# Enhancing Undergraduate Education in Applied Mathematics through Multidisciplinary and Global Problem solving


**Padmanabhan (Padhu) Seshaiyer**

**Professor, Mathematical Sciences**

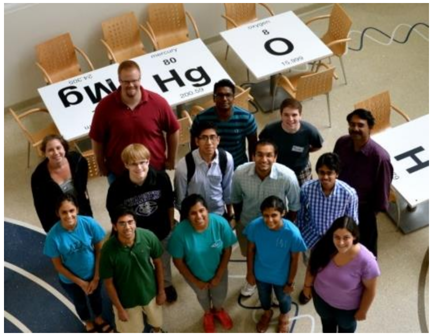
**Associate Dean for Academic Affairs**

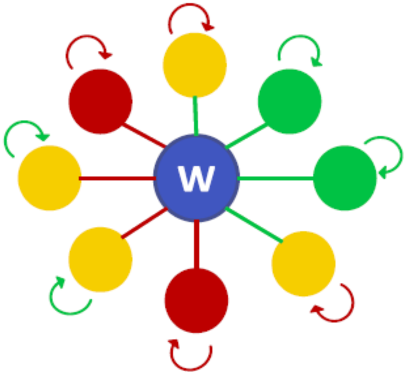
**Director, COMPLETE Center**

George Mason University

Email: **pseshaiy@gmu.edu**






Innovative Pedagogical Practices, Curricular Reforms and Teaching Resources in Applied Mathematics Education

***July 10, 2018***

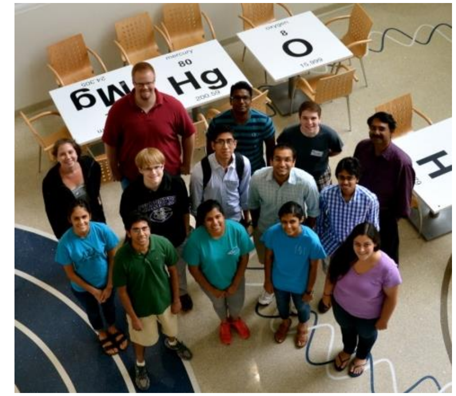
COLLEGE OF SCIENCE STEM ACCELERATOR

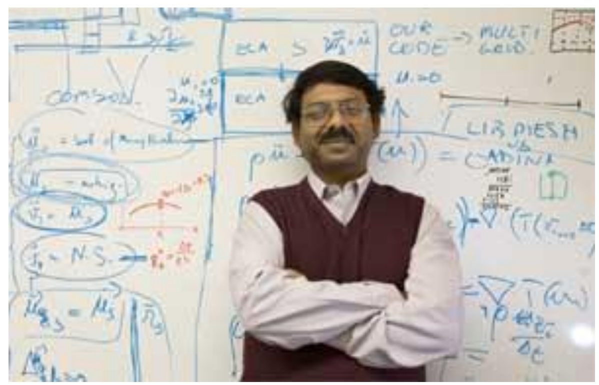
GEORGE MASON UNIVERSITY

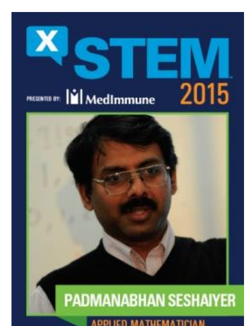
# About Me (Padhu)

NSF

GMU COMPLETE





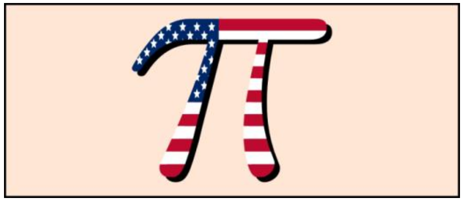

# Problem
# vs
# Exercise

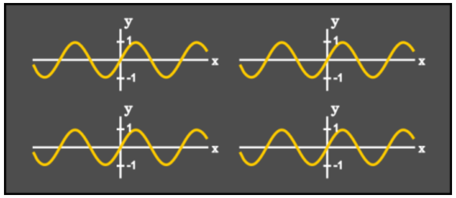
*Padmanabhan Seshaiyer*
*George Mason University*

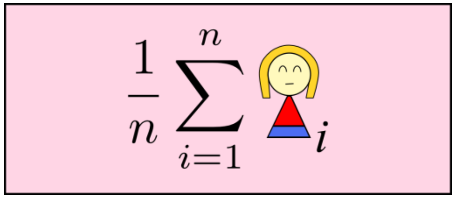
# Movie Math Quiz

## How many of the 16 movies can you find?

$$\begin{bmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \end{bmatrix}$$







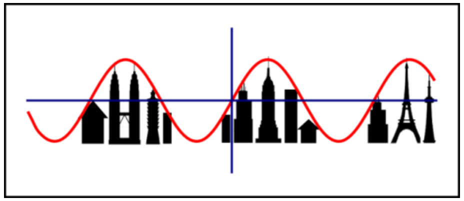
1609.344 METRES

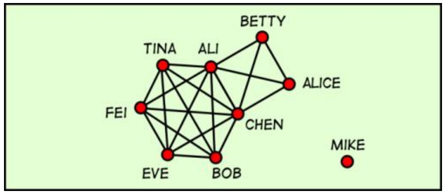
a+bi

$$F = \{x : x \text{ is a fear}\} \qquad \sum_{x \in F} x$$

$$\lfloor 13 \rfloor$$

$$x \vee \{\text{cist}\}$$






$$(2i+1, 2j+1)$$

$$e^{i\pi} + 1 = 0$$
and
6 6 6

$$\frac{\partial u}{\partial t} - \alpha \nabla^2 u = 0$$

$$\left| \frac{ds}{dt} \right|$$

*Padmanabhan Seshaiyer*
*George Mason University*

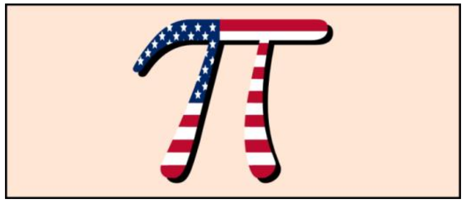
# Movie Math Quiz

## How many of the 16 movies can you find?

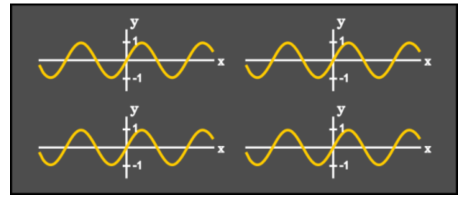
**MATRIX**

$$\begin{bmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \end{bmatrix}$$

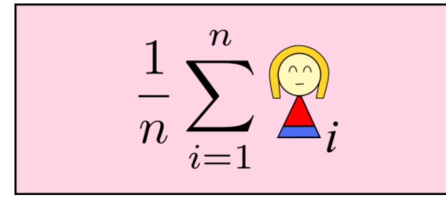
**AMERICAN PI**



**THE SIGNS**



**MEAN GIRLS**



**GREEN MILE**

1609.344 METRES

**GOLDEN EYE**

a+bi

**SUM OF ALL FEARS**

$$F = \{x : x \text{ is a fear}\}$$

$$\sum_{x \in F} x$$

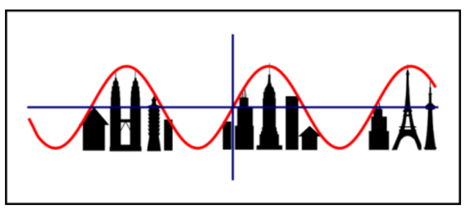
**13TH FLOOR**

$$\lfloor 13 \rfloor$$

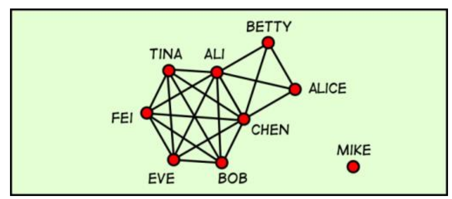
**EXORCIST**

$$x \vee \{\text{cist}\}$$

**SIN CITY**



**SOCIAL NETWORK**




**ODD COUPLE**

$$(2i+1, 2j+1)$$

**BEAUTY & THE BEAST**

$$e^{i\pi} + 1 = 0$$

and

666

**HEAT**

$$\frac{\partial u}{\partial t} - \alpha \nabla^2 u = 0$$

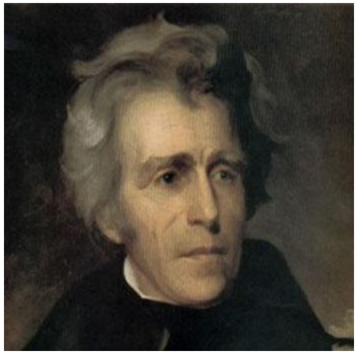
**SPEED**

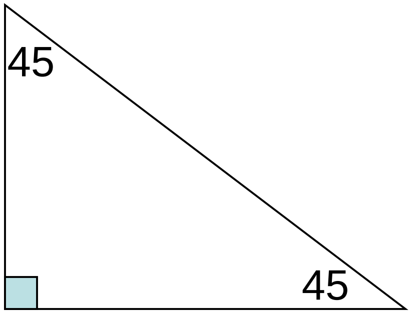
$$\left| \frac{ds}{dt} \right|$$

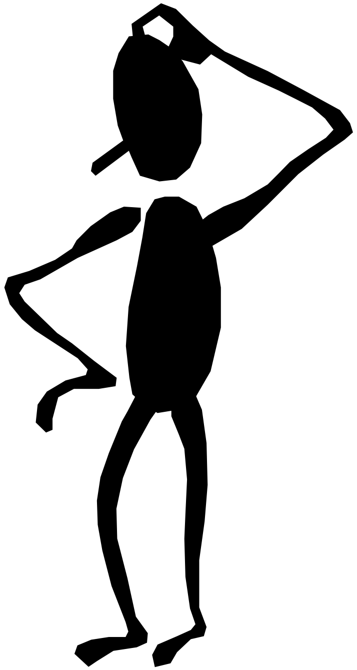
**WALL-E**

*Padmanabhan Seshaiyer*
*George Mason University*

# What is "e" ?





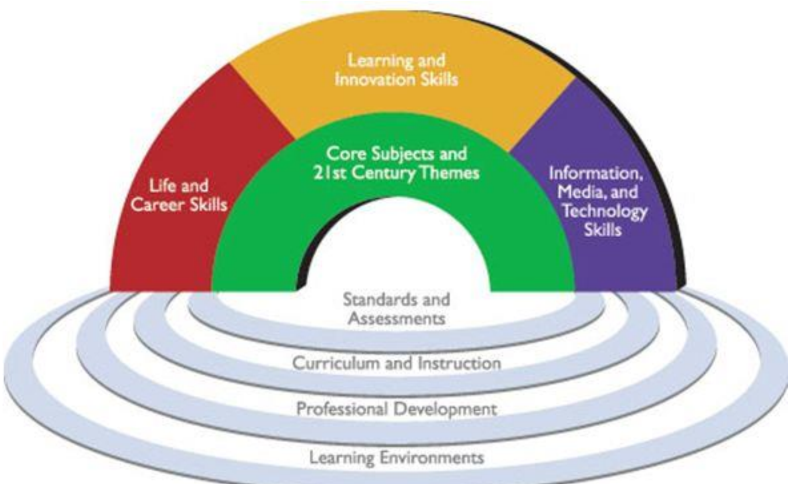
2.718281828 4590452

*Padmanabhan Seshaiyer*
*George Mason University*

# Student Engagement Model


Students as Consumers

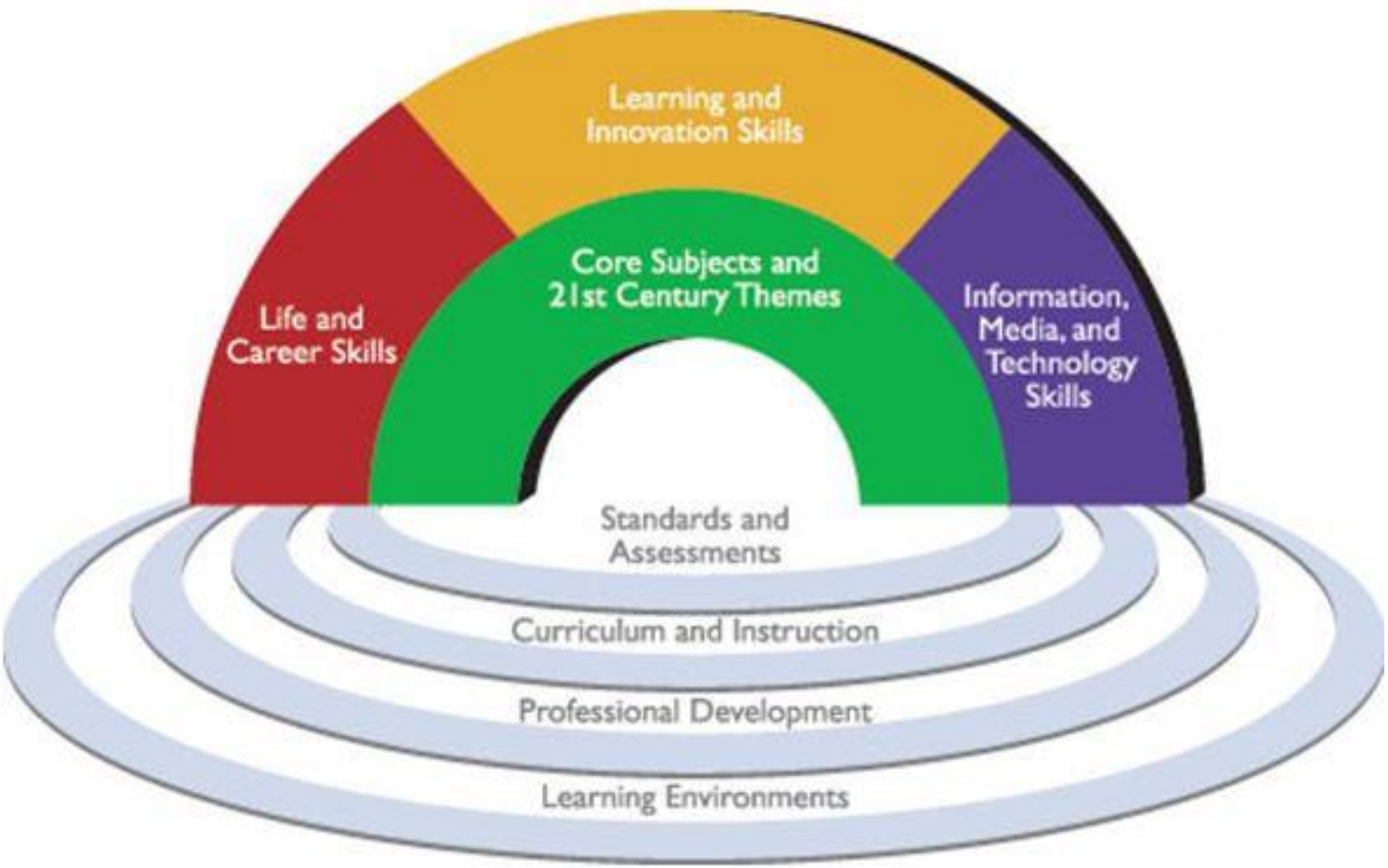
Students as Producers





Students as peer-reviewers

# Life-long Skills



# Teach less, Learn More

- Teacher-directed
- Direct Instruction
- Knowledge
- Content
- Basic Skills
- Facts and Principles
- Theory
- Curriculum
- Time-slotted
- One-size-fits-all
- Competitive
- Classroom
- Text-based
- Summative Tests
- Learning for School

- Learner-Centered
- Interactive exchange
- Skills
- Process
- Applied Skills
- Questions and Problems
- Practice
- Projects
- On-demand
- Personalized
- Collaborative
- Global Community
- Web-based
- Formative evaluations
- Learning for Life

# How Many?

- How many Piano Tuners are in Chicago?
- Population = 3,000,000

- Number of families in Chicago = 750,000
- Number of Pianos in Chicago = 150,000
- Number of Pianos Repaired in a year = 1000
- Number of Piano Tuners in Chicago = 150

***Padmanabhan Seshaiyer***
***George Mason University***

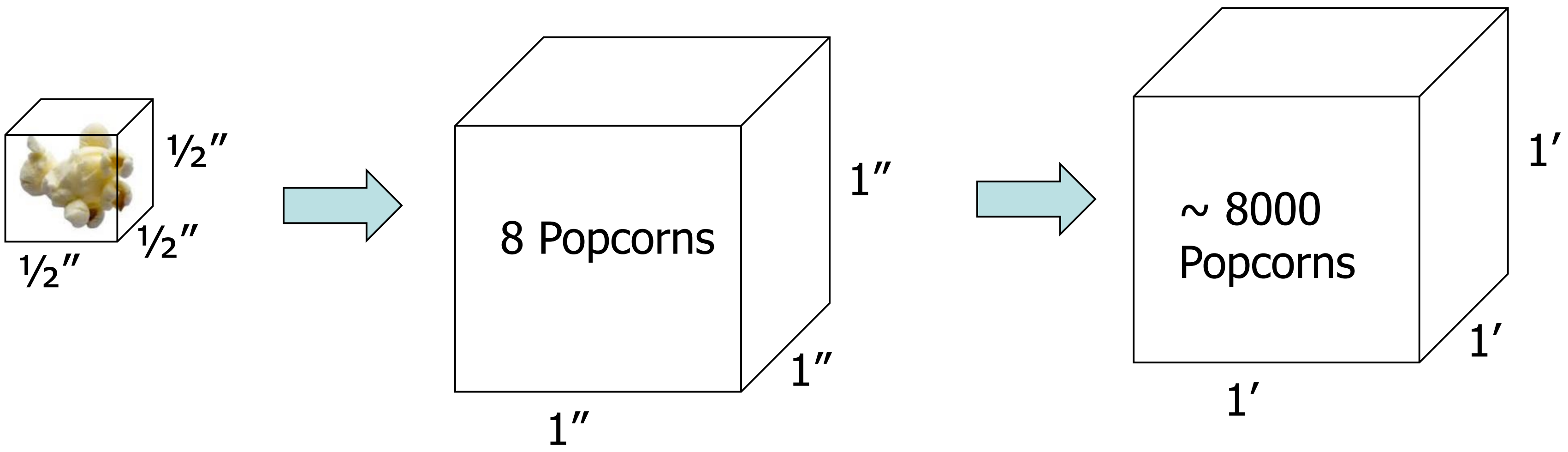
# How Many?

- How many kernels of popcorn would it take to fill this room?

*Padmanabhan Seshaiyer*
*George Mason University*

# How Many?

- How many kernels of popcorn would it take to fill this room?

