Bioenergetics and Individual Growth

Bioenergetics ⇒: conversion of energy from food into body mass

Individual growth ⇒: change in body mass

Modeling Bioenergetics

- Thermodynamics: energy transformations and exchanges
- Overall energy budget

  Dynamic Energy Budget (DEB): allocation to structure, reserves, and reproductive capacity
- Often a balance of respiration with energy intake
- How living cells produce and store energy (ATP)
- Ultimately models of growth

Modeling Growth

- Changes in individual weight
- Population biomass and structure
- Vulnerability to harvest
- Energy requirements
- Trophic changes
- Habitat changes

Parameter Types

POPULATION

- Describes the entire population

  Average height of everyone in this room

  Variance – how much values vary around the mean on average

SYSTEM

- Instantaneous rates of change

  Mortality rate

  Population growth (r,K)

  Individual growth (k,L_∞)

Estimation

DESIGN-BASED

- Follows a statistical sampling design
- No assumptions made about the population
- Variance reflects the design

MODEL-BASED

- Assumptions are made regarding how the system works
- Variance reflects the structure of the chosen model(s)

Mathematical models

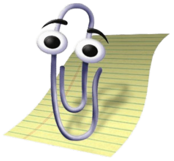
- Parametric vs. Non-parametric
- Mechanistic vs. Empirical
- von Bertalanffy growth equation (VBGE) = parametric and mechanistic

Ludwig von Bertalanffy (1901-1972)

”Why does an organism grow at all, and why, after a certain time, does its growth come to a stop?”

Where does the VBGE come from?

- Anabolism ⇒**:** the synthesis of molecules
- Catabolism ⇒**:** the breakdown of molecules
- Net synthesis: Anabolism – Catabolism

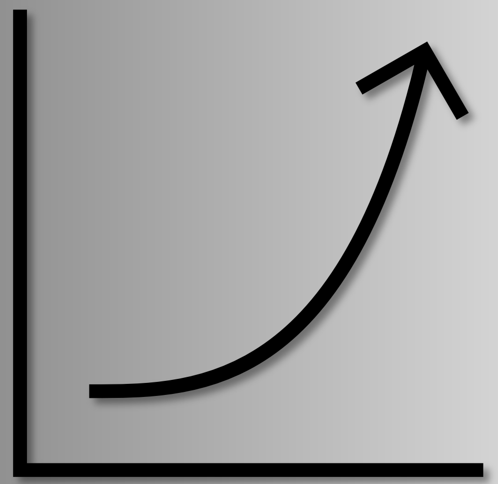


Note: ANAdromous fish go UPriver to spawn, CATAdromous fish go DOWNriver to spawn

$$\frac{dw}{dt} = As - Kw$$

- Growth is enormously complex, but follows the law of allometry i.e. physiological rates are a power function of body mass: $\xi(w) = aw^b$
- s = surface area = $w^{2/3}$
- w = weight
- A and S = coefficients
- Anabolism ~ metabolic rate ~ respiration ~ surface area
- Catabolism ~ total mass ~ weight

