Women mathematicians in Canada: Developing and shaping the field of mathematical biology

Gustavo Carrero

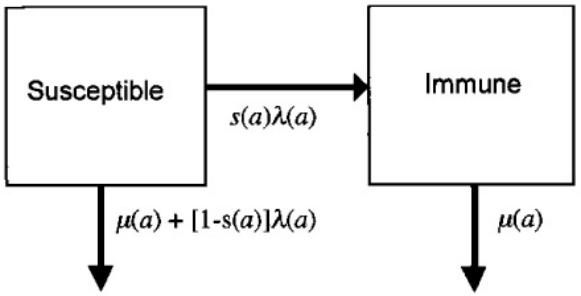
Athabasca University

Impact of Women Mathematicians on Research and Education in Mathematics BIRS Workshop
Banff, Canada, March 16-18, 2018

Outline

Mathematical Biology in the XVIII Century

- Epidemiology: Daniel Bernoulli (Swiss Mathematician)

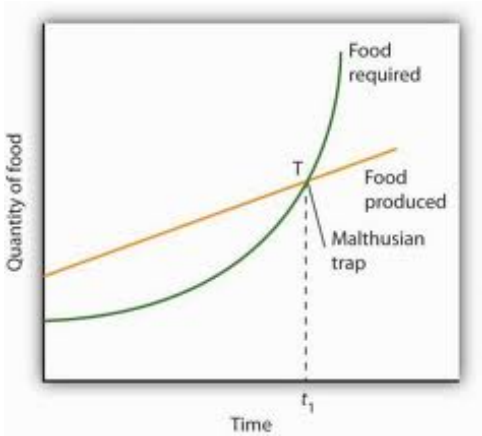


An SI-ODE model to calculate the life expectancy at birth if smallpox was eliminated as a cause of death.

source: Dietz, K., Heesterbeek, J.A.P., Mathematical Biosciences, 180(2002), pp.1-21.

Mathematical Biology in the XVIII Century

- Ecology: Robert Malthus (English Political Economist)



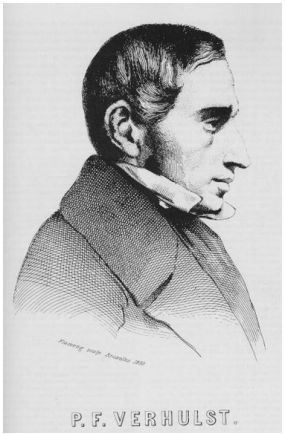
$$\frac{dP}{dt} = rP; \qquad P(t) = P_0 \exp(rt)$$

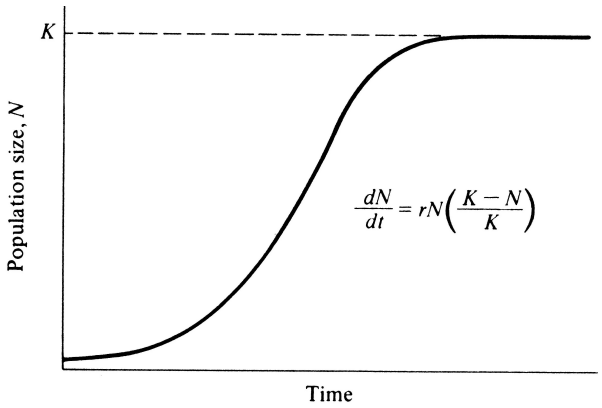
The exponential growth of the population will outpace food production.

figure source: https://images.flatworldknowledge.com/rittenmacro/rittenmacro-fig19_005.jpg

Mathematical Biology in the XIX Century

- Ecology: Pierre Verhulst (Belgian Mathematician)





