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| **Protocolo de tesis que para obtener el título de** |
| **Licenciado(a) en Física** |
| **Escriba en este espacio el título del protocolo,**  **mismo que será el título de la tesis** |
| **Presenta** |
| **Nombre del estudiante** |
| **Director: Nombre del Director o Directora** |
| **Guadalajara, Jal., Mes Año** |

1. **Introduction**

The Ising model is a foundational concept in statistical physics, originally developed to understand phase transitions in ferromagnetic systems. It represents a simplified framework where each site on a lattice is occupied by a magnetic moment, or "spin," which can take one of two values: up (+1) or down (-1). These spins interact with their nearest neighbors, and the system's overall energy depends on the alignment of adjacent spins, with a tendency for neighboring spins to align in the same direction due to ferromagnetic coupling. Despite its simplicity, the Ising model captures the essential features of complex phenomena like spontaneous magnetization and critical behavior near phase transitions.

Beyond its origins in statistical physics, the Ising model has found wide-ranging applications in fields such as sociophysics, biology, and economics. In the study of binary opinion dynamics, models inspired by the Ising framework are frequently used to investigate how opinions evolve and spread within a population. Each individual or agent, holds one of two opposing views and evolves based on interactions with their neighbors given by the dynamical rule of the model. Dynamical rules have been developed to emulate the features of social phenomena such as social pressure, cultural bias, rigidity, etc. A well-known social phenomenon that affects society's opinion consensus is the external influence of social media, news, political pressure, or widespread societal trends. To simulate this phenomenon, we introduce an external field into the models: BS model \cite{Biswas2011} and Weighted influence (WI) \cite{Biswas2013}. Both models mimic social pressure through its dynamical rule but WI also implements an influence parameter which is the relative influencing ability of the two groups.

This external field acts similarly to an external magnetic field in the Ising model, biasing the opinions of individuals toward a particular state, regardless of their local interactions. This extension adds another layer of realism to models of opinion dynamics, capturing the complex interplay between internal social forces and external interventions.

The dynamics of the Ising model are driven by changes in temperature. Quenching dynamics, in particular, occur when the system is suddenly cooled, initiating a rapid transition from a disordered to an ordered state. This sudden drop in temperature causes the formation and growth of aligned spin domains, where the system undergoes a process of coarsening as it approaches equilibrium. This process is characterized by universal scaling laws. A central aspect of this scaling is the emergence of power-law behavior. Dynamical exponents, such as the growth exponent , persistence exponent , and the autocorrelation exponent describe how the system evolves towards consensus. These exponents provide insight into the universality class of the system's dynamical behavior.

We extend our study to the effects of the external field on the binary opinion dynamics models which has gained considerable attention due to its relevance in understanding social phenomena such as consensus formation, polarization, and the spread of information. In these models, an individual's opinion is typically represented by binary states, modeled by spins of Ising spin systems, which evolve based on interactions with their neighbors given by the dynamical rule of the model.

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1. **Antecedentes**

**The models**

The **Ising model** describes a system of interacting spins placed on a lattice. Spins are intrinsic angular momenta associated with particles, such as electrons, that exhibit magnetic properties. In the Ising model, these spins can take only two values: "up" or "down," typically represented by +1 and -1, and can only interact with their nearest neighbors.

The energy of the system is quantified by the Hamiltonian:

where represents the sum of interacting pairs. In 1D we have for two neighbors and with periodic boundary conditions. A yields a ferromagnetic behavior where the spins tend to align in the same direction, in this project, we are using . A second term can be added to associate the potential energy due to an external magnetic field.

here will be an important feature as we are going to study the constant and random binary field cases and is the magnitude which we consider .

**BS-model (Domain-size dependent dynamics)**

The main idea of the **BS-model** is modeling social pressure assuming that the size of the neighboring domains of the selected spin is proportional to the number of people with the same opinion.

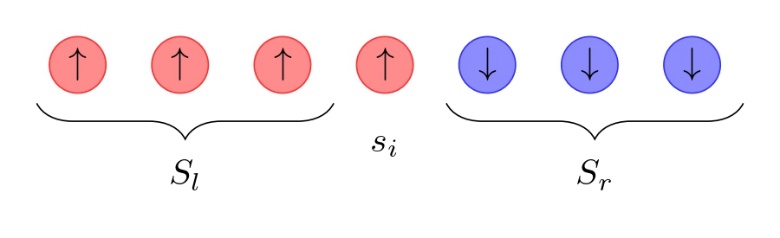


Figure 1 Seven interacting spins, have two neighboring domains and .

The **WI-model (Weighted influence)**, on the other hand, implements a bias for a specific state introducing the parameter, which is called the relative influence factor.

