Algorithmic Information Dynamics in Supply Chain Management

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Outline

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Background

“It seems to me that the most important discovery since Gödel was the discovery by Chaitin, Solomonoff and Kolmogorov of the concept called Algorithmic Probability which is a fundamental new theory of how to make predictions given a collection of experiences and this is a beautiful theory, everybody should learn it, but it’s got one problem, that is, that you cannot actually calculate what this theory predicts because it is too hard, it requires an infinite amount of work. However, it should be possible to make practical approximations to the Chaitin, Kolmogorov, Solomonoff theory that would make better predictions than anything we have today. Everybody should learn all about that and spend the rest of their lives working on it.”

Marvin Minsky
Panel discussion on The Limits of Understanding
World Science Festival
NYC, Dec 14, 2014

Background

Algorithmic Information Dynamics is a probabilistic framework for causal analysis. It combines three important elements:

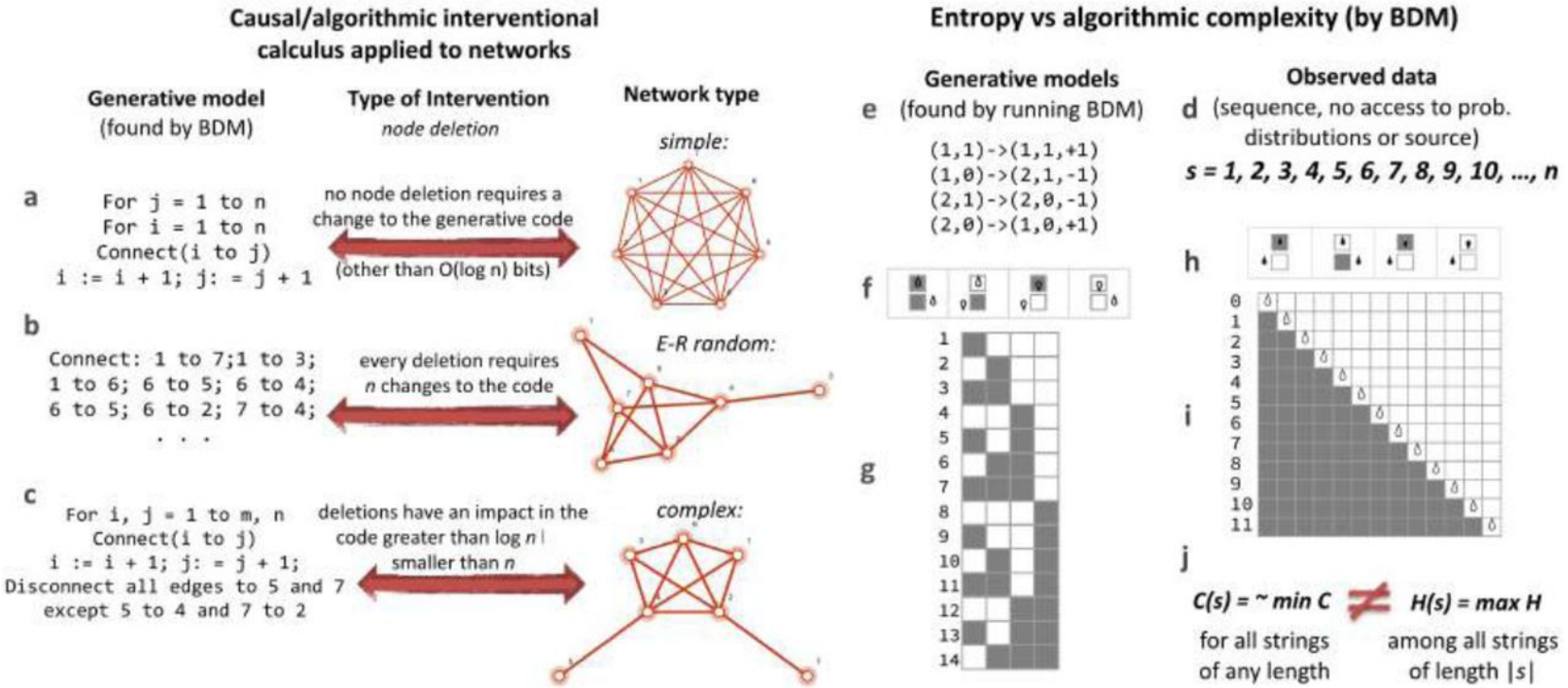
- **Information Theory:** Quantify the amount of uncertainty in the value of a random variable or process.
- **Algorithmic Complexity:** Compute probability of an object being produced by a computable mechanistic set of rules.
- **Causal Analysis:** Perturb networks to measure the change in algorithmic probability and thereby identify the importance of that edge/node toward constructing that object.