$$\frac{dP}{dt} = rP\left(1 - \frac{P}{K}\right);$$

r: growth rate

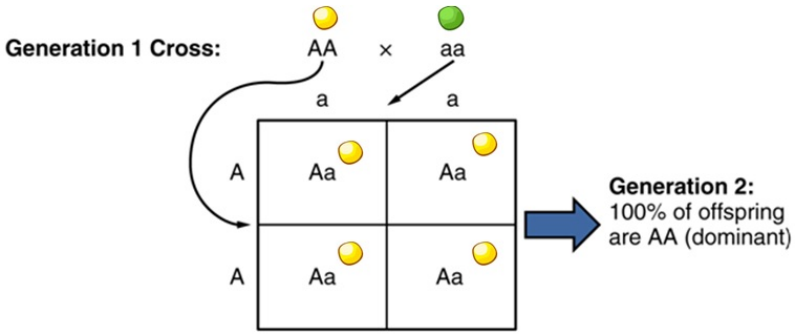
K: carrying capacity

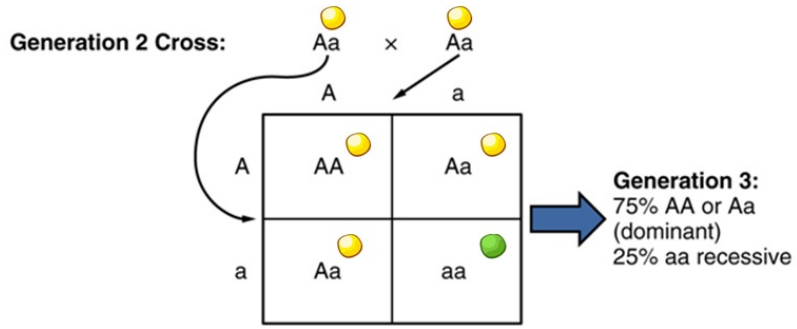
A population model where growth is bounded by limitation of resources. figure source:

http://www.zo.utexas.edu/courses/bio301/chapters/Chapter9/Chapter9.html

Mathematical Biology in the XIX Century

- Genetics: Gregor Mendel (Austrian Scientist/Monk)





Hybridisation experiments with pea plants. Mendel's Principles of Heredity explained in terms of probability.

figure source: https://opentextbc.ca/anatomyandphysiology/chapter/28-7-patterns-of-inheritance/

Mathematical Biology in the XX Century

- Genetics: Ronald Fisher
  (British Mathematician and Genetist)

- Introduced the statistical term "variance", σ^2, when studying the correlation between relatives based on Mendelian inheritance
- Fisher exact test (frequencies a, b, c and d known).

	XX	YY	*Row Total*
Case	***a***	***b***	*a + b*
Control	***c***	***d***	*c + d*
Column Total	*a + c*	*b + d*	*a + b + c + d*

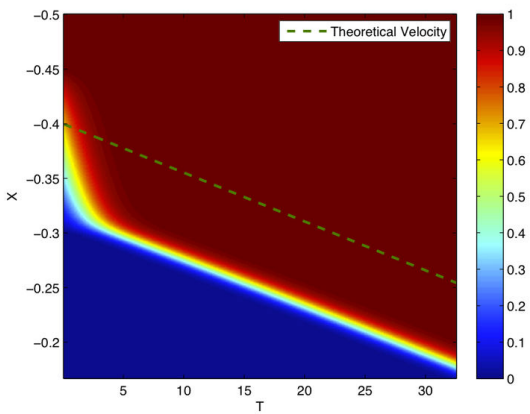
$$p = \frac{\binom{a+b}{a}\binom{c+d}{c}}{\binom{n}{a+c}} = \frac{(a+b)!\,(c+d)!\,(a+c)!\,(b+d)!}{a!\;b!\;c!\;d!\;n!}$$

Mathematical Biology in the XX Century

- Ecology: Ronald Fisher
  (British Mathematician and Genetist)

Fisher Equation and Travelling waves:

$$\frac{\partial u}{\partial t} = D\frac{\partial^2 u}{\partial x^2} + ru\left(1 - \frac{u}{K}\right);\quad r\text{: growth rate,}\quad K\text{: carrying capacity}$$



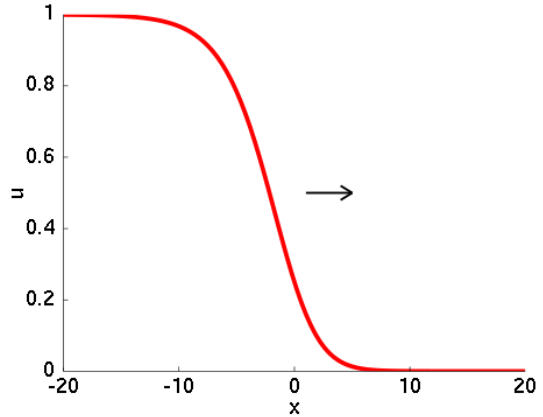
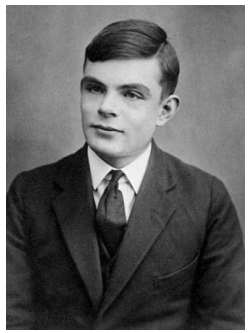


figure source: https://en.wikipedia.org/wiki/Fisher's_equation ;

http://www.wikiwand.com/en/Reaction-diffusion_system

Mathematical Biology in the XX Century

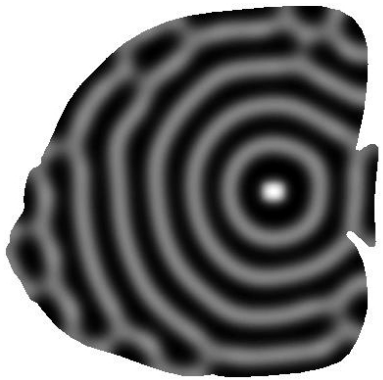


- Morphogenesis and Pattern Formation: Alan Turing (English Computer Scientist and Mathematician)