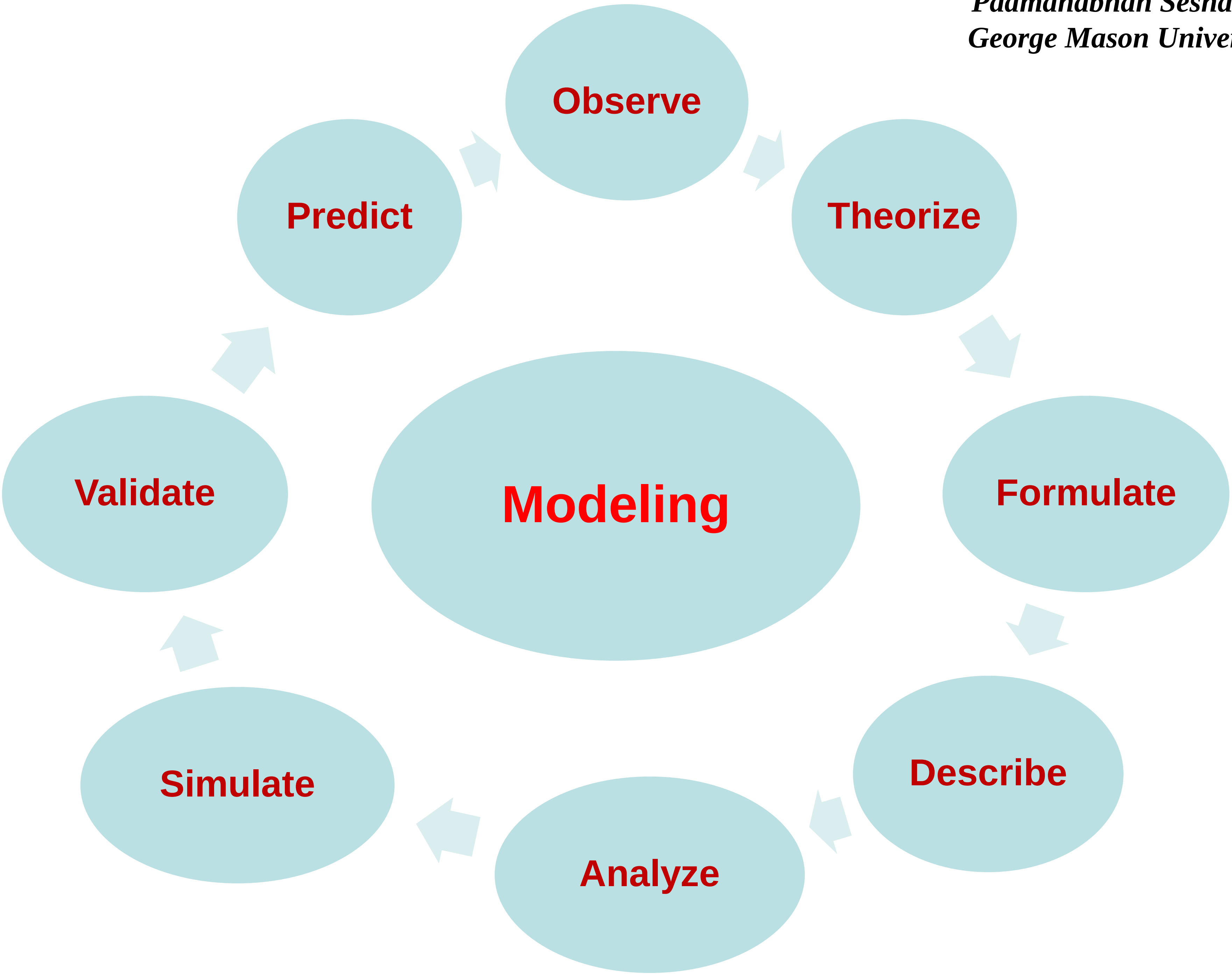


*Padmanabhan Seshaiyer*
*George Mason University*

# Fermi Problems

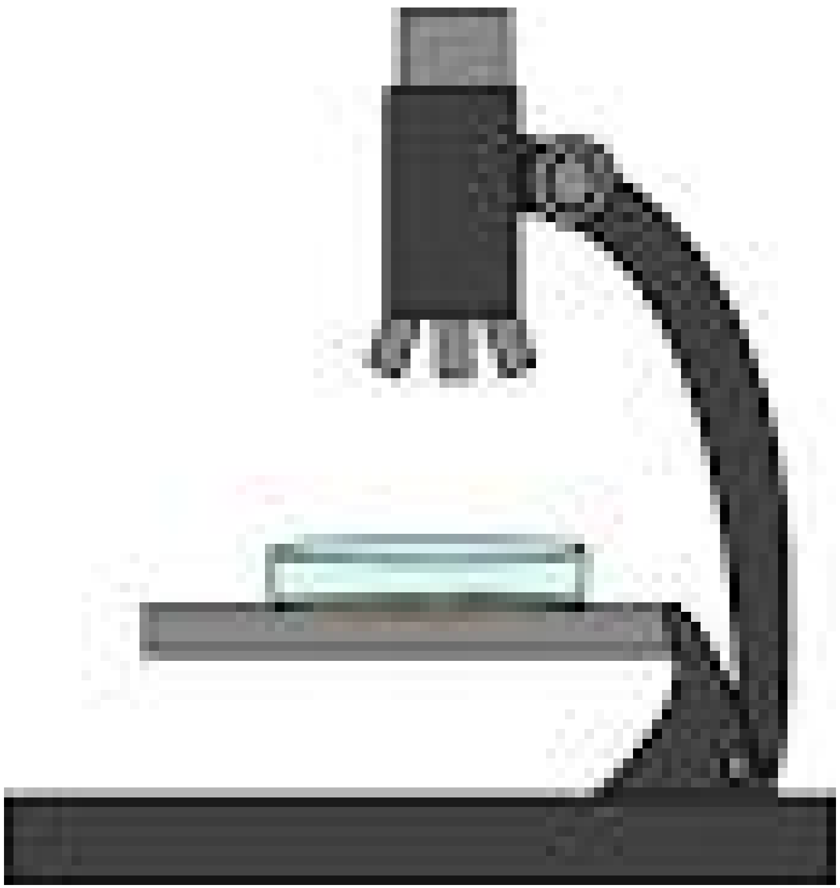
- How many piano tuners are there in Chicago?
- How many people in the world are talking on their cell phones in any given minute?
- How many kernels of popcorn would it take to fill this room?
- How many new passenger cars are sold each year in the USA?
- How many pennies would need to be stacked to reach the height of Mount Everest?

*Padmanabhan Seshaiyer*
*George Mason University*



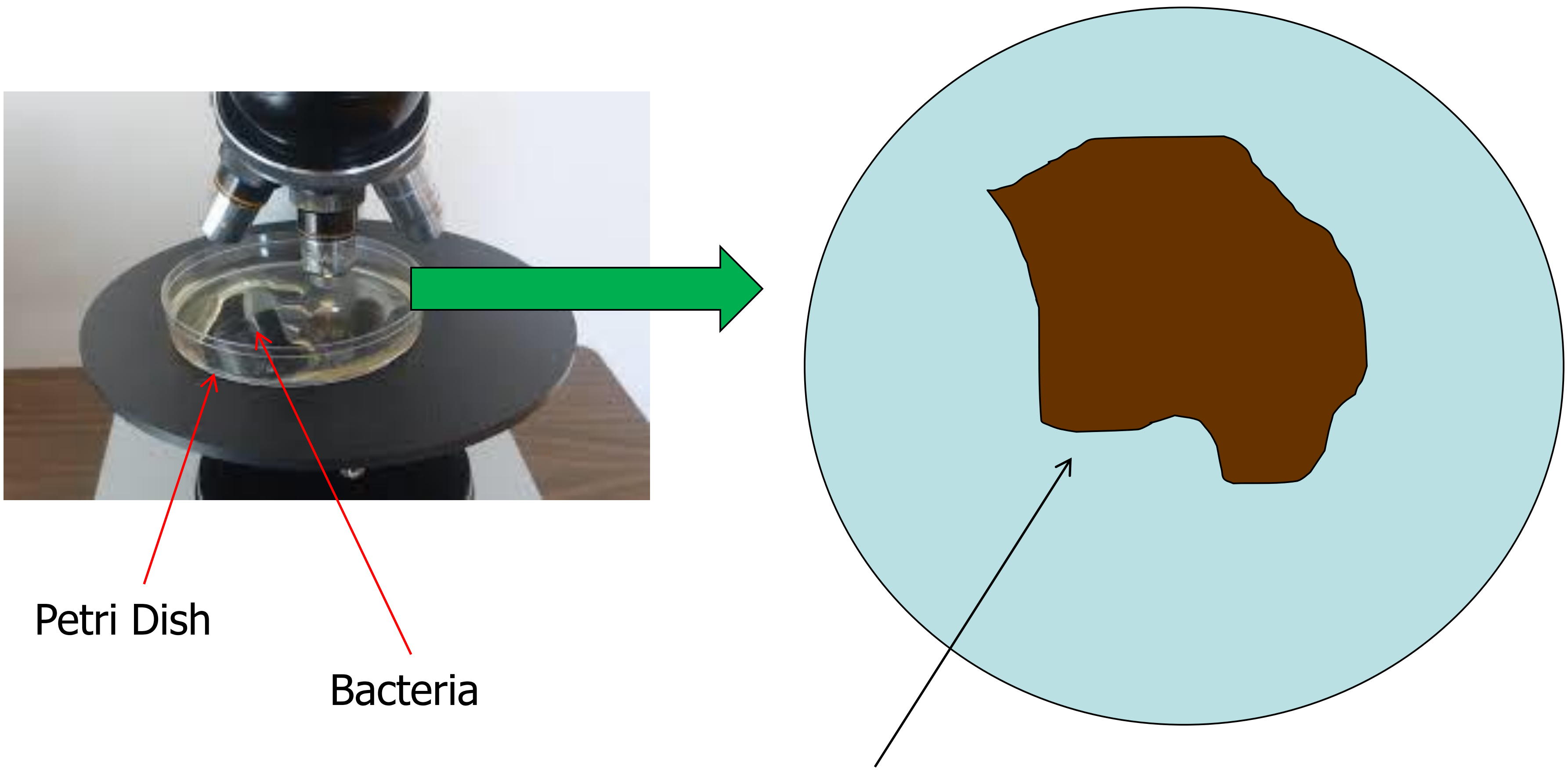
*Padmanabhan Seshaiyer*
*George Mason University*

# Imagine looking under the Microscope



*Padmanabhan Seshaiyer*
*George Mason University*

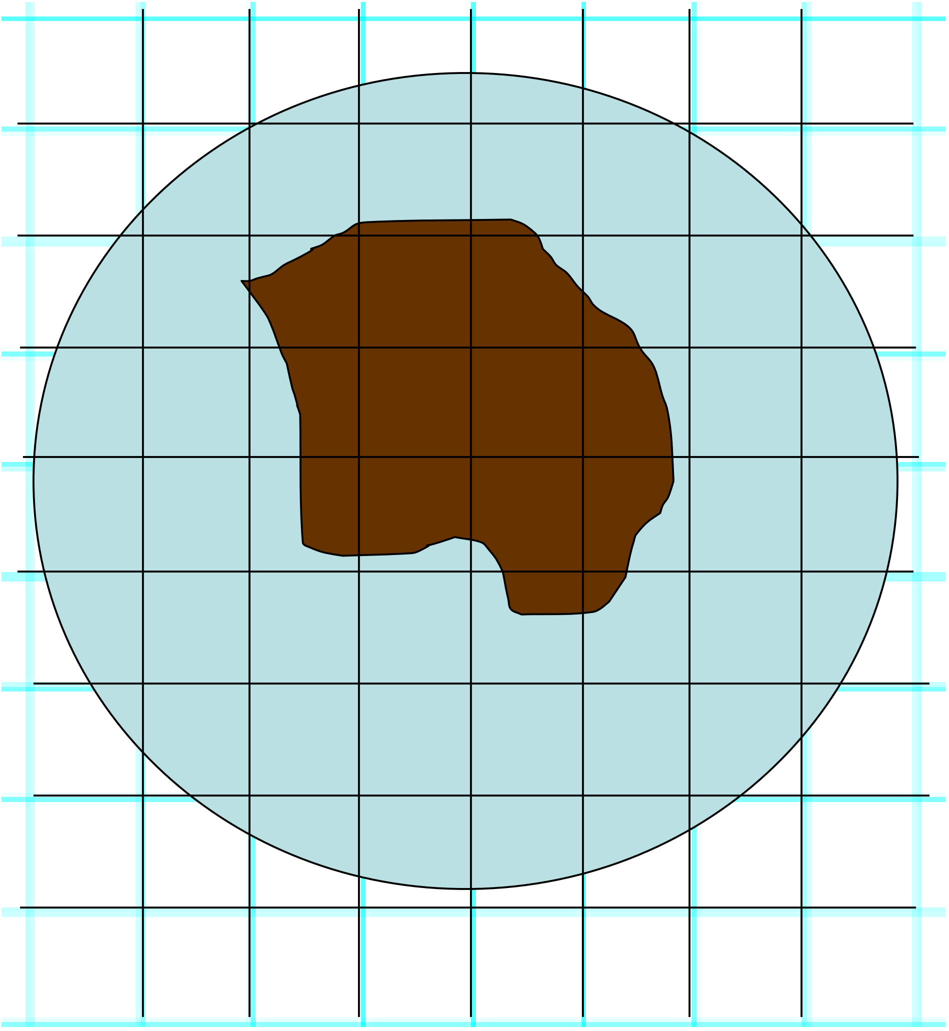
# Patch of Bacteria in the Petri-dish




**Find the AREA of the bacterial colony.**

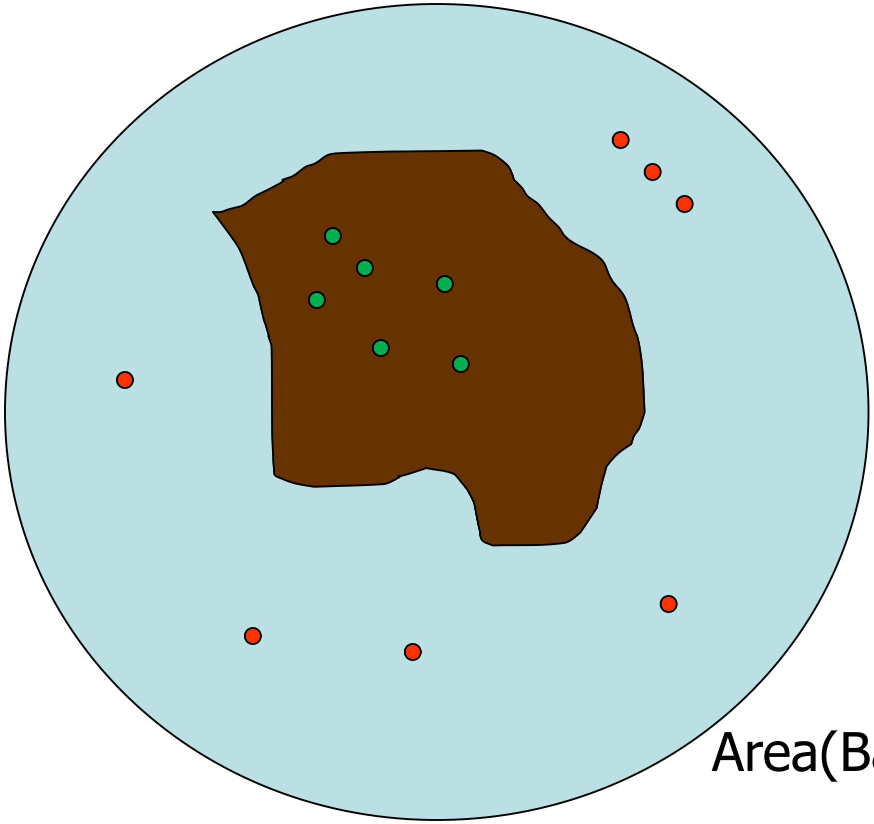
***Padmanabhan Seshaiyer***
***George Mason University***

