computability theory and computational economics

Introduction to Computability Theory and Computational Economics

The intersection of computability theory and computational economics offers a powerful lens through which to understand the fundamental limits and possibilities of economic modeling and decision-making. Computability theory, a cornerstone of theoretical computer science, delves into what can and cannot be computed algorithmically. In parallel, computational economics leverages computational methods to analyze, simulate, and solve complex economic problems. This article explores the profound synergy between these two disciplines, examining how the principles of computability theory inform our understanding of economic complexity, the limits of prediction, and the design of intelligent economic systems. We will investigate key concepts such as decidability, complexity classes, and the implications of uncomputable problems for economic forecasting, market design, and artificial intelligence in economics. By understanding what is computationally feasible, we can better navigate the intricate landscape of economic phenomena and develop more robust and insightful economic models.

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The Foundations of Computability Theory

Computability theory, also known as recursion theory, investigates the capabilities and limitations of algorithms. At its core, it seeks to answer the question: "What problems can be solved by a mechanical procedure?" This field originated from the work of mathematicians and logicians like Alan Turing, Alonzo Church, and Kurt Gödel, who sought to formalize the notion of computation. The Turing machine, a theoretical model of computation, is central to this understanding. It is an abstract machine that manipulates symbols on an infinite tape according to a table of rules. The Church-Turing thesis posits that any function that can be computed by an algorithm can be computed by a Turing machine.

Key concepts in computability theory include decidability and enumerability. A problem is decidable if there exists an algorithm that can determine, in a finite amount of time, whether an input satisfies a given property. Conversely, a problem is undecidable if no such algorithm exists. Undecidable problems, such as the Halting Problem, represent fundamental limits on what can be computed. The Halting Problem asks whether it's possible to determine, for an arbitrary program and an arbitrary input, whether the program will eventually halt or run forever. Turing proved that this problem is undecidable.

Turing Machines and the Limits of Computation

The Turing machine serves as a universal model of computation. Its simplicity belies its power, as it can simulate any other computing device. The concept of a universal Turing machine, capable of simulating any other Turing machine, is crucial. This universality implies that if a problem can be solved by any computational process, it can be solved by a Turing machine. This theoretical framework provides a rigorous definition of what it means for a function to be computable and sets the stage for understanding the inherent limitations of algorithmic processes.

Decidability and Undecidability in Formal Systems

Decidability refers to the existence of an algorithm that can determine, for any given input, whether it belongs to a specific set or satisfies a particular property. If such an algorithm exists, the problem is decidable. If not, it is undecidable. Many fundamental problems in logic and mathematics have been proven to be undecidable. For instance, Hilbert's tenth problem, concerning the Diophantine equation solvability, was shown to be undecidable by Yuri Matiyasevich. This concept of inherent uncomputability has significant implications when applied to complex domains like economics.

The Church-Turing Thesis: A Formal Definition of Computability

The Church-Turing thesis is a fundamental conjecture in computer science that states that any function that can be computed by an algorithm can be computed by a Turing machine. While it is a thesis and not a theorem (as "algorithm" and "computable" are informal notions), it is universally accepted due to the equivalence of many different formal models of computation, including lambda calculus and recursive functions. This thesis provides a robust foundation for understanding the scope of algorithmic problem-solving.

What is Computable in Economics?

In the realm of economics, almost every practical problem we attempt to solve is, in principle, computable. This means that, given sufficient computational resources and a well-defined problem statement, an algorithm can be devised to find a solution or approximation. Economic models, whether they involve calculating optimal resource allocation, forecasting market trends, or simulating agent behavior, are generally formulated using mathematical constructs that are amenable to algorithmic processing. The development of sophisticated software and algorithms has enabled economists to tackle increasingly complex datasets and model intricate economic systems.

Examples of computable economic problems include: calculating equilibrium prices in a general equilibrium model, solving optimization problems for firms and consumers, simulating the effects of fiscal or monetary policy, and performing statistical analysis on large datasets to identify economic patterns. The advent of computational power has transformed economic research, allowing for the exploration of models that were previously intractable due to their complexity. However, the efficiency of these computations, rather than their mere possibility, often becomes the critical factor.

