A Note on Look-Ahead in Real Life: Proposed Models and Novel Applications

Burle Sharma, Rakesh Mohanty and Sucheta Panda

November 29, 2024

A Note on Look-Ahead in Real Life: Proposed Models and Novel Applications

*Burle Sharma, **Rakesh Mohanty
Department of Computer Science and Engineering
Veer Surendra Sai University of Technology
Burla, Odisha, India
{*burlesharma, **rakesh.iitmphd}@gmail.com

Sucheta Panda
Department of Computer Application
Veer Surendra Sai University of Technology
Burla, Odisha, India
suchetapanda_mca@vssut.ac.in

***Abstract*—Past, Present and Future are considered to be temporal and logical concepts which are well defined in diversified contexts by human beings for their existence and growth. As human beings, we have the privilege of using our intelligence to mentally execute an activity before physical occurrence of the same in real world. Knowledge of the past, aplomb of present and visualisation for the future correspond to three concepts such as look-back, look-at and look-ahead respectively in real life. Look-Ahead(LA) deals with the future prediction of information and processing of input to produce the output in advance.**

In this article, our main objective is to learn, understand and explore the concept of LA by mapping to diversified practical applications from various domains. We introduce interesting real life scenarios where LA plays a significant role for making a process, system or algorithm efficient. Using the concept of LA, We identify and present many interesting and non-trivial research challenges as future potential research directions. Intuitively, we observe that LA can be used as a powerful tool and framework for future researchers in design of efficient computational models and algorithms for solving non-trivial and challenging optimization problems.

Keywords - Look-Ahead, Optimization, Models, Real-Life Applications

I. Introduction

Every individual's life is based on three phases of timeline such as past, present and future. The past can be mapped to the concept of look-back, present to the concept of look-at and future to the concept of look-ahead. Look-back is the concept which deals with the set of activities performed beforehand as history of the past. In emergency situation we instantly make decision at present by using the concept of look-at. To increase our efficiency and for productive outcome, we think, plan and act ahead of time by using the concept of look-ahead. The decision made in the past cannot be revocable whereas the decision to be made in the future can be adaptable.

Look-Ahead(LA) is one of the ubiquitous concepts which affects significantly the outcomes of various activities in our day to day life. LA deals with future prediction of input information and output. We make better decisions in our life by visualizing and planning for the future. Setting of any goal and attaining an objective to accomplish a task involves planning with looking ahead of time. According to our knowledge there is no standard generalized LA model for solving real life and computing challenges. To address the non-trivial challenge of designing high performance computing models with smart Artificial Intelligence driven approaches and efficient algorithms, we classify computational models into two types such as Look-Ahead(LA) and Non-Look-Ahead(NLA).

The NLA model processes data in a linear sequence without look-ahead, making decisions based solely on the current input. It begins with a Computing Machine for initial data transformations, followed by an Algorithm that generates intermediate results. The System then integrates and processes these results to produce the final output, ensuring efficient but straightforward processing.

The LA model incorporates look-ahead, combining current and future data for more intelligent processing. The Computing Machine integrates both types of data, and the Algorithm applies advanced logic for predictive analysis. The System refines the output using insights from both present and future data, enhancing decision-making and optimizing performance.

Real life problems can be represented as optimization problems for efficient usage of time and cost while solving through a computer.

A. Optimisation Problems

Optimisation is the process of obtaining best solution from a set of feasible solutions. The main aim of optimisation is to minimize the cost or maximize the profit. For instance, before we buy vegetables, we prepare a list of items to be purchased and make a plan to visit multiple vegetable shops in the whole market to learn about the price of vegetables beforehand to minimize the cost. In the manufacturing sector, people strive to manufacture high-quality goods with cheaper cost. An airline company optimizes flight schedules to minimize the fuel cost while meeting passenger demands and crew scheduling constraints. A logistics company must optimize transportation routes to minimize fuel consumption and transportation cost while delivering goods to various locations. A mutual fund manager seeks to minimize transaction costs, such as trading fees and taxes, while rebalancing a fund's portfolio. A home-owner aims to minimize energy costs by optimizing the use of heating and cooling systems, insulation, and renewable energy sources. A package delivery service aims to minimize delivery time and fuel cost by optimizing delivery routes and vehicle assignments. A marketing department minimizes advertising cost while achieving the desired level of brand exposure and customer engagement.

A shopkeeper plans and makes more money by selling fruits, vegetables, and groceries for maximizing profit. A student strives to achieve highest possible grades in an examination by following efficient strategies for maximizing the score. A manufacturing company must decide how many units of a product to produce to maximize profit while considering factors such as production cost, demand, and selling price. An investor aims to maximize portfolio's return while considering risk tolerance, asset allocation, and investment choices. A power plant operator maximizes profit by optimizing the generation of electricity while minimizing fuel consumption and emission. A ride-sharing company maximizes profit by matching drivers with passengers efficiently by considering factors such as demand, distance, and driver availability. A chemical plant manager maximizes the production of a high-value product while minimizing waste and energy consumption. An e-commerce company maximizes profit by optimizing online advertising spending, targeting the right audience, and adjusting pricing strategies.

B. Practical Motivation

In today's fast-paced world, the ability to think ahead is essential. We can anticipate obstacles, strategize actions, and adapt to changes effectively.

Incorporating foresight into our daily diet plan, we prepare breakfast, lunch, evening snacks, and dinner in advance for healthy living. Similarly, healthcare providers use foresight to foresee potential complications, enabling proactive care and improved patient outcomes. By anticipating issues like medication reactions or disease progression, they can tailor treatment plans to prevent escalation, enhancing care quality and patient satisfaction.

In business, foresight allows leaders to predict market trends and adjust strategies accordingly. By anticipating consumer preferences, emerging technologies, and economic conditions, they can position their companies for success, whether launching new products, entering new markets, or diversifying revenue streams.

These examples highlight the importance of looking ahead. This article explores the practical implications of foresight, examining real-world situations. By providing actionable insights, we aim to enhance foresight abilities, decision making capacities and address uncertainties in processes and systems.

C. Research Motivation

While many agree that thinking ahead is important, much remains unknown about how to design a model and implement the same. This research aims to explore about anticipatory thinking in various life areas using lookahead.

