HANDS-ON SESSIONS
Hands-On Research in Complex Systems Advanced Study Institute
University of Buea, Cameroon
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Communicable Diseases:

Dr Gideon A. Ngwa (U. Buea), assisted by Calistus Ngonghala and Professor Kenneth Showalter (West Virginia U.), Dr. Henry Dilonga (U. Buea), and Dr. Fidelis Cho-Ngwa (U. Buea)

Communicable diseases are carried by microorganisms and are diseases that can be communicated between persons. Examples of communicable diseases include malaria, HIV/AIDS, ringworm, and intestinal worms (Ascaries, Taenia, etc.). These diseases are called communicable because the infection can be "communicated" just as information can be communicated from one person to another. A human-to-human communicable disease could be passed through blood, mucus, uterine fluid, breast milk, semen, saliva, or breath.

Question: Can money harbor pathogens and thus serve as a communicable disease vector? Money is handled by persons of varying health and hygienic standards and is stored under varying environmental and personal hygienic conditions. Thus the chances of pathogens being present on money (coins and notes) and persisting through multiple handling are high.

In the first part of the session, participants will have the opportunity to carry out simple microscopic examinations to establish the existence of microorganisms (and the possible types) that can persist on the surfaces of money (coins and notes). In the second part, participants will learn how to develop simple mathematical models for indirectly transmitted diseases of humans. In the third part, participants will have the opportunity to formulate the hypotheses and mechanisms that may be useful in proposing mathematical models to assess the efficacy of money as a vector for communicating diseases between humans and then to use MATLAB to analyse these models.

<u>Simulation Introduction</u>: Participants will explore the existence and stability of equilibrium solutions to an SIR disease model with and without vital dynamics using standard analytical techniques. MATLAB codes for a SIR [for the three compartments or states S (for susceptible), I (for infectious) and R (for recovered)] disease model will be provided: The first two codes will be for a deterministic SIR model with and without vital dynamics, respectively. The third code will be a stochastic version of an SIR disease model. The fourth code will be a deterministic SIR infectious disease model with a periodic contact rate. Participants will vary the contact rate to observe different dynamical behavior, ranging from a stable steady state to a period doubling cascade. A MATLAB code for an SEIRS (where "E" is for exposed) model for endemic malaria (from Ngwa and Shu, 2000) that incorporates a spatial component will be examined. Participants will vary system parameters and diffusion coefficients to observe their effects on disease prevalence and the wave front of an infection process through the community.

Stem cells, wound healing and regeneration in flatworms:

Dr. Eva-Maria Schoetz (Princeton University), assisted by Chieze Ibeneche (U. Texas), Jared Talbot (Princeton U.)

Planarians are members of the phylum Platyhelminthes, the flatworms. They share with vertebrates key traits such as bilateral symmetry, three germ layers (ectoderm, mesoderm, and endoderm), and dorsoventral and anteroposterior polarities. Planarians are famous for their amazing regenerative capabilities, which are due to a large population of stem cells. These stem cells also allow the organism to alternate between sexual and asexual reproduction in the wild. In this Hands-On session, we will be working with the free-living planarian S. mediterranea.

S. mediterranea is closely related to Schistosoma mansoni, a significant parasite of humans that infects over 200 million people worldwide causing the disease intestinal schistosomiasis. Of the over 200 million people with schistosomiasis, 85% live in Africa (World Health Organization). Among human parasitic diseases, schistosomiasis ranks second behind malaria in terms of socio-economic and public health importance in tropical and subtropical areas (Carter Center). Thus, gaining a better understanding of flatworm biology using S. mediterranea as a model system may help our fight against this endemic parasite.

Since planarian regeneration is on the order of 1 week, we will only study this aspect as a side project. The main focus in this session will be to use planarians as a biological model system for introducing the concepts of the harmonic oscillator. The ventral side of a planarian is covered with cilia (participants will be able to view cilia on prepared samples using a fluorescent microscope), which allows it to swim with a gliding motion by moving its cilia in a layer of self-produced mucus. However, once a planarian gets cut, it displays inchworm motility for approximately one minute.