# Patch of Bacteria in the Petri-dish



***Padmanabhan Seshaiyer***
***George Mason University***

# Patch of Bacteria in the Petri-dish

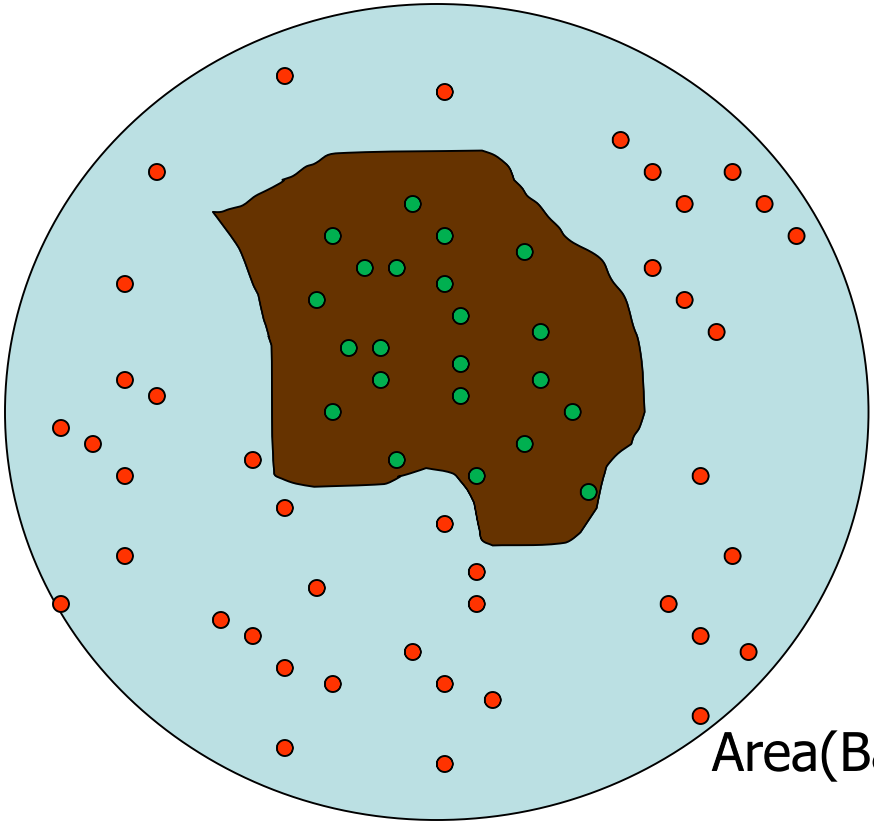


$$\frac{Inside}{Inside + Outside} = \frac{6}{13}$$

$$\text{Area(Bacterial Colony)} = \frac{6}{13}\ \text{Area (Petri Dish)}$$

***Padmanabhan Seshaiyer***
***George Mason University***

# Patch of Bacteria in the Petri-dish

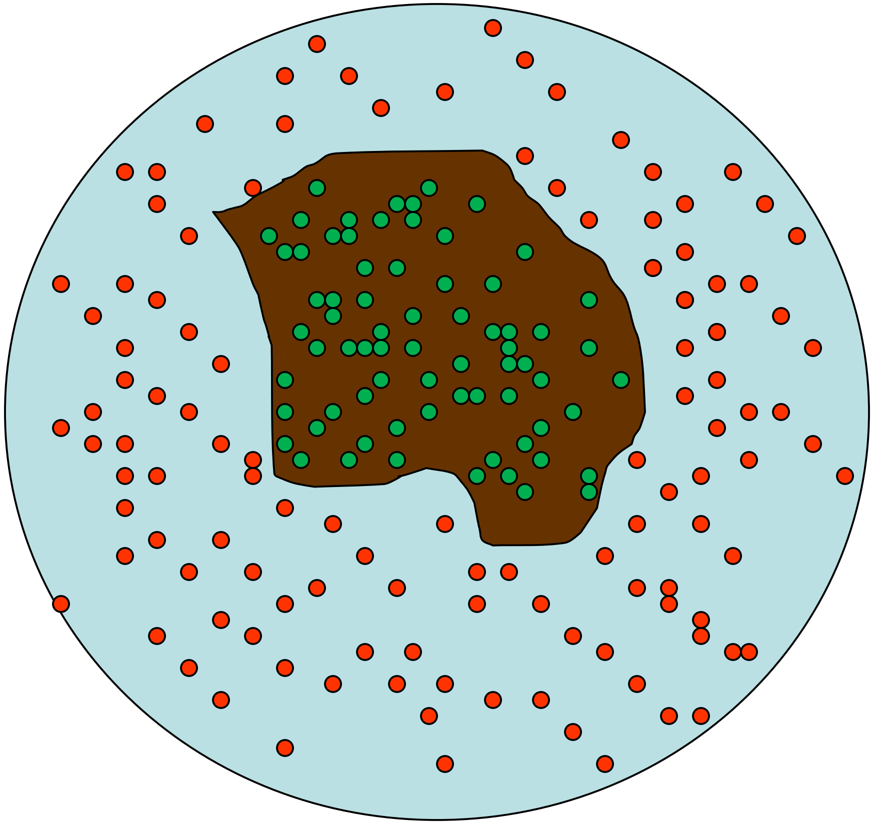


$$\frac{Inside}{Inside + Outside} = \frac{20}{41}$$

$$\text{Area(Bacterial Colony)} = \frac{20}{41}\ \text{Area (Petri Dish)}$$

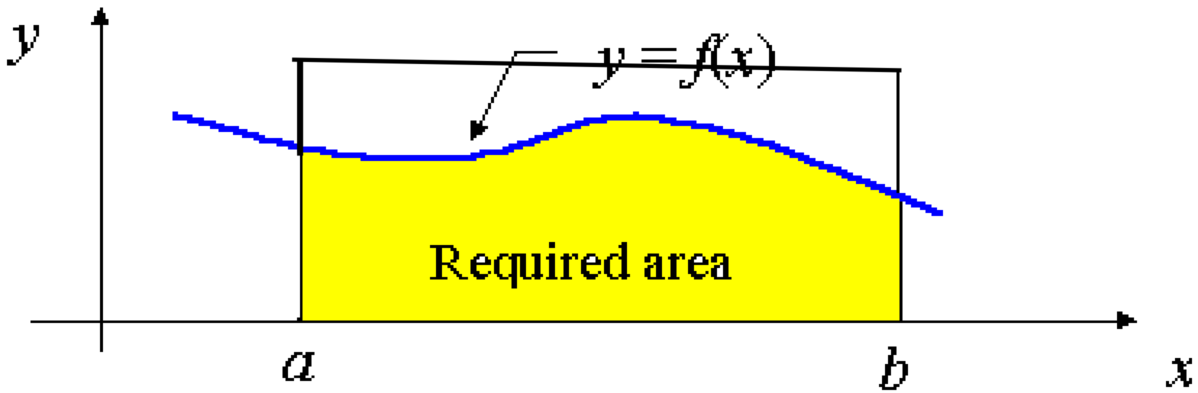
***Padmanabhan Seshaiyer***
***George Mason University***

# Patch of Bacteria in the Petri-dish



*Padmanabhan Seshaiyer*
*George Mason University*

# Can we connect the Petri-Dish Area finding with "Find the integral"?




***Padmanabhan Seshaiyer***
***George Mason University***

# Spectrophotometer

$$\text{Absorbance} = -\log_{10} \frac{I_t}{I_0}$$

***Padmanabhan Seshaiyer***
***George Mason University***

# *Developing a bacteria growth model from experimental data*

Measurements of bacterial density at pH 6.25.
The units of “Population Density” are those of absorbance as measured by a spectrophotometer.

| Time (min) | Population Density |
|---|---|
| 0 | 0.022 |
| 16 | 0.036 |
| 32 | 0.060 |
| 48 | 0.101 |
| 64 | 0.169 |
| 80 | 0.266 |

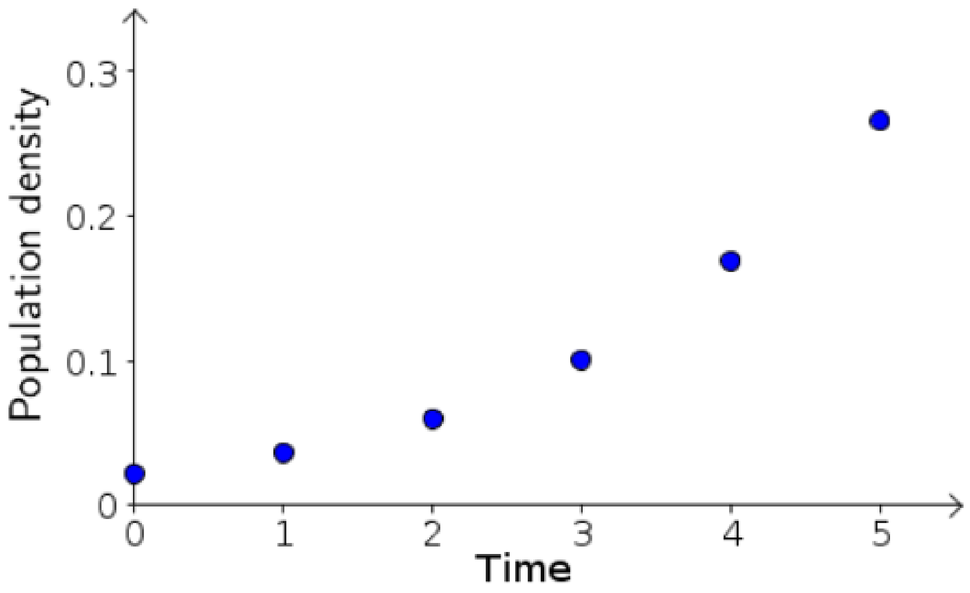
*Cells divide in half (fission)*

*Each cell takes the same time.*

***Padmanabhan Seshaiyer***
***George Mason University***

# *Visualizing Population **Density** with respect to Time*

| t | P(t) |
|---|---|
| 0 | 0.022 |
| 1 | 0.036 |
| 2 | 0.060 |
| 3 | 0.101 |
| 4 | 0.169 |
| 5 | 0.266 |



*Padmanabhan Seshaiyer*
*George Mason University*

# What is the change?

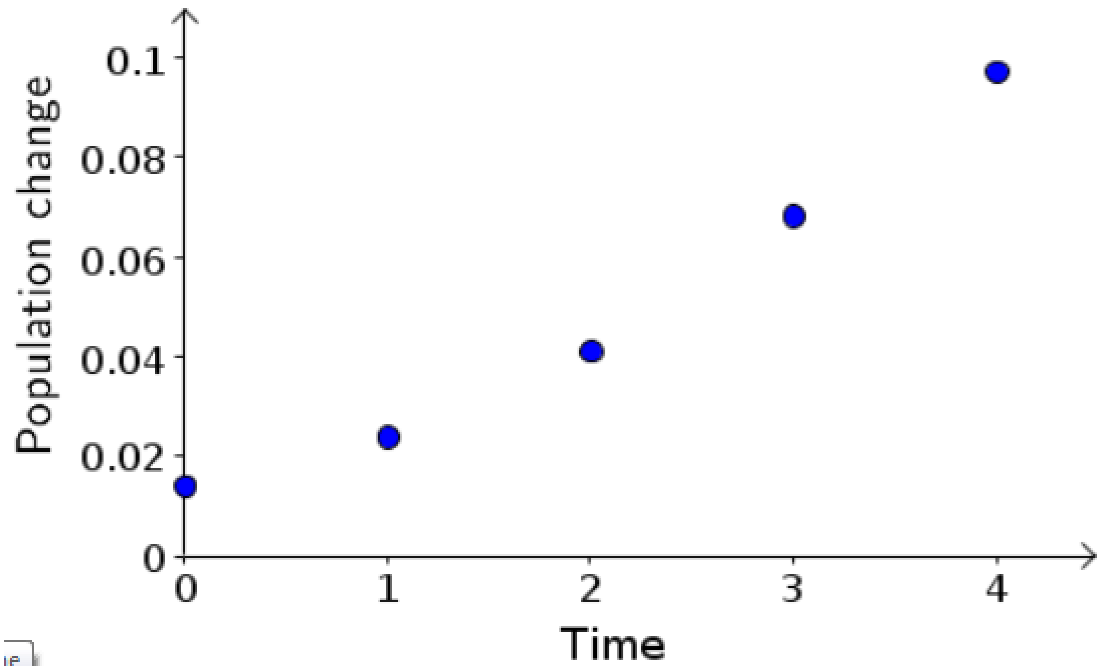
| t<br>Time | P(t)<br>Population density over time | P(t+1) – P(t)<br>Population Change over unit time |
|---|---|---|
| 0 | 0.022 | |
| 1 | 0.036 | 0.014 |
| 2 | 0.060 | 0.024 |
| 3 | 0.101 | 0.041 |
| 4 | 0.169 | 0.068 |
| 5 | 0.266 | 0.097 |

*Bacteria takes longer than 16 minutes to divide. That is more than 1 time step to mature and divide.*

*Padmanabhan Seshaiyer*
*George Mason University*

# *Visualizing Population* ***Change*** *with respect to Time*

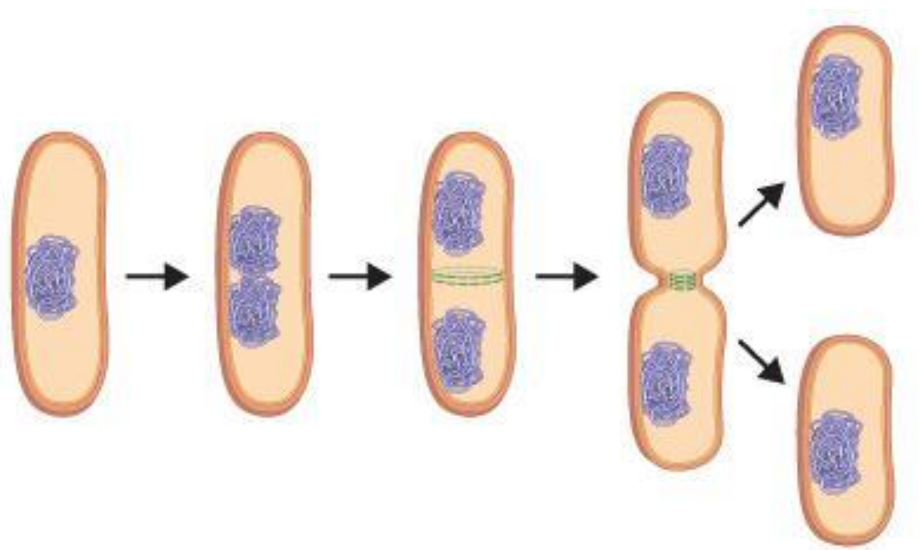
| t | P(t+1)-P(t) |
|---|---|
| 0 | 0 |
| 1 | 0.014 |
| 2 | 0.024 |
| 3 | 0.041 |
| 4 | 0.068 |
| 5 | 0.097 |



*Padmanabhan Seshaiyer*
*George Mason University*

# Some Cell Biology

- Bacteria cells reproduce by dividing into two cells
- Each cell takes about the same time to mature and divide



| t | P(t+1)-P(t) |
|---|---|
| 0 | 0 |
| 1 | 0.014 |
| 2 | 0.024 |
| 3 | 0.041 |
| 4 | 0.068 |
| 5 | 0.097 |

*Padmanabhan Seshaiyer*
*George Mason University*

# Some assumptions!

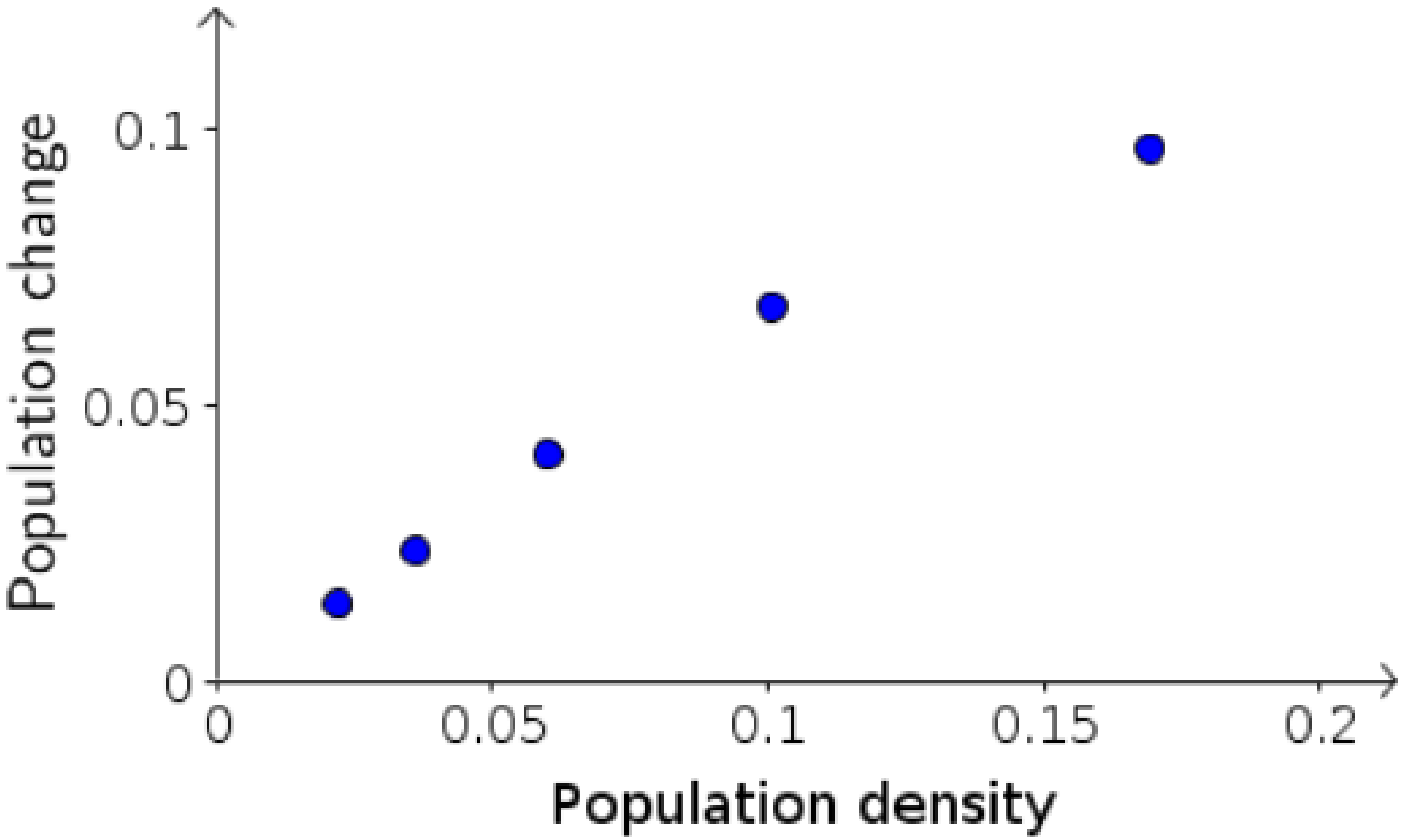
- A certain fraction of the cells divide each time step.
- Each cell takes about the same time to mature and divide

$$P(t+1) - P(t) = c\,P(t)$$

| t | P(t+1)-P(t) |
|---|---|
| 0 | 0 |
| 1 | 0.014 |
| 2 | 0.024 |
| 3 | 0.041 |
| 4 | 0.068 |
| 5 | 0.097 |