Economic Modeling as Algorithmic Processes

Economic modeling often translates into a series of algorithmic steps. Whether it's dynamic programming for optimal consumption and investment decisions, iterative methods for finding market equilibria, or agent-based simulations of market dynamics, these all rely on well-defined computational procedures. The translation of economic theories into computable models is a key activity in computational economics, enabling empirical validation and policy analysis.

Solvable Problems in Economic Theory

Many foundational economic problems are indeed solvable. For instance, finding the Nash equilibrium in a finite, two-player game is known to be computationally feasible. Similarly, linear programming can solve a vast array of resource allocation problems that are central to microeconomics. The ability to compute these solutions allows economists to test hypotheses and derive practical insights from theoretical frameworks.

The Role of Numerical Methods in Economic Analysis

Numerical methods are indispensable in computational economics. When analytical solutions are not available, economists resort to numerical techniques to approximate solutions. These include methods like finite difference methods for differential equations, Monte Carlo simulations for stochastic models, and optimization algorithms for complex objective functions. The computability of economic problems often relies on the effectiveness of these numerical approximations.

Uncomputability in Economic Models

While many economic problems are theoretically computable, the principles of computability theory reveal that certain economic phenomena or the exact solution to some idealized economic models might be inherently uncomputable. This arises when economic models, if formalized precisely, lead to problems equivalent to known undecidable problems. For example, if an economic system's behavior is described by a process that can be mapped to the Halting Problem, then perfectly predicting its long-term state or determining whether it will reach a certain stable condition becomes impossible algorithmically.

The implications of uncomputability in economics are profound. They suggest that perfect foresight or exact prediction in certain complex economic scenarios may be unattainable. This doesn't mean we cannot model or approximate these systems, but rather that there are inherent limits to the precision and certainty we can achieve through algorithmic means. Understanding these limits helps economists focus on developing robust approximations and decision-making strategies that are effective even in the face of fundamental unpredictability.

The Halting Problem's Shadow on Economic Forecasting

The undecidability of the Halting Problem can be metaphorically extended to economic forecasting. If an economic model's future trajectory depends on a process that can be encoded as a halting problem instance, then perfectly predicting when a particular economic state will be reached or if a crisis will be averted becomes an uncomputable task. This highlights that while we can build sophisticated forecasting models, there will always be an irreducible element of uncertainty stemming from the inherent nature of computation itself.

Undecidable Problems in Market Dynamics

Certain complex market dynamics, especially those involving infinite agent interactions or self-referential rules, might be formalized into problems equivalent to undecidable ones. For instance, determining if a dynamic trading strategy will perpetually remain profitable or if a market will eventually collapse could, in highly abstract or pathological cases, be linked to uncomputable questions. This doesn't mean current markets are uncomputable, but it provides a theoretical bound on what perfect algorithmic analysis can achieve.

Formalizing Economic States as Computable or Uncomputable

The task of formalizing economic states and transitions in a way that directly maps to computability theory requires careful consideration. If an economic system’s state can be represented by configurations of a Turing machine, and its evolution follows the machine's transitions, then the computability of its future states is directly governed by computability theory. This mapping allows us to identify specific economic questions that may be inherently unanswerable algorithmically.

Computational Complexity in Economic Analysis

Beyond decidability, computability theory also encompasses computational complexity, which studies the resources (time, memory) required to solve computable problems. In computational economics, complexity classes like P (problems solvable in polynomial time) and NP (problems solvable in non-deterministic polynomial time, whose solutions can be verified in polynomial time) are critical. Many economic optimization problems, such as finding the optimal assignment of resources or the equilibrium in complex markets, are NP-hard, meaning they are believed to be computationally intractable for large instances.

Understanding these complexity classes helps economists appreciate the practical limitations of finding exact solutions for real-world economic problems. It guides the development of approximation algorithms and heuristics. For instance, instead of finding the absolute best solution to a large combinatorial optimization problem in economics, we might aim for a good-enough solution that can be found efficiently.

Complexity Classes: P, NP, and NP-Hardness in Economics

Problems in class P are generally considered computationally tractable. Many standard economic calculations, like linear programming, fall into this category. NP-hard problems, on the other hand, are believed to require exponential time to solve exactly in the worst case. Examples in economics include the Traveling Salesperson Problem (relevant for logistics and supply chains) and certain forms of combinatorial auction design.