Reaction-Diffusion Equation:

$$\frac{\partial u}{\partial t} = D_u \frac{\partial^2 u}{\partial x^2} + f_1(u, v); \quad u(x, t) : \text{activator}$$

$$\frac{\partial v}{\partial t} = D_v \frac{\partial^2 v}{\partial x^2} + f_2(u, v); \quad u(x, t) : \text{inhibitor}$$

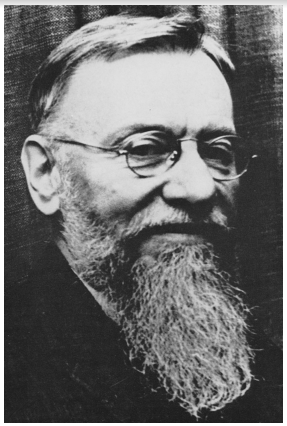


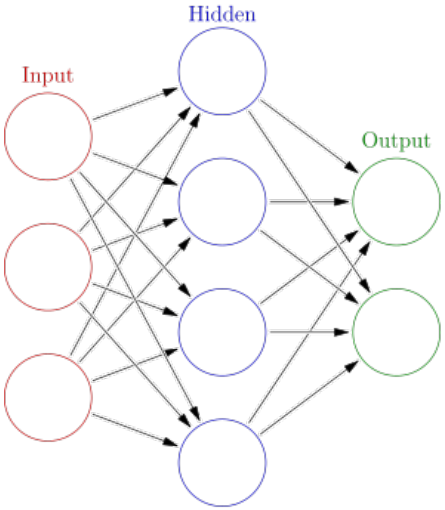
Real and simulated angel fish

https://www.uoguelph.ca/ mgarvie/turing.html

Mathematical Biology in the XX Century

- Neural Networks: Nicolas Rashevsky (Russian-American Physicist)





$$\text{Input}:=I(t)$$
$$\frac{de}{dt} = AI(t) - ae$$
$$\frac{dj}{dt} = BI(t) - bj$$
$$\text{Output}:=H(e - j - \theta)$$

- Mathematical Biology as Mathematical Biophysics

figure source: https://en.wikipedia.org/wiki/Artificial_neural_network; source: Cull, P., BioSystems, 88(2007), pp.178-184.

Mathematical Biology

- Interdisciplinary scientific field (Mathematics and Biology).
- It includes the vast subfields of Biology (Epidemiology, Ecology, Genetics, Physiology, Neuroscience, etc.) and the vast subfields of Applied Mathematics (Statistics, Dynamical Systems, Bifurcation Theory, Stability Analysis, etc).
- The description of biological processes may require the development of mathematical models which may be used to
  - quantify experimental observations
  - unfold the causes of a particular biological behaviour
  - predict future outcomes
  - support experimental observations
  - motivate the development of new experiments

Mathematical Biology and Math Departments. Mid 1900's

- Existence of a great interest in Mathematical Biology among mathematicians
- Mathematical Biology was not taken so seriously in the Math Departments
- Need for Biological Mathematics (Biomathematics)!
- Mathematical Biology was a male dominated field

Outline

First Wave of Women Mathematical Biologists in Canada (70's to 80's)

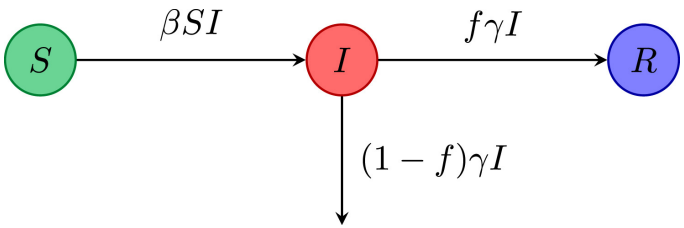
Pauline van den Driessche
(UVic)

Leah Edelstein-Keshet
(UBC)

Pauline van den Driessche

- British-Canadian Mathematical Biologist
  Works at UVic since mid 60's.
- Fields of study:
  Epidemiology, Ecology, Neural Networks

- Research Impact:
  Epidemiology: Basic Reproduction number R_0 for Compartmental Models of Disease Transmission. Matrix theory.



$$\frac{dS}{dt} = -\beta SI, \quad \frac{dI}{dt} = \beta SI - \gamma I, \quad \frac{dR}{dt} = f\gamma I.$$

$R_0 = \frac{\beta S_0}{\gamma}$: average number of secondary cases produced by one infected individual introduced into a population of susceptible individuals