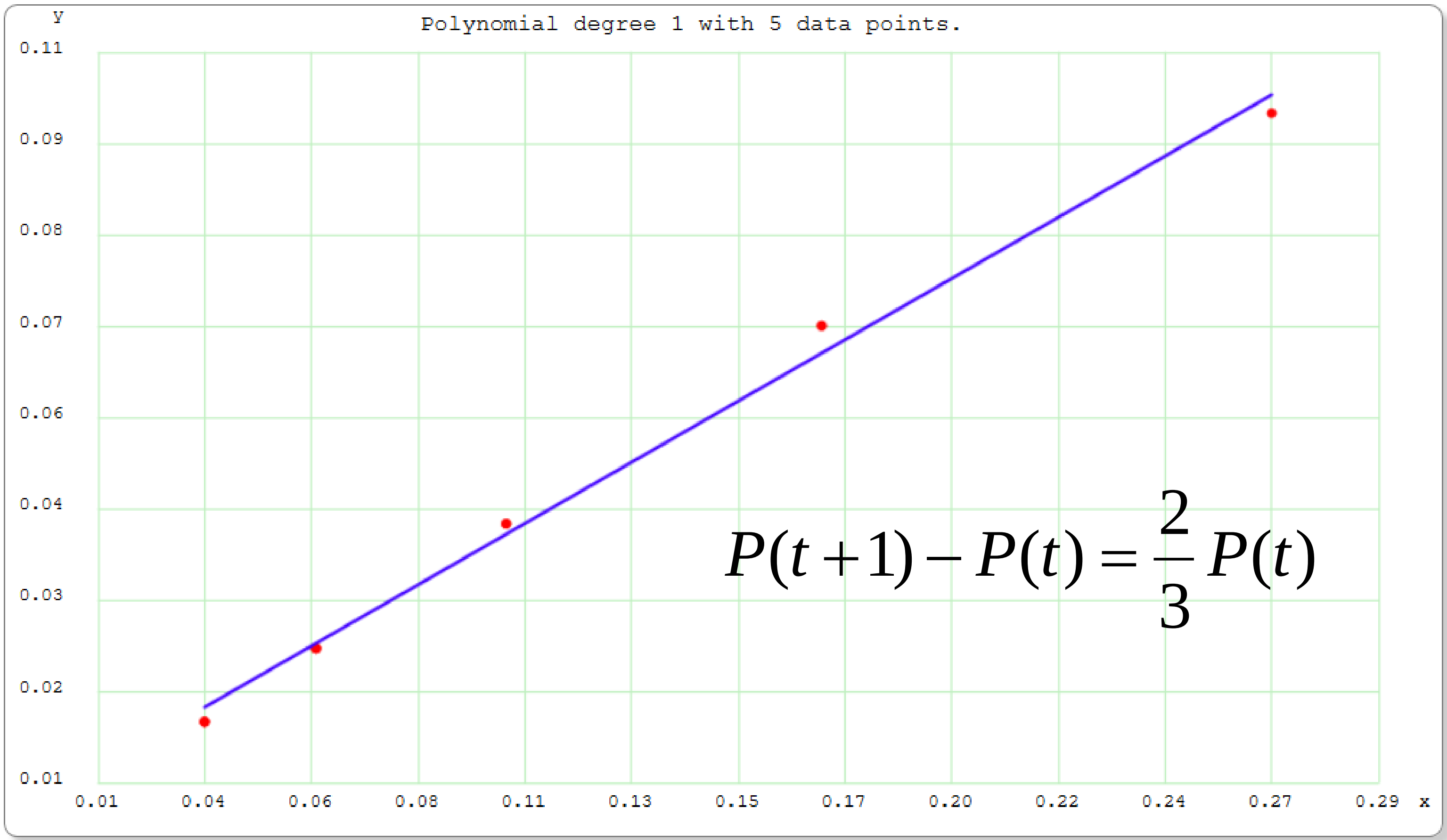
***Padmanabhan Seshaiyer***
***George Mason University***

# *Visualizing Population **Change** with respect to Population **Density***



*Padmanabhan Seshaiyer*
*George Mason University*

# Fitting a linear model!




$$P(t+1)-P(t)=\frac{2}{3}P(t)$$

*Padmanabhan Seshaiyer*
*George Mason University*

# Fitting an exponential model!

$$P(t+1)-P(t)=\frac{2}{3}P(t),\ P(0)=0.022$$

$$P(t+1)=\frac{5}{3}P(t)$$

$$P(t)=P(0)\left(\frac{5}{3}\right)^{t}$$

*Padmanabhan Seshaiyer*
*George Mason University*

# Fitting an exponential model!

RECURSIVE

$$\begin{cases} P(t+1) - P(t) = \dfrac{2}{3} P(t) \\ P(0) = 0.022 \end{cases}$$

EXPLICIT

$$P(t) = 0.022 \left( \frac{5}{3} \right)^t$$

*Padmanabhan Seshaiyer*
*George Mason University*

# How did we do?

$$P(t) = 0.022\left(\frac{5}{3}\right)^t$$

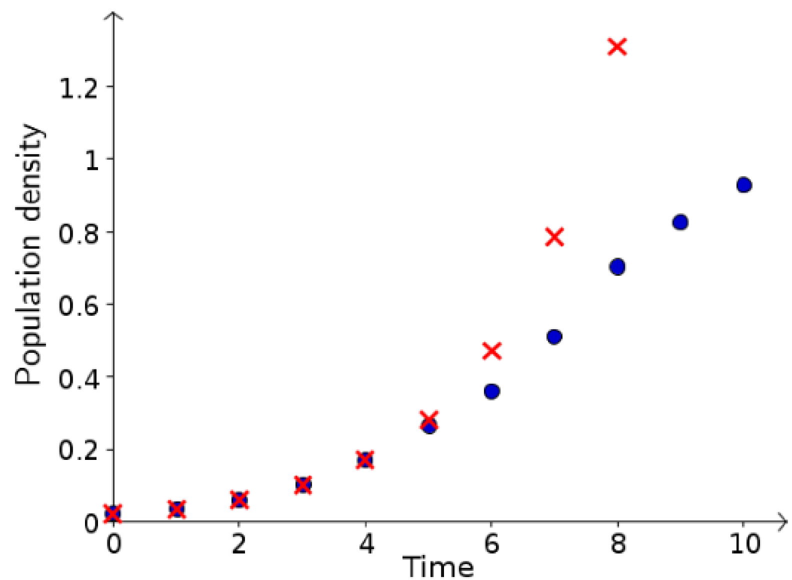
| Time | Population density over time | Computed Population density over unit time |
|---|---|---|
| 0 | 0.022 | 0.022 |
| 1 | 0.036 | 0.037 |
| 2 | 0.060 | 0.061 |
| 3 | 0.101 | 0.102 |
| 4 | 0.169 | 0.170 |
| 5 | 0.266 | 0.283 |

*Padmanabhan Seshaiyer*
*George Mason University*

# Wait…there is more!

Measurements of bacterial density at pH 6.25. The units of "Population Density" are those of absorbance as measured by a spectrophotometer.

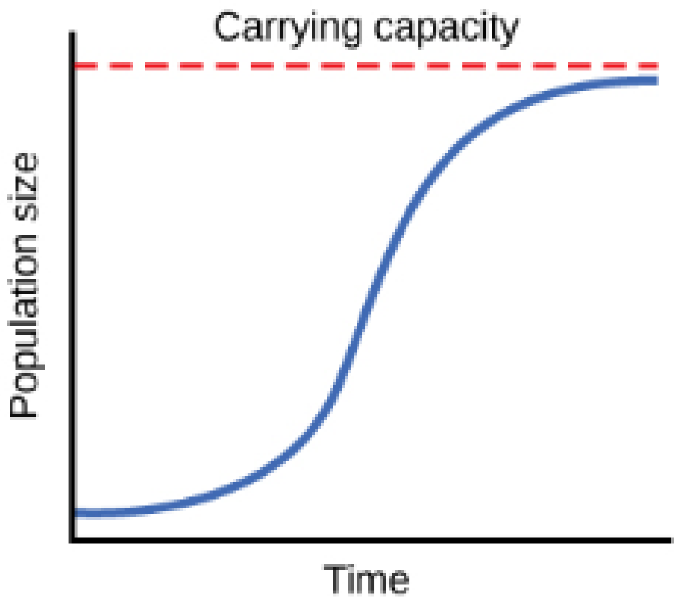
| Time (min) | Time index $t$ | Population Density |
|---|---|---|
| 0 | 0 | 0.022 |
| 16 | 1 | 0.036 |
| 32 | 2 | 0.060 |
| 48 | 3 | 0.101 |
| 64 | 4 | 0.169 |
| 80 | 5 | 0.266 |
| 96 | 6 | 0.360 |
| 112 | 7 | 0.510 |
| 128 | 8 | 0.704 |
| 144 | 9 | 0.827 |
| 160 | 10 | 0.928 |

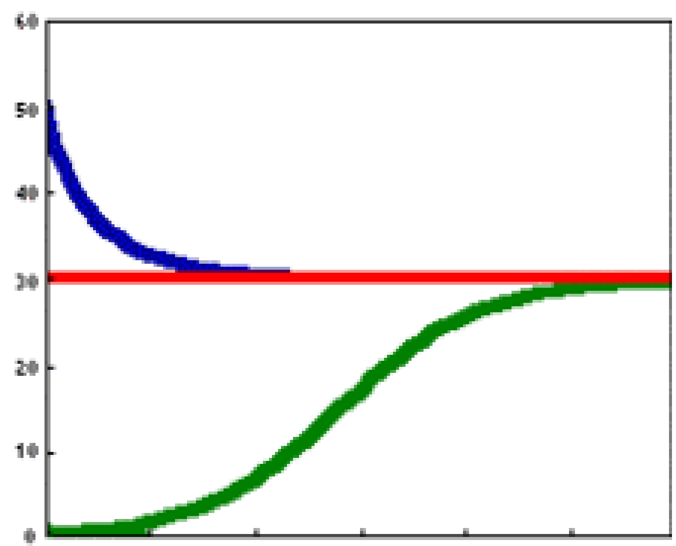


*Padmanabhan Seshaiyer*
*George Mason University*

# Carrying Capacity

- Maximum population size that the environment can sustain indefinitely.
- When the population reaches its environment limits, its growth slows down.



*Padmanabhan Seshaiyer*
*George Mason University*

# Incorporating Logistic Growth

- P(t) = Population size in time period t
- M = Carrying Capacity

$$\frac{P(t)}{M} = \text{fraction of carrying capacity that is used}$$

$$1 - \frac{P(t)}{M} = \text{unused fraction of carrying capacity}$$

$$P(t+1) - P(t) = r\,P(t)\left(1 - \frac{P(t)}{M}\right)$$

*Padmanabhan Seshaiyer*
*George Mason University*

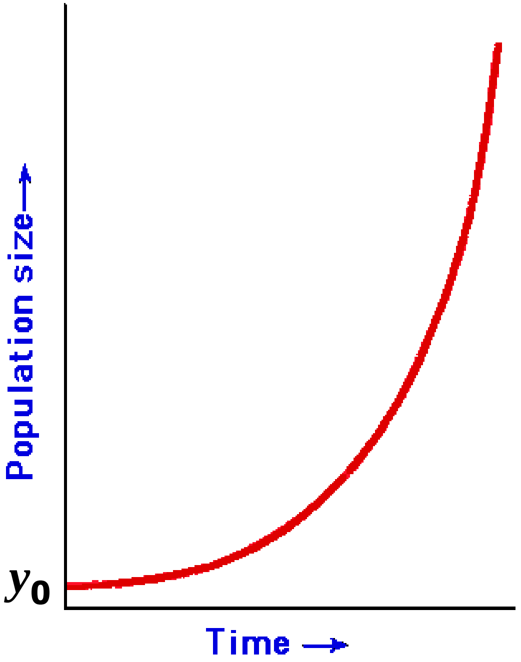
# Modeling Population

Let $y(t)$ be a homogeneous population density and $y_0$ be the initial population.

$$\frac{dy}{dt} \;\alpha\; y(t)$$

$$\Rightarrow \quad \frac{dy}{dt} = K\, y$$

$$\Rightarrow \quad y(t) = y_0\, e^{Kt}$$



*Padmanabhan Seshaiyer*
*George Mason University*

# Predator-Prey Problem

$$\frac{dY}{dt} = \alpha_1 \boldsymbol{Y} - \alpha_2 XY$$

$$\frac{dX}{dt} = -\alpha_3 \boldsymbol{X} + \alpha_4 XY$$

$Y(0) = Y_0$

$X(0) = X_0$

***Padmanabhan Seshaiyer***
***George Mason University***

# About those "Models"

*All models are wrong*,

*but*

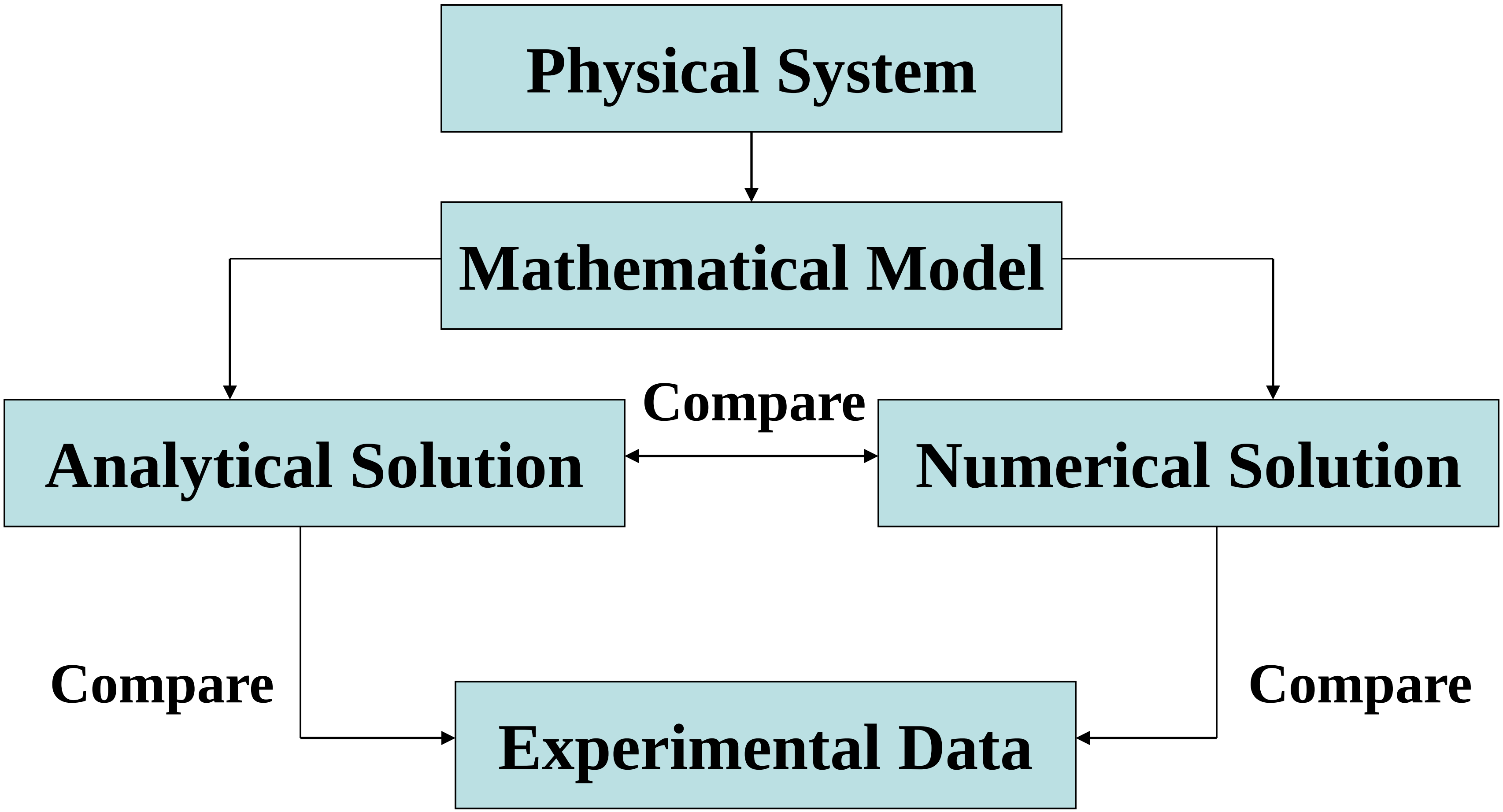
*some are more wrong than others.*

C.W. Clark and M. Mangel (2000)

Dynamic State Variable Models in Ecology.

*Padmanabhan Seshaiyer*
*George Mason University*

# Solution Methodology



# Multidisciplinary Research

- As concluded by the National Research Council: *Undergraduate education will not change in a permanent way through the efforts of "Lone Rangers." Change requires ongoing interaction among communities of people and institutions that will reinforce and drive reform.*

- Research that happens across traditional STEM disciplines and at the edges of traditional disciplines.

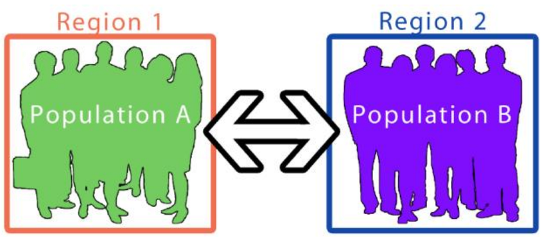
- *Here is the problem,*

  *find the Mathematics to solve it!*

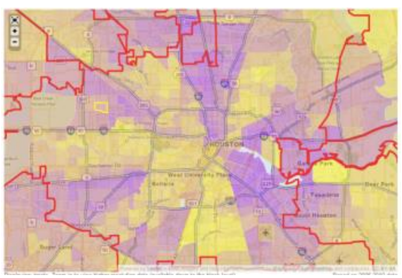

SUSTAINABLE DEVELOPMENT GOALS
1 NO POVERTY
2 ZERO HUNGER
3 GOOD HEALTH AND WELL-BEING
4 QUALITY EDUCATION
5 GENDER EQUALITY
6 CLEAN WATER AND SANITATION
7 AFFORDABLE AND CLEAN ENERGY
8 DECENT WORK AND ECONOMIC GROWTH
9 INDUSTRY, INNOVATION AND INFRASTRUCTURE
10 REDUCED INEQUALITIES
11 SUSTAINABLE CITIES AND COMMUNITIES
12 RESPONSIBLE CONSUMPTION AND PRODUCTION
13 CLIMATE ACTION
14 LIFE BELOW WATER
15 LIFE ON LAND
16 PEACE, JUSTICE AND STRONG INSTITUTIONS
17 PARTNERSHIPS FOR THE GOALS
SUSTAINABLE DEVELOPMENT GOALS

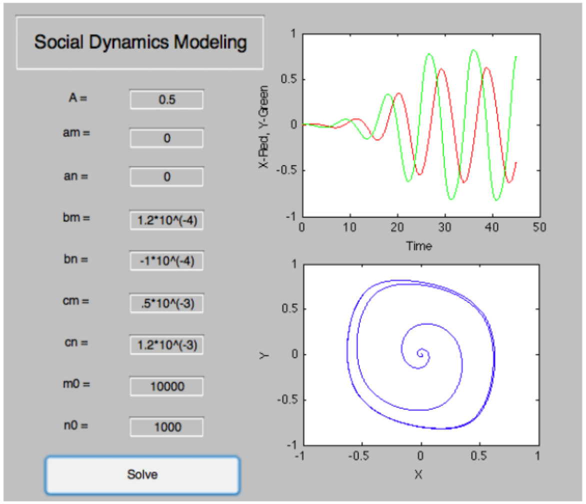
*Padmanabhan Seshaiyer*
*George Mason University*