Weight-Length Relationship



$$w = qL^3$$

WE OFTEN MEASURE LENGTH RATHER THAN WEIGHT

$$\frac{dw}{dt} = As - Kw$$

$$\frac{dw}{dt} = Aw^{2/3} - Kw$$

$$\frac{dw}{dt} = qAL^2 - qKL^3$$

Several steps to solve

$$w = qL^3$$

$$\frac{dw}{dL} = 3qL^2$$

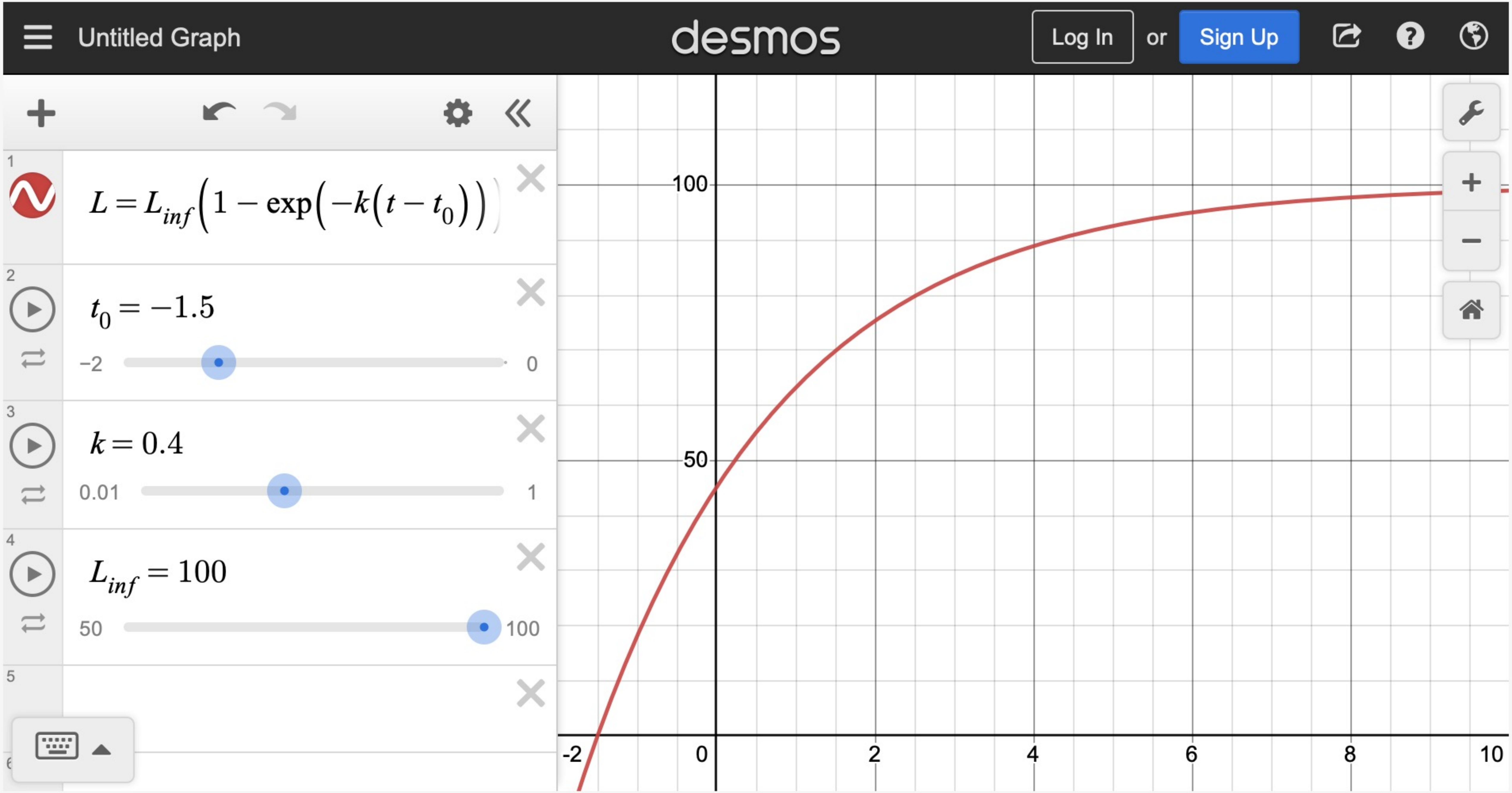
$$1 = \frac{dL}{dw} 3qL^2$$

$$\frac{dw}{dt}\frac{dL}{dw} 3qL^2 = qAL^2 - qKL^3$$

$$\frac{dw}{dt}\frac{dL}{dw}3qL^2 = qAL^2 - qKL^3$$

$$\frac{dL}{dt} = E - KL$$

$$\boxed{L_t = L_\infty\left(1 - e^{-K(t-t_0)}\right)}$$



Source: https://www.desmos.com/calculator/lzzmcqqnly

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Gompertz Equation

- Rate of absolute mortality/decay falls exponentially with increasing size

$$\frac{dL}{dt} = rL\ln\left(\frac{k}{L}\right)$$

$$L_t = L_\infty e^{-e^{-k(t-t_i)}}$$

Name	Form	Model $\mathrm{d}M/\mathrm{d}t$
Linear		r
Exponential		rM
Power law		rM^{β}
Monomolecular		$r(K-M)$
Three-parameter logistic		$rM\left(1-\frac{M}{K}\right)$
Four-parameter logistic*		$r(M-L)\left(\frac{K-M}{K-L}\right)$
Gompertz		$rM\left(\ln\frac{K}{M}\right)$