Participants will formulate their hypothesis on how they think the inchworm frequency and the duration of inchworm motility will depend on the size of the worm piece and cut. They will then test this hypothesis experimentally by recording the motion of cut worms using a simple experimental setup. Planarians are large enough (1-2 cm) that a microscope is not required and an inexpensive camera can give great data. We will then use Scilab to analyze and plot the data and extract the worm specific frequency. This experiment is a beautiful biological example of the harmonic oscillator and allows for the introduction of physical concepts such as damping, noise, sampling rate and fourier space. Other concepts that will be examined, as time permits, include wound healing, regeneration, tissue mechanics, normal cilia driven locomotion, behavior and chemotaxis -- the response of the worms to chemical stimuli.

Nonlinear Dynamics and Chaos in a Time Delayed Electro-Optic Feedback System:

Dr. Yanne Chembo (FEMTO-ST CNRS, France), and Professor Rajarshi Roy (University of Maryland), assisted by Adam Cohen and Bhargava Ravoori (U. Maryland), and by Vanatius Mborong (U. Buea)

Non-linear systems with self-feedback are known to demonstrate a rich variety of behavior ranging from simple oscillations to very fast chaos as parameters such as the feedback strength, delay, and signal bandwidth are varied. Several physical realizations of such systems are possible. Electro-optics systems have a wide operational bandwidth while being easily controllable. We will provide the participants with the opportunity to experiment with an electro-optic system and observe the route to chaos.

Our system consists of a semiconductor laser (commercially available and commonly used in telecom) emitting infrared radiation at 1550 nm that is fiber-optically coupled to a Mach-Zehnder electro-optic modulator. This modulator is the heart of the loop, and has a nonlinear optical transmission output characteristic as an electronic input is varied. The optical output of the modulator is converted into an electronic signal by a photo-receiver, which is amplified before being fed back to the modulator. We will observe how the dynamics of the system change as the feedback strength and time delay are varied.

The participants will vary the feedback strength and make a bifurcation diagram as they do this. This pictorial depiction of the dynamics of the system sheds light on the parameter ranges over which the system displays a variety of dynamical behavior. A mathematical model of the system will be introduced. Numerical simulations of this model, programmed in Matlab, will be shown to be a powerful tool in understanding the dynamics of the system. Bifurcation diagrams, Lyapunov exponents, as well as synchronization of experimentally measured and model dynamics will be explored. Applications of the system to communications and sensing will be discussed.

Nonlinear Dynamics of Locomotion:

Professor Daniel I. Goldman, assisted by Nick Gravish, and Ryan Maladen (Georgia Institute of Technology), and Dr. Irene Sumbele (U. Buea)

Organisms from six legged cockroaches to two legged humans display similar dynamics when walking and running. Below a non-dimensional speed (the Froude number), dynamics can generally be modeled as an inverted pendulum, while above, dynamics can be modeled as a spring-mass system. Walking as an inverted pendulum can save energy through trading potential and kinetic energy at each step. Bouncing during running in larger organisms allows for storage and return of energy using elastic elements in limbs like tendons. The transition is in part a result of the inability of gravity to supply enough force to accelerate the body downward for sufficiently large walking speed.

The Hands-On project's goal will be to measure level locomotion dynamics during walking and running of a large biped (a human) to illustrate concepts in biomechanics. Forces will be measured during locomotion using a custom-built three-axis force platforms while imultaneously measuring kinematics using high speed digital imaging. The force and video data will be analyzed in Matlab/Scilab and with custom tracking software. Physical and numerical dynamical models of walking and running will be constructed and analyzed, and will be used to compare to experimental observations, including force patterns and stability criteria.