The Practical Implications of NP-Hardness for Economic Optimization

The NP-hardness of many economic problems implies that finding the optimal solution for large-scale instances can be prohibitively time-consuming. This necessitates the use of approximation algorithms, metaheuristics, or specialized solvers that can find good solutions within a reasonable timeframe. For instance, a company trying to optimize its supply chain network might use algorithms that provide near-optimal solutions rather than waiting indefinitely for a perfectly optimal one.

Approximation Algorithms and Heuristics in Economic Modeling

Given the prevalence of NP-hard problems, approximation algorithms and heuristics are essential tools in computational economics. Approximation algorithms guarantee a solution within a certain factor of the optimal solution, while heuristics provide good solutions based on experience or intuition, without strict guarantees. The choice between these depends on the specific economic problem and the required trade-off between solution quality and computational cost.

The Halting Problem and Economic Prediction

The theoretical undecidability of the Halting Problem serves as a powerful metaphor for the inherent limits of economic prediction. If an economic system's behavior, or a specific prediction about it, can be mapped to an instance of the Halting Problem, then it is fundamentally impossible to create a perfect, universally applicable predictor. This means that no matter how sophisticated our algorithms or how much data we have, there will always be economic scenarios that defy precise, deterministic forecasting.

This does not imply that economic forecasting is futile. Instead, it suggests that forecasts should be probabilistic, accompanied by measures of uncertainty, and that models should be robust to unforeseen events. It encourages economists to focus on understanding the underlying mechanisms and probabilities rather than aiming for absolute certainty in predicting future economic states. The goal shifts from deterministic prediction to risk management and adaptive strategy.

Mapping Economic Processes to Turing Machines

The conceptual mapping of economic processes to Turing machines is a theoretical exercise. If we can describe the state of an economy and its transition rules in a way that mirrors the operation of a Turing machine, then the computability of its future states is constrained by the theory of computability. For example, a highly deterministic financial market where buy/sell orders are executed based on strict algorithmic rules might, in theory, be representable.

Limits to Perfect Economic Foresight

The undecidability of the Halting Problem implies that there are questions about any system, including economic ones, that cannot be answered by any algorithm. If predicting a specific economic outcome is equivalent to solving an instance of the Halting Problem, then perfect economic foresight is an impossibility. This fundamental limit underscores the importance of probabilistic forecasting and scenario planning.

Probabilistic Forecasting vs. Deterministic Prediction

In light of computability limits, probabilistic forecasting becomes the more realistic and informative approach. Instead of predicting a single future economic outcome, economists aim to assign probabilities to a range of possible outcomes. This acknowledges the inherent uncertainty and allows for better decision-making under risk. Understanding computability helps frame the appropriate goals for economic forecasting efforts.

Computability and Algorithmic Game Theory

Algorithmic game theory is a field that bridges computer science and game theory, focusing on the computational aspects of strategic interactions. Computability theory plays a vital role in understanding what can be computed in games, such as finding equilibria, determining strategy outcomes, and designing mechanisms. For instance, finding a Nash equilibrium in a general game is a computationally challenging problem, and its complexity is deeply rooted in computability theory.

The existence of equilibria is guaranteed by theorems like Nash's, but their computation can be difficult.

For finite games, algorithms exist, but their complexity can be high. For infinite games or games with continuous strategy spaces, the question of computability becomes even more nuanced. Understanding these computational constraints is crucial for designing effective markets, auctions, and other strategic environments.

Finding Equilibria: Computable or Uncomputable?

For many classes of games, finding equilibria is computable, albeit sometimes with high complexity. For example, finding a Nash equilibrium in a finite two-player game can be done using algorithms like Lemke-Howson, which is polynomial time for fixed number of strategies but can be exponential in the number of strategies. However, for certain complex games or specific equilibrium concepts, the problem might be computationally intractable or even uncomputable.

Mechanism Design and Computational Feasibility

Mechanism design, a subfield of game theory, focuses on designing rules for interaction to achieve desired outcomes. The feasibility of a mechanism often depends on its computational tractability. For instance, designing an auction that is incentive-compatible and efficient requires algorithms that can determine optimal bids or allocation rules. If these computational tasks are too complex, the mechanism might not be practically implementable.

The Impact of Computability on Strategic Decision-Making

The understanding of what is computationally feasible influences strategic decision-making. If a competitor's optimal strategy is uncomputable or extremely difficult to compute, then a player might adopt simpler, more robust strategies. This perspective is particularly relevant in areas like cybersecurity, where adversaries may use complex, even computationally intensive, strategies.

