Interdisciplinary Dual Degree in Complex Systems and Dynamics

1. Introduction

Complex systems consist of a large number of smaller entities that interact with each other – usually in a nonlinear and stochastic manner. Examples of complex systems can be diverse including, but not limited to, coupled neurons in the brain, spatially distributed interacting systems like the movement of tectonic plates in a planet, transportation network of a large metropolitan, online social networks like Twitter and Facebook, and the ocean-atmosphere coupling in the climate system. Predicting phenomena such as brain epilepsy, climate change and global warming, pandemics, failure of networks involving distributed computing, power or transportation, species extinction in biological ecosystems, earthquakes, bio-mimetic flows and fluid-structure interactions, viral social media posts, forecasting financial crisis, crowd management etc.; these require a deeper understanding of the overall dynamics of the associated multi-physics systems and a complex system approach to investigate it. Mathematical models of such systems are complex, are typically nonlinear and stochastic and involve modeling the coupling between the interacting individual systems. The traditional reductionist approach that builds an understanding of the individual components, is not suitable for analyzing the collective behaviour. This necessitates the development of new techniques and approaches that have come to be known collectively as complex systems approach.

This is a rapidly emerging interdisciplinary field that enables bridging the gap between fundamental knowledge and mathematical models with the empirical observations as well as copious dataset available on account of the advent of new technological innovations that were unthinkable even a few years ago The identification, organization and analysis of such data need to draw on the methods of data mining, artificial intelligence, neural nets and deep learning algorithms. The efficient use of this data in conjunction with the methods of probabilistic and causal analysis can lead to significant improvements in the construction of realistic models, as well as in the prediction of catastrophic events such as earthquakes, fluid structure interaction problems, power grid collapses, stock market collapses, and pandemics of disease that can occur in such systems. The impact of these technical skills has the potential to directly address global challenges arising from human-nature interactions such as, climate change, pandemics, mass migration and ecological disorders, together with the possibility of harnessing technology towards growth and the improvement of life and the environment.

2. Program Objectives

The aim of the proposed program is to introduce students to new techniques and tools for mathematical modelling and analysis of complex dynamical systems and to investigate some of the challenging dynamical problems in climate science, neuroscience, biological systems, Multiphysics systems and active flows, that are the focus of current research worldwide. In addition to enhancing the fundamental understanding of the universal features, which contribute to similar phenomena that occur across a diversity of systems, the effort could also translate into delivering technology which is useful in industrial and societal contexts.

The primary objectives are to train students

- In building network based mathematical models for large scale complex dynamical systems using observational data and use the new theories of complex networks for analysis
- In theories of nonlinear dynamical systems that enables analysis of complex systems which are inherently nonlinear
- In high performance computing skills and data analysis

To achieve these objectives, the course curriculum consists of three compulsory core courses

(a) one from Complex Networks basket that introduces students to complex networks analysis
(b) one from Nonlinear Dynamics basket that exposes students on this subject
(c) one from a select set of Mathematics and Numerical Techniques courses. The courses have been selected to ensure that students can cater to be trained in appropriate skill sets that will be more suitable for their project.

The electives are to be selected from a basket of carefully curated courses that encompass the interdisciplinary nature of the program. The electives can be selected from courses on Data Science, High performance computing, as well as a mix of elective courses applicable to diverse engineering fields, which will enable the students to combine the traditional skills with the new approaches of complex dynamical systems.

Semester VI

Sl. No	Course No	Course Name	L	T	E	P	O	C
1	Core 1 (any one)	Core Basket 1	4	0	0	0	8	12
		Core Basket 2	3	0	0	0	6	9
		Total Credits				**12 or 9**		

Semester VII

Sl. No	Course No	Course Name	L	T	E	P	O	C
1	Core 2 (any one)	Core Basket 2	3	0	0	0	6	9
		Core Basket 1	4	0	0	0	8	12
		Total Credits				**9 or 12**		

Semester VIII

Sl. No	Course No	Course Name	L	T	E	P	O	C
1	Core 3	Core Basket 3	3	0	0	0	6	9
		Total Credits						**9**

Summer

Sl. No	Course No	Course Name	L	T	E	P	O	C
1	ID5890	Project – I	0	0	0	0	20	15
		Total Credits						**15**

Semester IX

Sl. No	Course No	Course Name	L	T	E	P	O	C
1	ID5891	Project – II	0	0	0	0	30	30
		Total Credits						**30**

Semester X

Sl. No	Course No	Course Name	L	T	E	P	O	C
1	ID5892	Project – III	0	0	0	0	40	40
		Total Credits						**40**

Note:
Core Courses – 30 credits
Electives – 45 credits (5 x 9 credit courses or 3x12 credits +1x 9 credit course)
Project – 85 credits
Total IDDD credits - 160

- Core 1 and Core 2 must be completed by Semester 7.
- Core 3 can be credited in Semester 8 in lieu of Semester 9
- Electives are to be completed in Semesters 7, 8 and 9.

