfat thickness

van Milgen *et al*. (2008). Anim. Feed Sci. Technol. 143: 387-405

Concepts used in nutritional growth models

Feed intake (push)

ME_{CP} | ME_{starch} | ME_{sugars} | ME_{lipids} | $ME_{residue}$

$AMEn_{excess\ CP}$ | $AMEn_{starch}$ | $AMEn_{sugars}$ | $AMEn_{lipids}$ | $AMEn_{residue}$

PD-free NE

lipid deposition | maintenance & physical activity | cost of protein deposition

endogenous losses
amino acid balance
phenotypic potential

protein deposition

feather protein | feather-free body protein | body lipid

feather loss

body weight
breast meat %

Feed-a-Gene

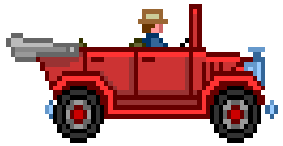
Dukhta *et al*. (2017, 2018). PhD thesis, Kaposvár University

Processes involved in amino acid utilization

- Digestion
- Absorption
- Maintenance
- Synthesis of non-protein nitrogen compounds
- Transamination
- Amino acid imbalance
- Catabolism due to an excess supply
- (Preferential) catabolism to supply energy
- Inevitable catabolism
- Deposition (but the amino acid composition differs among proteins)

Moughan (2008). In: Mathematical modeling in animal nutrition. J. France and E. Kebreab (eds.)

From a model to a decision support tool



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Animal Feed Science and Technology
143 (2008) 387–405

ANIMAL FEED SCIENCE AND TECHNOLOGY
www.elsevier.com/locate/anifeedsci

InraPorc: A model and decision support tool for the nutrition of growing pigs☆

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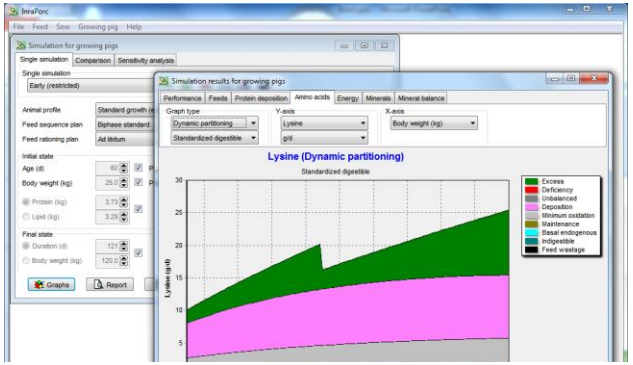
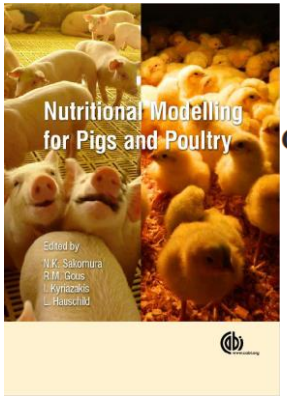
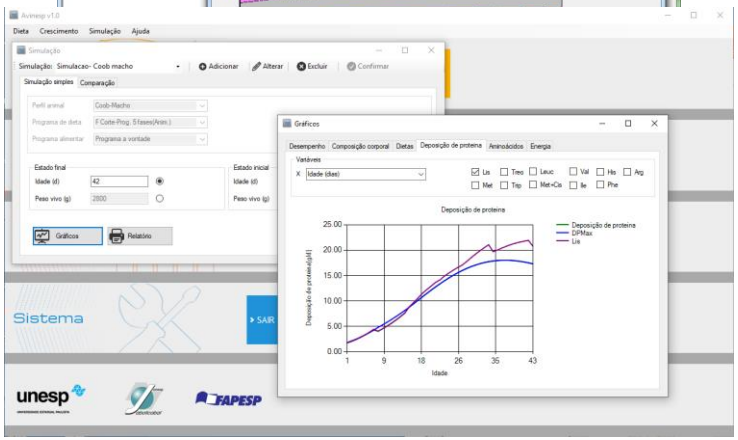
INRA, UMR Systèmes d'Élevage, Nutrition Animale et Humaine, 35590 Saint-Gilles, France





