Spatio-Temporal Routing Algorithms

Panel on Space-Time Research in GIScience

Intl. Conference on Geographic Information Science 2012

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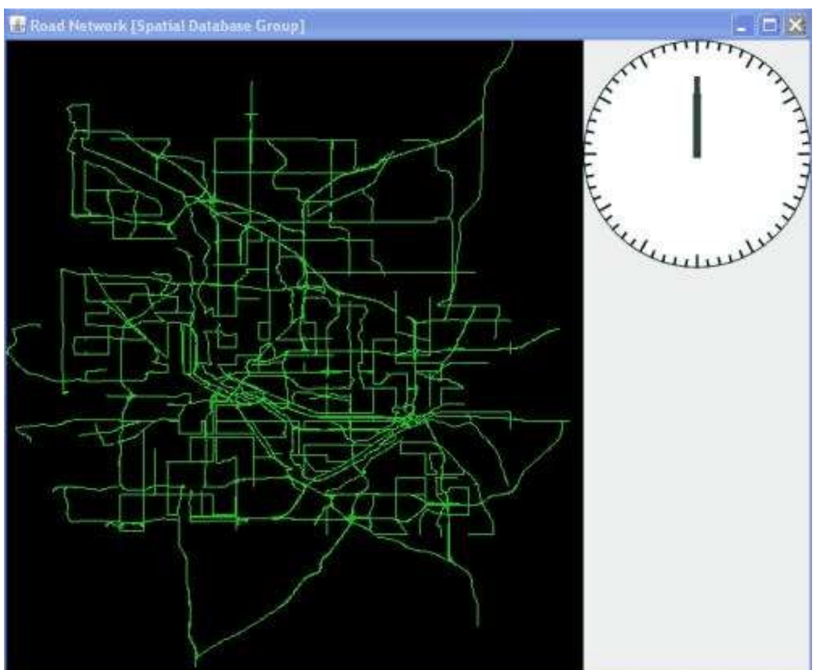
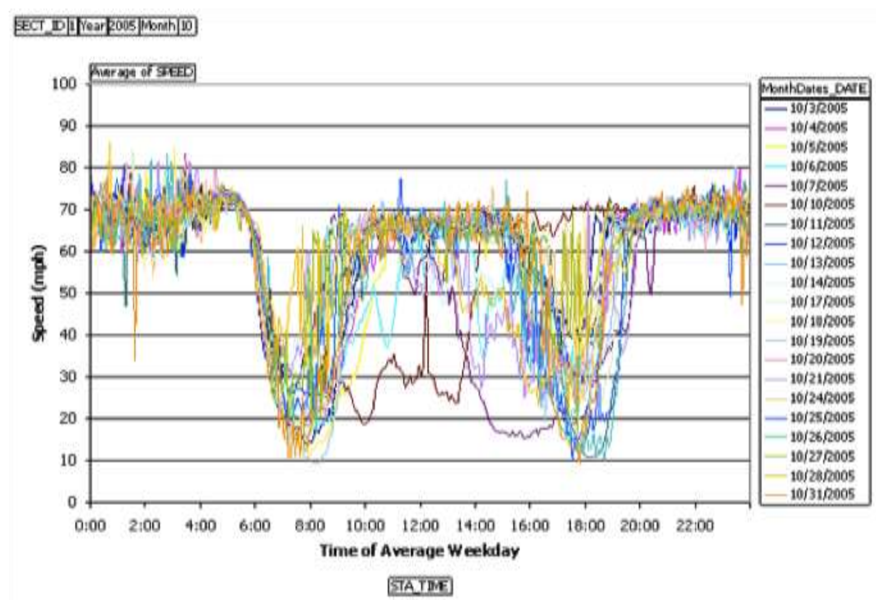
Dynamic Nature of Transportation Network

Traffic during non-rush hours

Traffic during Rush hours





Implication of Dynamic Nature

The New York Times

U.P.S. Embraces High-Tech Delivery Methods (July 12, 2007)

*By "The research at U.P.S. is paying off. ....— **saving roughly three million gallons** of fuel in good part by mapping routes that minimize left turns."*

Problem 1: Time-dependent network models

- Input：
  a) A Spatial Network
  b) Temporal changes of the network topology and parameters.

- Output： A model that supports efficient correct algorithms for computing the query results.

- Objective：Minimize storage and computation costs.