Methods

- **Coding Theorem Method (CTM):**
  - Generate short computer programs in a Turing Universal language to generate the desired mathematical object.
  - This is difficult to do for large objects, so we use the following method as a divide and conquer method to estimate the algorithmic complexity of the object.
- **Block Decomposition Method (BDM):**
  - Precompute CTM values for all possible small objects of a given type and store them in a table to efficiently look them up.
  - Decompose larger objects into smaller sizes for which we've computed CTM values.
  - Sum together the CTM values to get a global estimate of Kolmogorov complexity.
  - BDM is bounded above by Shannon entropy and below by algorithmic complexity.

https://www.algorithmicdynamics.net/

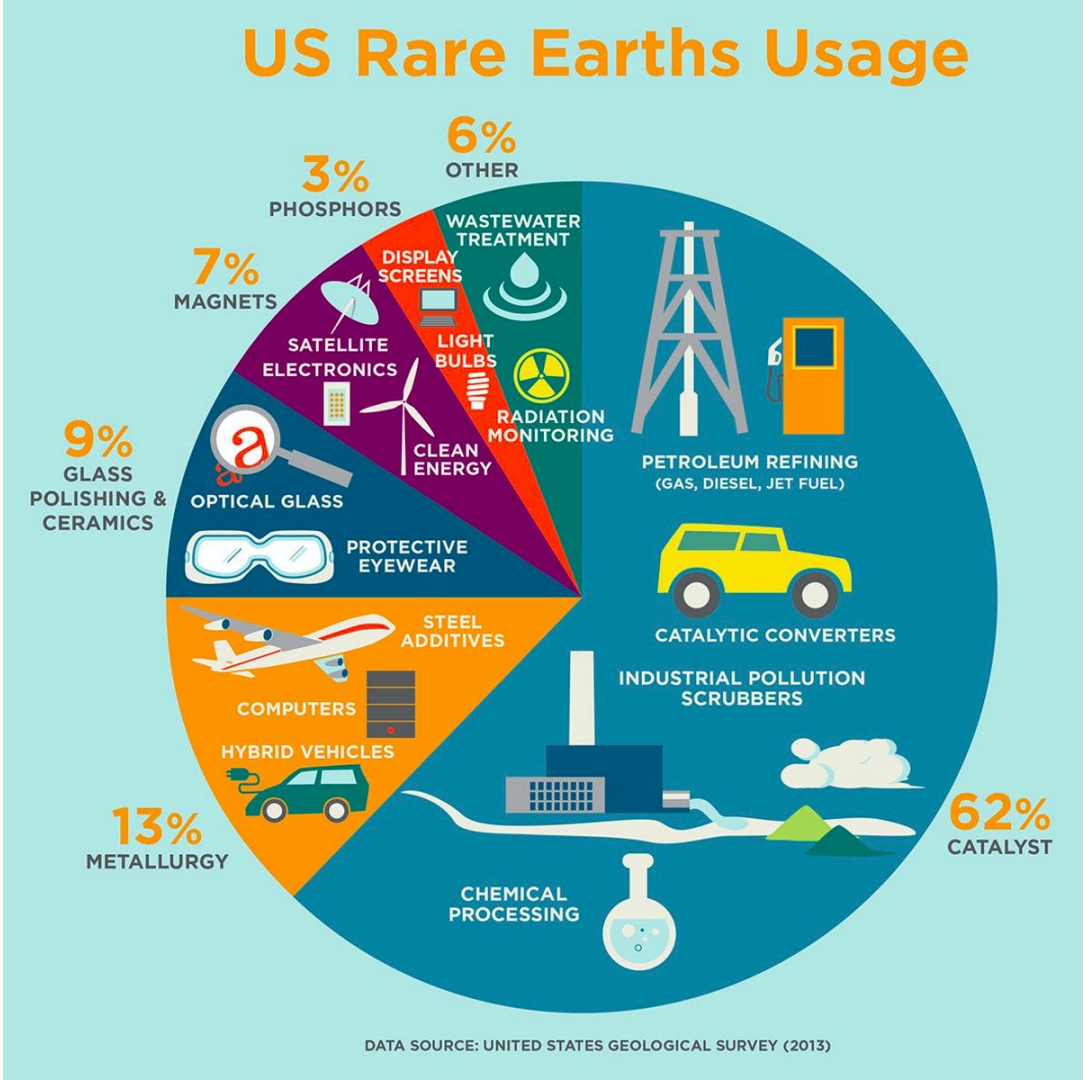
Methods



"An Algorithmic Information Calculus for Causal Discovery and Reprogramming Systems" (Zenil et. al, 2018)