14 AvinespModel: Predicting Poultry Growth, Energy and Amino Acid Requirements

L. Hauschild,* N.K. Sakomura and E.P. Silva
Universidade Estadual Paulista, Jaboticabal, São Paulo, Brazil



Towards more mechanistic models

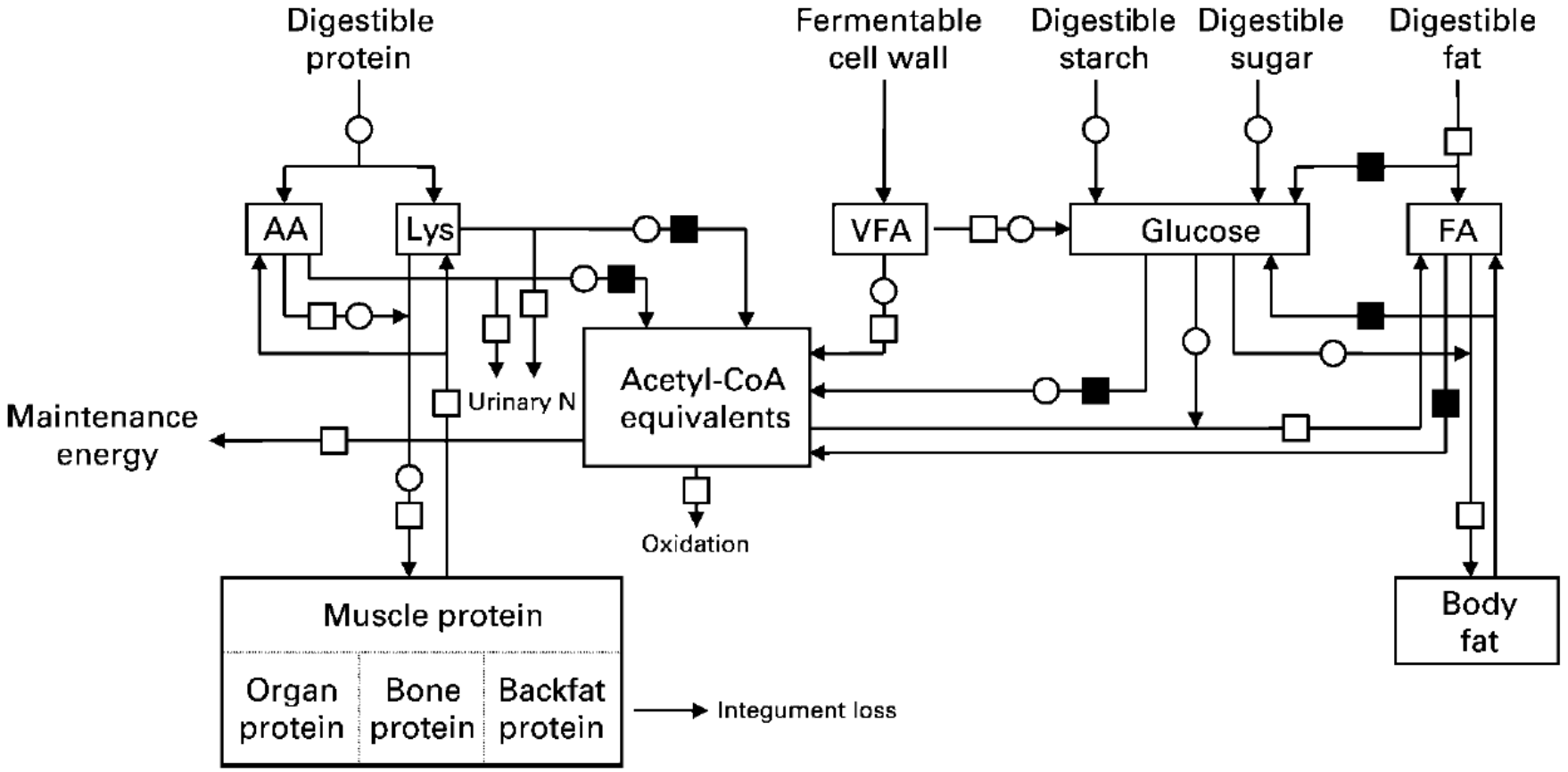


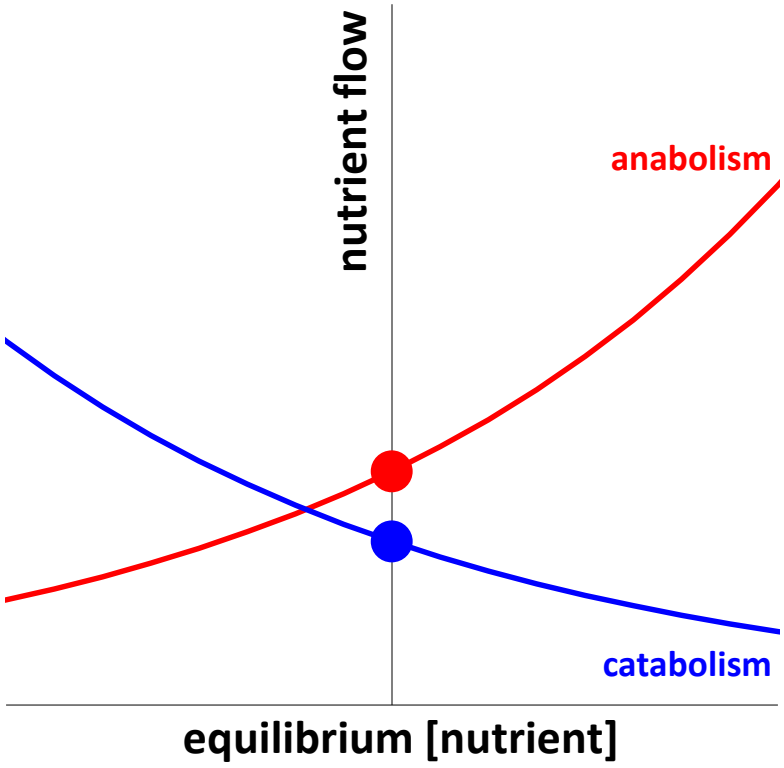
Fig. 2. Diagrammatic representation of the pig growth model. AA, amino acid; VFA, volatile fatty acid; FA, fatty acid. ○, Energy use in transport; □, energy use in reaction; ■, ATP production in reaction.