Pauline van den Driessche

ELSEVIER

Mathematical Biosciences 180 (2002) 29–48

Mathematical Biosciences

www.elsevier.com/locate/mbs

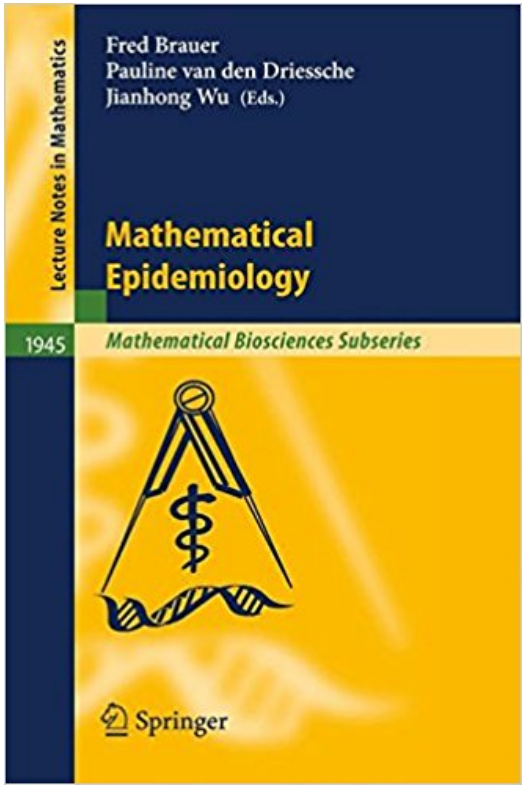
Reproduction numbers and sub-threshold endemic equilibria for compartmental models of disease transmission

P. van den Driessche [a,1], James Watmough [b,*,2]

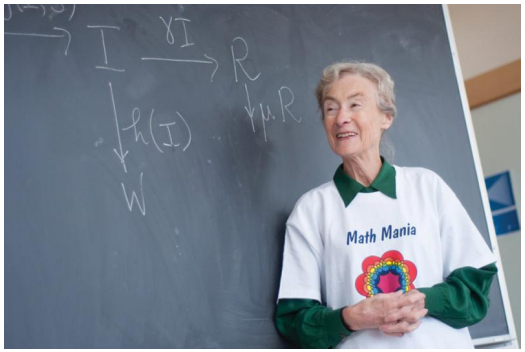
[a] *Department of Mathematics and Statistics, University of Victoria, Victoria, BC, Canada V8W 3P4*
[b] *Department of Mathematics and Statistics, University of New Brunswick, Fredericton, NB, Canada E3B 5A3*

Received 26 April 2001; received in revised form 27 June 2001; accepted 27 June 2001

Dedicated to the memory of John Jacquez



Pauline van den Driessche



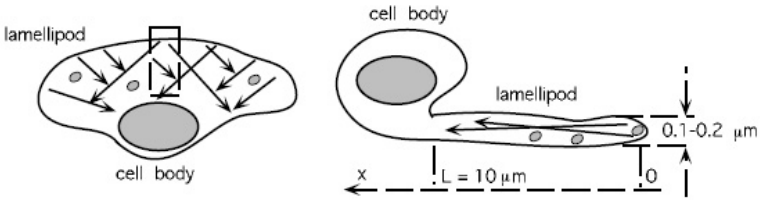
- British-Canadian Mathematical Biologist
  Works at UVic since mid 60's.
- Passions:
  Combinatorial Matrix Analysis, Help Young Researchers, Organize Workshops

- Impact in Education:
  - Building the Mathematical Biology group at UVic
  - Supporting the PIMS training Centre in Mathematical Biology
  - Success of her supervised students
  - Combined degree between the Department of Mathematics and Statistics and the Biology Department at UVic

Leah Edelstein-Keshet

- Israeli-Canadian Mathematical Biologist
  Works at UBC since the late 80's.
- Fields of study:
  Cell Biology, Immunology, Ecology, Pattern Formation

- Research Impact:
  - *Cellular Biology: Cell Motility*



$$\frac{\partial s}{\partial t} = -V\frac{\partial s}{\partial x} + D\frac{\partial^2 s}{\partial x^2} - k_1 s + k_{-1} p + J_d(x),$$

$$\frac{\partial p}{\partial t} = -V\frac{\partial p}{\partial x} + D\frac{\partial^2 p}{\partial x^2} + k_1 s - k_{-1} p - k_2 p,$$

$$\frac{\partial \beta}{\partial t} = -V\frac{\partial \beta}{\partial x} + D\frac{\partial^2 \beta}{\partial x^2} - k_{-3}\beta + k_3 a,$$

$$\frac{\partial a}{\partial t} = -V\frac{\partial a}{\partial x} + D\frac{\partial^2 a}{\partial x^2} + k_{-3}\beta - k_3 a + k_2 p.$$

