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EDITORIAL ANNOUNCEMENT

From integro-differential models to data-oriented approaches for emergent phenomena

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Many systems across the physical, biological and social sciences consist of numerous interacting agents, whose collective behaviour often generates emergent and complex phenomena that are absent in systems of non-interacting agents. Modelling and analysing these collective behaviours using the language of partial differential equations is a delicate mathematical challenge.

As the systems we study grow larger, more complex and more interconnected, the modelling and analytical techniques required to understand them also become increasingly sophisticated. This complexity often calls for a statistical perspective, focusing on the evolution of entire populations of agents. In such cases, kinetic equations – and more generally, integro-differential equations – prove particularly useful. These frameworks offer flexible modelling approaches that describe the evolution of many-agent systems in statistical terms, linking microscopic decision-making tasks to macroscopic observable patterns and thereby permitting an efficient investigation of emergent collective phenomena. This powerful tool attracts not only engineers and domain experts for modelling purposes but also mathematicians, who study the equations in broader settings and examine their analytical and numerical properties.

Given the growing interest and the need for comprehensive tools in this field, we believe it is timely to present a special issue that summarises key mathematical insights while showcasing the application of these theories and numerical methods across various research domains.

This special issue includes 11 papers contributed by experts with a wide range of expertise. The collected works cover diverse topics, including numerical strategies such as kernel methods, consensus-based optimization, and neural ordinary differential equations (ODEs). They also span applications in the physical sciences, such as quantum synchronization, as well as in social and biological systems, including studies on the Cucker–Smale model, cancer invasion, opinion dynamics, swarming rigid bodies and Kuramoto oscillators. While this issue is not an exhaustive representation of the field, it offers a valuable snapshot of the broad and growing body of work in this area.

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