Halas *et al*. (2004). Br. J. Nutr. 92:707-723

Towards more mechanistic models

Homeostatic regulation

(short-term regulation)



Homerhetic regulation

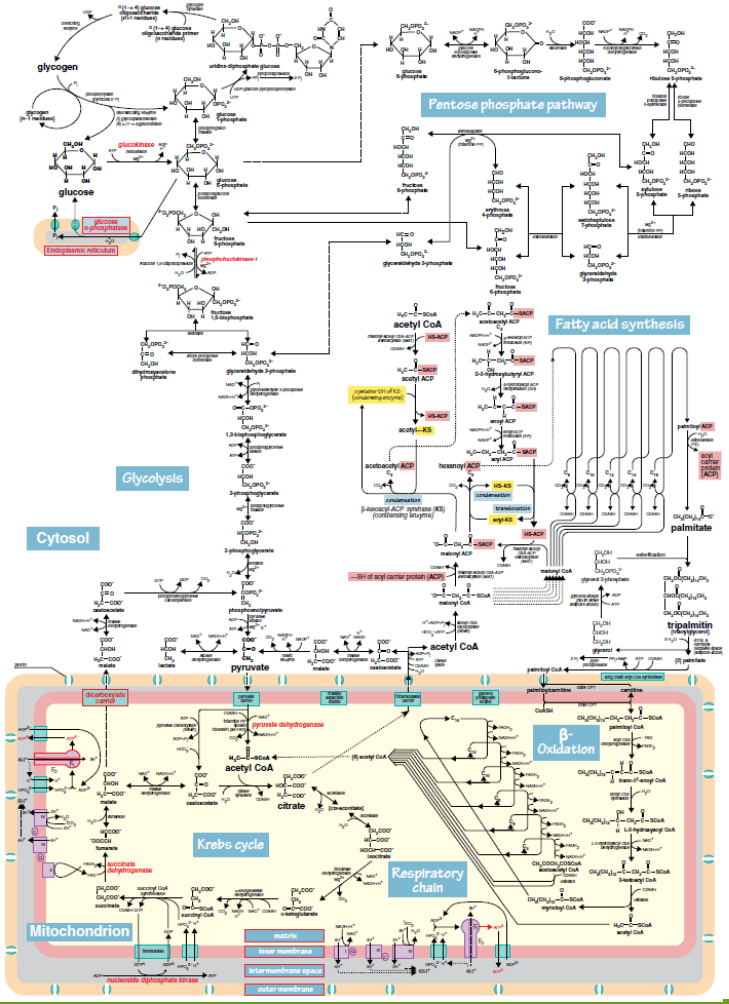
(long-term regulation)

- $dS/dt = (\mathbf{A} - \mathbf{C}) \times S$
- $\mathbf{A} = k_1 + k_2 \exp(-k_3 \times \text{time})$
- $\mathbf{C} = k_1 + k_4 \exp(-k_5 \times \text{time})$