In this model the dynamical rule is determined by the probability of flipping up or down, when we implement an external magnetic field the probability of a spin flipping up follows the equation:

where in a selected site, and are the negative and positive domain respectively, is the local external magnetic field and is the relative influence parameter. The probability of flipping down is:

Due to the influence of an external magnetic field, when a spin is selected into a domain, there is still a low probability of flipping to the opposite state. For example, the probability of flipping to the down state is given by:

The non-zero probability allows spins to adopt up states, enabling spontaneous flips even when the spin is energetically favored to stay aligned. This behavior contributes to nucleation phenomena, where small regions of oppositely aligned spins can emerge and potentially grow over time.

This study considers two external fields: a constant and a random binary field. The constant field is set to a value of +1, while the random binary field is generated with a random uniform distribution of values +1 and -1.

The dynamical rules followed by these models are related to the energy of the spin system. The minimum energy occurs when all spins align in the all-up or all-down state, while the maximum energy corresponds to a random configuration. Then, the consensus is reached once the system is at its minimum energy state. To minimize energy, we calculate the energy change of flipping the selected spin . Let represent the selected spin, while and denote the nearest neighboring domains, as illustrated in Figure 1. Then, is calculated as:

A system that follows this dynamical rule is seeking the minimum energy state i.e. it self-organizes to the all-up or down state \cite{Glauber1963}. This leads the entire population to reach a consensus. A typical situation is shown in Figure 1, neighboring domains anneal one another, after which the external magnetic field determines the spin state.

The behavior of magnetizationhas been studied for 1D Ising Model with Hamiltonian of Eq.1 \cite{1Dcoarsening, autoExp, Persistence}, and it's known that this quantities evolve as power law with its respective dynamical critical exponents. In this section, we define these quantities and present the known results.

**Measurements**

During the system's time evolution, spins interact, forming regions that compete for dominance in determining the final equilibrium configuration, these regions are called domains. In Ising spin systems in 1D, this coarsening process is typically characterized by a power-law growth of domain size in which the average domain size scales as

where is known as the growth exponent. To analyze this coarsening process computationally, a typical measurement is **fraction of domain walls**  representing the total number of domain walls per lattice size, where domain walls are the interface between regions. This quantity is related to by relation

Another typical measurement is **magnetization** which is calculated as the absolute value of the average spin states over the lattice Magnetization is also related to growth exponent by equation

For the Ising model BS and WI models the growth exponent is z \simeq 1.0.\cite{Biswas2011,Biswas2013}.

1. **Justificación**

The study of zero-temperature quenching dynamics of spin systems under external fields is a critical step in understanding the behavior of physical systems under non-equilibrium conditions. Spin systems, such as the Ising model, provide an idealized yet robust framework for examining how interactions and external fields drive the evolution of states in a system. At zero temperature, the dynamics become particularly intriguing, as thermal noise is absent, allowing for the pure influence of deterministic or stochastic interactions to dictate the evolution.

Quenching a system reveal how systems relax, align, or stabilize under the influence of local interactions and global biases. This study employs Monte Carlo simulations to explore these phenomena, focusing on the interplay between quenching rates, external field strength, and the resulting spin alignment dynamics. Such analyses deepen our understanding of non-equilibrium statistical mechanics and the role of external fields in guiding system evolution.

This research is expected to yield novel insights into the relaxation processes and metastable states that emerge in spin systems at zero temperature. By systematically analyzing the effects of external fields on spin alignment, the project contributes to the broader understanding of domain growth and coarsening behavior. The knowledge generated will also enrich ongoing discussions about the universality of non-equilibrium dynamics in diverse systems.

By extending the spin system framework to binary opinion models, this research highlights the parallels between physical and social systems. The incorporation of stochastic dynamics, external influences, and domain-based interactions in opinion models provides fresh insights into processes like consensus formation, polarization, and the impact of external bias. These results could pave the way for better modeling of real-world social phenomena.

Finally, the analogies between spins and opinions allow us to apply well-established physical theories to sociological questions, offering a unified framework for analyzing dynamical systems across disciplines.

Understanding zero-temperature quenching dynamics under external fields addresses fundamental questions about how systems respond to sudden changes in their environment. This knowledge is vital not only for theoretical advancements but also for practical applications in designing and controlling systems in non-equilibrium states. The project stands to make a meaningful contribution to the field of statistical physics and inspire future research exploring similar dynamics in more complex systems.

1. **Objetivo general (usar estilo letra Arial, tamaño 12, negritas, continuar la numeración romana)**

(Usar el estilo letra Arial, tamaño 11, interlineado 1.5, justificado). Los objetivos deben redactarse comenzando con un verbo en infinitivo, con claridad y con base a la hipótesis formulada. Los objetivos deben ser lógicos, claros y alcanzables, deben estar dirigidos a la obtención de conocimientos.

1. **Objetivos específicos (usar estilo letra Arial, tamaño 12, negritas, continuar la numeración romana)**

(Usar el estilo letra Arial, tamaño 11, interlineado 1.5, justificado). Emplear números arábigos para los objetivos particulares (los necesarios para lograr el objetivo general). La redacción de esta sección es forma de lista para los objetivos. Seguir la misma configuración de página, márgenes, subtítulos y texto señalado en la sección de Antecedentes.

