Neuroevolution in UTM Research

Subject: Information Technology in a Global Society (ITGS)
Theme: Artificial Intelligence & Deep Learning

Research Question: How can artificial neural networks be implemented in traffic control systems to significantly reduce traffic congestion in an urban setting?

Neural Networks for Real-Time Traffic Signal Control

Optimization of Traffic Lights Timing based on Multiple Neural Networks

Toronto to test new 'smart' traffic signals

A comparison of different methods for combining multiple neural networks models

An Artificial Neural Network Model for Road Accident Prediction: A Case Study of a Developing Country

Evolving Neural Networks through Augmenting Topologies

A comparison of different methods for combining multiple neural networks models

Urban Population Chart (database)

Americans will Waste $2.8 Trillion on Traffic if Gridlock Persists

The Hidden Cost of Congestion

Neural Networks for Real-Time Traffic Signal Control
Source: http://www.jhuapl.edu/sPsA/PDF-SPSA/Srinivasan_etal_IEEETITS06.pdf (published paper)

Page 261
- Traffic signal control is one of the cheapest ways to solve urban traffic congestion.
- Retiming and coordinating existing traffic signals are proven to substantially reduce traffic delays, energy costs, and traffic time. As a result, safety on city streets is also increased.
- Different complexities of traffic signal controls are feasible/can be implemented using many methods.
    - Historical data - data gathered from a previous time frame with similar traffic flow rates and congestion.
    - Adaptive signal control - uses real-time traffic data to efficiently control traffic signals, optimizing travel times.
- Different ways of timing traffic lights:
    - cycle time adjustment
    - split adjustment (amount of time allocated to each part of the cycle)
    - offset adjustment (linking lights together to make more chains of green lights for more continuous movement)
- Efficiency of a network can be determined by many factors such as average vehicle speed, average delay, or total delay.
    - However, can be faulty since the network may leave a red light on a minor road for excessive amounts of time if long periods of time have more weight on them.
- Urban traffic control systems (UTCS) must consider both on a small scale (individual intersections) and on a large scale (city- or community-wide) in order to optimize efficiency.

Page 262
- UTCS should be able to manage various aspects of each intersection (cycle time, split, offset, etc.)
- However, over the scope of a couple communities or an entire city, may be extremely hard to account to assess overall efficiency. UTCS should be adaptive to overcome the random nature of traffic patterns.
- Interdependency of different individual intersections makes it challenging to set individual values for every single intersection without it affecting other ones.
    - A multiagent solution is proposed to counteract the network of intersections. Rather than having independent systems manage individual intersections, the network as a whole measures changes in traffic volume.

    - Independent agents over a city can be represented as an infinite distribution horizon problem, making themselves
- The problem of traffic signal control for a large traffic network can be divided into subproblems, where each subproblem is handled by a local traffic signal controller or an agent. For such a distributed approach, each agent will generate its own control variables based on the local information it receives.

Optimization of Traffic Lights Timing based on Multiple Neural Networks
Source:
https://zapdf.com/optimization-of-traffic-lights-timing-based-on-multiple-neur.html (published paper)

Page 825

- Lots of negative effects of traffic congestion: loss of economic production, higher fuel consumption (environmental impact), and delays.
- Traditional mathematical models & conventional methods for signal control are passable but very inefficient at dealing with the complexity of traffic.
- Recent advancements in machine learning allow for complex computational approaches such as fuzzy sets, genetic algorithms (which I will be covering), and artificial neural network control (main topic).
- This paper improves upon a system known as Environment Observation Method (EOM), developed by S. Ejzenberg, which is a program that calculates optimal cycle times for individual intersections.
    - Paper makes the system adaptable to various conditions instead of having only one parameter in traffic density/flow.
    - Tests using Simulation of Urban Mobility (SUMO), a traffic simulation program.
- "Urban mobility is the displacement ability of moving people and goods in urban space to perform daily activities in time, comfortable and safe. Thus, the dependence on motor vehicles has provided an uncontrolled increase in the worldwide fleet, causing great impact on traffic flows, and providing greater difficulties in mobility."
- Definitions:
    - *Cycle*: A complete sequence of all signal indications. Can be modified to adjust green time, turn time, etc. and adjust for pedestrians.
    - *Cycle Length*: Time needed per cycle.
    - *Phase/Split*: A section of a cycle (green for each direction, turning, all red, etc.).
- Traffic control systems deal only with the timing of each cycle, and, in more complex macro systems, deal with grids of traffic lights as a whole.
- A very popular program in urban areas that deals with traffic is TRANSYT (Traffic Network Study Tool) that determines optimal *fixed-time* intervals to control traffic for certain periods of time (rush hour, off-peak, mid-day, etc,). Known as an actuated signal controller.
    - While it is an improvement over using purely fixed-time intervals, using a fixed-time interval is still extremely subpar compared to using real-time data.
- Real-time systems are known as adaptive control systems that optimize timing plans in real time.
    - Such systems are rising in popularity due to their unrivaled efficiency.