Nonlinear dynamics of coupled nonlinear electronic oscillators:

Dr. Abhijit Sen, Dr. Gautam C. Sethia, and Dr. Mitesh S. Patel (Institute for Plasma Research, India), assisted by Michael Ekonde Sone (U. Buea) and Dr. Bonaventure Nana (U. Buea)

The dynamics of single and coupled nonlinear electronic circuits will be explored through both simulation and experiments. An introduction to circuit simulation and to analysis software will be followed by the use of the software in designing and simulating some simple electronics circuits (e.g., clipper, clamper, amplifier). These steps will familiarize students with the basic building blocks necessary for the design and simulation of classic systems such as the Chua, Lorenz and Roessler models. Phenomena such as period doubling, period adding, and bifurcation routes to chaos will be studied using a digital oscilloscope and will be compared to numerical simulations conducted using MATLAB. Synchronization and antiphase oscillations will be studied using coupled Chua oscillators, both with and without time delay. New dynamical states will be identified and studied as a function of coupling strength and time delay.

Turbulent fluid flow:

Professor Michael Schatz (Georgia Tech, Atlanta, Georgia), assisted by Daniel Borrero-Echeverry (Georgia Tech), Dr. Djieto-Lordon Anatol (U. Buea), and Dr. David Afungchi (U. Buea)

Turbulent flows play a central role in many natural and technological processes; developing a fundamental understanding of turbulence stands as one of the greatest challenges in physics. This Hands-on Session will explore the problem of turbulence in table-top experiments on two dimensional (2D) flows. The simple design of the experiments will enable Hands-on participants to learn quickly essential techniques that permit exploration of scientific questions at the forefront of turbulence research.

Turbulence has long been associated with the idea of fluid flow that is irregular and unpredictable. However, decades of experimental observations demonstrate that characteristic patterns arise repeatedly. Numerous empirical methods have been devised to characterize these patterns, known as "coherent structures"; however, recent theory suggests that coherent structures observed in experiments are closely related to special unstable solutions (e.g., fixed points and periodic orbits) in the fluid equations (the Navier-Stokes equations). Firm evidence supporting the connection between these unstable solutions and experimentally-observed coherent structures has not yet been found. The Hands-on experiments will search for such evidence by visualizing 2D fluid flows using tracer particles. Movies of the visualized flow will be recorded using standard web cameras. The velocity fields of the turbulent flow will be extracted from the movies by the widely-used technique of particle image velocimetry (PIV). The velocity fields will be examined for evidence of the existence of unstable fixed-point and periodic-orbit solutions.

Instabilities in a Fluid Flow:

Professor Harry Swinney (University of Texas), assisted by Bruce Rodenborn (University of Texas) and Dr. Kennedy Fozao (U. Buea).

Flow between concentric independently rotating cylinders has become a paradigm for the study of instability in fluid dynamics and other systems. The primary instability that occurs in flow between rotating cylinders with increasing inner cylinder rotation rate (if the outer cylinder is at rest) leads to axisymmetric toroidal shaped vortices, discovered by G. I. Taylor in 1923. In recent years, a variety of higher instabilities has been discovered, some of which will be examined in this Hands-On session.

Participants will learn about dynamical instabilities and their characterization by using an inexpensive digital camera to obtain movies of flow patterns as a function of inner cylinder rotation rate. The flow patterns will be made visible by suspending small flat flakes into the fluid. Participants will analyze the movies using Matlab to identify transitions (bifurcations) and to characterize the increasingly complex dynamics. Topics that will be discussed include multiple stable states, quasi-periodicity, analysis of power spectra, construction of phase space attractors by the time delay method, types of attractors (limit cycles, tori, strange attractors), chaos, fractal dimension, and Lyapunov exponents.

Synchronization in Populations of Chemical Oscillators:

Dr. Mark Tinsley (Scottish Agricultural College) and Professor Kenneth Showalter (West Virginia University), assisted by Dr. Paul Chongwain and Dr. Emmanuel Nfor (University of Buea)

Populations of coupled oscillators are common in physical, chemical, and biological systems. The Belousov-Zhabotinsky (BZ) reaction proves to be a particularly amenable system for the study of large populations of oscillators. In our experiment, each individual oscillator consists of a small (50 - 200 μm) catalyst-loaded bead. When placed into a catalyst-free BZ solution, these beads can be maintained in an excitable or oscillatory state. Global coupling of such systems can be realized by stirring a suspension of the beads, and in unstirred systems, diffusion leads to local coupling. More complex networks of coupling may be realized by using a photosensitive catalyst and light intensity feedback between the beads.

