Urban Traffic Simulated From A Dual Perspective

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Introduction: Traffic Jam in Big Cities
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Traffic Problem

- Transition from free flow to jam
- Efficient navigation strategy
- Balance of overall capacity and individual traveling time
- City planning & Environment
2. Dual Graph
Micro & Macro Approaches

- Road (High Way) Traffic --Microscopic
  1. Interaction of vehicles on highway
  2. Occurrence/development of jam
  3. Focus on vehicle speed, density, flux

- Network Traffic – Macroscopic
  1. Urban Planning
  2. Static/dynamic Traffic distribution
Two Representations of Urban Network System

- **Primal:**
  intersections (or settlements) are turned into nodes and roads (or lines of relationship) are turned into edges.

- **Dual:**
  roads are turned into nodes, intersections are turned into links between the corresponding nodes.
Steps of Dual Representation
six 1-square mile samples
Primal Graphs of the 6 cities
dual graphs of the 6 cities

The dual graphs of the six cities, shown in the same order
Compare Primal & Dual

- Primal: intuitive, the value of distance can be easily associated to edges. But it can not characterize the common notion of “main roads” in urban traffic systems. It violates the intuitive notion that an intersection is where two roads cross, not where four roads begin.

- Dual: one can have many “conceptually countless” edges for each node. This leads to the recognition of scale-free behavior for the degree distribution of urban street networks.
Empirical Statistical Results of Urban Dual Graphs

- Planned Cities --- The degree distribution is exponential.

- Self-Organized Cities --- Power-Law Scaling of degree distribution:

  A Few Main Roads: Many Intersections
  Most are Minor Roads: few intersections
Shortcoming of Space Syntax

- Largely subjective construction process of axial mapping

- Abandonment of any reference to geographic-Euclidean space: a street is one node no matter how long its real length is.

- Metric distance is the core element of most traffic flow studies
3. Traffic Model on Dual Graph

- **Degree \( K_i \):** number of intersections
- **Holding Ability \( C_i \):** maximum number of vehicles the road can hold.
  \[ C_i = \alpha \times K_i, \quad \alpha \text{-ability of one segment} \]
Node Related Terms

- **Turning Ability $T_i$:** maximum number of vehicles turning from the road into the neighboring roads per time step $-$
  $T_i = \beta \times K_i$, $\beta$ - ability of one intersection
1) Adding of Vehicles

- The entering of vehicles into the system is controlled by a Poisson process with an entering rate $R$. Each new vehicle is given a random origin and destination.
2) Navigation of Vehicles

- A conceptual local searching strategy is considered in this paper. Each vehicle performs local searching among the neighboring roads of the current road. If a vehicle's destination is found in the nearest neighborhood, its direction will be set to the target. Otherwise, the vehicle performs random walk in the system. Once a vehicle reaches its destination, it is removed from the system.

- Other Strategies: Shortest Path, Local Routing, Efficient Routing ...
3) Movement of Vehicles in the Road

- **Vehicle Speed**: assuming a homogeneous vehicle movement along one given road:
  \[ V_i = V_{\text{max}} \times (1.0 - \rho_i) \]

- \( V_{\text{max}} \) is the maximum velocity possible in the urban system, \( \rho_i = N_i/C_i \) is the local vehicle density (\( N_i \) is the number of vehicles on road \( i \)).

- This equation reflects that the vehicles will take \( V_{\text{max}} \) when there is no vehicle on the road, and that the velocity decreases linearly until no vehicle can move when \( \rho_i = 1.0 \).
3) Movement of Vehicles in the Road

- **Travel Distance**: a vehicle enters a road at the $m$th intersection and leaves at the $n$th intersection, it must travel the distance along the road:
  \[ d = L_0 \times |m-n| \]

$Lo$: average length of one segment
Empirical Statistical Results of Urban Dual Graphs

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Underlying Dual Network

- 1) Self-organized **Scale-Free** network
- 2) Well-Planned **Lattice Grid**
4. Simulation Results: Flow States & Phase Transition

- Free Flow, Flow with Crisis, Congestion
2) Flux Fluctuation Near Critical Point

- The ‘crisis’-like behavior is one of the manifestations of the approach to a congested regime at the critical posting rate \( R_c \).
There is more fluctuation of flux in the lattice grid. But the number of running vehicles on lattice is much larger than that on the SF network.

Rc is a critical point for the phase transition from free flow to jam.

Rc can be used to determine the overall capacity of the urban system.
3) Overall Capacity I – SF

$R_c$ increase with $V_{\text{max}}$ (beta) and then come to saturation.
To improve the overall efficiency of the urban system, we need to enhance the road capacity together with the intersection capacity.

However, because the vehicle speed can not go beyond a certain value in cities, and because the intersection capacity can only be limitedly improved, there will be an unavoidable limit to the improvement of urban traffic efficiency, given that the network topology is fixed.

One should think of other ways to improve urban traffic efficiency when the limit is reached, such as adding shortcuts, developing subways, employing better navigation strategies, and so on.
Overall Capacity II- Lattice Grid
4) Traveling Time I – SF network

- a power-law and an exponential cutoff (due to the finite network size)
Traveling Time II – Lattice Grid

- Roughly follows an exponential distribution
Comparing SF network & Lattice

- Lattice grids are **more efficient** than a self-organized network:

  1) The average number of vehicles running on the grid is much higher than that on the scale-free network

  2) The critical entering rate $R_c$ takes much larger value on the lattice grid

  3) The vehicles have to travel for a much longer time in the self-organized network, probably because of the high cost of navigating in the system
5. Conclusions

- Urban traffic can be studied on dual graph with more efficiency.

- Flux fluctuation, Phase Transition, overall Capacity, Traveling time can be easily investigated.

- Lattice grids perform better than self-organized networks

- The model can be beneficial to:
  1) the evaluation of overall efficiency of urban system
  2) the alleviation of congestion of modern cities
  3) Urban planning and some other related problems
Open Questions

1) the role of traffic control methods

2) interaction of vehicles in the road

3) differences between major and minor roads

4) more rational driving behaviors of the vehicles – Better navigation strategy

5) urban network generation models
Thank You VERY much!!!