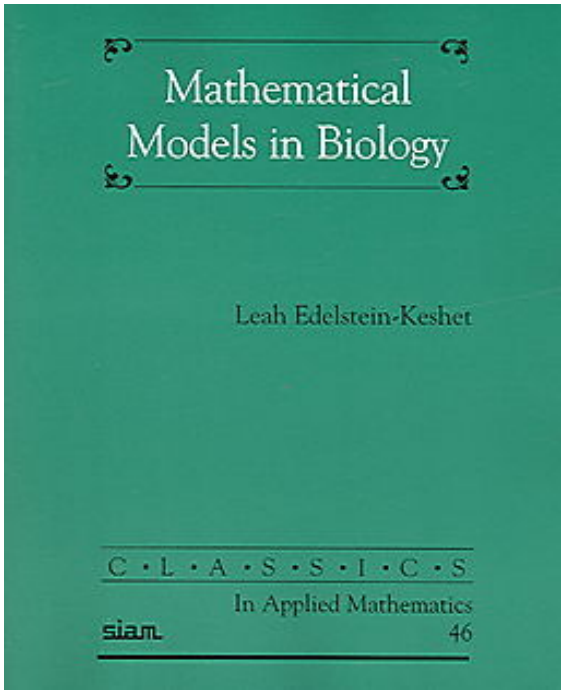
The model describes how actin dynamics regulates cell protrusion and motility

Leah Edelstein-Keshet

Biophysical Journal Volume 83 September 2002 1237–1258

Regulation of Actin Dynamics in Rapidly Moving Cells: A Quantitative Analysis

Alex Mogilner* and Leah Edelstein-Keshet†
*Department of Mathematics and Institute of Theoretical Dynamics, University of California, Davis, California 95616 USA; and
†Department of Mathematics, University of British Columbia, Vancouver, British Columbia V6T 1Z2, Canada



According to Leah, her most interesting article:

Physical Biology

CrossMark

PAPER

RECEIVED
20 February 2016

REVISED
10 May 2016

ACCEPTED FOR PUBLICATION
16 May 2016

PUBLISHED
18 July 2016

Analysis of a minimal Rho-GTPase circuit regulating cell shape

William R Holmes[1,3] and Leah Edelstein-Keshet[2]

[1] Department of Physics and Astronomy, Vanderbilt University, Nashville, TN, USA
[2] Department of Mathematics, University of British Columbia, Vancouver, Canada
[3] Author to whom any correspondence should be addressed.

E-mail: william.holmes@vanderbilt.edu and keshet@math.ubc.ca

Keywords: Rac–Rho, cell shape, ameboid/mesenchymal motility, local perturbation analysis

Leah Edelstein-Keshet

- Israeli-Canadian Mathematical Biologist
  Works at UBC since late 80's.
- Passions:
  Family (2 scientist sons), Gardening, Audio Books, World History

- Impact in Education:
  - Her highly influential textbook "Mathematical Models in Biology"
  - The development of the UBC course MATH 102 (Differential Calculus for Life Sciences) and MATH 103 (Integral Calculus for Life Sciences); 600 to 900 students/year running since late 90's
  - Her new open access book "Life Sciences in Calculus"
  - The success of her many undergraduate and graduate students

Leah Edelstein-Keshet's video

First Wave of Women Mathematical Biologists in Canada

Pauline van den Driessche
(UVic)

Leah Edelstein-Keshet
(UBC)

- Built the credibility of the interdisciplinary field of Mathematical Biology in Canada
- Brought back the essence of Mathematical Biology from the strongly rooted tendency to do Biological Mathematics
- Open the field to the Second Wave of Women Mathematical Biologists in Canada

Second Wave of Women Mathematical Biologists in Canada (90's)

Gerda de Vries
(UofA)

Sue Ann Campbell
(UW)

Rebecca Tyson
(UBC-Okanagan)

Lindi Wahl
(UWO)

Second Wave of Women Mathematical Biologists in Canada (90's)

Gerda de Vries
(UofA)

Sue Ann Campbell
(UW)

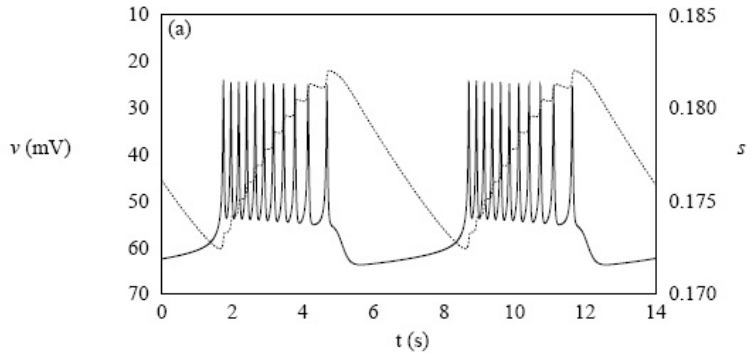
Rebecca Tyson
(UBC-Okanagan)

Jane Heffernan
(YU)

Gerda de Vries

- Dutch-Canadian Mathematical Biologist
  Works at UofA since late 90's.
- Fields of study:
  Physiology, Cell Biology, Ecology