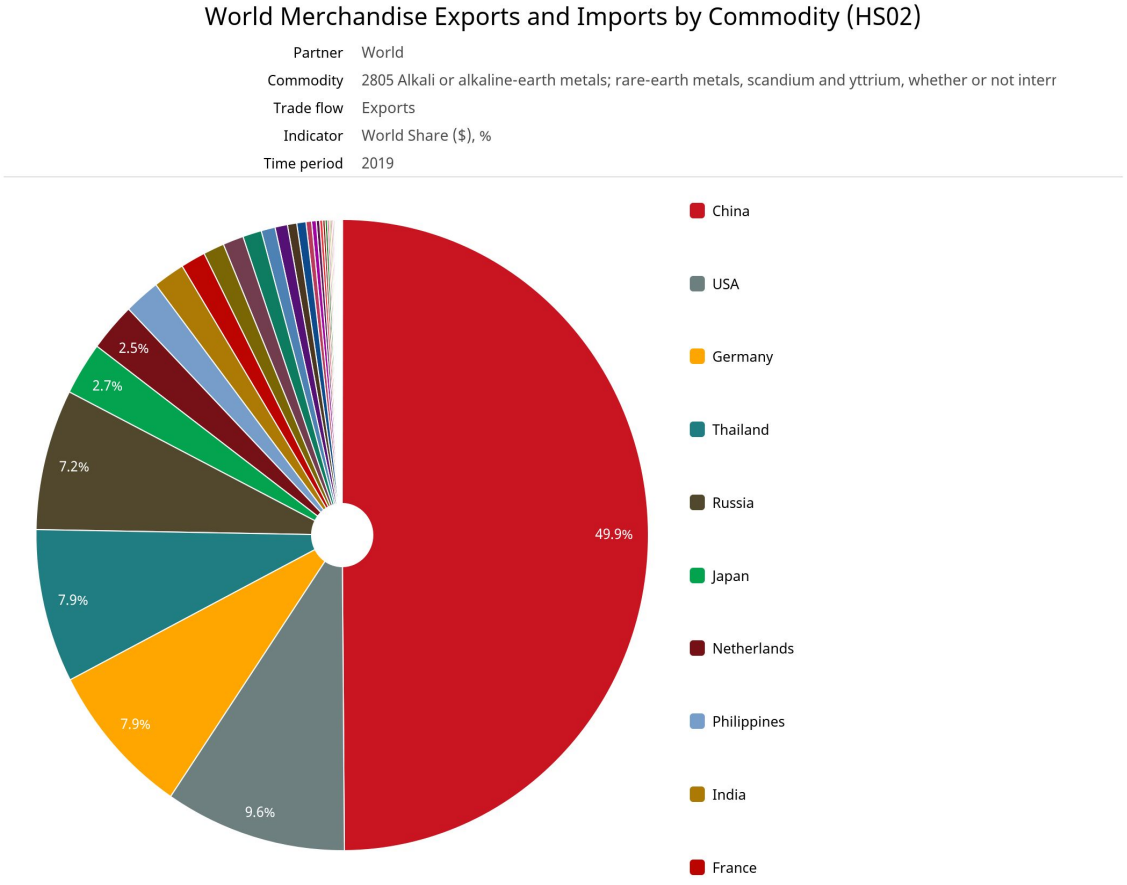
Applications

- Although the worldwide value of rare earth imports in 2019 was only $1.15 billion, rare earth elements are essential in manufacturing numerous high-value products.
- We analyzed global trade of rare earth metals in 2019 using data from the International Trade Statistics Database.



Applications

- Constructed a network for worldwide imports of rare earth metals (REM), and conducted BDM-based Perturbation Analysis.
- Validated that the top 5 exporters of rare earth metals were vital in generating causal models of the REM network.



UN Comtrade Database

Future Directions

- Utilize AID to identify logistical bottlenecks in supply chain networks and unravel causal relationships in data.
- Intersect this with Climate Change models using GIS data in order to quantify the robustness of supply chains to potential perturbations, particularly in the South China Sea where there is high trade volume and climate risk.
- Develop causal reinforcement learning models based on AID to automatically generate alternative supply chain processes that maximize profit while minimizing climate risk.