We study how our minds can work effectively in the LA model framework with anticipatory thinking for future events to make efficient decisions. This includes examining thoughts, feelings, and behaviors during future planning, and analyzing real-life examples of foresight in work and personal situations.

Our goal extends beyond understanding anticipatory thinking. By identifying obstacles to thinking ahead in the LA model, we can develop strategies to overcome challenges. Ultimately, we seek to empower individuals and organizations to use foresight effectively with the help of LA model in a constantly changing world.

D. Our Contribution

In this paper, we explain a comprehensive exploration of the Look-Ahead (LA) concept, which revolves around predicting and utilizing future inputs to inform current decision-making processes. We provide a formal classification of computational models into two categories: Look-Ahead (LA) and Non-Look-Ahead (NLA). This classification serves as a foundational framework for understanding how different models approach problem-solving.

The Non-Look-Ahead (NLA) model processes data sequentially, relying only on present inputs to make decisions. In contrast, the Look-Ahead (LA) model integrates both present and anticipated future data, allowing for more informed and optimized decision-making. By comparing these two approaches, we underline the added value that predictive analysis brings to computational models, particularly in terms of performance, efficiency, and adaptability.

We apply this framework across diverse real-world scenarios, illustrating how the Look-Ahead concept significantly improves the efficiency of various processes, systems, and algorithms. Through these examples, we demonstrate that Look-Ahead is not just a theoretical construct but a powerful, practical tool for enhancing performance in fields ranging from artificial intelligence to optimization problems.

Furthermore, we identify several key research challenges related to the application of Look-Ahead in complex systems, positioning these challenges as potential directions for future inquiry. Our contribution also emphasizes the potential of Look-Ahead to become a critical framework for future research in computational model design, particularly in high-performance computing, algorithm development, and solving non-trivial optimization problems.

By presenting these insights, we aim to lay the groundwork for the development of more advanced Look-Ahead-driven models and algorithms, which can effectively address both current and emerging challenges in various fields.

II. Overview of State of the Art Literature

A. Related Work

The Fig.1 offers a structured visual progression of key advancements in the study of lookahead, spanning pivotal developments and trends over the years. It highlights notable works, methodologies, and findings that have shaped the field, allowing a comprehensive overview of the chronological flow of research contributions. This diagram facilitates quick reference to the evolution of lookahead concepts and aids in understanding how current practices are built on foundational studies.

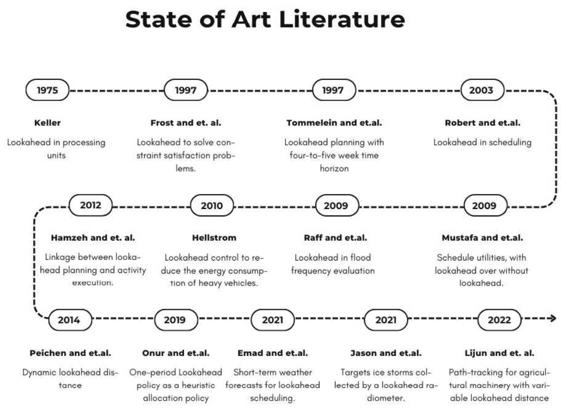

Fig. 1. Time-line diagram of state of the art literature

The following table provides a chronological overview of key contributions in the field, highlighting the progression of research and advancements over time. This structured summary offers a concise view of the major developments, methodologies, and outcomes presented in the literature. A more detailed discussion of these contributions follows the table, where the insights and trends identified are elaborated upon in the context of the evolving research landscape.

TABLE I
THIS IS THE TABLE TITLE

Year	Author	Contribution
1975	Keller [7]	Lookahead in processing units
1997	Frost and et. al. [3]	Lookahead to solve constraint satisfaction problems.
1997	Tommelein and et.al. [12]	Lookahead planning with four-to-five week time horizon
2003	Robert and et.al. [9]	Lookahead in scheduling
2009	Raff and et.al. [10]	Schedule utilities, with lookahead over without lookahead.
2010	Hellstrom [5]	Lookahead control to reduce the energy consumption of heavy vehicles.
2012	Hamzeh and et. al. [4]	Linkage between lookahead planning and activity execution.
2014	Peichen and et.al. [6]	Linkage between lookahead planning and activity execution.
2019	Onur and et.al. [2]	One-period Lookahead policy as a heuristic allocation policy
2021	Jason and et.al. [11]	Short-term weather forecasts for lookahead scheduling.
2021	Jason and et.al. [11]	Targets ice storms collected by a lookahead radiometer.
2022	Lijun and et.al. [13]	Path-tracking for agricultural machinery with variable lookahead distance

Building on the summary presented in the table, the following sections delve into the key advancements in the field. Each entry is discussed in terms of its contributions, methodology, and impact on subsequent research. This analysis highlights the evolution of ideas, identifies critical innovations, and underscores the gaps that have driven further inquiry. Through this exploration, a clearer understanding of the research development emerges, providing context for the current state of the art.

Keller [7] discussed methods for achieving look-ahead in processing units. An optimality criteria was proposed, and various schemes were compared against this criteria. These schemes included both existing and new machine organizations. The issues of eliminating associative searches in processor control and managing loop-forming decisions were addressed. The inherent limitations of such processors were explored, and enhancements capacity of processor through look-ahead were surveyed.

Keller [7] examined techniques for enhancing processor speed through look-ahead methods. These methods allowed processors to execute instructions out of sequence, provided no logical inconsistencies arose. The processor included local registers, function units, and an instruction buffer. The look-ahead processor's task was to identify and schedule instructions that could be executed concurrently without altering the execution semantics. Keller emphasized optimal parallelism detection, distinguishing between global and local optimality, and further dividing local optimality into static and dynamic types.

Frost et. al [3] discussed the benefits of looking ahead during search in solving constraint satisfaction problems. Previous studies had shown that looking ahead caused dead-ends to occur earlier and provided useful information for dynamic variable ordering. A domain value ordering heuristic called look-ahead value ordering (LVO) was introduced. LVO worked by counting how many times each value of the current variable conflicted with some value of a future variable, choosing the value with the fewest conflicts first. Experiments demonstrated that LVO could be significantly beneficial, especially for difficult constraint satisfaction problems.