- The timing plans are calculated in real-time with actual traffic conditions, since rush hour one day may differ from rush hour during another, especially during holidays and such.
    - Examples include: SCATS (Sydney Coordinated Adaptive Traffic System), SCOOT (Split, Cycle and Offset Optimization Technique) and ITACA (Intelligent Traffic Adaptive Control Agent).
- EOM described in this paper features both actuated and adaptive methods to vary phase time, with actuated serving as framework for the adaptive to vary off of.
    - EOM is formed using neural modules (networks) that determines actual conditions and uses mathematical models to vary times.
    - Method uses “environmental” observations of the traffic and simple mathematical computations to obtain results far better than a purely actuated system with even the most complicated factors such as public transit, width of lanes, slope of roads, etc.
- With EOM, signal timing is treated as the interaction between approximations of traffic routes at an intersection and phase time.
    - Approximations of traffic routes refers to whether or not a direction is congested or not. A direction is considered congested when there are still cars who have waited a light yet have not crossed when the phase ends. Idle refers to when a path is not congested; does not have cars waiting more than one light.
        - But what if both sides of an intersection are congested and extremely busy? Is this too simple or actually feasible?

Page 827

- Ejzenberg approximates the amount of time it takes for a vehicle to travel an approximation after the previous vehicle departed as 2 seconds, allowing for a maximum saturated flow of 1800 cars per hour per lane.
    - This value is used to calculate minimum green time for each direction, serving as a basis for an adaptive control system over time.
    - However, using constants and averages as parameters in equations is still extremely flawed.
- The paper aims to use ANNs to provide dynamic and far more accurate values for the relationships (parameters),
- The main advantage of ANNs is its learning skill over time with or without a set of learning instructions.
- While simple parameters can be easily obtained with a single network, more complex problems require a group of neural networks connected with one of three systems:
    - Ensemble combination has all the networks perform the same tasks with the same goal.
    - Modular combination has the problem divided into sub-tasks for the networks.

        - Mixed combination uses a mix of the two combinations above.

Toronto to test new 'smart' traffic signals
Source:
https://globalnews.ca/news/3878879/toronto-to-test-new-smart-traffic-signals/
Toronto is a great example of a city that has fixed-rate systems, with testing of new real-time systems starting recently in 2017. Toronto was one of the first cities to have a computerized traffic system in the 1960s, however, the system needs to be modernized.

A comparison of different methods for combining multiple neural networks models
Source:
https://www.researchgate.net/publication/3950135_A_comparison_of_different_methods_for_combining_multiple_neural_networks_models (published paper)

An Artificial Neural Network Model for Road Accident Prediction: A Case Study of a Developing Country
Source:
https://www.researchgate.net/publication/263007726_An_Artificial_Neural_Network_Model_for_Road_Accident_Prediction_A_Case_Study_of_a_Developing_Country (published paper)
Might not be very useful since it's for predicting road accidents, which is way too narrow for this essay topic.

Artificial Neural Networks: How To Understand Them And Why They're Important
Source:
https://www.forbes.com/sites/forbestechcouncil/2018/08/13/artificial-neural-networks-how-to-understand-them-and-why-theyre-important/#70d76cac5ecd

- Neural networks are a series of interconnected nodes, hundreds, thousands, or even millions of nodes. This is similar to the neurons in our brain.
- Each node can either receive inputs, send outputs, or be part of the hidden layers, similar to the axons in our brain.
- Every group of nodes forms a layer, and a neural network can have an absurd amount of layers as well.
    - The hidden layer are nodes that we cannot see that process the information.
- The connections send information between nodes, similar to dendrites.

Evolving Neural Networks through Augmenting Topologies
Source:
http://nn.cs.utexas.edu/downloads/papers/stanley.ec02.pdf (published paper)

- Neuroevolution (NE), the artificial evolution of neural networks using genetic algorithms, has shown great promise in complex reinforcement learning tasks
- Neuroevolution searches through the space of behaviors for a network that performs well at a given task. This approach to solving complex control problems represents an alternative to statistical techniques that attempt to estimate the utility of particular actions in particular states of the world
- Because NE searches for a behavior instead of a value function, it is effective in problems with continuous and high-dimensional state spaces.
- Species are split across generations and genomes.
- Success of a specific trial/network are measured with a value known as fitness, which takes into account the behaviour of the neural network.
- Each evolution takes the fittest genomes of the previous generation to breed.

A comparison of different methods for combining multiple neural networks models
Source:
https://www.researchgate.net/publication/3950135_A_comparison_of_different_methods_for_combining_multiple_neural_networks_models (published paper)
Paper discusses solely the use of multiple neural networks to accomplish a task.

Urban Population Chart (database)
Source:
https://data.worldbank.org/indicator/SP.URB.TOTL.IN.ZS?end=2017&start=1960 (database)
Urban population (% of total)
- 1968: 35.978% Global
- 2017: 54.827% Global
- Vast majority of countries have seen an increase in the urban population in the past half century, particularly in more developed regions such as Europe and parts of the Americas.

Americans will Waste $2.8 Trillion on Traffic if Gridlock Persists
Source:
http://inrix.com/press-releases/americans-will-waste-2-8-trillion-on-traffic-by-2030-if-gridlock-persists/ (article)
- In 2013 alone, traffic congestion cost the U.S. Economy 124 billion USD through loss of production.By 2030, as a result of urbanization, this cost is expected to rise by 50%, up to 184 billion USD.
- From 2013 to 2030, the estimated total cost of traffic congestion is 2.8 trillion USD, comparable to how much the U.S. population pays in taxes annually.

The Hidden Cost of Congestion
Source:
https://www.economist.com/graphic-detail/2018/02/28/the-hidden-cost-of-congestion
- In megacities such as NYC, L.A., and London, the average driver can lose nearly $3,000 a year from spending extra time during commutes due to traffic congestion.
- The study found that the average person in Germany, the U.K., and the U.S. loses $975 dollars annually from traffic, spending up to 100 extra hours a year during peak times stuck in the streets.