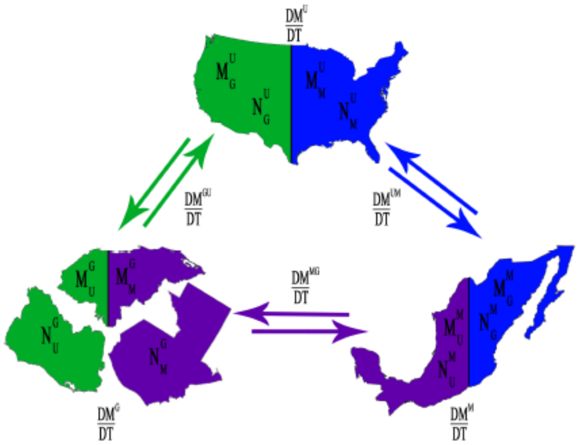
# Social Dynamics Modeling

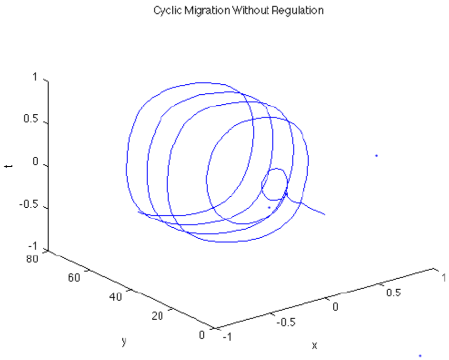


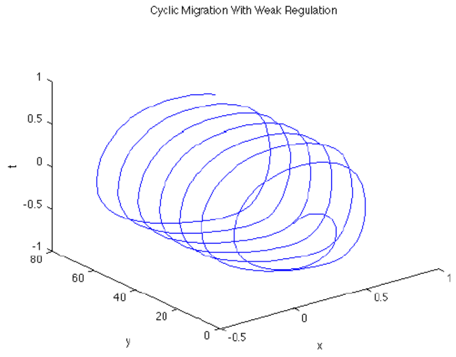

$$\frac{dm_i^{\alpha}(t)}{dt} = \sum_{j=i,j\neq i}^{s} m_j^{\alpha}(t)w_{ij}^{\alpha}(t) - m_i^{\alpha}(t)w_{ji}^{\alpha}(t) + P_i$$



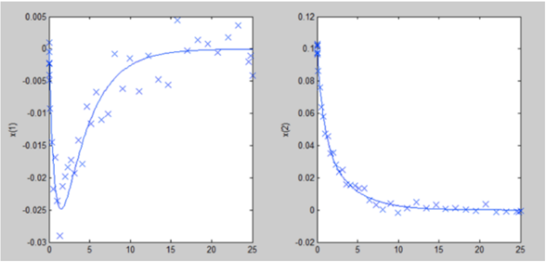



*Posters on the Hill*



Parameter Estimation


SUSTAINABLE DEVELOPMENT GOALS
1 NO POVERTY
2 ZERO HUNGER
3 GOOD HEALTH AND WELL-BEING
4 QUALITY EDUCATION
5 GENDER EQUALITY
6 CLEAN WATER AND SANITATION
7 AFFORDABLE AND CLEAN ENERGY
8 DECENT WORK AND ECONOMIC GROWTH
9 INDUSTRY, INNOVATION AND INFRASTRUCTURE
10 REDUCED INEQUALITIES
11 SUSTAINABLE CITIES AND COMMUNITIES
12 RESPONSIBLE CONSUMPTION AND PRODUCTION
13 CLIMATE ACTION
14 LIFE BELOW WATER
15 LIFE ON LAND
16 PEACE, JUSTICE AND STRONG INSTITUTIONS
17 PARTNERSHIPS FOR THE GOALS
SUSTAINABLE DEVELOPMENT GOALS


Make solar energy economical


Provide energy from fusion


Develop carbon sequestration methods


Manage the nitrogen cycle


Provide access to clean water


Restore and improve urban infrastructure


Advance health informatics


Engineer better medicines


Reverse-engineer the brain


Prevent nuclear terror


Secure cyberspace


Enhance virtual reality


Advance personalized learning


Engineer the tools of scientific discovery

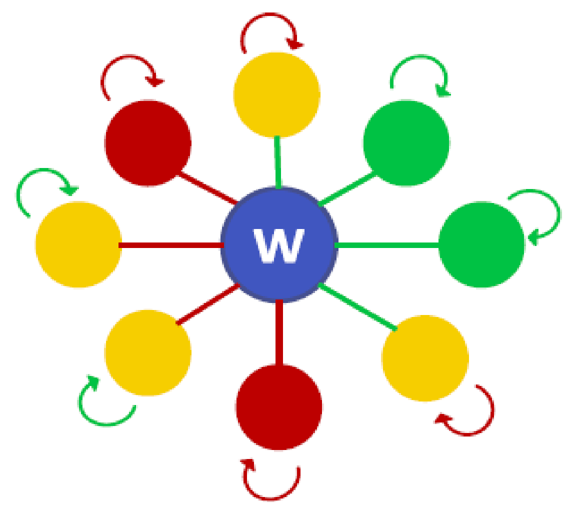
GRAND CHALLENGES FOR ENGINEERING

# India’s Water and Sanitation Crisis



**163 M** | people lack access to safe water

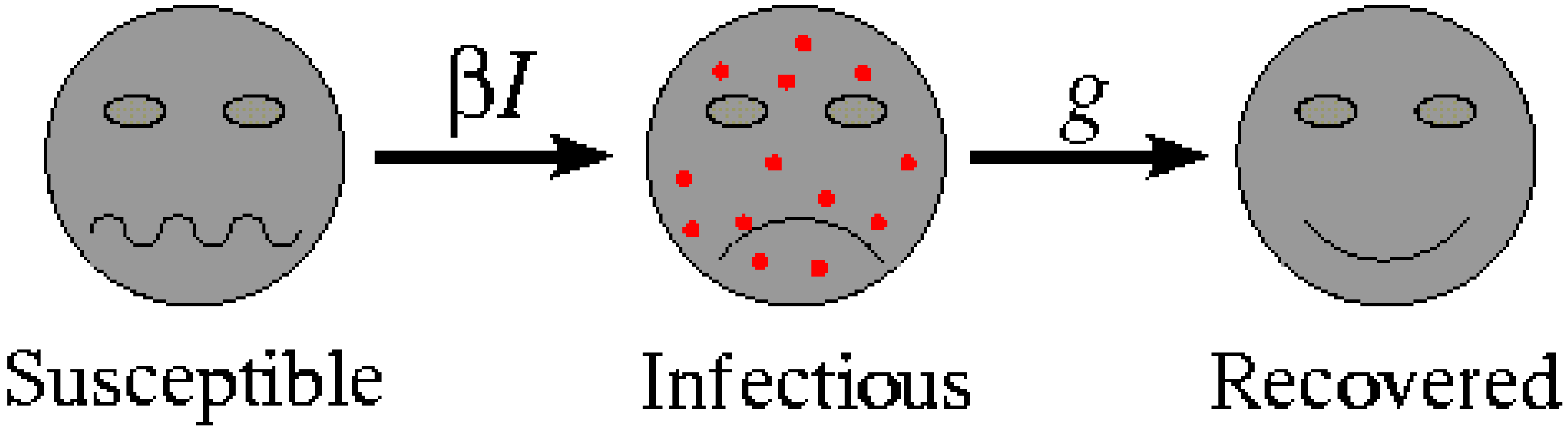
**210 M** | people lack access to improved sanitation



*Padmanabhan Seshaiyer*
*George Mason University*

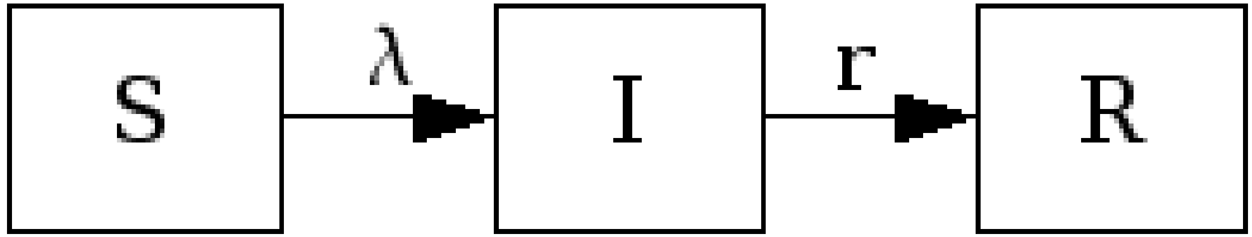
# Disease Dynamics Modeling
## **Identifying the threshold or tipping point**
(Kermack and McKendrick, 1927, 1932, 1933)

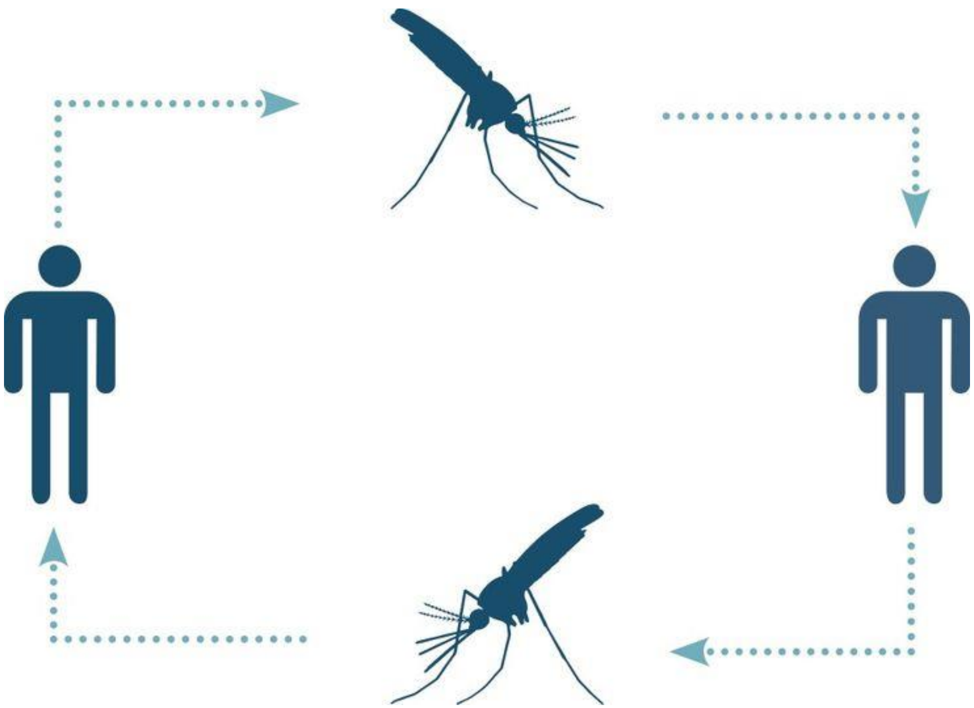
- Individuals are found in three stages
  - **Susceptible**
  - **Infected**
  - **Recovered**



***Padmanabhan Seshaiyer***
***George Mason University***

SIR



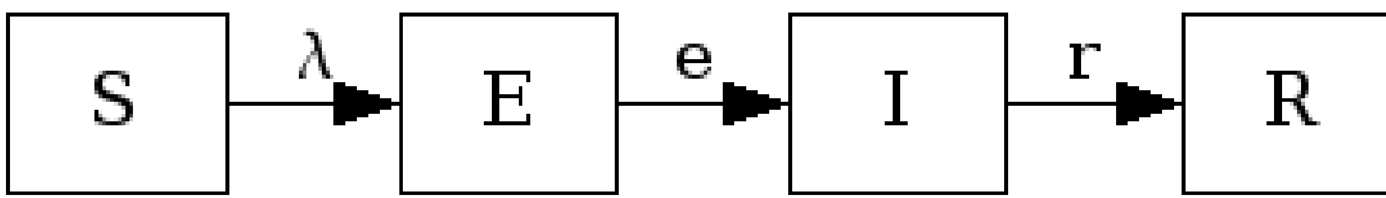
$$\frac{dS}{dt} = -\lambda S I$$

$$\frac{dI}{dt} = \lambda S I - r I$$

$$\frac{dR}{dt} = r I$$

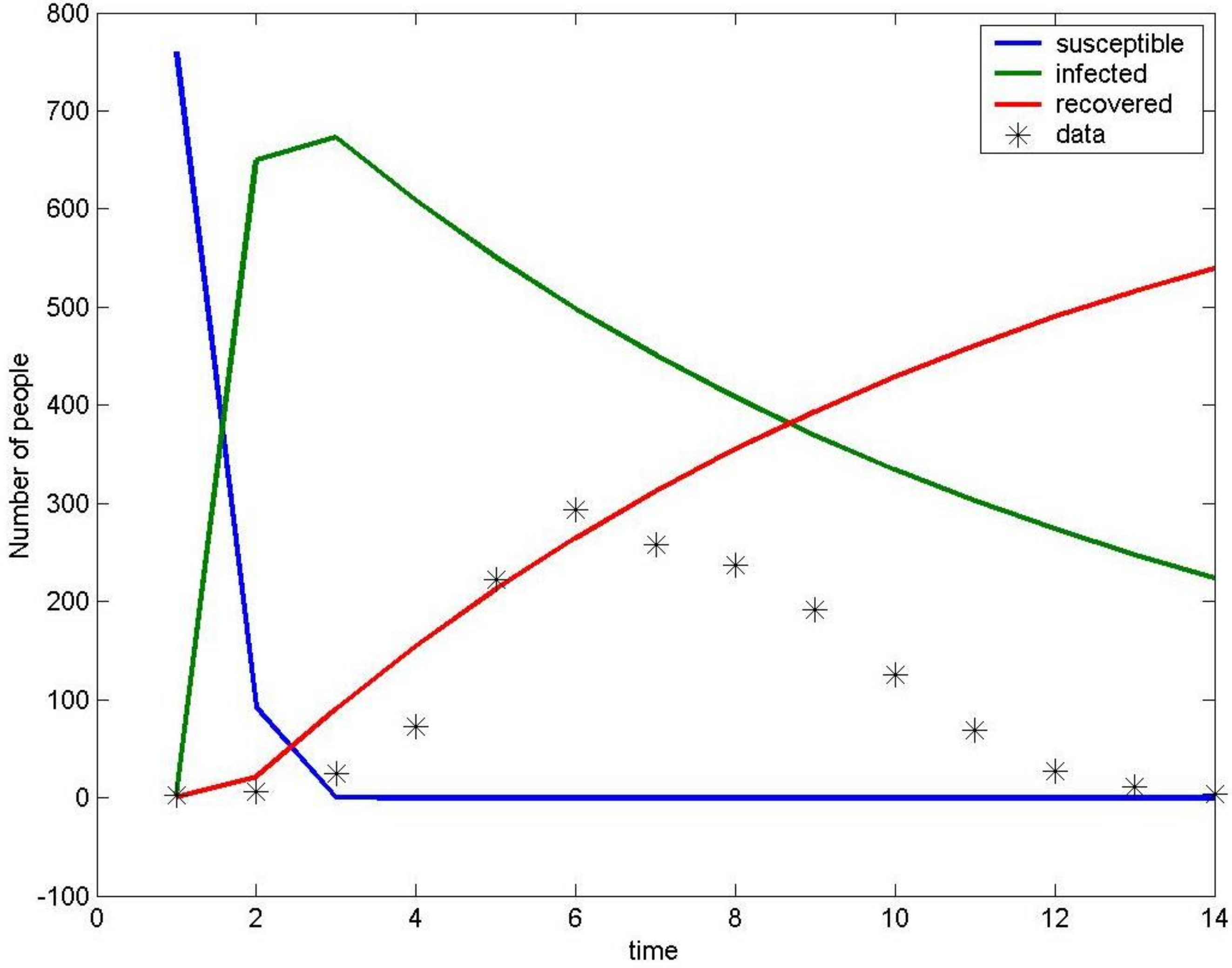
$$S(t) + I(t) + R(t) = N$$

SEIR



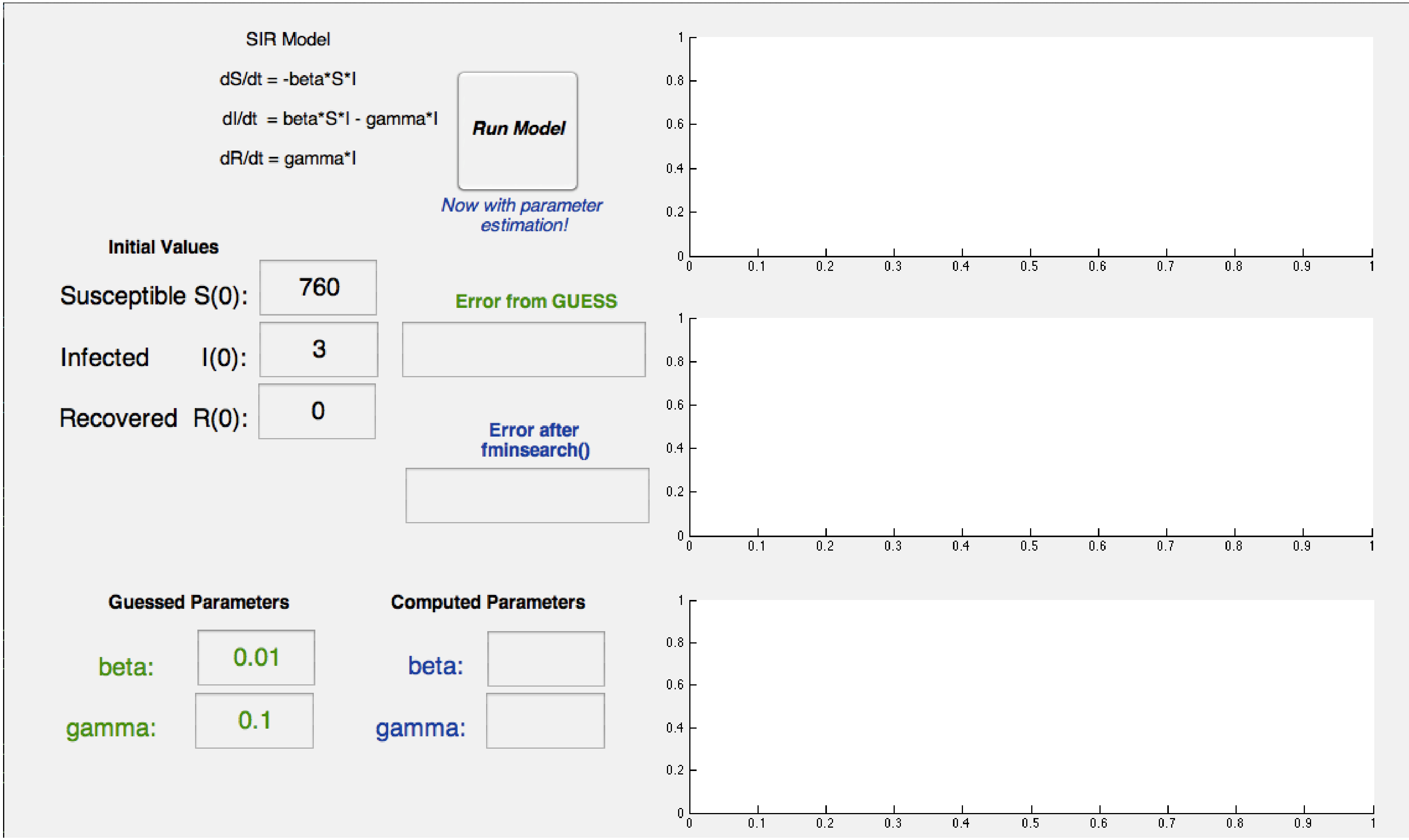
***Padmanabhan Seshaiyer***
***George Mason University***