Computational Economics: Methods and Applications

Computational economics utilizes a wide array of computational methods to analyze economic phenomena. These methods include numerical simulation, optimization techniques, agent-based modeling, econometrics, and machine learning. The goal is to build more realistic and empirically grounded economic models, test complex theories, and solve problems that are intractable with traditional analytical methods alone.

Applications are diverse, spanning macroeconomic forecasting, financial market analysis, microeconomic modeling of consumer behavior, industrial organization, and policy evaluation. The increasing availability of data and computational power has fueled the growth of this field, enabling economists to explore intricate interactions and emergent properties within economic systems that were previously inaccessible.

Agent-Based Modeling (ABM) in Economics

Agent-based modeling is a powerful computational approach where economic systems are simulated as collections of autonomous agents interacting according to defined rules. This allows for the study of emergent phenomena that arise from micro-level interactions. Examples include modeling market crashes, the diffusion of innovations, and the formation of social networks, all of which can exhibit complex, non-linear behaviors.

Numerical Simulation and Optimization in Macroeconomics

In macroeconomics, numerical simulation and optimization are used extensively to solve dynamic stochastic general equilibrium (DSGE) models. These models capture the interactions between households, firms, and governments and are used for policy analysis and forecasting. Computable general equilibrium (CGE) models are also widely used for analyzing the economy-wide impact of policies such as taxes or trade agreements.

Econometrics and Machine Learning for Economic Data Analysis

Econometrics, the application of statistical methods to economic data, increasingly incorporates machine learning techniques. Machine learning algorithms can handle large, complex datasets, identify non-linear relationships, and improve predictive accuracy. This integration is transforming fields like forecasting, risk management, and the analysis of consumer behavior.

High-Frequency Trading and Algorithmic Finance

The financial sector is a prime example of computational economics in action. High-frequency trading, algorithmic portfolio management, and risk assessment all rely heavily on sophisticated computational models and algorithms. The speed and accuracy of these computational processes are paramount, highlighting the practical importance of efficient algorithms and the theoretical understanding of their limitations.

Implications for Economic Policy and Design

The insights from computability theory and computational economics have significant implications for economic policy and the design of economic systems. Understanding computational limits can inform regulatory approaches, especially in areas like financial markets and artificial intelligence. For instance, the complexity of algorithms used in trading could necessitate specific regulations to ensure market stability.

Furthermore, the ability to computationally model and simulate complex systems allows policymakers to test the potential impact of various policies before implementation. This includes designing more efficient markets, optimizing resource allocation, and understanding the potential unintended consequences of interventions. The focus shifts towards designing systems that are not only theoretically optimal but also computationally feasible and robust.

Regulating Algorithmic Trading and AI in Finance

The increasing prevalence of algorithmic trading and AI-driven financial decisions raises regulatory questions. Policymakers must consider the computational complexity of these systems and their potential systemic risks. Understanding computability helps in designing regulations that can mitigate risks without stifling innovation.

Designing Efficient Markets and Auctions

Computational economics provides tools for designing efficient markets and auctions. By understanding the computational feasibility of determining optimal allocations and prices, economists can design mechanisms that are incentive-compatible, revenue-maximizing (for the seller), and welfare-improving for participants. This often involves ensuring that the calculations required for bidding or participation are computationally manageable.

The Role of Computability in Social Welfare Maximization

When considering policies aimed at social welfare maximization, the computational tractability of achieving these goals is crucial. If a policy requires solving an NP-hard problem to determine the optimal resource allocation for societal benefit, then practical implementation might be impossible. This leads to a focus on designing policies with computable welfare-maximizing strategies.

Data-Driven Policy and Computational Governance

The rise of big data and computational power enables data-driven policy-making. By analyzing vast datasets, policymakers can identify trends, predict outcomes, and tailor interventions. However, the ability to process and interpret this data relies on computable algorithms, and the limitations of these algorithms must be understood for effective computational governance.

The Future of Computability Theory in Economics

The integration of computability theory and computational economics is likely to deepen in the future. As economic systems become more complex and reliant on sophisticated algorithms, understanding their fundamental computational properties will become increasingly important. This includes exploring the computability of new economic models, analyzing the complexity of AI-driven economic agents, and developing robust economic systems in the face of inherent computational limits.