At maturity: $\mathbf{A} = \mathbf{C} = k_1$

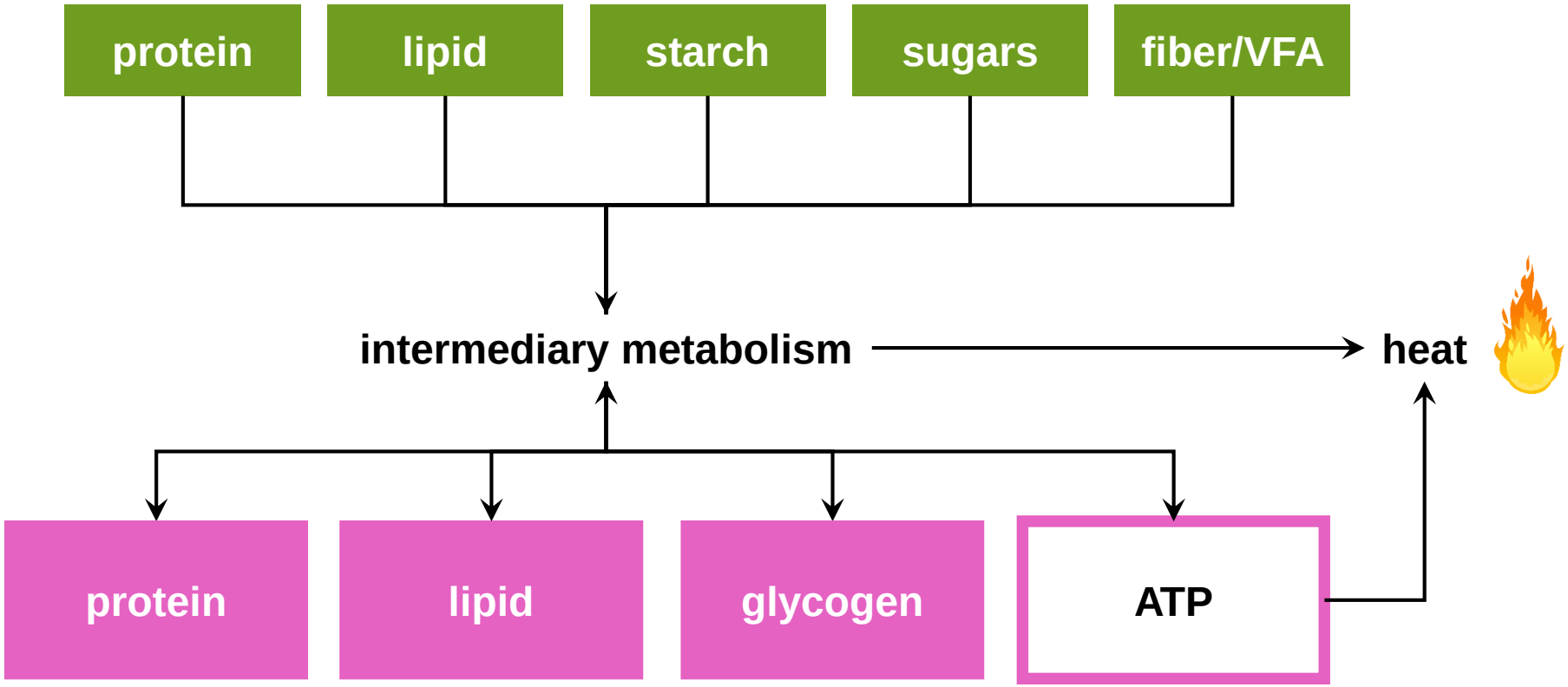
Lovatto and Sauvant (2003). J. Anim. Sci. 81:683-696
Rivera-Torres *et al.* (2011). J. Anim. Sci. 89:3170-3505

How far should we go in further refining our nutritional models?



Salway (2017). Metabolism at a glance, 4th edition. Wiley Blackwell

How far should we go in further refining our nutritional models?



Energy efficiency of glucose → ATP

$$1\ \text{glucose} + 6\ O_2 \rightarrow 31\ \text{ATP} + 6\ CO_2$$

(1 glucose = 2820 kJ/mol = 74.2 kJ/g)