# SIR Dynamics



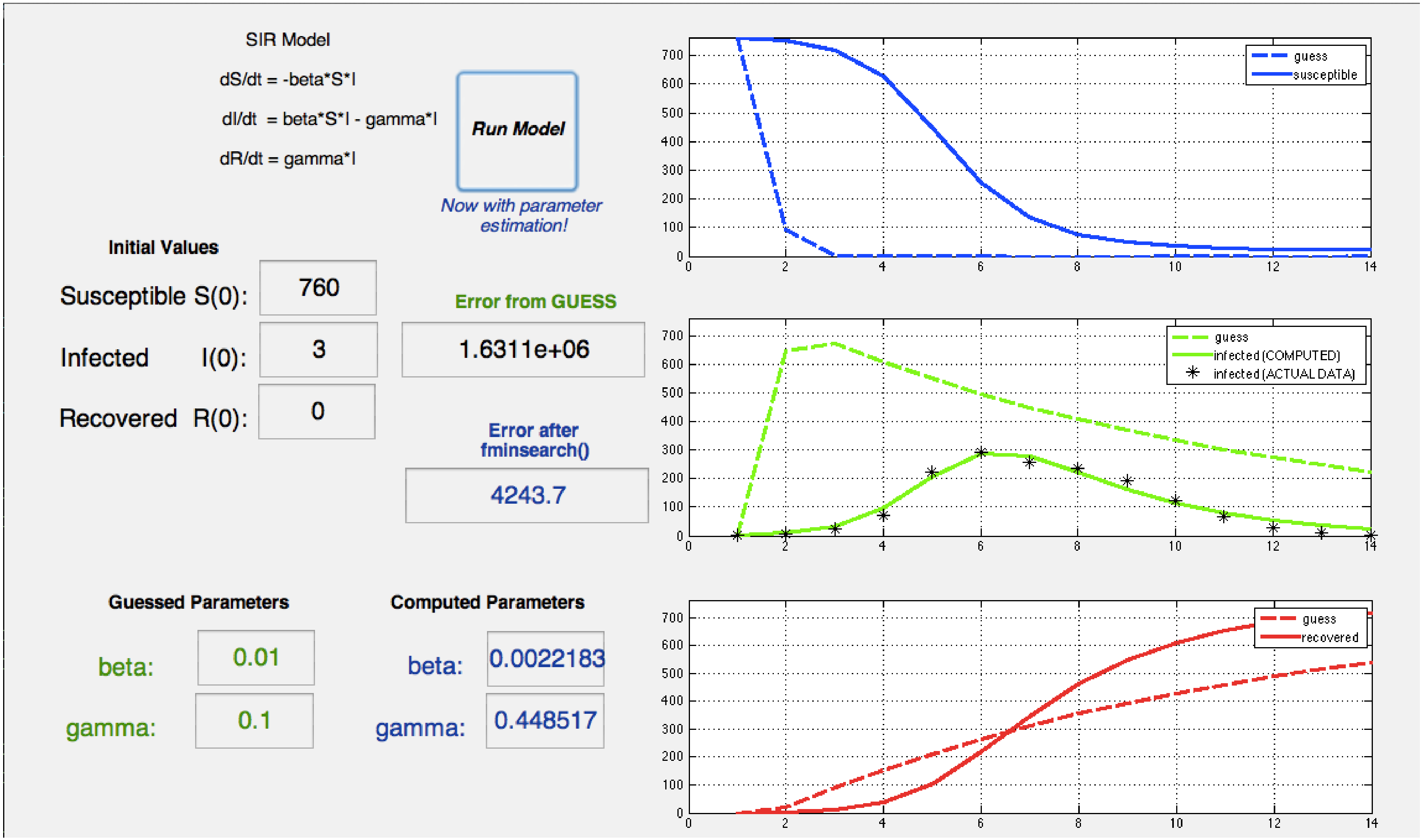
*Padmanabhan Seshaiyer*
*George Mason University*

# Graphical User Interface



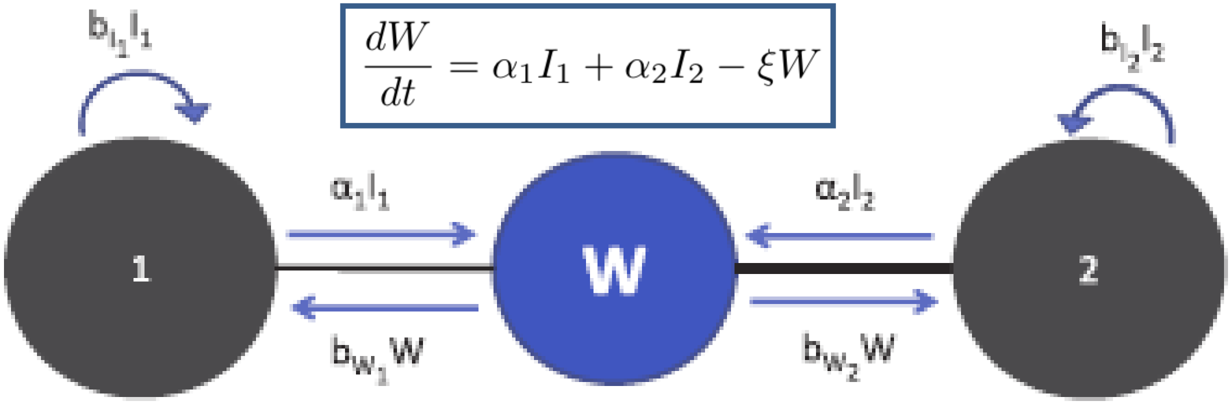
*Padmanabhan Seshaiyer*
*George Mason University*

# Graphical User Interface (data)



# 2-patch SIWR Model

$$\frac{dW}{dt} = \alpha_1 I_1 + \alpha_2 I_2 - \xi W$$

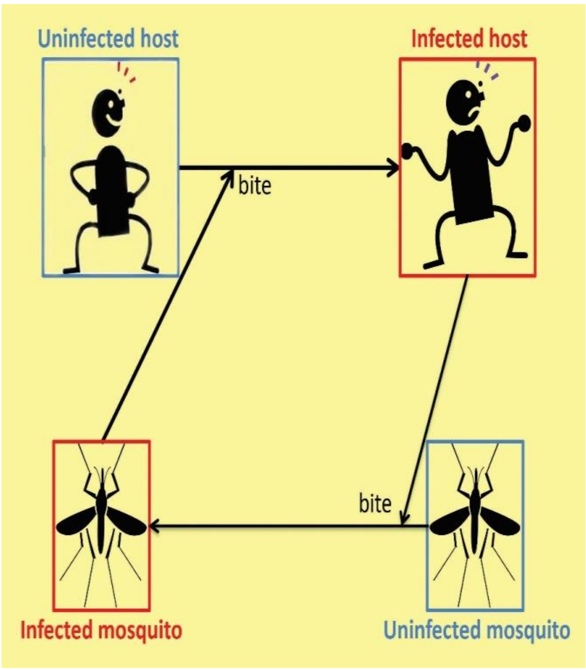


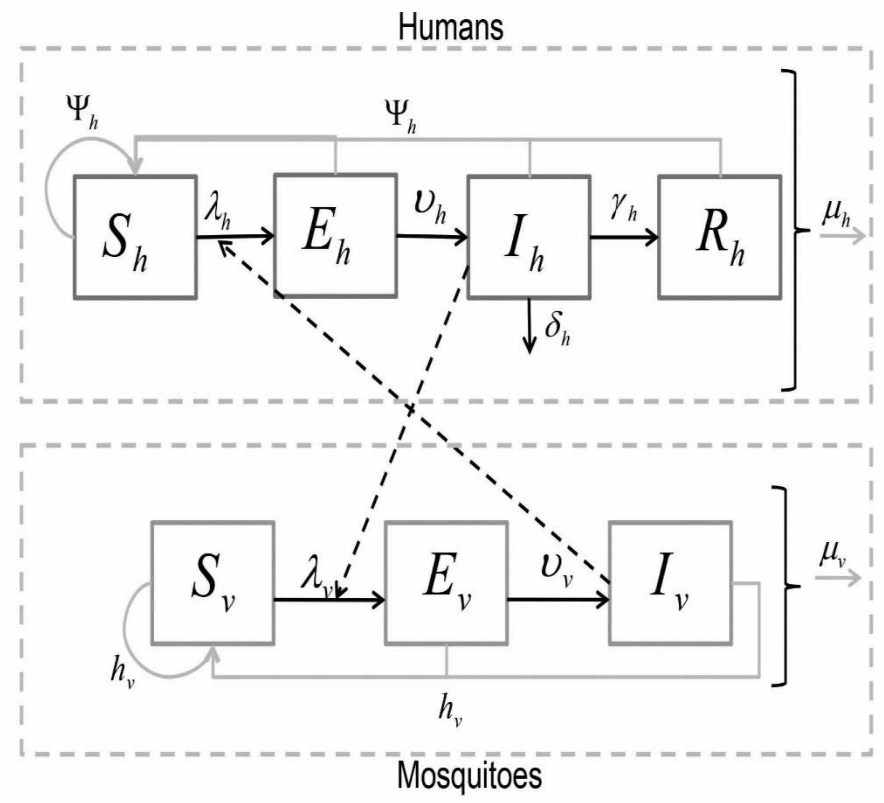

$$\begin{aligned}
\frac{dS_1}{dt} &= \mu N_1 - b_{w_1} W S_1 - b_{I_1} S_1 I_1 - \mu S_1 \\
\frac{dI_1}{dt} &= b_{w_1} W S_1 + b_{I_1} S_1 I_1 - \gamma I_1 - \mu I_1 \\
\frac{dR_1}{dt} &= \gamma I_1 - \mu R_1
\end{aligned}$$

$$\begin{aligned}
\frac{dS_2}{dt} &= \mu N_2 - b_{w_2} W S_2 - b_{I_2} S_2 I_2 - \mu S_2 \\
\frac{dI_2}{dt} &= b_{w_2} W S_2 + b_{I_2} S_2 I_2 - \gamma I_2 - \mu I_2 \\
\frac{dR_2}{dt} &= \gamma I_2 - \mu R_2
\end{aligned}$$

*Padmanabhan Seshaiyer*
*George Mason University*

# Mathematical Models for Zika Transmission



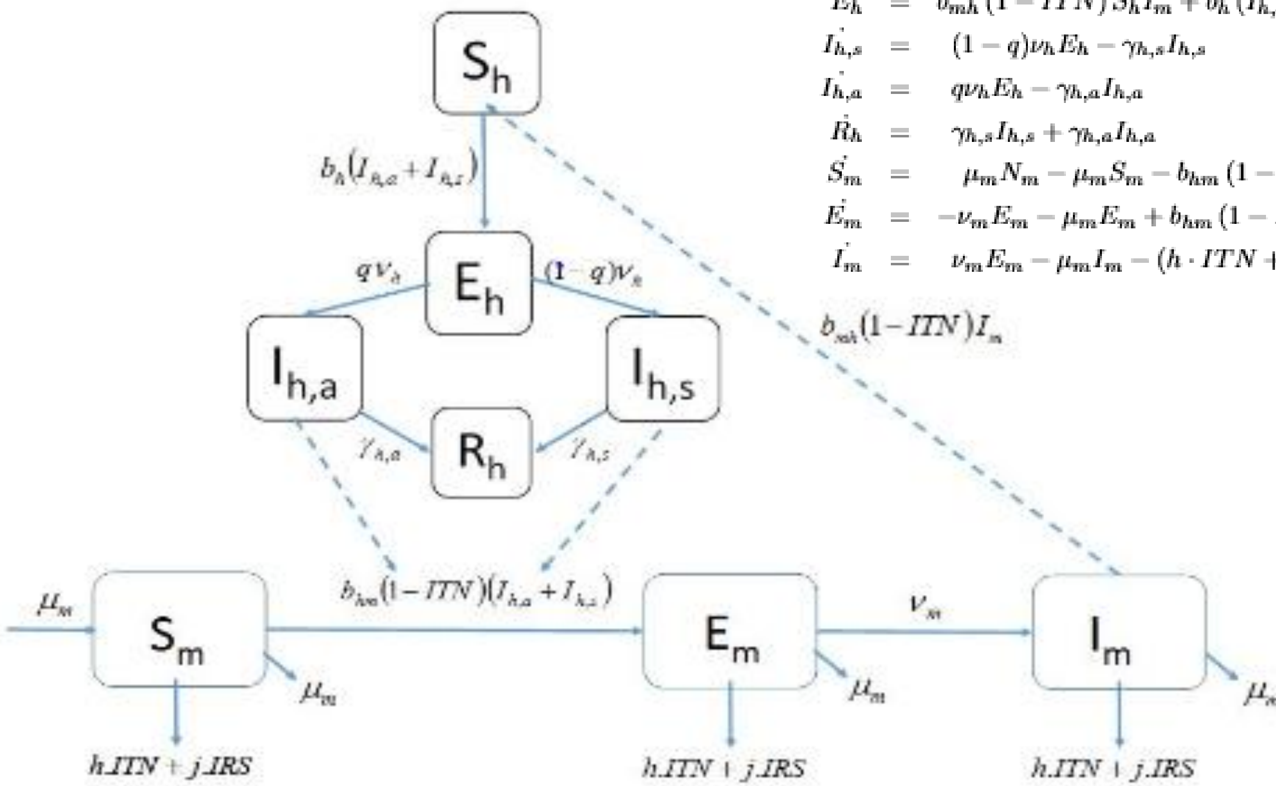




**Mathematical Models for Fighting Zika Virus, Carrie Manore and Mac Hyman, SIAM News, May 2016**

*Padmanabhan Seshaiyer*
*George Mason University*

# Mathematical Models for Zika Transmission

$$
\begin{aligned}
\dot{S_h} &= -b_{mh}\,(1-ITN)\,S_h I_m - b_h\,(I_{h,a}+I_{h,s})\,S_h \\
\dot{E_h} &= b_{mh}\,(1-ITN)\,S_h I_m + b_h\,(I_{h,a}+I_{h,s})\,S_h - \nu_h E_h \\
\dot{I_{h,s}} &= (1-q)\nu_h E_h - \gamma_{h,s} I_{h,s} \\
\dot{I_{h,a}} &= q\nu_h E_h - \gamma_{h,a} I_{h,a} \\
\dot{R_h} &= \gamma_{h,s} I_{h,s} + \gamma_{h,a} I_{h,a} \\
\dot{S_m} &= \mu_m N_m - \mu_m S_m - b_{hm}\,(1-ITN)\,S_m\,(I_{h,s}+I_{h,a}) - (h\cdot ITN + j\cdot IRS)\,S_m \\
\dot{E_m} &= -\nu_m E_m - \mu_m E_m + b_{hm}\,(1-ITN)\,S_m\,(I_{h,s}+I_{h,a}) - (h\cdot ITN + j\cdot IRS)\,E_m \\
\dot{I_m} &= \nu_m E_m - \mu_m I_m - (h\cdot ITN + j\cdot IRS)\,I_m
\end{aligned}
$$



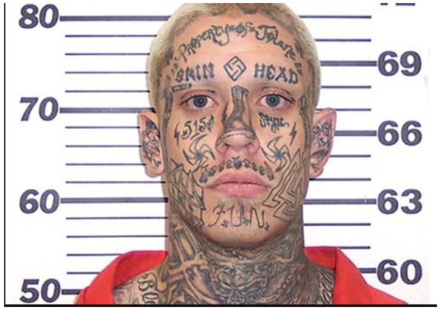

**Mathematical modeling, analysis and simulation of the spread of Zika with influence of sexual transmission and preventive measures, Letters in Biomathematics, Vol 4, pp 148-166, 2017.**

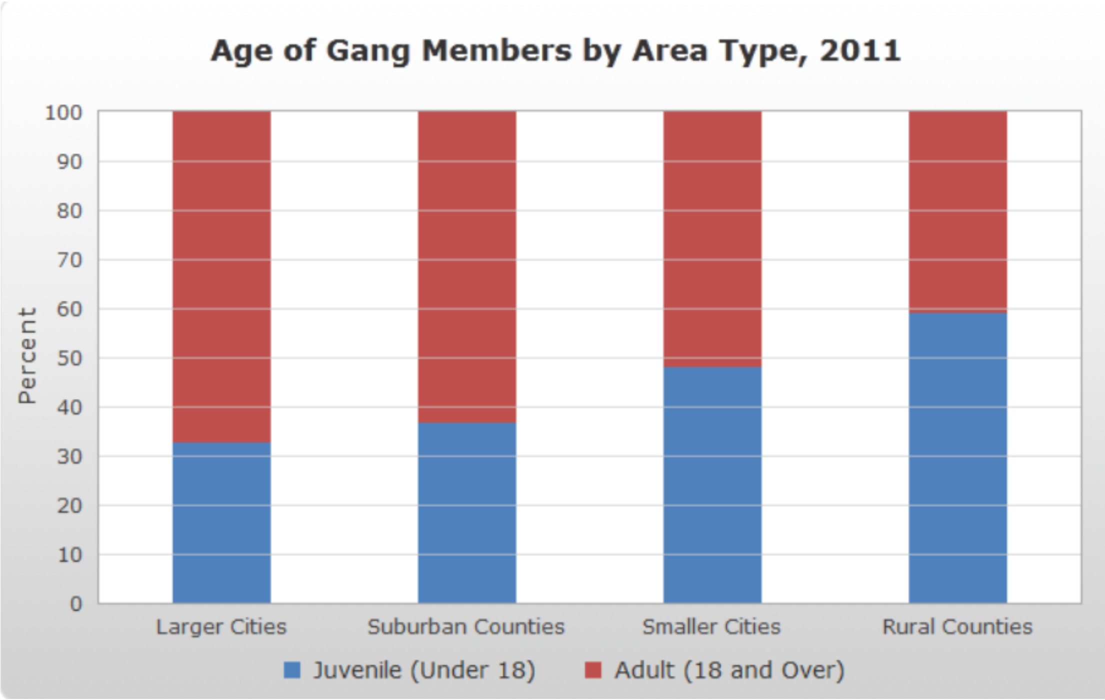
***Padmanabhan Seshaiyer***
***George Mason University***

*Padmanabhan Seshaiyer*
*George Mason University*

# Global Challenge

- Recruitment of Gangs



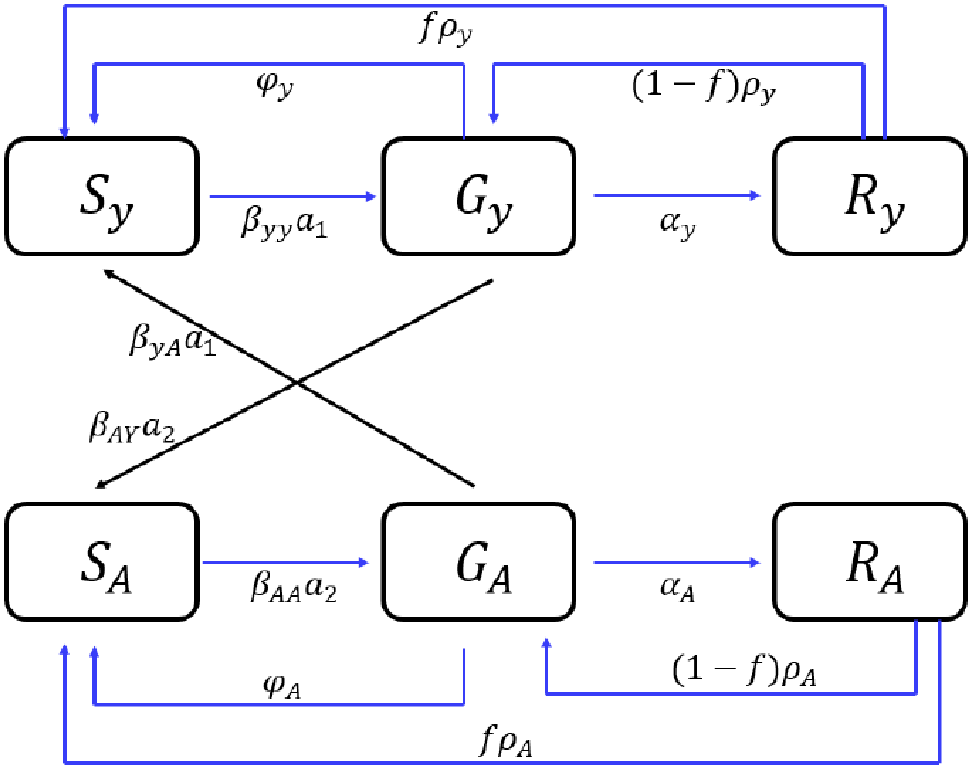



*Padmanabhan Seshaiyer*
*George Mason University*

# Modeling Gangs in Puerto-Rico

Gang Model Assumptions:

- Population is constant.
- No prior history of infection.
- Long period of time.
- 2 SGR classifications:
  a. Youth class (12-24 years).
  b. Adult class (25-65).