A new heuristic for prioritizing value selection when searching for a solution to a constraint satisfaction problem was presented. Given that such problem has been shown to be NP-complete and non-trivial, no single solution technique worked well in all cases. However, algorithms and heuristics had been developed that improved upon simple backtracking. It was noted that when a constraint satisfaction problem had few solutions, much time was often spent exploring branches of the search space that did not lead to a solution. To minimize backtracking, values more likely to lead to a consistent solution were tried first. LVO ranked the values of a variable by looking ahead to determine their compatibility with future variables. Although not always accurate, LVO often provided a more informed value ordering than random selection. Experiments showed that while LVO's overhead typically outweighed its benefits on easy problems, it provided substantial improvements on large, difficult problems. LVO also enhanced the performance of backjumping on problems without solutions. While LVO did the same type of look-ahead as the forward checking algorithm, it was more refined by also ordering values that might be part of a solution.

Experiments showed that LVO could improve the performance of the BJ+DVO algorithm by a factor of over five on large and hard problems. However, LVO had some drawbacks, such as its complexity and the CPU overhead incurred by manipulating tables used in the ranking process. LVO was less effective on easy problems, where many solutions existed, and it unnecessarily examined every value of each variable. Despite these drawbacks, LVO was almost always beneficial on difficult instances requiring extensive consistency checks and even helped on unsolvable problems when used with backjumping. Further exploration of more computationally expensive schemes and methods to reduce LVO's overhead on easy problems was planned, such as employing it selectively during the search process.

Iris D. [12] presented three levels of production planning, with a particular focus on look-ahead planning, which effectively utilized lean construction techniques. Look-ahead planning involved a four-to-five week time horizon, incorporating methods such as screening, pulling, and rescheduling. While pulling was highlighted as an effective technique to expedite resources, its necessity could be reduced by establishing an integrated, real-time, and transparent production planning system. This system would enable upstream suppliers to adjust their schedules according to downstream needs without relying on pull signals. By adopting this proactive approach, suppliers would be better prepared for demand and more responsive when pull signals, like kanban cards indicating specific delivery needs, were issued. Although construction is still far from implementing such systems, establishing them would significantly contribute to achieving lean production in the industry.

Robert et. al. [9] addressed the growing need for effective management of Earth observation missions as the number of missions and the capabilities of observing instruments increase. With more than eighty Earth observing missions planned by international space agencies over the next fifteen years, and additional systems expected from the commercial sector, the volume of data requests is set to rise significantly. Traditionally, mission management involved separate teams for each mission with minimal coordination, a practice that is no longer sufficient given the demand for coordinated imaging.

Robert et. al. [9] described a system designed to enhance the management of these missions, which includes a central scheduler for generating high-priority observation sequences for multiple satellites and an on-board schedule revision system that updates schedules based on changing observation utilities. The scheduling algorithm evaluated requests based on their utility, considering both current and future requests to optimize the overall schedule. Two approaches to lookahead scheduling were explored: a fixed strategy with a set lookahead depth and a variable strategy that adjusted the lookahead horizon to avoid the "horizon effect," where future-looking decisions might lead to suboptimal outcomes.

The variable lookahead approach depended on factors such as the Required Quiescence Length (RQL) and Maximum Lookahead Horizon (MLH), aiming to ensure that the best scheduling choices were consistently made. The on-board scheduler used these strategies to assign heuristic values to observation requests, applying a greedy strategy to revise schedules by adding or discarding requests based on the available storage space and the utility of the data. The process sought to maximize the scientific value of the observations while efficiently managing storage resources.

Mustafa Baniker [1] developed a multi-regional general equilibrium model for climate policy analysis, building on the latest MIT Emissions Prediction and Policy Analysis (EPPA) model. Two versions of the model were created: one as a fully inter-temporal optimization problem (forward-looking, perfect foresight) and the other as a recursive-dynamic model. The forward-looking model allowed for better handling of issues such as GHG allowances, environmental tax recycling, fossil resource depletion, international capital flows, and emissions abatement paths. The models were benchmarked against the same macroeconomic path and compared under a climate policy restricting greenhouse gas emissions.

The comparison revealed that while both models showed similar behavior in the energy sector and CO2 price dynamics, the forward-looking model resulted in substantially lower macroeconomic costs. This was attributed to its ability to shift consumption as an adjustment mechanism. However, solving the model inter-temporally required simplifications, such as dropping full vintaging of capital and fewer technological options, which affected the results. The recursive model, though less flexible, produced similar energy sector behavior and was better suited for detailed system representation.

The study concluded that the forward-looking model was valuable for certain problems but highlighted that the recursive model offered a more practical approach for other issues. The trade-off between perfect foresight and structural detail raised questions about the realism of policy cost estimates, with stochastic solutions being a potential but currently infeasible alternative.

DA Raff [10] focused on developing advanced methods to assess flood potential by incorporating climate projections, with a strong emphasis on a lookahead approach. This approach contrasts with traditional methods that rely primarily on historical observations, which may no longer be adequate in the context of changing climate patterns. The study was motivated by the critical need for water resources management agencies, responsible for operating and maintaining reservoir systems, to accurately evaluate flood risks when planning infrastructure alterations or operational changes.

The methodology introduced by Raff [10] involved three core components. First, the study established a rationale for selecting climate projections that represent a range of possible future climate conditions, emphasizing the importance of capturing variability in temperature and precipitation. Second, runoff projections were generated using a process-based hydrologic model, with monthly downscaled climate projections disaggregated into 6-hour weather forcings required by the model. This step was crucial for ensuring that the runoff simulations were consistent with the selected climate scenarios. Finally, the study analyzed flood frequency distributions based on these runoff projections, providing insights into how flood risks might evolve over time.

The lookahead approach was demonstrated through four case studies involving the Boise River above Lucky Peak Dam, the San Joaquin River above Friant Dam, the James River above Jamestown Dam, and the Gunnison River above Blue Mesa Dam. The results indicated a consistent increase in simulated annual maximum flood potential across the lookahead periods of 2011–2040, 2041–2070, and 2071–2099. This trend suggests that as time progresses, the traditional expanding retrospective method—currently the standard for flood frequency estimation—could increasingly underestimate future flood risks.