1. **Hipótesis (usar estilo letra Arial, tamaño 12, negritas, continuar la numeración romana)**

This study hypothesizes that the dynamics of spin alignment in zero-temperature quenching under external fields are governed by the interplay between local spin interactions and the strength of the external field. Specifically, it is expected that deterministic and stochastic quenching dynamics will produce distinct patterns in domain coarsening and alignment, with stochastic influences leading to novel persistence and relaxation behaviors. Furthermore, the presence of an external field is anticipated to introduce a critical threshold effect, determining whether the system achieves complete alignment or stabilizes in a fragmented configuration. These dynamics are expected to reveal novel universality class characterized by a truncated ordering process. By extending this framework to binary opinion dynamics, we hypothesize that analogous behaviors will emerge, with opinion clusters reflecting spin domains and external biases mimicking external fields.

1. **Metodología (usar estilo letra Arial, tamaño 12, negritas, continuar la numeración romana)**

(Usar el estilo letra Arial, tamaño 11, interlineado 1.5, justificado). La metodología permite conocer las actividades y estrategias seguidas para validar la hipótesis y el cumplimiento de los objetivos planteados. La finalidad principal es describir (y en caso necesario, defender) el diseño experimental y proporcionar detalles suficientes para que pueda entenderse su factibilidad. Se debe mencionar las actividades que se realizarán durante el trabajo experimental, los fundamentos, parámetros y condiciones a medir. Incluir las técnicas, métodos, procedimientos y herramientas estadísticas necesarias, citando siempre las fuentes de información consultadas como se describió en la sección de Antecedentes.

Esta sección se redacta en tiempo futuro (verbos en futuro, tercera persona). La redacción de esta sección es en prosa, en párrafos y no en texto continuo. Seguir la misma configuración de página, márgenes, subtítulos y texto señalado en la sección de Antecedentes. Se recomienda que la sección de metodología no sea mayor a dos páginas.

1. **Cronograma de actividades (usar estilo letra Arial, tamaño 12, negritas, continuar la numeración romana)**

(Usar el estilo letra Arial, tamaño 11, interlineado 1.5, justificado). Se sugiere presentarlo a manera de cuadro, señalando cada una de las actividades a realizar para el desarrollo de la tesis y la obtención del grado en una escala de tiempo (semanas, meses). Corresponde a la síntesis de las actividades más relevantes del trabajo de tesis, las cuales deben responder a los objetivos planteados. El cuadro de abajo es un ejemplo, pudiendo ser modificado a criterio de quien dirige la tesis.

| **Actividad** | **Mes 1, año** | **Mes 2, año** | **Mes 3, año** | **Mes 4, año** | **Mes 5, año** | **Mes 6, año** |
| --- | --- | --- | --- | --- | --- | --- |
| Revisión bibliográfica | **✓** | **✓** | **✓** | **✓** | **✓** |  |
| Elaboración y registro del protocolo de tesis | **✓** |  |  |  |  |  |
| Desarrollo de objetivo general |  | **✓** |  |  |  |  |
| Desarrollo de objetivos específicos |  |  | **✓** |  |  |  |
| Análisis de resultados |  | **✓** | **✓** | **✓** |  |  |
| Elaboración del manuscrito de tesis |  |  |  | **✓** | **✓** |  |
| Defensa de tesis |  |  |  |  |  | **✓** |

1. **Referencias (usar estilo letra Arial, tamaño 12, negritas, continuar la numeración romana)**

Esta sección contiene todas las referencias de los documentos utilizados como apoyo para la realización de los antecedentes, el planteamiento del problema, la hipótesis, la definición de objetivos y/o metodología. Deben incorporarse solamente las referencias que fueron utilizadas para el desarrollo del protocolo de tesis (mínimo 10 referencias).

Como bibliografía pueden citarse capítulos de libros, artículos científicos, notas periodísticas, informes, etc., pero no páginas web. Si usted obtiene información de una página web, vaya al artículo que consultó el sitio para realizar la página web.

Todas las referencias deben estar citadas en el texto como se describe en la sección de Antecedentes. La extensión máxima de este documento debe ser de 7 páginas incluyendo la portada.

El formato de las referencias es Vancouver. Los siguientes son algunos ejemplos:

[1] Aceves-Medina G. et al. “Fish larvae assemblages in the Gulf of California”. Journal of Fish Biology. 2004; 65(3):832-847.

[2] Bakun A. “Global climate change and intensification of coastal ocean upwelling”. Science. 1990; 247(4939):198-201.

[4] INEGI. Mapa Digital de México [Internet]. Available from: https://gaia.inegi.org.mx/mdm6/?v=bGF00j1zLJypMD4LAGxvbjotMTAXLjuWmDAWLoH06MSxs0nMxMTFzZXJ2awNpb3N8dGMxMTFzZXJ2awNpb3N8dGMxMTFzZXJ2aWpNP1. Accessed 2024 Apr 3.

[5] Stewart RH. Introduction to physical oceanography. 2008. Chapter 9, p. 142-144.