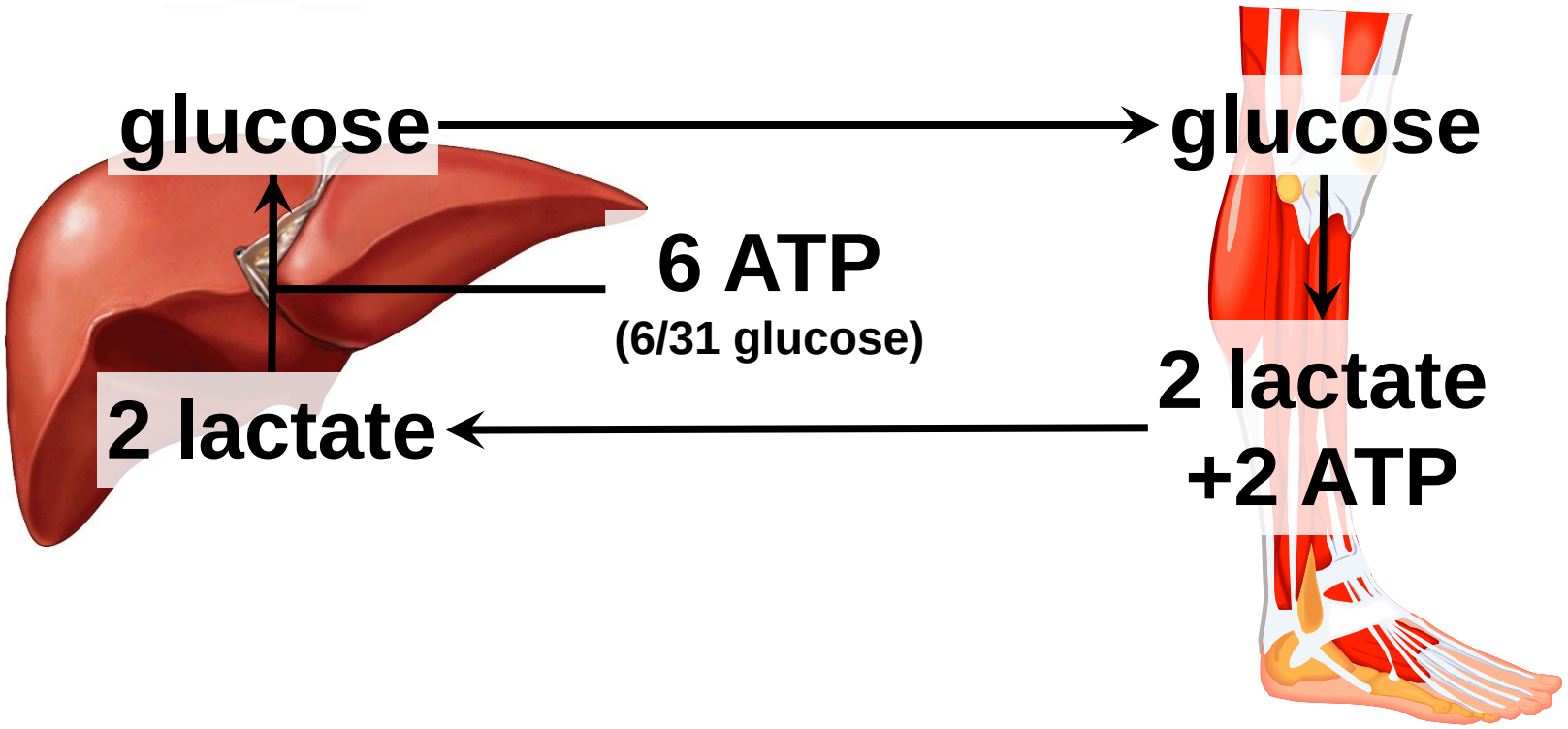
cost = 2820/31 = 91.0 kJ/ATP

Energy efficiency of glucose → ATP

1 glucose → glycogen → 30 ATP

cost = 2820/30 = 94.0 kJ/ATP

Energy efficiency of glucose → ATP

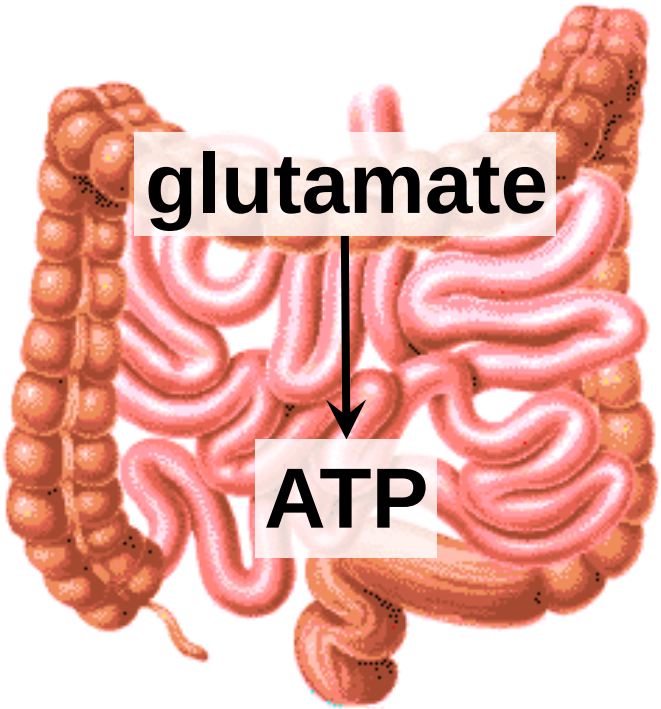


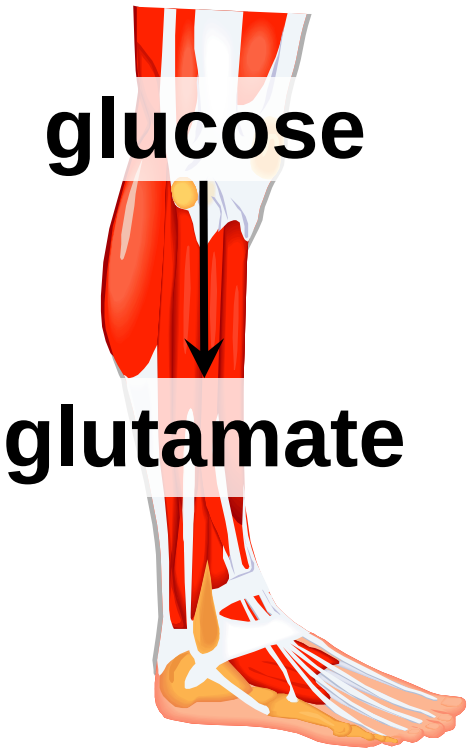
cost = (2820*6/31)/2 = 272.9 kJ/ATP

Energy efficiency of glucose → ATP

cost = 2820*14/334 = 118.2 kJ/ATP