- Research Impact:
  Physiolgy: Bursting in Pancreatic β Cells



β cells produce insulin during bursting in response to high glucose levels

$$\tau \frac{dv}{dt} = -I_{Ca}(v) - I_K(v,n) - I_s(v,s),$$

$$\tau \frac{dn}{dt} = \lambda[n_\infty(v) - n],$$

$$\tau_s \frac{ds}{dt} = s_\infty(v) - s,$$

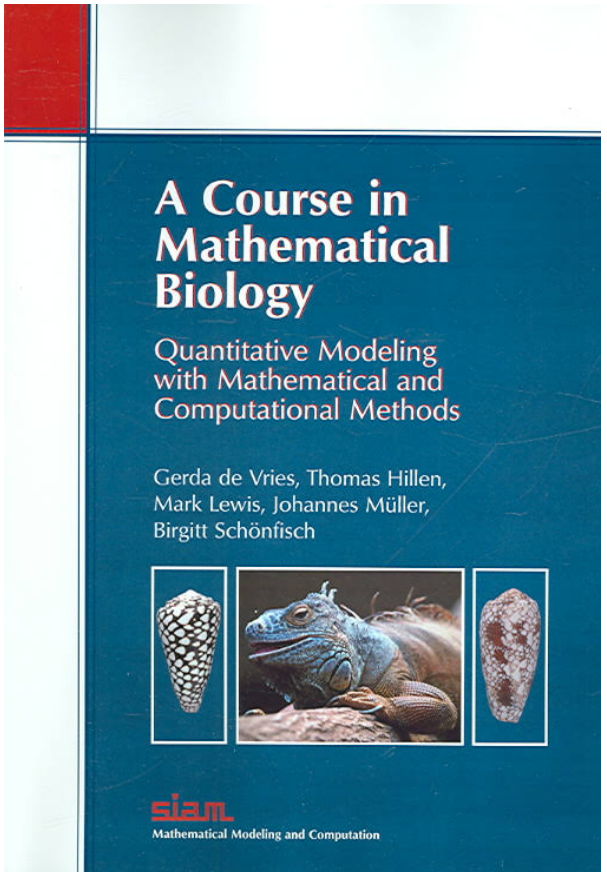
Gerda de Vries

Bulletin of Mathematical Biology (1998) **60**, 1167–1200
Article No. bu980057

Diffusively Coupled Bursters: Effects of Cell Heterogeneity

GERDA DE VRIES, ARTHUR SHERMAN
Mathematical Research Branch,
NIDDK, National Institutes of Health,
Bethesda, MD 20892, U.S.A.
E-mail: gerda@helix.nih.gov
E-mail: sherman@helix.nih.gov

HSIU-RONG ZHU
16203 S. 26th Place, Phoenix, AZ 85048, U.S.A.
E-mail: zhu@jchslab.la.asu.edu



Gerda de Vries

According to Gustavo, Gerda's most interesting article:

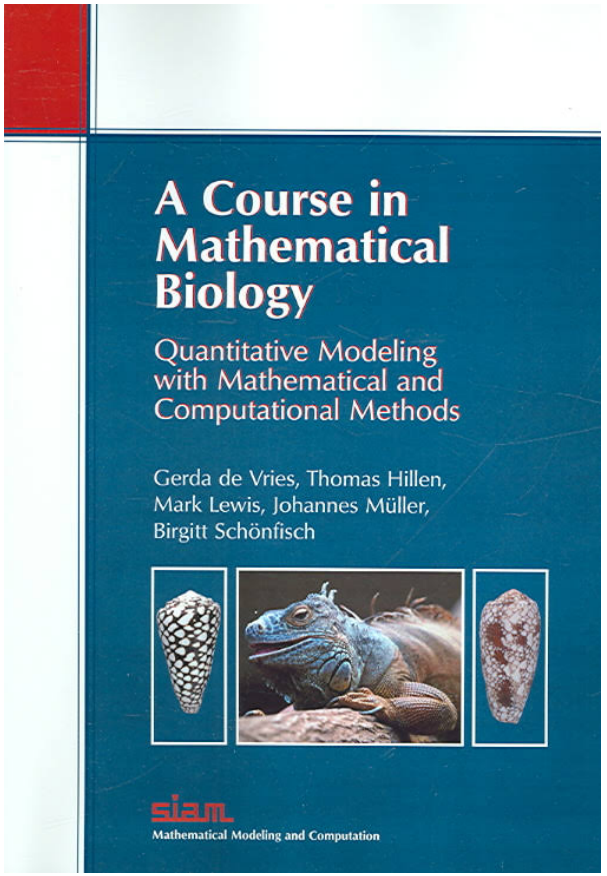
Bulletin of Mathematical Biology (2004) 66, 1515–1545
doi:10.1016/j.bulm.2004.02.005

Characterizing Fluorescence Recovery Curves for Nuclear Proteins Undergoing Binding Events

