Active Diffusion Catechism

2023-AD —— Initiative Overview

Field	Value
Project title	**Towards Active Diffusion** ***A Tale of Multiple (den)Cities***
Short name	2023-AD
Call opened	December 2022
Project start	January 2023
Team Name	The Diffusion Detectives
Facilitators	Jakub Smékal & Daniel Friedman
To join the project as a participant:	1. Read the entire document and prepare any thoughts or questions you have. 2. Email ActiveInference@gmail.com to express interest and provide thoughts (use the project short name 2023-AD in email subject. 3. The details of work, beginning in January 2023, will be communicated to those who have expressed interest.

Mission

- The Mission of 2023-AD is to characterize mathematical formalisms and computational applications of Active Inference and Diffusion Models, and to explore relevant applications.
- Broadly, we are interested in a number of research threads that have impacted the development of applied Active Inference models, such as: Bayesian Graphs, Bayesian Physics, Hierarchical Gaussian Filter (HGF), Forney Factor Graphs (FFG), Predictive Processing (PP), entropy production, and other topics that might become relevant over the course of our research.
- We will combine both theoretical and applied approaches to elucidate the connection between Diffusion Models (DM) used in contemporary Artificial Intelligence research and Active Inference (ActInf) generative models from the cognitive sciences. Specifically, we are interested in exploring how DMs can be used to represent internal beliefs about an agent's environment and their role in decision making and planning under the Free Energy Principle — such that outputs can actually *be* strategic, rather than stochastically parroting the syntax of strategy.

Situation

- This initiative will elucidate and develop connections among Active Inference (ActInf), Diffusion Models (DM), Large Language Models (LLM), and related topics.
    - Active Inference (ActInf) describes perception and action through the lens of Bayesian statistics. In ActInf, each autonomous entity performs inference over the causes of its sensory input and adjusts its internal representations about itself and environment, called beliefs. This belief adjustment is finessed through the duality of perception and action, whereby the agent can either passively alter its model to fit the incoming sensory input (change its mind), or equivalently adjust its sensory input to fit the internal model by interacting with the environment (change the world).

    - Diffusion Models (DM) and the recent Latent Diffusion Models (LDM) are deep learning architectures used to create stochastic representations of their input data and to equivalently remove noise and produce clean outputs. DMs have been successful at learning representations of high-dimensional, complex data and are finding diverse applications in synthetic data generation whereby noise is gradually removed from a noisy prior through a Markov chain.
- ActInf and DM models display many salient areas of similarity. For example:
    - **Fundamentals**: Both ActInf and DM draw important notions from stochastic thermodynamics in their formulation of internal representations.
    - **Implementations**: Both ActInf and DM are deployed using modern computational methods, and are undergoing rapid advancements.
    - **Applications**: Both ActInf and DM have overlapping areas of concern and possible application (e.g. in multimedia, cyberphysical settings, conversational systems).
- This project and direction has multiple possible implications in areas where the models are currently being applied (e.g. ActInf in behavioral neuroscience, DM in multimedia creation) and in emerging areas (e.g. Autonomous Cognitive Agents using Active Diffusion).
- This catechism is being distributed at the end of 2022, to solicit and engage interest in the 2023-AD initiative, which will operate during 2023.

Avenues of Approach

- With the team of committed individuals assembled at the beginning of 2023, we will assess relevant Avenues of Approach from two primary angles: Theoretical and Applied

Theoretical

- Write an analytical paper on the formal relationships between ActInf and DM.
- Provide a thorough review of the relevant literature on LDM and belief propagation in ActInf. We will compare and contrast the mathematical formalism and computational implementations of different models within applied active inference and predictive processing research and attempt to identify the relevant connections to LDMs.
- LDMs succeed in condensing high dimensional input data to latent representations which can be efficiently manipulated. This capacity is analogous to the manner in which agents encode their beliefs about their environment in ActInf. Such an approach might bridge the gap between the continuous and discrete time formulation of generative models in active inference, enabling work intersection of contemporary Artificial Intelligence and ActInf research (e.g. “shared intelligence”).
- The diffusion process itself may have multiple interpretations within the ActInf formalism and we hope to investigate its link to different belief propagation schemes such as variational message passing, marginal message passing, and others. The diffusion process may also connect to different techniques used to make approximations about the latent states of the environment, including the Mean Field approximation and Bethe approximation.
- Different tasks may result in a different classification of LDMs within the perception-action loop, including important questions relating to action selection and planning. The latent state representations in LDMs may also offer a novel way to do sophisticated inference in high-dimensional state-spaces without performing computational operations over all observational modalities.

Applied

- We can generate open source repositories that demonstrate concordances among ActInf, DM, and related methods. Such repositories serve as didactic examples, as well as kernels for related research work.
- We can demonstrate benchmarks on standard datasets and formats (e.g. MNIST diffusion, discrete-time decision tasks, multi-agent simulations).
- After creating an initial theoretical synthesis of Active Inference and Latent Diffusion Models, we will integrate diffusion models within the active inference formalism, building on top of existing implementations, and devise experiments to test the effectiveness of DMs in learning representations of a dynamic environment within the action-perception loop.
- Explore the applicability of individual components within the LDM architectures in the action-perception loop (e.g. UNet architecture) as well as in their theoretical significance (e.g. What is the nature of noising and denoising regimes in the context of dynamic, nested Markov Blankets? What does an “Active Diffusion” look like in terms of inference about action?)
- Leverage the abilities of ChatGPT and related LLM models and tools to develop interactive systems capable of inference and action.
- Utilize the complex adaptive dynamics Computer-Aided Design (cadCAD) package to develop frameworks, use cases, and applications in cognitive ecosystems design, wherein we can leverage the power of diffusion models to scale previously limited experiments of multi-agent systems. The use of cadCAD will also open up the possibility to explore the connection between DMs and ActInf from the perspective of category theory, in particular generalized dynamical systems. This work will continue to develop the Active Blockference package and extend its capabilities.
- Consider and co-create the future of Decentralized Science (DeSci) ecosystems, in terms of how such systems will be enabled and challenged by rapid technological development.

Milestones

- To be determined in January 2023 by the team assembled.