Table 1 from Paine et al 2012

Model Assumptions

- Homogeneous error variance
- Constant relationship of length in time

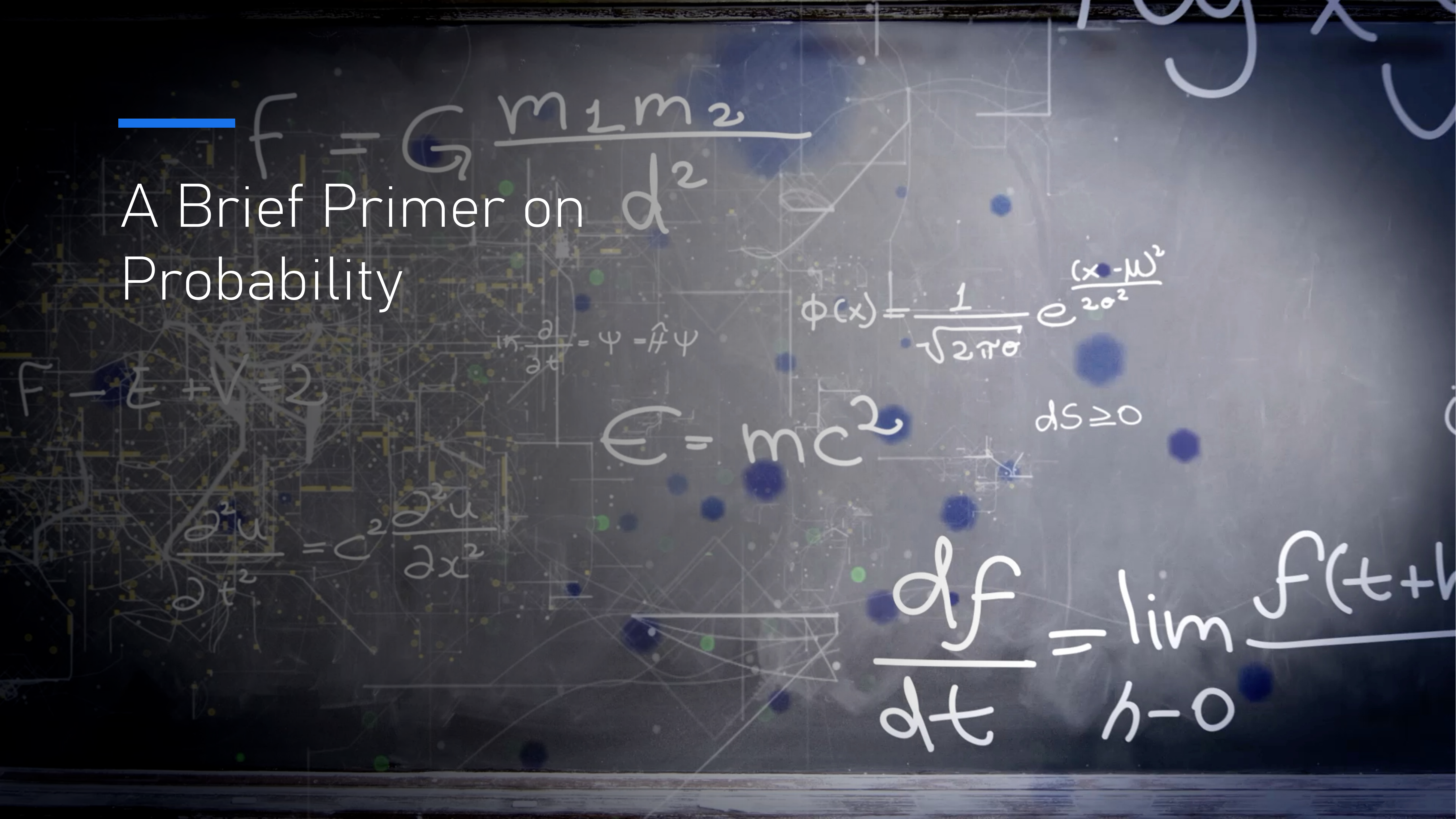
  Slow-fast dynamics

- How adequate is our model?

  Is it representative of our system?

  Are the parameters estimable from our data?

A Brief Primer on Probability



$P(X)$: how likely is it that X will happen?

- $P(X) = 0$ i.e. it will “almost surely” not happen
- $P(X) = 1$ i.e. it will “almost surely” happen

P(X|Y): how likely is it that X will happen if Y is given?

- X: the "event" in which a plant has leaves
- P(X) = 0.9
- Y: the "event" in which the plant is a tree
- P(X|Y) = the probability that a plant has leaves GIVEN it is a tree = 1

Bayes' Law

$$P(\theta|X) = \frac{P(X|\theta)P(\theta)}{P(X)}$$

$$P(\theta|X) \sim P(X|\theta)P(\theta)$$

Likelihood: $P(X|\theta)$

Prior: $P(\theta)$