# Governing Differential Equations

- Youth Population

$$(1)\quad \frac{dS_y}{dt} = -\left[\beta_{yy} a_1 \left(\frac{S_y G_y}{N_y}\right) + \beta_{yA} a_1 \left(\frac{S_y G_A}{N_A}\right)\right] + f\rho_y R_y + \phi_y G_y$$

$$(2)\quad \frac{dG_y}{dt} = \beta_{yy} a_1 \left(\frac{S_y G_y}{N_y}\right) + \beta_{yA} a_1 \left(\frac{S_y G_A}{N_A}\right) + (1-f)\,\rho_y R_y - \phi_y G_y - \alpha_y G_y$$

$$(3)\quad \frac{dR_y}{dt} = \alpha_y G_y - \rho_y R_y$$

- Adult Population

$$(4)\quad \frac{dS_A}{dt} = -\left[\beta_{AA} a_2 \left(\frac{S_A G_A}{N_A}\right) + \beta_{Ay} a_2 \left(\frac{S_A G_y}{N_y}\right)\right] + f\rho_A R_A + \phi_A G_A$$

$$(5)\quad \frac{dG_A}{dt} = \beta_{AA} a_2 \left(\frac{S_A G_A}{N_A}\right) + \beta_{Ay} a_2 \left(\frac{S_A G_y}{N_y}\right) + (1-f)\,\rho_A R_A - \phi_A G_A - \alpha_A G_A$$

$$(6)\quad \frac{dR_A}{dt} = \alpha_A G_A - \rho_A R_A$$

Partnerships for Enhanced Engagement in Research (PEER) Science

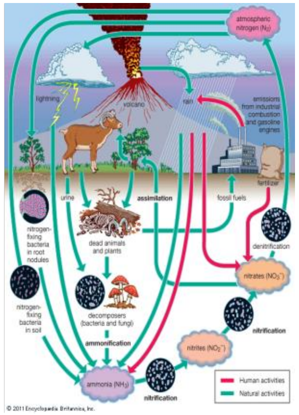
**Computational Mathematics, Modeling and Analysis of Biological, Bio-inspired and Engineering Systems**

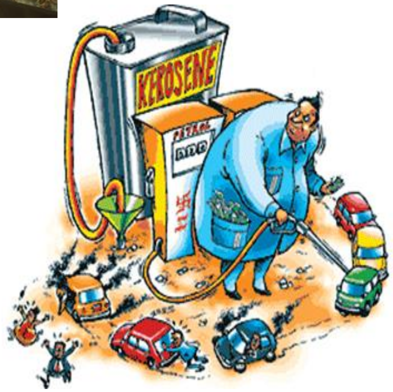
PI: Burton Mwamila

Vice Chancellor, The Nelson Mandela African Institute of Science and Technology

U.S. Partner: Padmanabhan Seshaiyer (Professor, George Mason University)

**http://sites.nationalacademies.org/PGA/dsc/peerscience/PGA_084056**





*Padmanabhan Seshaiyer*
*George Mason University*

# Global Problem Solving

- Location: Tanzania
- Problem: Poaching

*Padmanabhan Seshaiyer*
*George Mason University*

# Why is this a rich STEM Problem?

- Dynamics and Mechanics
- Search Algorithms
- Sensors and Electronics
- Control Systems and Feedback
- Communications
- Swarming
- Mapping Algorithms
- Machine Learning

- **Applications**: Anti-poaching, Remote Sensing, Agriculture, Transporting materials, Oil-gas-mineral exploration, Search & Rescue, Surveillance and many more!

- STEM Education

*Padmanabhan Seshaiyer*
*George Mason University*

# Modeling using Drones

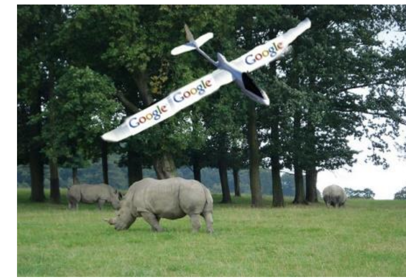
Agriculture


*credit: diydrone.com*

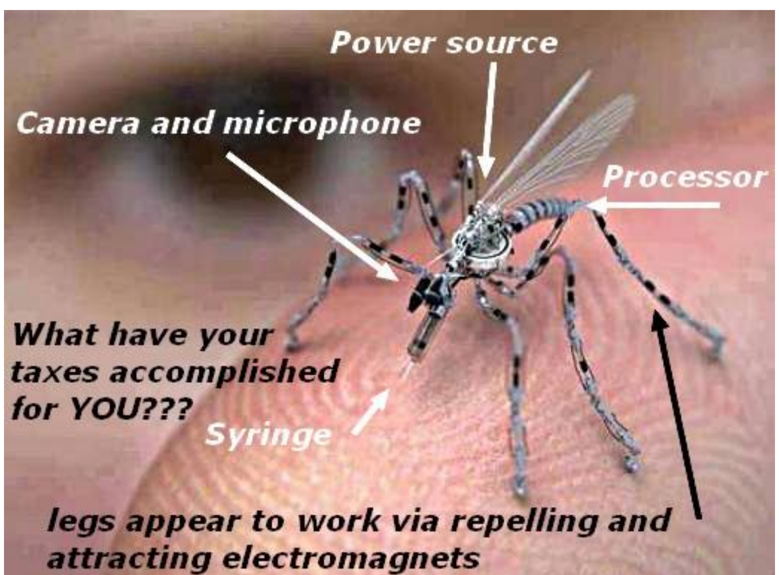
Search and Rescue

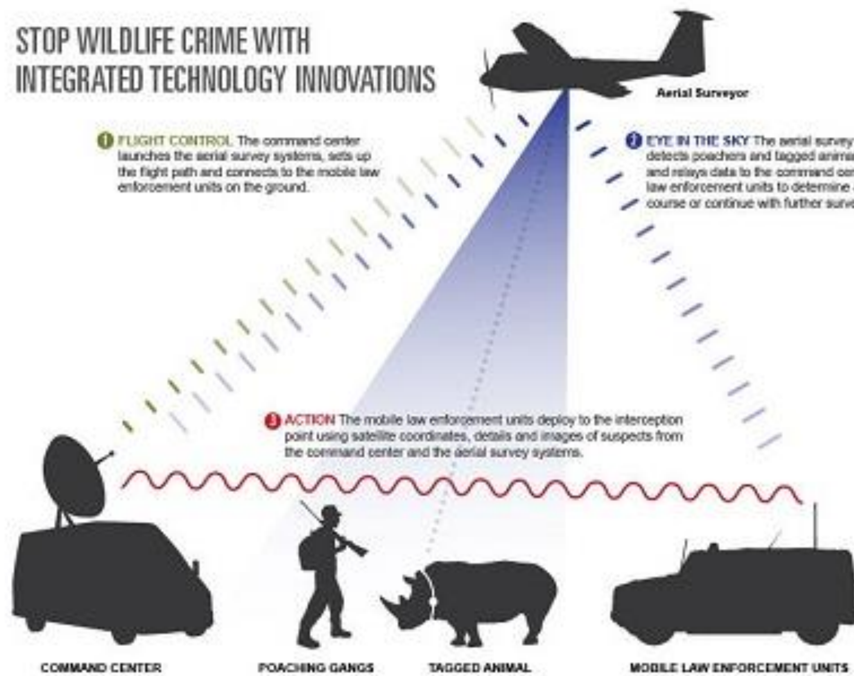
*credit: gizmag.com*

Surveillance



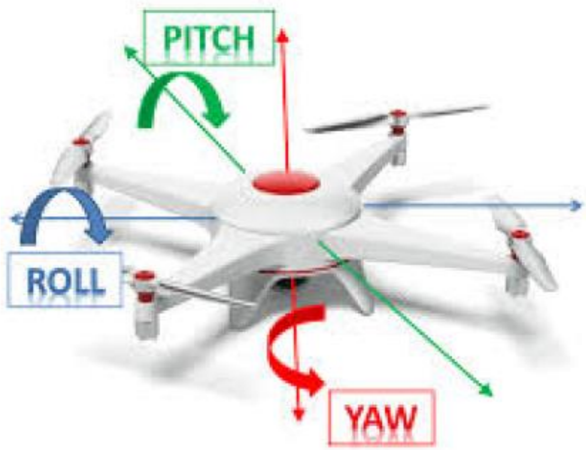

*credit: Far-drone-hull-repair.rcquadcopterkit.net*



*Padmanabhan Seshaiyer*
*George Mason University*

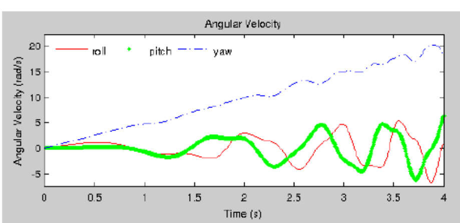
# Drones and Mechanics

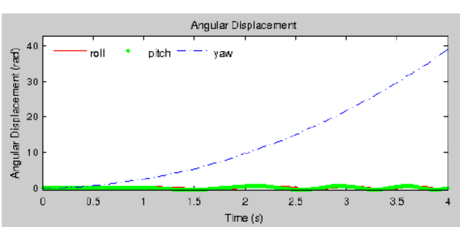


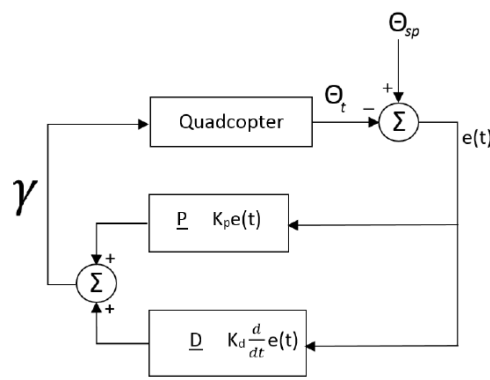

*credit: norunway.com*

$$\begin{bmatrix} \ddot{x} \\ \ddot{y} \\ \ddot{z} \end{bmatrix} = \sum \frac{\mathbf{F}}{m} = \frac{1}{m} f_T \, \mathbf{R} \begin{bmatrix} 0 \\ 0 \\ \sum_{i=1}^{4} \gamma_i^2 \end{bmatrix} + \begin{bmatrix} 0 \\ 0 \\ g \end{bmatrix} + \frac{1}{m} f_D \begin{bmatrix} \dot{x} \\ \dot{y} \\ \dot{z} \end{bmatrix}$$

$$\begin{bmatrix} \dot{\omega}_\phi \\ \dot{\omega}_\theta \\ \dot{\omega}_\psi \end{bmatrix} = \begin{bmatrix} I_{xx} & 0 & 0 \\ 0 & I_{yy} & 0 \\ 0 & 0 & I_{zz} \end{bmatrix}^{-1} \begin{bmatrix} \tau_\phi - (I_{zz} - I_{yy})\omega_\theta\omega_\psi \\ \tau_\theta - (I_{xx} - I_{zz})\omega_\psi\omega_\phi \\ \tau_\psi - (I_{yy} - I_{xx})\omega_\phi\omega_\theta \end{bmatrix}$$



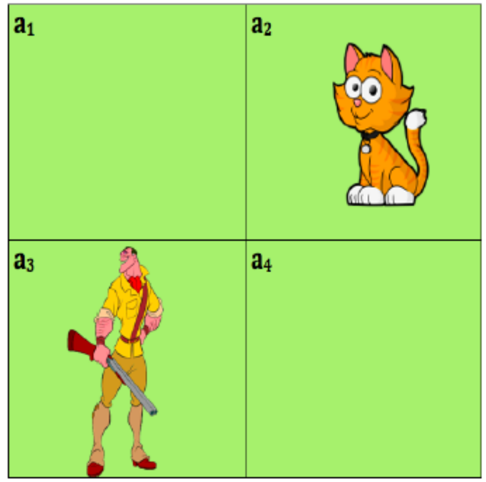




- $e(t) = \Theta_{sp} - \Theta_t$
- $\Theta_{sp} = \begin{bmatrix} 0 \\ 0 \\ \psi_o \end{bmatrix}$
- $K_p, K_d > 0$

$$PD\ Control = K_p e(t) + K_d \frac{d}{dt} e(t) \rightarrow \gamma = [\gamma_1, \gamma_2, \gamma_3, \gamma_4,]$$

***Padmanabhan Seshaiyer***
***George Mason University***

# Drones and Target Detection




Target Detection

$$d_{a_i}^t = \begin{cases} 0 & \text{if } x_T \neq a_i \text{ at time } t \\ 1 & \text{if } x_T = a_i \text{ at time } t \end{cases}$$

Measurement Error

- $\beta$ = missed detection (missing the poacher)
- $\alpha$ = false alarm (detecting something that's not there; a ranger, a cat, etc)

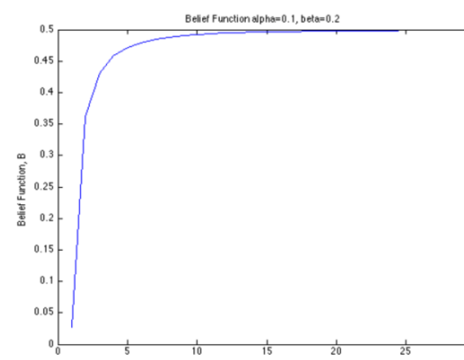
$$Bel(x_T) = Pr(x_T = a_k | D^t) = \frac{Pr(d_k^t | x_T = a_k, D^{t-1}) Pr(x_T = a_k | D^{t-1})}{Pr(d_k^t | D^{t-1})}$$

**Theorem**

*For a uniform distribution, the belief function:*

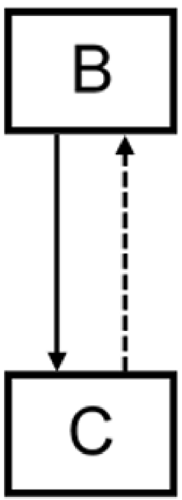
$$Pr(x_T \in A | D^t = \mathbf{0}) = \frac{t\beta\delta + (1-\alpha)(|A| - t)\delta}{t\beta\delta + (1-\alpha)(|A| - t\delta)}$$

*converges to the prior belief,* $\delta$.