The micro-beads exhibit periodic oscillations when placed in the catalyst-free BZ solution, which will be monitored at the characteristic wavelength of the catalyst. At low bead densities, the beads are effectively independent oscillators. Following the identification of the location of a bead, the frequency and phase distributions will be determined from the time series of the grayscale intensity. All image analysis and data processing will be carried out using Matlab. At higher densities, local coupling of the beads may occur. Phase and frequency information for each bead may then be used to investigate the various entrainments which occur in the system as a function of local bead density.

MATHEMATICAL MODELING

Sessions A, B, and C on mathematical modeling will be led by Professors Shattuck and Hunt:

Professor Mark Shattuck (City College of New York), assisted by David Boy (U. California Santa Barbara) and Florence Njinto and Dr. Christopher Agyingi (U. Buea)

Professor Brian Hunt (University of Maryland), assisted by Shelby Wilson (U. Maryland) and Siewe Nouridine (U. Buea).

Mathematical modeling: A. Introduction via imaging a double pendulum

This session will introduce participants to some basic and intermediate MATLAB skills for data analysis and modeling using a "double pendulum" as an example system. The double pendulum is a simple physical system that behaves "chaotically": it is very unpredictable until friction dissipates most of its energy. Using a digital camera, we will make a movie of the apparatus. Participants will learn to extract system state information (position and velocity) from the images and compare the data with computational results from a mathematical model. Modules ranging from introductory to more advanced will be provided so that participants with or without MATLAB experience can start at an appropriate level.

Mathematical modeling: B. Dynamical systems

Participants will learn about model development, analysis, and interpretation of computational results using a variety of mathematical models. Our main focus will be on models that are ordinary differential equations, and participants will gain practice in using MATLAB's differential equation solvers. Participants can choose among the following examples:

(1) Dynamics and bifurcation diagrams for low-dimensional chaotic models;
(2) Spatiotemporal chaos and predictability in a (very) simplified weather model;
(3) Modeling the human immune system.

Participants can also suggest systems they are interested in modeling.

Mathematical modeling: C. Molecular Dynamics

This session will introduce the participants to the basics of Molecular Dynamics (MD) using MATLAB. A Molecular Dynamics code solves Newton’s laws for a collection of particles or molecules. We will discuss the advantages/disadvantages to using MATLAB as compared with traditional programing languages like C/C++, Fortran, or Java. Each participant will develop his or her own simple MD simulator using less than a page of Matlab code. We will then add more advanced features like better integrators (Velocity Verlet, Gear Predictor/Corrector) and important code acceleration techniques like cell-list and Verlet list. More advanced participants may work on event-driven codes including delayed-states algorithm during this session or during an extended session.

Mathematical Modeling: Data encryption and information security

Professor Wayne Patterson (Howard University, Washington, DC), assisted by Nana Yaw Osafo (Howard University) and Eric Ngang Che (U. Buea).

Who can doubt that with the proliferation of computers, the Internet, the World-Wide Web, e-mail, social networking, and so on, that protecting information has become an increasingly important research activity? The entire field of information security requires specialists in many fields, from software design to hardware design to network management to psychology! But central to understanding the backbone of security is the need for specialization in very sophisticated computational methods that draw from abstract algebra, number theory, statistics, and algebraic geometry among others.

Several hands-on computational experiments will be conducted that will enable the participant to gain an understanding of some of the main techniques that are at the heart of today’s applications in data encryption (cryptology). The participant will also learn how it is that the most important discovery regarding encryption in the computer era is the result of research by Fermat in the year 1640.