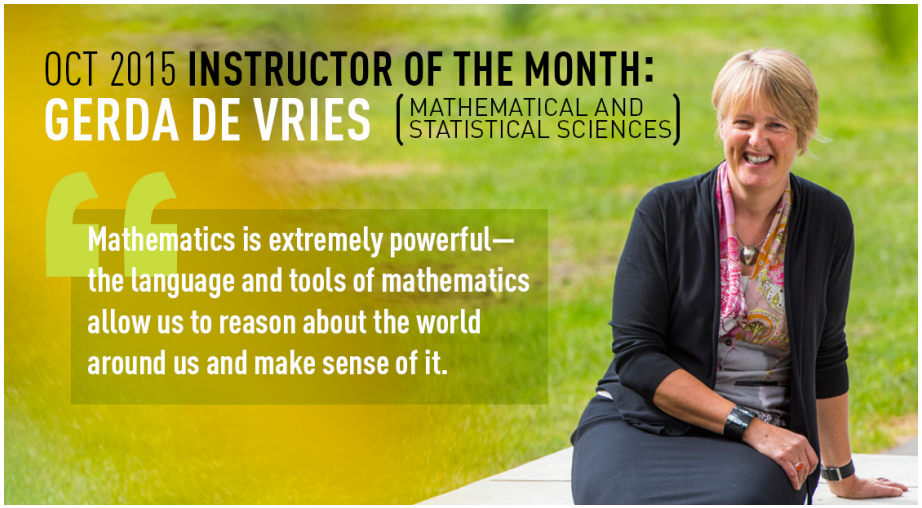
G. CARRERO
Department of Mathematical and Statistical Sciences,
University of Alberta,
Edmonton, AB,
T6G 2G1,
Canada

E. CRAWFORD AND M. J. HENDZEL
Department of Oncology,
University of Alberta,
Cross Cancer Institute,
11560 University Avenue,
Edmonton, AB,
T6G 1Z2,
Canada

G. DE VRIES*
Department of Mathematical and Statistical Sciences,
University of Alberta,
Edmonton, AB,
T6G 2G1,
Canada
E-mail: devries@math.ualberta.ca



Gerda de Vries

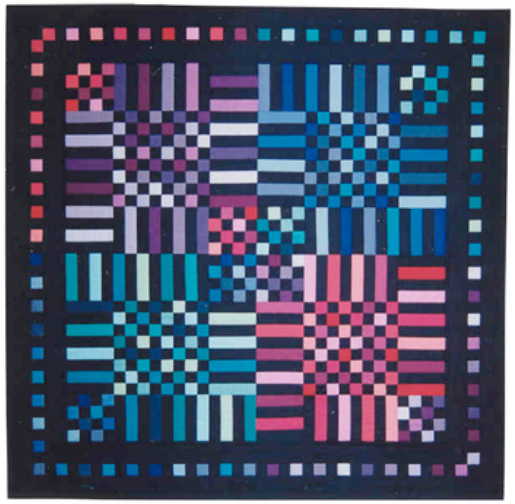


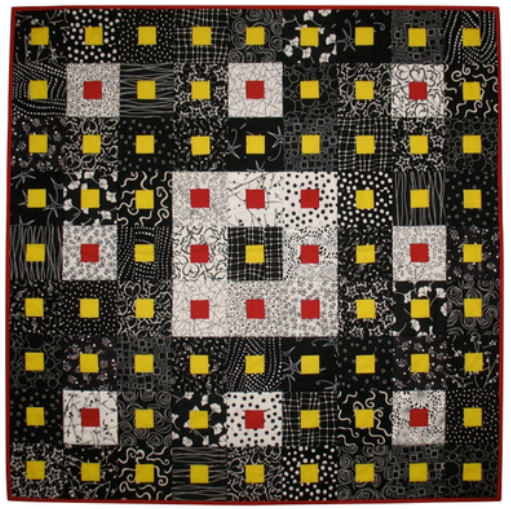
- Dutch-Canadian Mathematical Biologist
  Works at UofA since late 90's.
- Passions:
  Biking, Quilting, Gardening

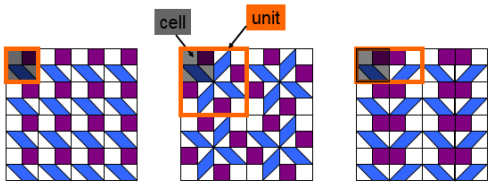
- Impact in Education:

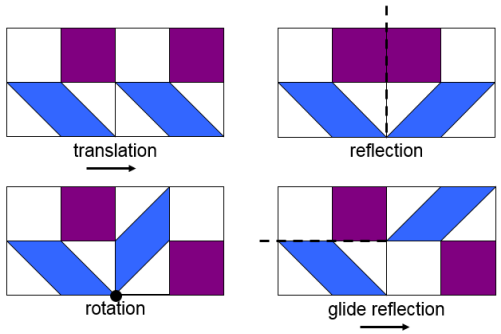
- Founder of the Mathematical Biology Group at UofA
- Her influential textbook "A Course in Mathematical Biology"
- The development of the graduate Math Biology courses
- Her role in reshaping all Calculus courses at UofA as applied courses
- Her continuously changing and up to date inspiration to all her students