# Bees, Coffee and Maria

$$\frac{dC}{dt} = C\left[r_1 - \frac{r_1}{k_1}C + c_1\left(\frac{s_2 B}{1+\tau_2 s_2 B}\right) - q_1\left(\frac{s_1 B}{1+\tau_1 s_1 C}\right)\right]$$




$$\frac{dB}{dt} = B\left[r_2 - \frac{r_2}{k_2}B + c_2\left(\frac{s_1 C}{1+\tau_1 s_1 C}\right)\right]$$

| | |
|---|---|
| $\tau_1$ | Bee Feeding Time |
| $\tau_2$ | Bee Pollination Time |
| $s_1$ | Coffee Attraction Rate (Pollination) |
| $s_2$ | Bees Search Rate (Food) |
| $k_1$, $k_2$ | Carrying Capacity |

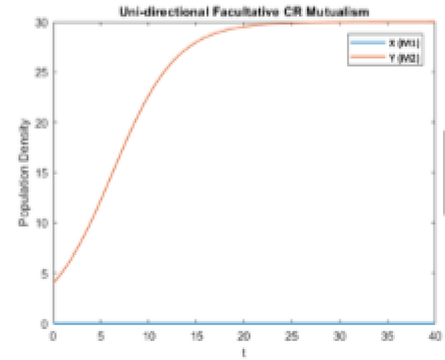



Figure 1:

$X_0 = 0$, $Y_0 = 4$

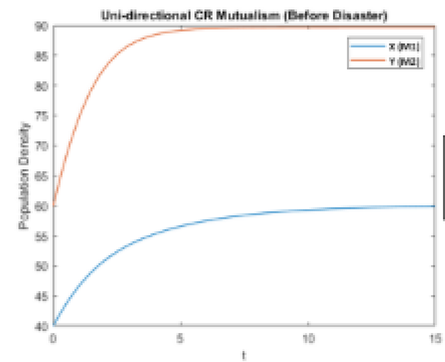



Figure 2:

$X_0 = 40$, $Y_0 = 60$

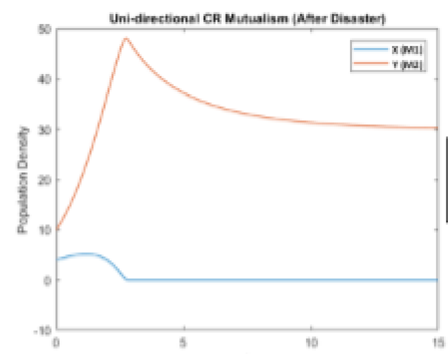


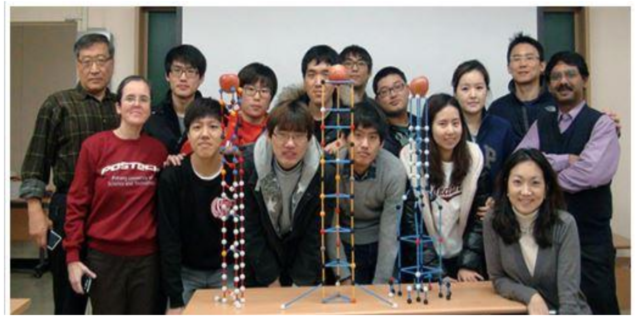

Figure 3:

$X_0 = 4$, $Y_0 = 10$

# Design Thinking in Higher Education

## DICE: Design Thinking, Innovation, Creativity & Entrepreneurship


**Padmanabhan Seshaiyer**
Email: pseshaiy@gmu.edu

- Ask the USER
- Affinity maps
- Brainstorming
- Requirements (estimates)

**Needs statement**

- SCAMPER
- 6-3-5
- Decision matrix
- deBono hats

**Engineer Solutions**

**Research & Prototype**

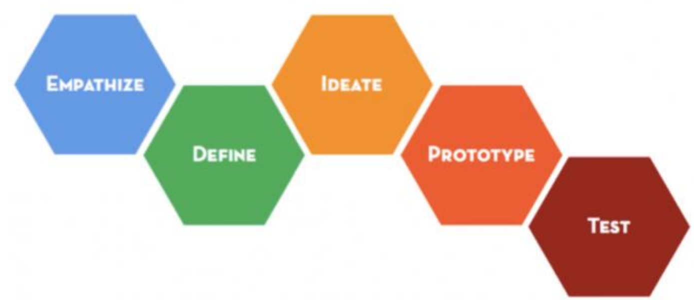
- C-sketching
- Find similar ideas
- Cardboard building
- Proof of concept

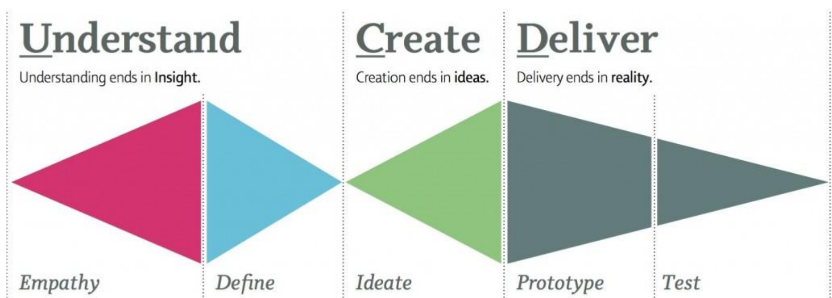
**Test, debug, test, test.**

- Requirements met?
- Qualitative tests
- Quantitative measurements

# Project PROGRESS: Promoting Renewable energy research On the Grid to create a Responsible and Engaged STEM workforce in Solar Sustainability across the Commonwealth

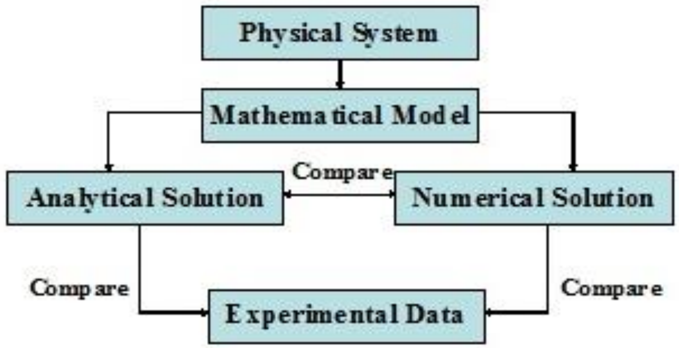

**Padmanabhan Seshaiyer**
**STEM Accelerator Program**


# Modeling of real-world applications

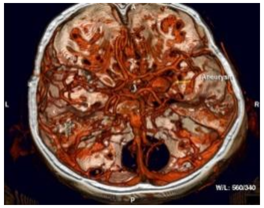
*Modeling Across the Curriculum*
*Problem Solving Methodology*

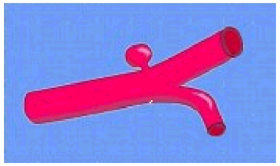


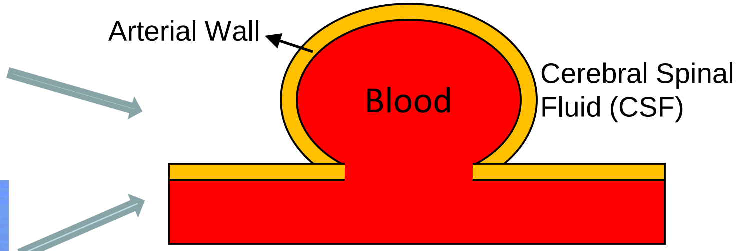

*Engaging students in modeling and computation*

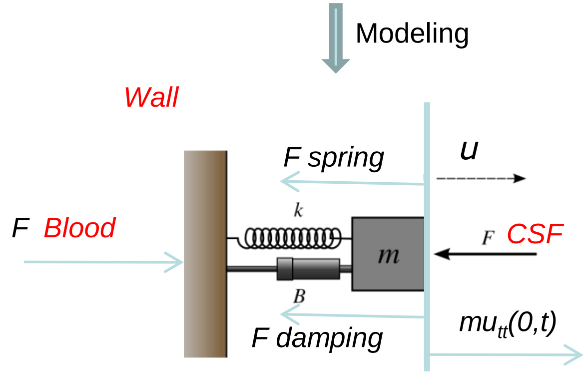

**Padmanabhan Seshaiyer (Padhu)**
Professor, Mathematical Sciences
George Mason University, Fairfax, VA
Director, Center for Outreach in Mathematics Professional Learning and Educational Technology (COMPLETE)
Director, STEM Accelerator Program
Phone: (703) 993-9787
Email: pseshaiy@gmu.edu
Web: http://math.gmu.edu/~pseshaiy/outreach.html


*Engaging students in multidisciplinary research*
*Modeling Aneurysms, Arterial-wall, blood flow interaction*



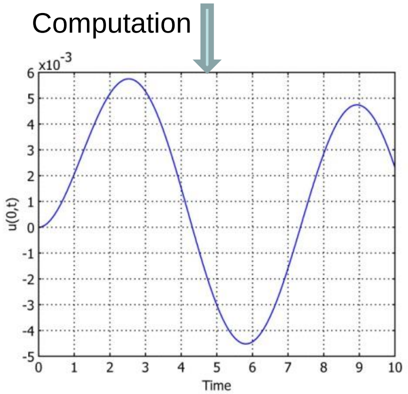





*Engaging Students in Communicating Research*

*Posters on the Hill*

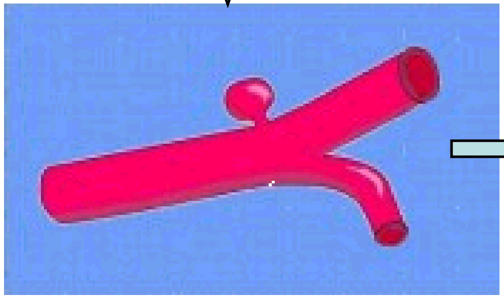


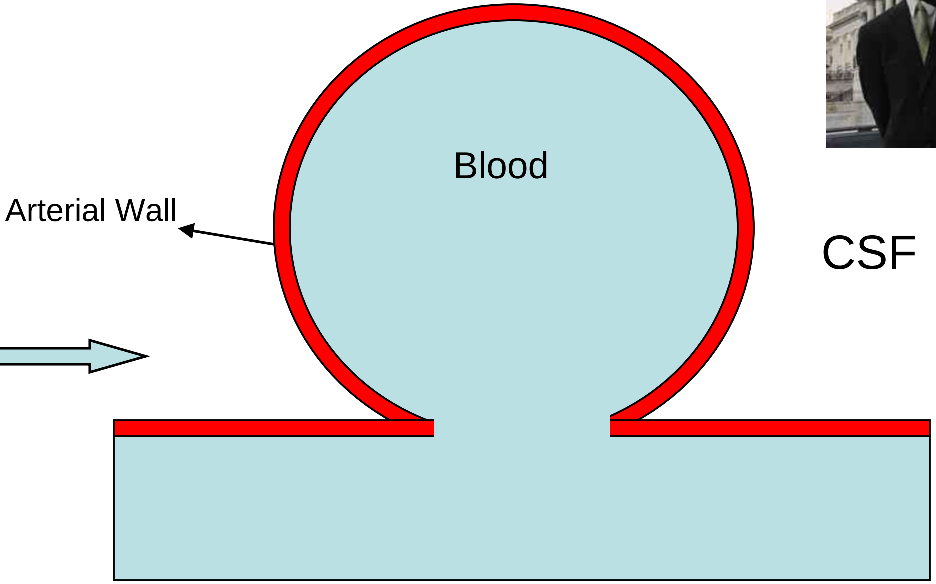


1. **Modeling, Analysis and Computation of Fluid Structure Interaction Models for Biological Systems**, S. Minerva Venuti and P. Seshaiyer (Mentor), SIAM Undergraduate Research Online, Vol. 3, pp 1-17 (2010).
2. **Transforming Practice Through Undergraduate Researchers**, P. Seshaiyer, Council on undergraduate research Quarterly, Fall 2012.

# University, Community College, K-12 STEM Collaboration

Sarah M. Venuti (Undergraduate Student)
Avis Foster (Undergraduate Student)
Courtney Chancellor (Undergraduate Student)
Stephanie Alley (Undergraduate Student)
Kris Kappmeyer (K-12 Teacher)
Kurt Litsch (High School Student)
Alicia Hamar (High School Student)
Archis Bhandarkar (High School Student)
Rohan Banerjee (High School Student)
James Nong (Graduate Student)
Andrew Samuelson (Graduate Student)

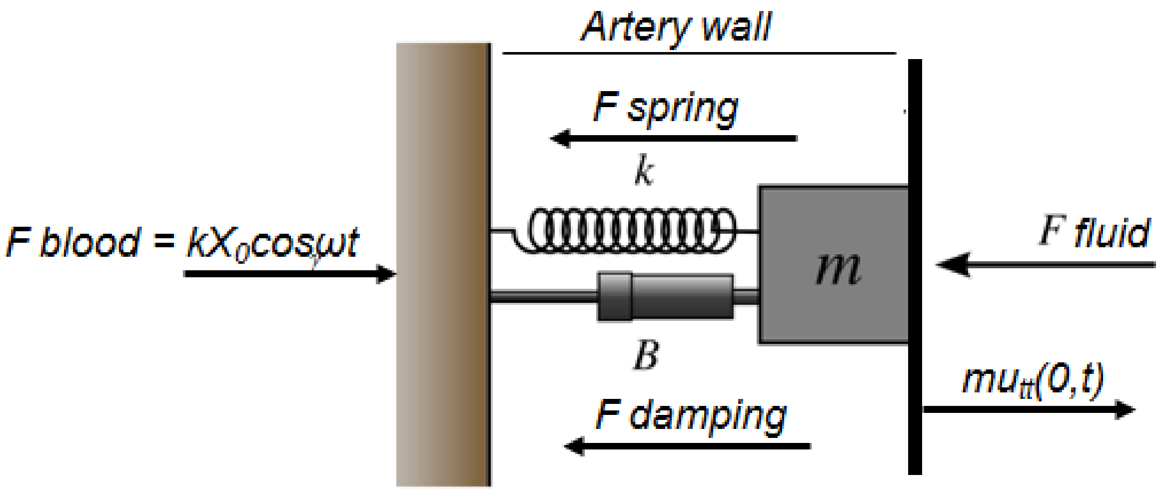



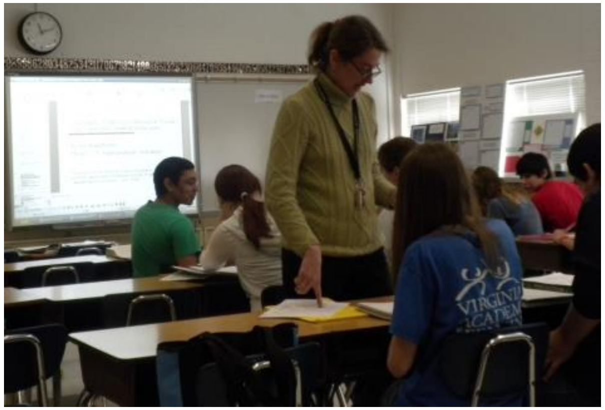



Transforming Practice Through Undergraduate Researchers, P. Seshaiyer, Council on undergraduate research Quarterly, Fall 2012.

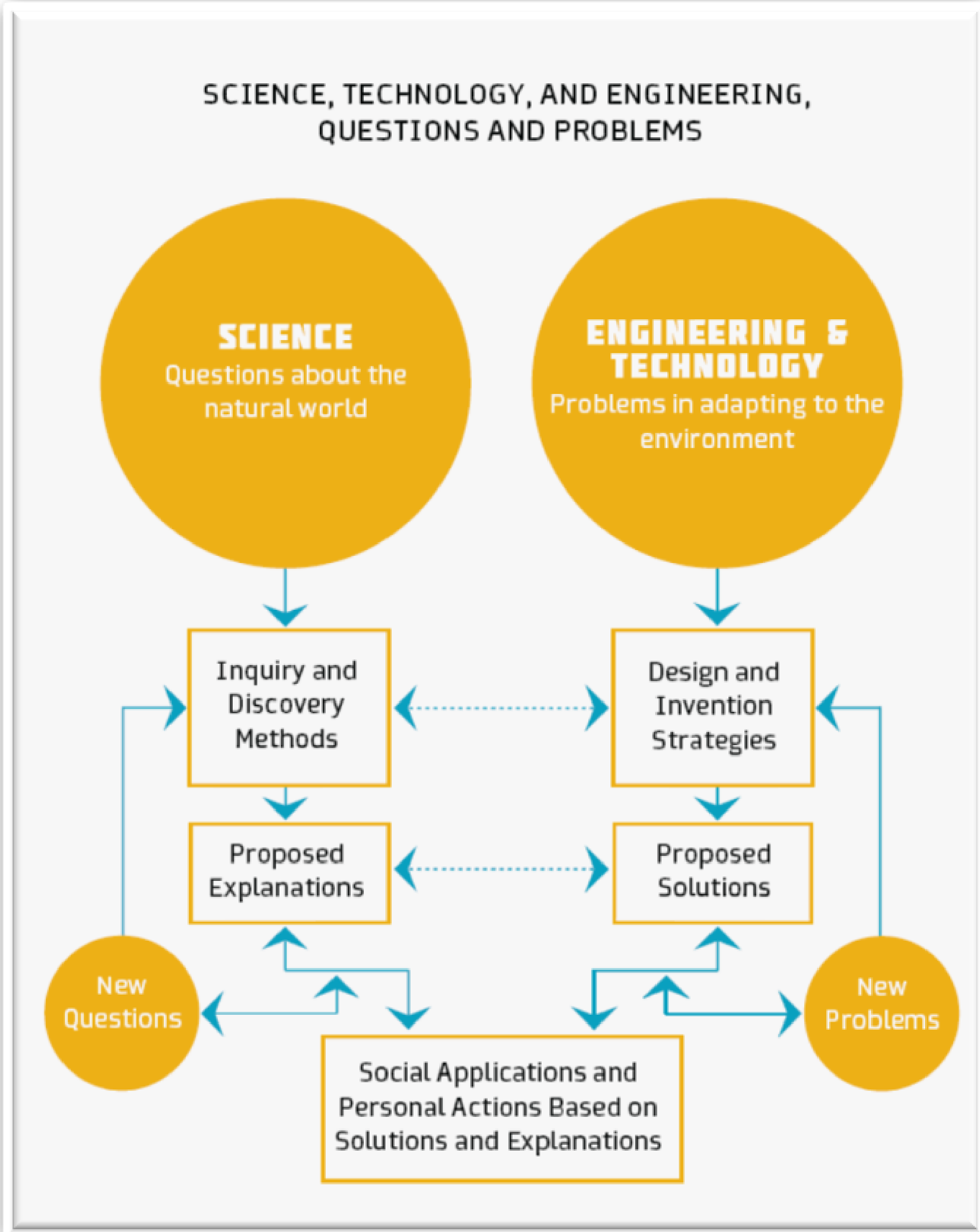
*Padmanabhan Seshaiyer*
*George Mason University*

# How does new research/innovations evolve?



$$\rho \frac{\partial v}{\partial t} + \rho\ v \frac{\partial v}{\partial x} + \frac{\partial P}{\partial x} + \mu \frac{\partial^2 v}{\partial x^2} = F$$


SCIENCE, TECHNOLOGY, AND ENGINEERING, QUESTIONS AND PROBLEMS
SCIENCE
Questions about the natural world
ENGINEERING & TECHNOLOGY
Problems in adapting to the environment
Inquiry and Discovery Methods
Design and Invention Strategies
Proposed Explanations
Proposed Solutions
New Questions
New Problems
Social Applications and Personal Actions Based on Solutions and Explanations

| Scientific Experimental Method | Engineering Design Method |
|---|---|
| • Pose a question | • Define a problem |
| • Research the question | • Research the problem |
| • Construct an answer, explanation, or hypothesis to be tested | • Design, plan, and build a prototype or solution to be tested |
| • Test the hypothesis through experiments that attempt to disprove it | • Test the prototype or solution to see if it solves the problem |
| • Analyze the results and draw a conclusion about the answer | • Analyze the results and improve the solution to the problem |
| • Communicate the results and compare with the others' results | • Communicate the results and implement or market the solution as a product or service |
| • Repeat the process with more refined questions or with new questions that arose in the process | • Repeat the process with refined or new ideas for better solutions, or with new problems that arose in the process |

# What type of transformative research and training can one do?

- Modify Key Assumptions
- Build Realistic Geometry
- Optimize Mathematical Techniques
- Enhance Mathematical Software
- Match Experimental Data
- Refine Mathematical Model
- Perform Parameter Estimation Studies

# Contact


**Padmanabhan (Padhu) Seshaiyer**

**Email: pseshaiy@gmu.edu**

**Professor, Mathematical Sciences**

**Director, COMPLETE Center**

**Director, STEM Accelerator Program**

**George Mason University**

**Phone: (703) 993 9787**

**web: http://math.gmu.edu/~pseshaiy/outreach.html**