Raff's [10] study highlighted the potential biases introduced by relying solely on historical data, particularly in the context of a non-stationary climate where past patterns may not accurately predict future conditions. The lookahead approach offers a more forward-thinking framework for flood risk assessment, enabling better-informed decisions regarding infrastructure and operational strategies. The research underscored the necessity of integrating non-stationarity assumptions into flood risk models and called for additional work to understand the varying responses of different basins to climate forcings. Overall, the study demonstrated that a lookahead perspective is essential for accurately estimating flood risks in a changing climate, ensuring that water resources management strategies remain effective and resilient in the face of future uncertainties.

Erik Hellstrom's [5]research focused on reducing fuel consumption in heavy trucks, particularly those carrying heavy loads on long trips. He used look-ahead control to predict and respond to future road conditions, with an emphasis on road topography. The study involved highway experiments with a truck using a real-time control system based on receding horizon control (RHC), which repeatedly solved optimization problems for a specific distance ahead of the vehicle.

The experiments demonstrated significant fuel savings. The control system was effective in real-world settings, offering intuitive and comfortable operation for drivers and passengers. Hellstrom [5]developed a dynamic programming-based algorithm to efficiently handle gear shifting and optimize fuel consumption. This algorithm was designed to be accurate and computationally efficient for on-board controllers.

The research also investigated the impact of residual cost approximation and horizon length in the RHC approach. The study emphasized the importance of managing kinetic energy through look-ahead algorithms for fuel efficiency. Additionally, Hellstrom [5] found that a hybrid powertrain could offer further fuel savings by recovering brake energy, although these gains might be offset by motor losses and increased drag.

Overall, Hellstrom's [5] contributions included the development of algorithms, design tools, and practical experiments, establishing a viable framework for on-board fuel-optimal look-ahead control. The research highlighted the significant impact of road topography on fuel economy and demonstrated that combining a hybrid powertrain with look-ahead control could further enhance fuel efficiency.

Farook Hamzeh [4] conducted a study to enhance lookahead planning practices in the construction industry, aiming to increase the reliability of production planning. The research employed case studies, industry interviews, and surveys across North America, South America, and Europe. It identified issues such as non-compliance with Last Planner System rules, inadequate lookahead planning, slow constraint removal, and a lack of analysis for plan failures.

The study recommended implementing standardized practices to improve the connection between lookahead planning and activity execution. It suggested breaking tasks into smaller processes and operations, removing constraints, and using first-run studies to design each operation. Additionally, the research highlighted the importance of metrics to assess and monitor the performance of lookahead planning.

Findings indicated that improper lookahead planning resulted in poor linkage between weekly and long-term plans, reducing the effectiveness of Percent Plan Complete (PPC) as a progress indicator. The guidelines proposed aimed to enhance the performance of lookahead planning and overall project outcomes. Further research was suggested to explore the relationship between lookahead planning performance, weekly work planning, and project performance.

Peichen Huang [6]presented new path planning and headland turning control algorithms for autonomous agricultural machines. The study introduced a path planning method that used three straight lines to address the minimum turning radius and headland space, and proposed a path tracking algorithm based on an improved pure pursuit model. The dynamical look-ahead distance control was implemented using a BP neural network to enhance the pure pursuit model's effectiveness. MATLAB/Simulink simulations demonstrated that the path planning algorithm was simple, required minimal headland space, and achieved high tracking accuracy. The control method proved to be feasible and practical.

The paper noted the distinction between headland turning and straight-line travel, emphasizing the importance of minimizing headland space and improving tracking accuracy to boost farming efficiency. Huang's [6]approach, using a simplified bicycle kinematics model and a dynamic look-ahead distance, offered a simpler and more effective solution. The study concluded that the new control method was effective, with improved time and space efficiency, and recommended further development to refine path positioning for optimal accuracy.

Emad Mohamed [8] examined the effects of adverse weather on the construction of onshore wind farms, with a particular focus on short-term weather fluctuations and their impact on schedules. The study proposed a hybrid simulation-based approach that integrates short-term weather forecasts (including precipitation, wind speed, and temperature) with planned and actual activity durations to develop enhanced 14-day lookahead schedules. This method aims to improve project planning and control by providing better decision-support tools for managing weather-related uncertainties.

The research demonstrated the applicability of this approach through a case study of a 40 MW wind project. The method was validated using event validity, face validation, and sensitivity analysis. The results indicated that favorable weather conditions had minimal impact on productivity (less than 10% reduction), while poor weather conditions could reduce productivity by up to 50%. The framework proved to be more responsive and accurate compared to traditional scheduling methods.

The study highlighted that existing methods typically relied on historical weather data, which did not account for short-term weather variability during the execution phase. Mohamed's [8] approach addressed this gap by combining short-term weather forecasts with as-built data, thus providing a more realistic and actionable lookahead schedule. This framework was expected to improve project management and control by allowing practitioners to monitor and mitigate weather-induced delays more effectively.

Json Wope [11] explored the Smart Ice Cloud Sensing (SMICES) concept, a small-satellite approach where radar targets ice storms based on information from a lookahead radiometer. Unlike traditional methods that collect data directly beneath the satellite (nadir view), SMICES aimed to enhance data collection by intelligently selecting high-interest features despite power and thermal constraints.

The study proposed algorithms to optimize radar measurements by classifying five cloud types and targeting significant storms. It evaluated six algorithms, from blind to selective targeting, using a dataset of 13 ground swaths covering about 72 million km^2. Results showed that using the lookahead radiometer and advanced algorithms led to a 23.7-fold increase in detecting convection core pixels and nearly a 2-fold increase in rainy anvil pixels compared to a baseline algorithm.

The trial results suggested that smart targeting greatly improved data collection efficiency. The best algorithm, the greedy path, achieved significant gains in detecting important cloud features compared to the random baseline. However, the dataset's higher proportion of clouds might have exaggerated the performance increase, indicating that real-world scenarios might show more modest improvements.