Future research may focus on identifying specific economic problems that are provably uncomputable or computationally intractable in practical settings. This could lead to new theoretical frameworks for economic analysis and inspire the development of novel approaches to economic decision-making and policy design. The ongoing advancements in computing power will also enable the exploration of more complex economic models, pushing the boundaries of what is computationally feasible and further illuminating the interplay between computation and economic reality.

Emerging Economic Models and Computability

As economists develop new models, especially those involving emergent behavior, feedback loops, and adaptive agents, the question of their computability will remain central. Investigating whether these models can be solved or simulated efficiently will be a key area of research.

Artificial Intelligence and the Computability of Economic Agents

The increasing sophistication of AI in economic applications, from automated trading to personalized recommendations, raises new questions about the computability of their strategies and learning processes. Understanding the computational limits of AI agents is vital for predicting their behavior and managing their impact.

Bridging Theoretical Computability and Practical Economic Applications

The ongoing challenge is to effectively bridge the gap between abstract theoretical concepts in computability theory and the practical realities of economic modeling and decision-making. This involves developing methodologies to identify and address computational bottlenecks in economic analysis and policy.

Conclusion

In conclusion, the exploration of computability theory within the domain of computational economics reveals a rich landscape of both possibility and inherent limitation. We have seen how the fundamental principles of computability, such as decidability and complexity classes, provide a crucial framework for understanding what can and cannot be algorithmically achieved in economic modeling and analysis. The undecidability of problems like the Halting Problem offers a powerful metaphor for the irreducible uncertainty in economic prediction, guiding us towards probabilistic forecasting and robust decision-making strategies.

Furthermore, the study of computational complexity highlights the practical challenges of solving many economic optimization problems, necessitating the use of approximation algorithms and heuristics. Algorithmic game theory and various computational economics methods, from agent-based modeling to machine learning, demonstrate the practical application of these concepts in building more realistic models and solving complex economic questions. Ultimately, a deep understanding of computability theory enriches our approach to economic policy and system design, ensuring that our pursuit of optimal outcomes is grounded in what is computationally feasible and robust.

Frequently Asked Questions

How does the concept of computability in theoretical computer science inform models of rational decision-making in computational economics?

Computability theory highlights that not all problems are solvable by algorithms. In computational economics, this translates to understanding the limitations of agents in complex economic environments. If an economic decision problem is uncomputable (or computationally intractable), it implies that agents, even if perfectly rational, might not be able to find optimal solutions within a reasonable timeframe or with available resources, leading to bounded rationality, heuristics, and emergent complex behaviors.

What are the implications of undecidable problems (from computability theory) for economic forecasting and policy-making?

Undecidable problems, such as the Halting Problem, imply that there are fundamental limits to what can be predicted or controlled. In economics, this means certain future economic states or the precise outcomes of policy interventions might be inherently unpredictable, regardless of the sophistication of our models or data. This necessitates building resilience into economic systems and acknowledging inherent uncertainty in forecasting and policy evaluation.

How can complexity classes (P, NP, PSPACE) from computability theory be used to categorize and analyze the difficulty of economic optimization problems?

Complexity classes provide a framework to classify economic problems based on their computational resources (time, memory). Problems in 'P' (polynomial time) are considered efficiently solvable, while 'NP-complete' problems (like many combinatorial optimization tasks in finance or logistics) are thought to be intractable for large instances. Understanding these classes helps economists identify when exact solutions are feasible and when approximate or heuristic methods are necessary for practical economic modeling and decision-making.

In what ways does the study of algorithmic game theory, a field bridging computability and economics, address issues of strategic interaction and equilibrium computation?

Algorithmic game theory uses tools from computability theory to analyze the computational complexity of finding equilibria in games. For instance, finding Nash equilibria in many-player games is often computationally hard. This field explores whether equilibria are computable, how efficiently they can be found, and what this implies for the behavior of agents in markets and strategic settings. It also investigates how computational limitations can lead to different outcomes than predicted by classical game theory.

How does the concept of formal verification, stemming from computability theory, apply to ensuring the robustness and correctness of economic models and algorithms, particularly in finance?