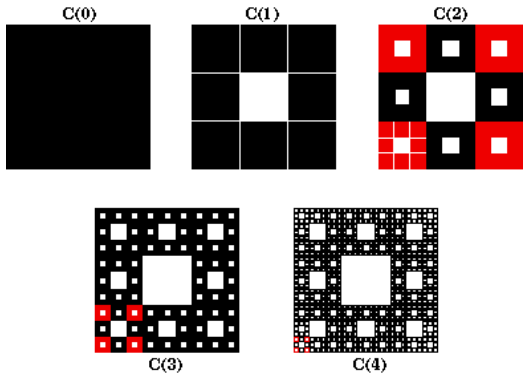
Gerda de Vries: A Mathematical Quilter







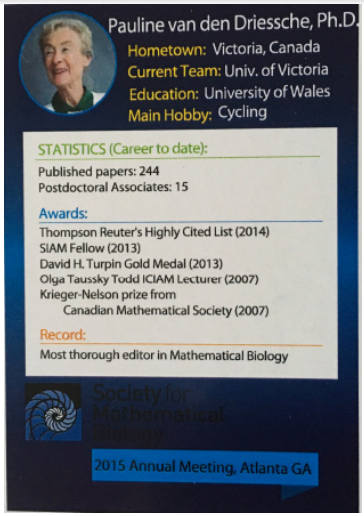


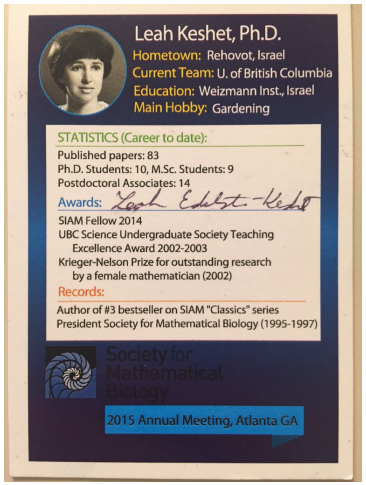


Linear Transformations: Translations, Reflections, Rotations

Fractals: Sierpinski Carpet

- Leah was the first female president of the SMB. Gerda was the second.
- Pauline and Leah have been awarded the Krieger-Nelson Prize of the CMS.
- Leah's inspiring woman in Mathematical Biology: Gerda.
- Gerda's inspiring woman in Mathematical Biology: Leah.
- Pauline's words of advise to Mathematical Biologists: "Make sure that you read the books authored by Leah and coauthored by Gerda".
- The only Canadian women mathematicians with SMB baseball cards





- Leah was the first female president of the SMB. Gerda was the second.
- Pauline and Leah have been awarded the Krieger-Nelson Prize of the CMS.
- Leah's inspiring woman in Mathematical Biology: Gerda.
- Gerda's inspiring woman in Mathematical Biology: Leah.
- Pauline's words of advise to Mathematical Biologists: "Make sure that you read the books authored by Leah and coauthored by Gerda".
- The only Canadian women mathematicians with SMB baseball cards

Rebecca Tyson

(UBC-Okanagan)

Ecology, Pattern Formation

Sue Ann Campbell

(UW)

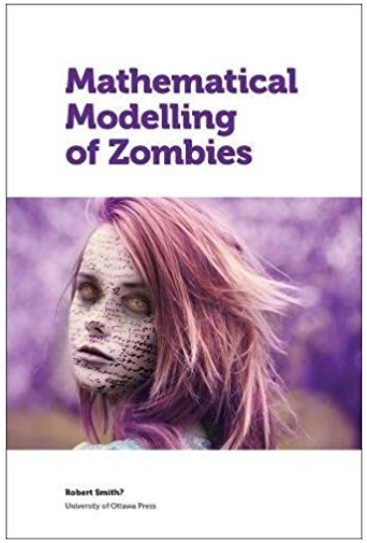
Neuroscience, Neural Networks

Jane Heffernan

(YU)

Immunology, Epidemiology

- The first Faculty members doing Mathematical Biology in their Institutions.
- Founders of the Mathematical Biology groups in their Universities.
- Served in the SMB board.
- Passion for family .



Rebecca Tyson's video

Sue Ann Campbell's video

Jane Heffernan's video

Wonderful Canadian Women Mathematical Biologists

THANK YOU TO THESE BRIGHT AND WISE WOMEN WHO HAVE OPENED THE FASCINATING OCEAN OF MATHEMATICAL BIOLOGY IN CANADA!