III. Our Proposed Look-Ahead Model for Computation

In recent computational systems, the power to make informed and accurate decisions is vital. Traditional models often rely solely on current input data, which can restrict their efficiency in vibrant and prophetic environments. To address this constraint, we introduce our proposed Look-Ahead Model for Computation, designed to boost decision-making by including anticipatory data. Our model is built around a constructed framework that includes three core components: the Computing Machine, the Algorithm, and the System. Each of these components processes data sequentially, but with the inclusion of lookahead as input. This additional data flow provides future information that allows the system to predict and train for upcoming events, leading to more accurate and improved outcomes. By integrating lookahead data, our model

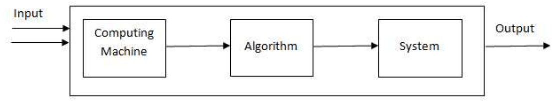

Fig. 2. Non-Look-Ahead Computation Model

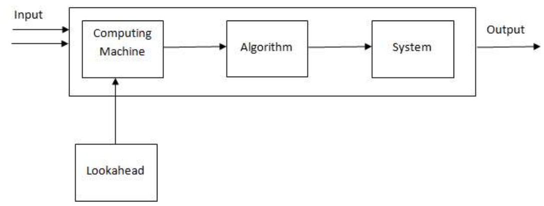

Fig. 3. Look-Ahead Computation Model

exceeds traditional approaches in several ways. It enhances accuracy by reducing the margin for misplay, enables preemptive adjustments by anticipating future trends, optimizes execution through better resource allocation, and reduces potential by preparing for future inputs.

A. Non-Look-Ahead Computation Model

In Fig.2 , we present the Non-Look-Ahead computation model which consist of set of inputs, computing machine followed by design of algorithm and system to generate the output without lookahead. The components are

- Computing Machine : The initial processing of the input data is performed by computing machine and involve basic computations or any transformation if required. It acts as the first stage of the data processing pipeline.
- Algorithm(Algo) : This is the core component of the model and applies specific computational logic like sorting, searching, data analysis or any other algorithm operation to the data processed by the computing machine. It serves as the central processing unit where the main computation occurs.
- System : The system integrates the results from the algorithm and prepares the final output. This may involve further formatting, processing or aggregation of results. It acts as the final stage in the processing pipeline and produce the output.

The above computational model is a linear processing pipeline with three key stages i.e. computing matching, algo and system. Every stage of the model process data based on the current input as it does not have any lookahead mechanism. This model works well in situations where decisions must be made on the basis of the available data without taking future data into account. It make sure that there is an efficient processing from input to output.

B. Look-Ahead Computation Model

The Fig.3 shows that an extra input lookahead with the regular input passes through the black box which has three elements computing machine, algo and system where the final output is generated using lookahead into account. The lookahead input provides future data that the system use to improve its decision making process. The components are

- Computing Machine : The computing machine process both input data along with lookahead input. It performs preliminary computation and combines various data points for more intelligent processing. It acts as the first stage of processing combining present and future data.
- Algorithm(Algo) : This form the basis of the model and applies complex computational logic to the current and lookahead data that computing machine processes to perform sophisticated operations such as trend analysis, predictive analysis or optimized decision making process. It makes use of lookahead data for improved outcomes along with current input and acts as central processing unit.
- System : The system finalizes the result by integrating the insights gained from both cureent and future data. It may perform additional computation to refine the output based on the lookahead information. It acts as the final stage producing the output from the anticipatory data.

The enhanced computational model with lookahead includes a mechanism to consider future inputs alongside current data. This model operates through three key stages: Computing Machine, Algorithm, and System, each of which leverages both present and anticipatory data. By incorporating lookahead, the model improves decision-making accuracy, allows for proactive adjustments, optimizes performance, and reduces latency. This results in a more robust and efficient processing pipeline from input to output.

IV. Look-Ahead in Algorithmic Frameworks

A. Non-Look-Ahead Algorithmic Model

1) **Initialize Data Processing**:
   - **Input**: Raw data.
   - **Action**: Send raw data to the Computing Machine.
   - **Output**: Pre-processed data.
2) **Apply Computational Logic**:
   - **Input**: Pre-processed data.
   - **Action**: Pass data to the Algorithm component for processing (e.g., sorting, searching, data analysis).
   - **Output**: Intermediate results.
3) **Generate Final Output**:
   - **Input**: Intermediate results.
   - **Action**: Pass results to the System for integration, formatting, and final processing.
   - **Output**: Final output.

Processing Steps

1) **Data Input Handling**:
   - Receive raw data.
   - Process initial transformations in the Computing Machine.
2) **Core Computation**:
   - Feed pre-processed data into the Algorithm.
   - Perform specific computations and generate intermediate results.
3) **Output Preparation**:
   - Integrate intermediate results in the System.
   - Format and produce the final output.

Notes:

- The model processes data in a linear sequence without look-ahead capabilities.
- Decisions are made based solely on the available input data, ensuring efficient processing from start to finish.

B. Look-Ahead Algorithmic Model

Initialize Data Processing:

- **Input:** Raw data and lookahead data.
- **Action:** Send both the raw data and lookahead data to the Computing Machine.
- **Output:** Pre-processed data integrating present and future information.

Apply Computational Logic:

- **Input:** Pre-processed data (current and lookahead).
- **Action:** Pass data to the Algorithm component for advanced processing (e.g., trend analysis, predictive analysis, optimized decision making).
- **Output:** Intermediate results, enhanced by lookahead data.

Generate Final Output:

- **Input:** Intermediate results.
- **Action:** Pass results to the System for further integration, refinement, and final processing, utilizing lookahead insights.
- **Output:** Final output, optimized with anticipatory data.

Processing Steps:

1. Data Input Handling:

- **Step 1:** Receive raw data and lookahead data.
- **Step 2:** Perform preliminary computations in the Computing Machine, integrating present and future data points.

2. Core Computation:

- **Step 3:** Feed the combined pre-processed data (current and lookahead) into the Algorithm.
- **Step 4:** Execute specific computations, using both current and future data, to generate enhanced intermediate results.