Core Basket 1: Networks								
ID XXXX	Complex Networks	4	0	0	0	8	12	New
EE5154	Complex Network Analysis	4	0	0	0	8	12	Existing
CS6012	Social Network Analysis	4	0	0	0	8	12	Existing

*The proposed new course on ID XXXX Complex Networks will be offered by a faculty from thisteam.

Core Basket 2: Nonlinear Dynamics								
AM5650	Nonlinear Dynamics	3	0	0	0	6	9	Existing
PH5500	Dynamical Systems	3	0	0	0	6	9	Existing
PH5830	Advanced Dynamical Systems	3	0	0	0	6	9	Existing
MA6050	Dynamical Systems	3	0	0	0	6	9	Existing

*At least AM5650 & PH5500 will be offered by faculty members from this team.

Core Basket 3: Mathematics and numerical analysis								
PH5050	Mathematical Physics II	3	0	0	0	6	9	Existing
PH5730	Methods of Computational Physics	3	0	0	0	6	9	Existing
MA5470	Numerical Analysis	3	0	0	0	6	9	Existing
MA6005	Applied Linear Algebra	3	0	0	0	6	9	Existing
MA5014	Applied Stochastic Processes	3	0	0	0	6	9	Existing
MA5312	Stochastic Differential Equations	3	0	0	0	6	9	Existing
MA5890	Numerical Linear Algebra	3	0	0	0	6	9	Existing
MA5892	Numerical Methods in Scientific Computing	3	0	0	0	6	9	Existing
AM5117	Analytical Methods in Engineering Mechanics	3	0	0	0	6	9	Existing
AM5600	Computational Methods in Mechanics	3	0	0	0	6	9	Existing
AS6520	Mathematics for Aerospace Engg	3	0	0	0	6	9	Existing

Electives basket								
MA5013	Applied Regression Analysis	3	0	0	0	6	9	Existing
AM5340	Stochastic processes in mechanics	3	0	0	0	6	9	Existing
AM5630	Foundation of Computational Fluid Dynamics	3	0	0	0	6	9	Existing
AM5116	Structural Control	3	0	0	0	6	9	Existing
AM5450	Fundamentals of Finite Element Analysis	3	0	0	0	6	9	Existing
AM5030	Linear Dynamical Systems	3	0	0	0	6	9	Existing
AM6513	Advanced Computational Fluid Dynamics	3	0	0	0	6	9	Existing
AS6050	Dynamic Fluid Structure Interaction	3	0	0	0	6	9	Existing
AS5850	Finite Element Analysis	3	0	0	0	6	9	Existing
AS5470	Unsteady aerodynamics of moving bodies	3	0	0	0	6	9	Existing
AS6041	Advanced CFD-Eddy Resolving Methods	3	0	0	0	6	9	Existing
BT6270	Computational Neuroscience	3	0	0	0	6	9	Existing
CH5350	Applied Time Series Analysis	3	0	0	0	6	9	Existing
CH6020	Computational Fluid Dynamics Tech	3	0	0	0	6	9	Existing
CH5230	Data driven modelling of Process Systems	3	0	0	0	6	9	Existing
CH6760	Hydrodynamics of Complex Fluids	3	0	0	0	6	9	Existing
MA5013	Applied Regression Analysis	3	0	0	0	6	9	Existing
ME6151	Computational Heat and Fluid Flow	3	0	0	0	6	9	Existing
ID6107	Perturbation Methods for Engineering Problems	3	0	0	0	6	9	Existing
PH5010	Mathematical Physics-1	4	0	0	0	6	10	Existing
XXXXXX	Parallel Scientific Computing	3	0	0	1	6	10	New
BT5240	Computational Systems Biology	4	0	0	0	6	10	Existing
CH5019	Mathematical Foundations for Data Science	4	0	0	0	8	12	Existing
CS5011	Introduction to Machine Learning	4	0	0	0	8	12	Existing
CS5820	Probability and Computing	4	0	0	0	8	12	Existing
CS6023	GPU Computing	4	0	0	0	8	12	Existing
CS6750	Grid Computing	4	0	0	0	8	12	Existing
CS6847	Cloud Computing	4	0	0	0	8	12	Existing
CS6440	Distributed Computing	4	0	0	0	8	12	Existing
CS 6310	Artificial Neural Networks	4	0	0	0	8	12	Existing
CS7015	Deep Learning	4	0	0	0	8	12	Existing

The projects are expected to be on the following areas: climate science, computational neuroscience, machine learning in fluid dynamics, complex flows and physics of living matter, urbanclimate modelling, machine learning in climate science, dynamics of multi-physics systems such us fluid structure interactions, dynamics of social behaviour, causal dynamical networks, stochastic dynamics of spatio-temporal systems etc.

4. Employment opportunities

Students graduating from this program will be proficient in the theories and techniques of modelling and analysis of complex dynamical systems, curating voluminous data for mathematical modelling, high performance computing and will have hands-on experience in applying these techniques for analysis of cutting edge niche problems that encompass fields of electrical engineering sciences, mechanical engineering sciences, biology, physics and mathematics. This is an emerging field and students trained in this area will have opportunities for placement in niche companies and start-ups dedicated to analysis of problems that typically have been difficult for mathematical modelling and analysis.