Energy efficiency of glucose → ATP





glucose → glutamate → ATP

cost = 2820/(29.75) = 94.8 kJ/ATP

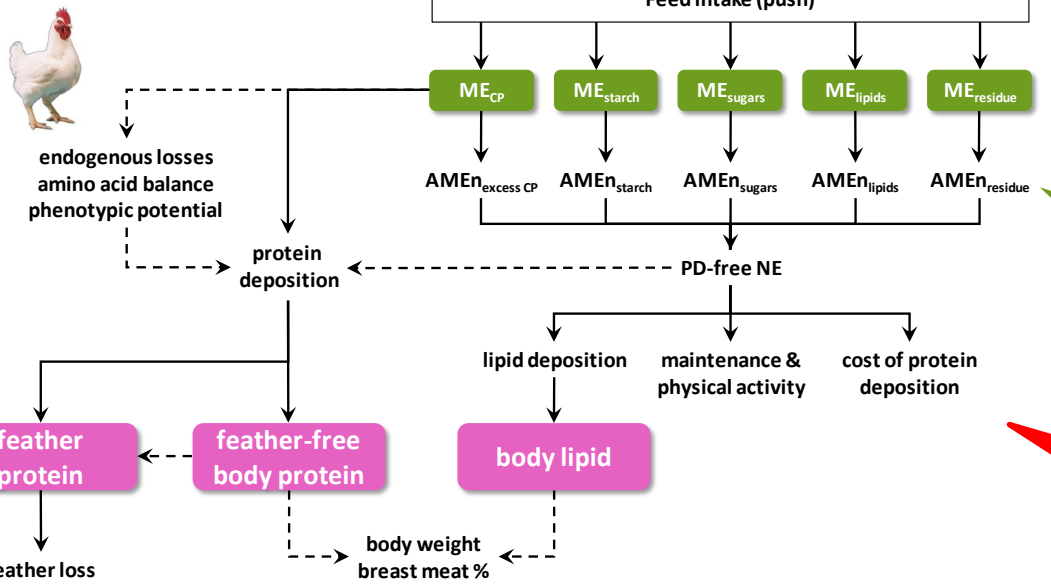
Energy efficiency of glucose → ATP

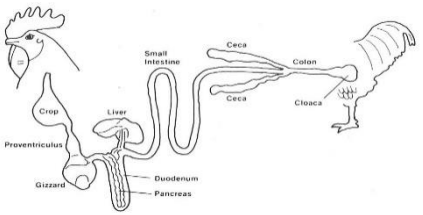
1 glucose + 6 O_2 → 31 ATP + 6 CO_2

direct	91.0 kJ/ATP = 100%
via glycogen (muscle)	97%
via lactate (gluconeogenesis)	33%
via lactate (oxidation)	100%
via lipid	77%
via glutamate	96%