3. Output Preparation:

- **Step 5:** Integrate and refine intermediate results in the System.
- **Step 6:** Produce and format the final output, leveraging lookahead data for improved accuracy and performance.

Notes:

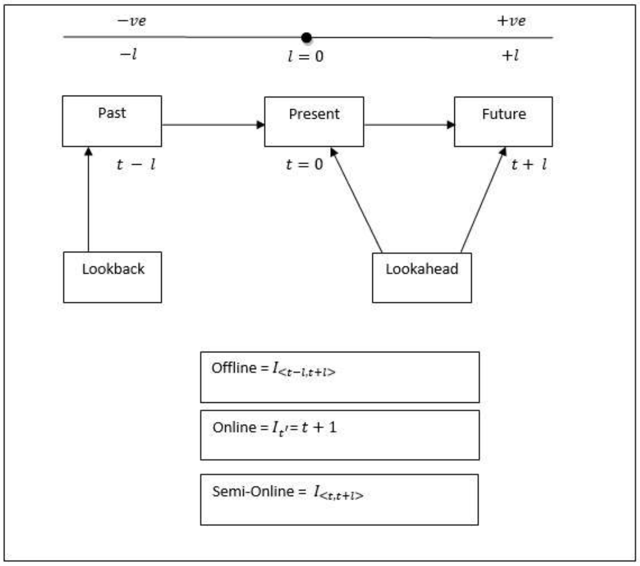

Fig. 4. Look-Ahead in Algorithmic Framework

- The model processes data in a sequence that includes look-ahead capabilities, allowing for improved decision-making by considering both current and future data.
- By integrating lookahead data at every stage, the model enhances processing accuracy, enables proactive adjustments, and optimizes the overall output.

The Fig.4 comprises of three evenly positioned boxes marked as Past, Present, and Future. These boxes represent different time periods in timeline. The different time notations are given below :

- Past(t - l) : This represents a time period before the present. The notation t - l indicates lookback period from the present time t.
- Present(t=0) : This represents the current time.
- Future(t+ l) : This represents a time period after the present. The notation t+ l indicates a lookahead period from the present time t.

On the basis of the above statements, the following three statements are provided to define the different modes of operation i.e. offline, online and semionline.

- Offline Mode : $I_{<t-l,t+l>}$ In offline mode the interval I includes both the past and future relative to present. This means we have access the information from a period before the present(lookback) and after the present(lookahead). The interval ¡t-l,t+l¿ spans from t-l and t+l which indicates that all the data within this time frame is available for processing. This mode is one where we can analyse and predict data with complete knowledge of the past, present and future.
- Online Mode : $I_{(t')} = t + 1$ In online mode the interval I is limited to the immediate time from the current time frame. Here, $I_{(t')} = t + 1$ signifies that the decision are made on real time based on the information available at the present moment. So, here no lookback or lookahead is applied. In this mode only present and immediate future data are considered for processing.
- Semionline mode : $I_{<t,t+l>}$ In semi-online mode, the interval I spans from the present to a lookahead period. This means we have access to the information from the present time t upto the future point t+l . The interval ¡t,t+l¿ indicates that we can utilize the current and future data within this time frame for processing. There is no access to the past information. This mode is one where we can analyse and predict data with the real time processing with a short prediction widow.

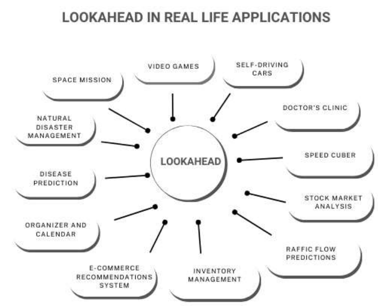

Fig. 5. Look-ahead in Real life applications

V. Novel Applications of Look Ahead in Real Life

We often make better decisions by visualizing the future. Based on the knowledge of future information, we can perform a task more efficiently by planning the steps of action ahead to save time and cost. The future may be one day, one month, one year or more than that. Like the human decision making process, lookahead is a technique used in algorithms for economical usage of time and space. It is applied by looking more inputs ahead before making a cost effective decision. Providing additional lookahead can enhance performance by incorporating more information on inputs as a strategy for efficient algorithm design. Planning ahead helps to boost the level of productivity and the efficiency of the outcome of a task. Through lookahead we gain additional information and knowledge which helps us to make better decisions to find efficient solutions. We present some well known and interesting real life applications of lookahead as follows.

A. *Doctor's Clinic*

In real-life, the concept of Look-Ahead is seamlessly integrated into the functioning of a doctor's clinic during medical check-ups. Upon patients' arrival at the clinic, a systematic approach is adopted to streamline the process. At the reception counter, an organized system issues a serial number and a corresponding ticket to each patient. This simple practice serves as an efficient mechanism, enabling the medical staff and the attending physician to have a comprehensive Look-Ahead into the day's appointments. By assigning a serial number and ticket, the clinic ensures that there is a structured order in which patients are examined. This measure facilitates a smooth workflow, allowing the medical professionals to anticipate and prepare for each patient's arrival. The doctor works smoothly with the information provided by the serial number and ticket, gains valuable insight into the upcoming consultations, helping them plan and prioritize time effectively. As a result, the Look-Ahead system implemented at the doctor's clinic not only benefits the healthcare providers but also enhances the overall patient experience. Patients can appreciate the organized approach, reducing waiting time and ensuring that they are addressed promptly. In this real-world application of Look-Ahead, the integration of such a system confirms how thoughtful planning can significantly optimize processes and improve the efficiency of medical services.

B. Speed Cuber

In the speed cubing, enthusiasts are well aware that achieving optimum solving time requires turning speed and lookahead. Turning speed refers to the rapid and precise execution of cube rotations during the solving process. Look-Ahead in speed cubing involves the art of anticipating and strategizing moves by continuously scanning and identifying pieces while executing the current steps. This advanced skill demands a deep understanding of the cube's state. The synchronization of lookahead with turning speed is the major part of a speed cuber's success. Look-Ahead, in particular, stands out as a crucial technique that sets the pace for speed cubers aiming to push the boundaries of their solving skills. In essence, the relationship between lookahead and turning speed allows speed cubers to achieve optimal performance.