Formal verification uses rigorous mathematical methods to prove the correctness of algorithms and systems. In computational economics, especially in high-frequency trading, algorithmic execution, and complex financial derivatives, formal verification can be used to ensure that the underlying algorithms behave as intended, are free from critical bugs, and adhere to regulatory requirements. This is crucial for building trust and stability in computationally intensive economic applications.

What are the connections between computability theory and the emergence of complex economic phenomena, such as market crashes or evolutionary dynamics, when agents operate with bounded computational capabilities?

When economic agents have limited computational power or face uncomputable problems, their decision-making processes can become simplified or heuristic-driven. This, aggregated across many agents, can lead to emergent behaviors that are difficult to predict from individual rationality assumptions. Computability theory helps us understand the fundamental limits on agent intelligence and information processing, providing a foundation for studying how these limitations can contribute to emergent properties like market volatility, systemic risk, and the evolution of economic strategies.

Additional Resources

Here are 9 book titles related to computability theory and computational economics, with descriptions:

1.

Computability and Logic: A Foundation for Theoretical Computer Science

This foundational text delves into the core principles of computability theory, exploring what can and cannot be computed by algorithms. It lays out the logical underpinnings of computation, introducing concepts like Turing machines, recursive functions, and undecidability. Understanding these limits is crucial for appreciating the challenges and possibilities within computational economics, particularly when dealing with complex economic models.

2.

The Structure of Scientific Revolutions and its relation to Economic Theory

While not directly about computability, this seminal work by Thomas Kuhn provides a framework for understanding paradigm shifts in scientific thought. Its insights are highly relevant to computational economics, as the field itself is undergoing significant evolution. Examining how new computational tools and theoretical approaches emerge and challenge existing economic paradigms offers valuable perspective on the development of the discipline.

3.

An Introduction to Computational Economics

This book serves as an excellent starting point for those interested in the intersection of computation and economics. It covers the basic concepts of economic modeling using computational methods, including simulation techniques, agent-based modeling, and optimization algorithms. The text bridges the gap between economic theory and practical implementation, showcasing how computation can be used to analyze and solve economic problems.

4.

Computability and Complexity from a Theoretical Computer Science Perspective

This text provides a rigorous treatment of computability theory, focusing on the inherent difficulty and resource requirements of computational problems. It introduces complexity classes like P and NP, offering essential tools for analyzing the tractability of economic problems. Understanding these complexities is vital for designing efficient algorithms and assessing the feasibility of computational solutions in economics.

5.

Algorithmic Game Theory

This book explores the synergy between computer science and game theory, with a strong emphasis on algorithmic approaches. It examines how concepts from computability and complexity theory are applied to design and analyze strategic interactions in economic settings. Topics include mechanism design, computational social choice, and the computability of equilibria, all critical for understanding economic behavior in a computationally intensive world.

6.

Computational Complexity: A Modern Approach

This comprehensive volume offers a deep dive into the theory of computational complexity, a field intrinsically linked to computability theory. It covers advanced topics such as randomized algorithms, approximation algorithms, and interactive proof systems. For computational economics, this book provides the theoretical foundation for assessing the tractability of solving complex economic optimization problems and analyzing the limits of rational economic agents.

7.

Agent-Based Computational Economics: From Theory to Practice

This book focuses on the practical application of agent-based modeling (ABM) in economics. ABM, which relies heavily on computational methods, allows for the simulation of decentralized economic systems where agents interact based on simple rules. The text guides readers through building and analyzing these models, offering a powerful computational lens through which to explore emergent economic phenomena and test economic theories.

8.

Theory of Computation: With Applications to Computer Science and Beyond

This work offers a broad perspective on computability theory, demonstrating its relevance across various fields, including economics. It covers fundamental topics like formal languages, automata theory, and computability, while also highlighting the implications of these concepts for real-world problems. The book's applications section is particularly useful for understanding how abstract computability concepts can inform the design and analysis of economic models.

9.

Economic Modeling: Theory, Computation, and Estimation

This book presents a comprehensive overview of economic modeling, integrating theoretical frameworks with computational techniques and estimation methods. It discusses how computational tools are used to build, solve, and validate economic models, encompassing both micro- and macroeconomics. The emphasis on computation makes it highly relevant for understanding how modern economics leverages computability theory to tackle complex empirical and theoretical questions.

Computability Theory And Computational Economics

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