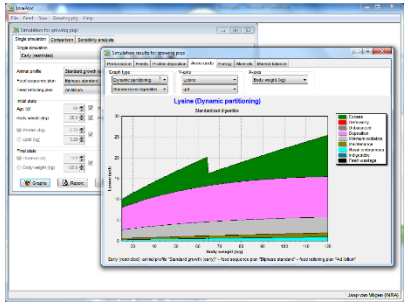
Feed-a-Gene

Modeling biological functions



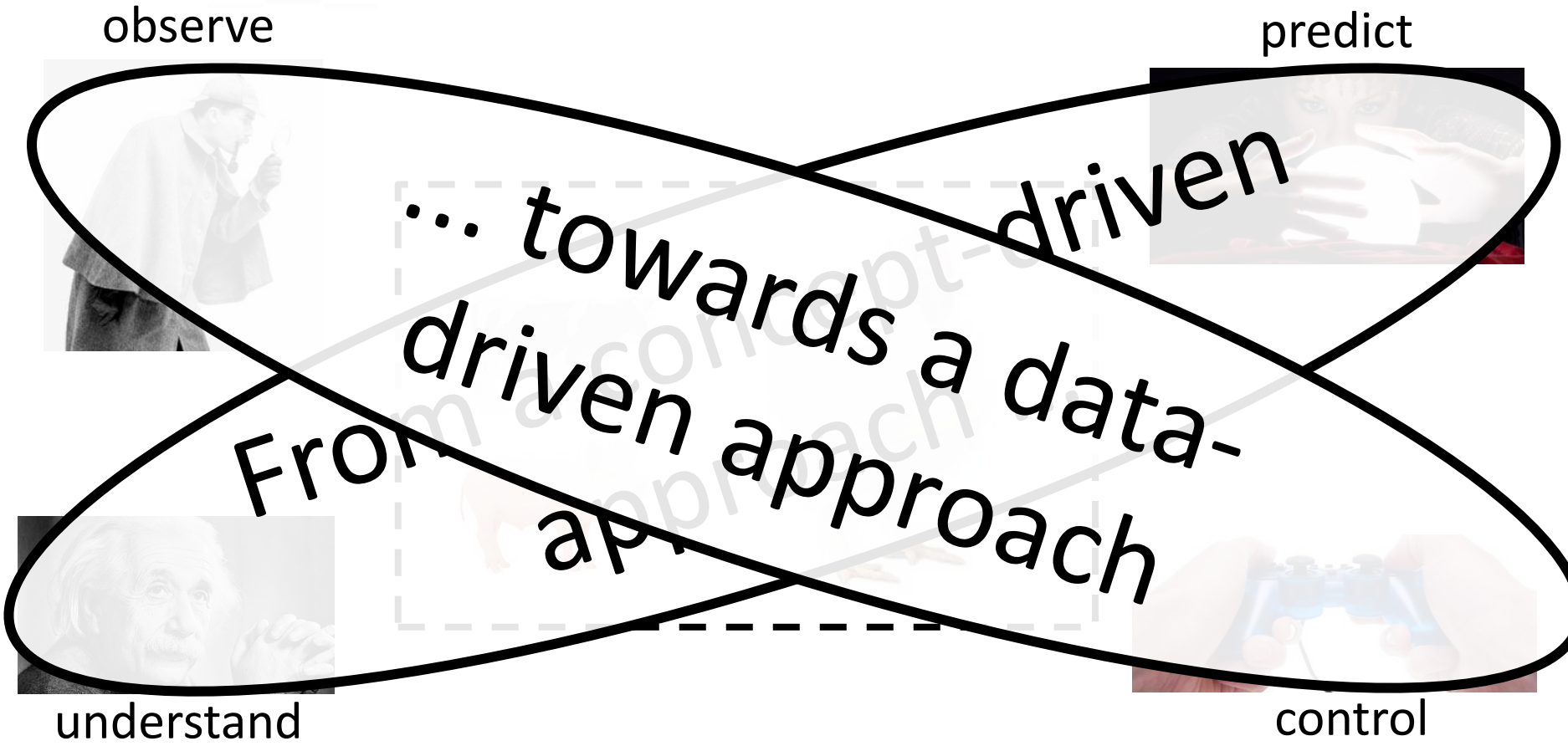


Nutritional growth models use digestible nutrients as model inputs …



… to predict performance traits of a single animal in a “standard” environment

Our capacity to observe is increasing exponentially



Our capacity to observe is increasing exponentially

behavior and welfare

image analysis
serotonin,
cortisol

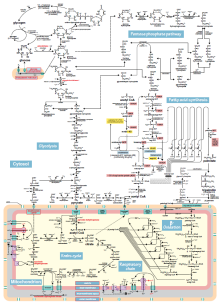
individual feed intake

feed intake patterns
feeding behavior

digestive efficiency

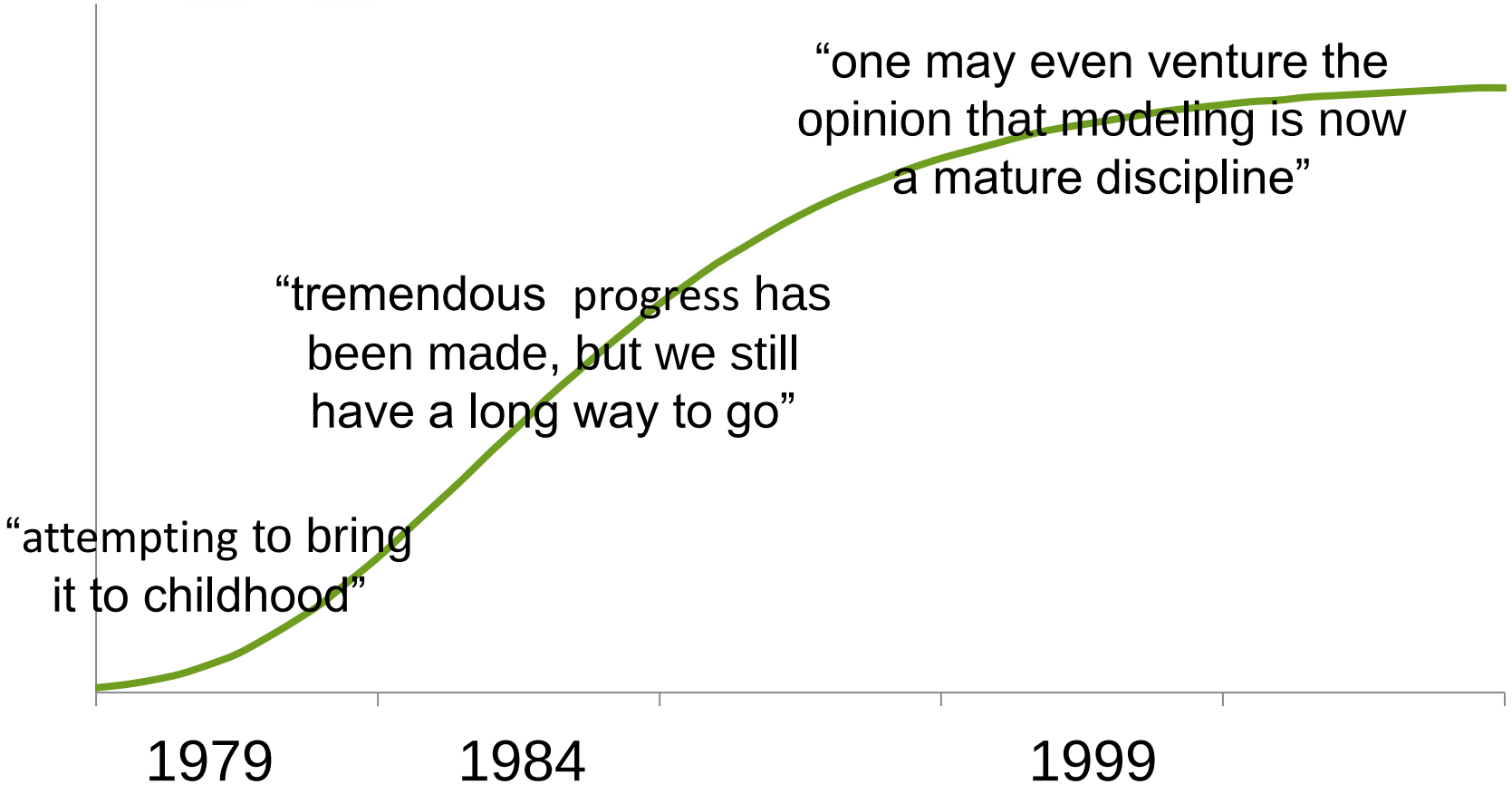
digestibility markers
gut health
microbiota

metabolic efficiency



transcriptomics
proteomics
metabolomics

Modeling: where do we come from?
(Lee Baldwin, 1999)



Conclusions

- We still have a long way to go to understand the full story of nutrition and metabolism
- Tool development is an essential element in model uptake
- Monitoring/phenotyping/big data will bring new life and new challenges to nutritional modeling

EU funded Research project

2015
2020

€10 M Budget

Feed-a-Gene

Adapting the **feed**, the **animal** and the **feeding techniques** to improve the efficiency and sustainability of monogastric livestock production systems

(www.feed-a-gene.eu)

The Feed-a-Gene Project has received funding from the European Union's H2020 Programme under grant agreement no 633531

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