C. Stock Market Analysis

In the dynamic world of stock market analysis, the lookahead emerges as a fundamental strategy employed by investors and traders to gain future stock prices. Look-Ahead technique uses a comprehensive examination of historical price data and a study of market trends. The analysis of historical price data provides insights into the past performance of a stock, allowing investors to identify patterns, trends, and potential market behaviors. By using this information, investors can then project likely scenarios and outcomes involving the future stock prices. Market trends play a crucial role in lookahead analysis, as they offer valuable clues about the trends of the market. This forward-looking perspective enables investors to position themselves strategically, aligning their portfolios with emerging trends. In addition, technical indicators such as moving averages serve as powerful tools for lookahead analysis. By smoothing out price data over a specific time period, moving averages offer clear representation of trends and help to identify potential reversal points. Traders use this information to make informed decisions about when to buy or sell stocks, aligning their actions with the anticipated future movements of the market. In essence, the application of lookahead techniques in stock market analysis provides a strategic investment decisions. This decision applied by using lookahead always allows investors and traders to gain in the investments.

D. Traffic flow predictions

In transportation planning, the implementation of lookahead technique plays a vital role in predicting and managing traffic flow effectively. Forward-thinking allows transportation authorities to anticipate potential traffic congestion by using advanced technologies and data analytic. This enables them to actively plan and implement strategies for enhanced traffic management. The traffic flow deals with the collection and analysis of real-time data from a network of cameras and sensors strategically placed throughout the roadways. These sensors capture vital information about the volume, speed, and density of vehicle movement, creating a dynamic and comprehensive dataset. Through sophisticated algorithms and predictive modeling, transportation authorities from this data identify patterns, trends, and potential congestion points. With the insights gained from lookahead analysis, transportation authorities can take timely and strategic actions to remove congestion and improve overall traffic flow. This may involve adjusting traffic signal timings for smoother vehicle movements. Additionally, in cases where congestion is unavoidable, authorities can reroute vehicles through intelligent traffic management systems, diverting traffic away from heavily congested areas to more efficient routes. The real-time adjustments facilitated by lookahead techniques not only enhance the efficiency of traffic management but also contribute to a reduction in travel times, fuel consumption, and environmental impact. In essence, the utilization of lookahead in traffic flow predictions represents a shift in transportation planning.

E. Inventory management

In business operations, the strategic utilization of lookahead techniques proves optimizing inventory management. Enterprises uses the power of foresight by analyzing past data to forecast future demand accurately. The foundation of this forward-looking approach is based on a thorough examination of historical data by using factors such as sales patterns, seasonal fluctuations, and market trends. Through a proper analysis, businesses gain valuable insights into the consumer demand and employ predictive modeling to anticipate future requirements. The first objective of lookahead in inventory management is to prevent overstocking of valuable capital and warehouse space. The second objective is to avoid stock-outs that can result in lost sales and dissatisfied customers. By accurately predicting future demand, businesses can make a required balance, ensuring they have the right amount of stock on hand to meet customer needs while minimizing excess inventory costs. In essence, the application of lookahead in inventory management applies with supply chain optimization. Businesses that use this methodology not only enhance their operational efficiency but also cultivate a competitive edge by consistently meeting customer demands, reducing carrying costs, and creating a responsive business model.

F. E-commerce recommendations system

In e-commerce, the integration of lookahead techniques is a stepping stone in the development and effectiveness of recommendation systems. Online retailers use the power of anticipation by analyzing users' browsing and purchase history. They use this data to predict and recommend products as per individual preferences. The recommendation system begins its work by comprehensively examining the user's interaction with the platform. This includes scrutinizing the user's browsing history. viewed products and past purchase behavior. By extracting patterns and trends from this historical data, the system can find the user's preferences, interests, and future needs. Furthermore, the incorporation of machine learning algorithms enhances the use of the lookahead process. These algorithms continuously learn and adapt, refining their predictions over time as users engage with the platform. The result is a recommendation system that becomes increasingly accurate and personalized, providing users with suggestions that is more closely associated with their evolving tastes and preferences. In essence, the use of lookahead in e-commerce recommendation systems represent a strategic effort to enhance the user experience and drive engagement. By accurately anticipating user preferences and suggesting relevant products, online retailers not only increase the likelihood of successful conversions but also cultivate a more personalized and customer-centric shopping experience, with increasing loyalty and satisfaction among their user base.

G. Organizer and calendar

In the case of personal and professional scheduling, the role of lookahead is applied through the integration of calendar applications such as Google Calendar and Microsoft Outlook, as well as various task management tools and organizers. Look-Ahead, in this context, enables individuals to plan and prioritize tasks and deadlines with foresight and efficiency. Calendar applications such as Google Calendar and Microsoft Outlook, harness the power of lookahead to offer users a comprehensive view of their upcoming schedule by allowing users to input events, appointments, and deadlines. These applications facilitate a proactive approach to time management. Task management tools and organizers further use lookahead techniques to enhance productivity. By analyzing task lists, deadlines, and project timelines, these tools empower users to prioritize their activities based on a forward-looking perspective. The ability to anticipate upcoming tasks and deadlines allows individuals to allocate time and resources effectively thereby reducing the likelihood of last-minute rushes or missed deadlines. In essence, the incorporation of lookahead in calendar applications, task management tools, and organizers signify how individuals approach time management. By providing a proactive and organized framework, these tools empower users to not only meet their immediate responsibilities but also plan ahead, by allowing a sense of control and efficiency in both personal and professional endeavors.

H. Disease prediction

In the public health, the application of lookahead concept represents a vital approach to disease prediction. Public health agencies find out the patterns underlying the emergence and spread of diseases with the help of advanced technological tools and analytical methodologies. This analysis includes an examination of symptoms, geographical locations, and historical disease patterns upon which predictive models are constructed. In public health, experts use a smart method called lookahead to diagnose diseases. They look for relevant information, like symptoms, demography of population and historical information on diseases. Based on relevant advance information, it can be determined how diseases might spread for the further treatment and recovery. Looking ahead helps them in advance preparation to reduce or stop spreading of the diseases for keeping the community safe. With better technology and advance tools the prediction and prevention of diseases can be ensured at the earliest stage.

I. Natural Disaster Management

To handle and manage natural disasters such as floods, wildfires, volcanoes, and extreme weather conditions, special agencies use LA models. The models are used to predict the expected time and location of occurrence of such disasters. For example, weather radar and rainfall data are used to predict the likelihood of heavy rain for causing of unexpected floods. Emergency warnings and weather alerts are issued to ensure public safety. Proactive measures can be taken ahead of time by monitoring the potential threats of wildfires caused by strong winds, high temperatures, and low humidity. To prevent rapid spreading of fire, firefighters and equipment can be placed in appropriate locations a priori.

J. Space mission

Space agencies such as NASA and ISRO utilize LA approaches to carefully plan and execute space missions. LA is an essential concept in this planning process, involving the consideration of future events and developments from the inception of the mission. When planning a space mission, agencies use LA models to anticipate expected possibilities of consequential events in the future. The events include predicting the positions of planets, the availability of certain resources, and the best time to launch spacecraft to reach respective destination. By using LA, space agencies can optimize the launch time of spacecraft through the most efficient and optimal route. LA in space mission involves the long-term objectives like exploring a distant planet, studying a specific concept, or conducting experiments in space. In essence, the use of LA in space mission reflects a commitment of thorough preparation and foresight. As technology advances, the LA concept continues to evolve, enabling space agencies to push the limits of exploration and expand the understanding of the universe.

K. Video games

In video games, LA is a smart technique used by computer-controlled enemies. These enemies can guess beforehand what players might do next, making the game more fun and challenging. The next moves are predicted and responded dynamically by the enemy players against a virtual bad guy. Game developers use LA to make video games feel more real and exciting by making it dynamic with unpredictable experience. As technology gets better, these smart features in video games keep evolving, making the enemies in games smarter and the game play more engaging for players.

L. Self-driving cars

Self-driving cars, also known as cars that can drive themselves, use LA to stay safe on the roads. Special sensors are used to predict the presence of objects and occurrence of events in the surrounding. In real life, LA is like a superpower for self-driving cars which helps them plan where to go, make good decisions, and use their resources wisely. For example, the car's sensors check how fast other cars are going and figure out if there are any obstacles by looking at the whole traffic situation. This helps the self-driving car to decide the best way to drive, following the rules and keeping everyone safe. LA makes the self-driving car really smart at making quick decisions when something unexpected happens, like a car suddenly stops in front, then the car can slow down or change lanes to avoid problems. In simple terms, LA is like having a smart helper in the self-driving car that looks into the future, plans the best route, and ensures safety.

VI. Research Challenges and Future Directions

Intuitively, we observe that LA can be used as a powerful tool and framework for future researchers in design of efficient computational models and algorithms for solving non-trivial and challenging optimization problems. Using the concept of LA, We identify and present the following interesting and non-trivial research challenges as future potential research directions.

- Development of novel temporal lookahead models to solve real life and computational problems
- Design of specific classes of lookahead models based on real life applications
- Design of bounded size lookahead models with upper bound and lower bound on the size of the input for improving the performance of algorithms and computing systems
- Design and analysis of new paradigms and algorithms based on lookahead models for efficiently solving real world problems

References

[1] Mustafa Babiker, Angelo Gurgel, Sergey Paltsev, and John Reilly. Forward-looking versus recursive-dynamic modeling in climate policy analysis: A comparison. *Economic Modelling*, 26(6):1341–1354, 2009.

[2] Onur Boyabatlı, Javad Nasiry, and Yangfang Zhou. Crop planning in sustainable agriculture: Dynamic farmland allocation in the presence of crop rotation benefits. *Management Science*, 65(5):2060–2076, 2019.

[3] Daniel Frost, Rina Dechter, et al. Look-ahead value ordering for constraint satisfaction problems. *IJCAI*, 1(14):572–578, 1995.

[4] Farook Hamzeh, Glenn Ballard, and Iris D Tommelein. Rethinking lookahead planning to optimize construction workflow. *Lean construction journal*, 2012.

[5] Erik Hellstrm. *Look-ahead Control of Heavy Vehicles*. PhD thesis, Linköping University, 2010.

[6] Peichen Huang, Xiwen Luo, and Zhigang Zhang. Headland turning control method simulation of autonomous agricultural machine based on improved pure pursuit model. In *Computer and Computing Technologies in Agriculture III: Third IFIP TC 12 International Conference, CCTA 2009, Beijing, China, October 14-17, 2009, Revised Selected Papers 3*, pages 176–184. Springer, 2010.

[7] Robert M Keller. Look-ahead processors. *ACM Computing Surveys (CSUR)*, 7(4):177–195, 1975.

[8] Emad Mohamed, Parinaz Jafari, Adam Chehouri, and Simaan AbouRizk. Simulation-based approach for lookahead scheduling of onshore wind projects subject to weather risk. *Sustainability*, 13(18):10060, 2021.

[9] Robert Morris, Jennifer Dungan, Jeremy Frank, Lina Khatib, and David Smith. An integrated approach to earth science observation scheduling. In *Proc. of the 3rd NASA Earth Science Technology Conference (ESTC-03), University of Maryland, USA*, 2003.

[10] DA Raff, T Pruitt, and LD Brekke. A framework for assessing flood frequency based on climate projection information. *Hydrology and Earth System Sciences*, 13(11):2119–2136, 2009.

[11] Jason Swope, Steve Chien, Xavier Bosch-Lluis, Qin Yue, Peyman Tavallali, Mehmet Ogut, Isaac Ramos, Pekka Kangaslahti, William Deal, and Caitlyn Cooke. Using intelligent targeting to increase the science return of a smart ice storm hunting radar. *jais*, 2021.

[12] Iris D Tommelein and Glenn Ballard. Look-ahead planning: screening and pulling. *Proceedings of the Second International Seminar on Lean Construction*, pages 1–12, 1997.

[13] Lijun Xu, Yankun Yang, Qinhan Chen, Fengcheng Fu, Bihang Yang, and Lijian Yao. Path tracking of a 4wis–4wid agricultural machinery based on variable look-ahead distance. *Applied sciences*, 12(17):8651, 2022.