- Constraints：
  (i) Predictable future
  (ii) Changes occur at discrete instants of time,
  (iii) Logical & Physical independence,

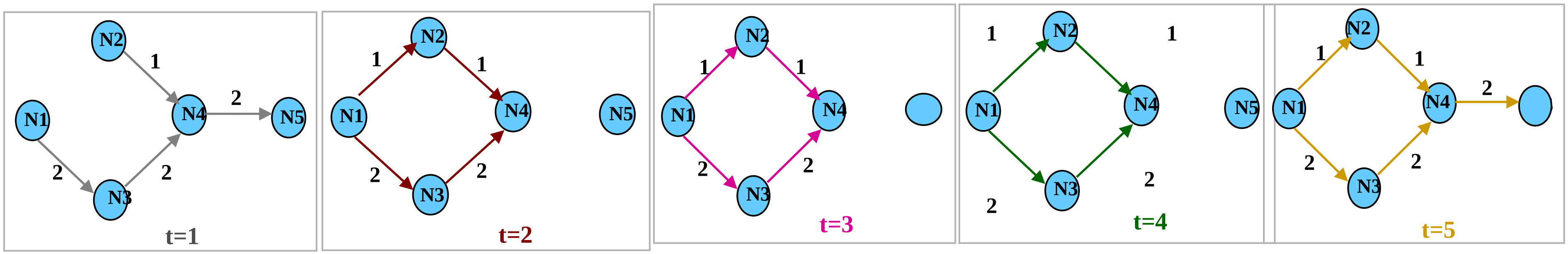
Challenges in Representation

- Conflicting Requirements
  - Expressive power
  - Storage efficiency
- New Semantics for network concepts
  - Lagrangian shortest paths
  - Time dependence of shortest paths
  - Best start-time paths
- Violates assumptions behind algorithms
  - Prefix optimality, stationary ranking of alternative paths
  - Dijkstra's, A*, Dynamic Programming

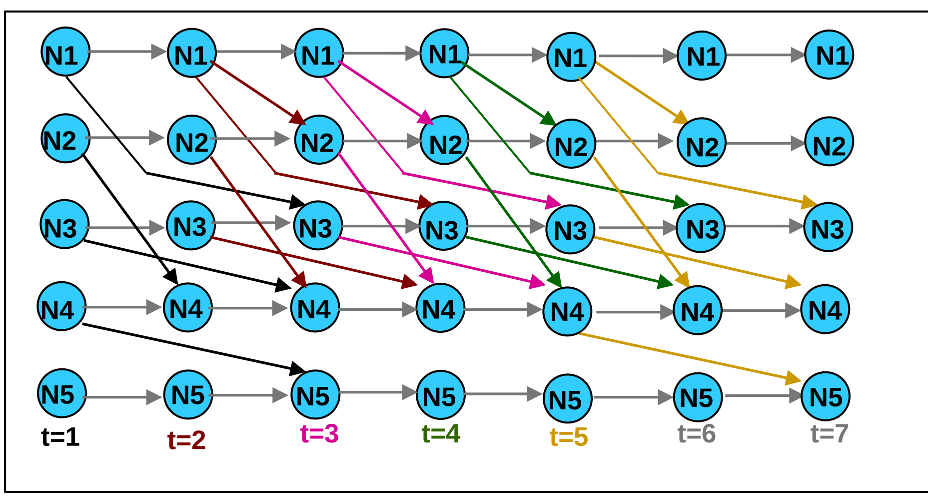
Representations of (Spatio-)temporal Networks

(1) Snapshot Model [Guting 04]

Node: N.. Edge: Travel time



(2) Time Expanded Graph (TEG) [Ford 65]

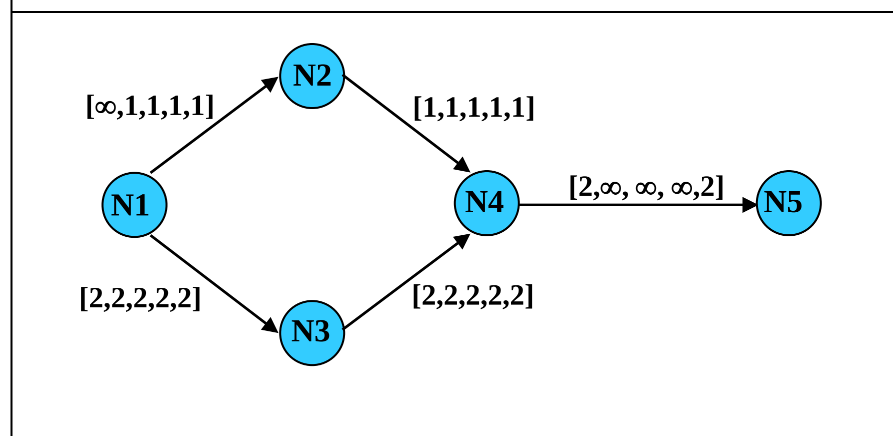


Holdover Edge

Transfer Edges

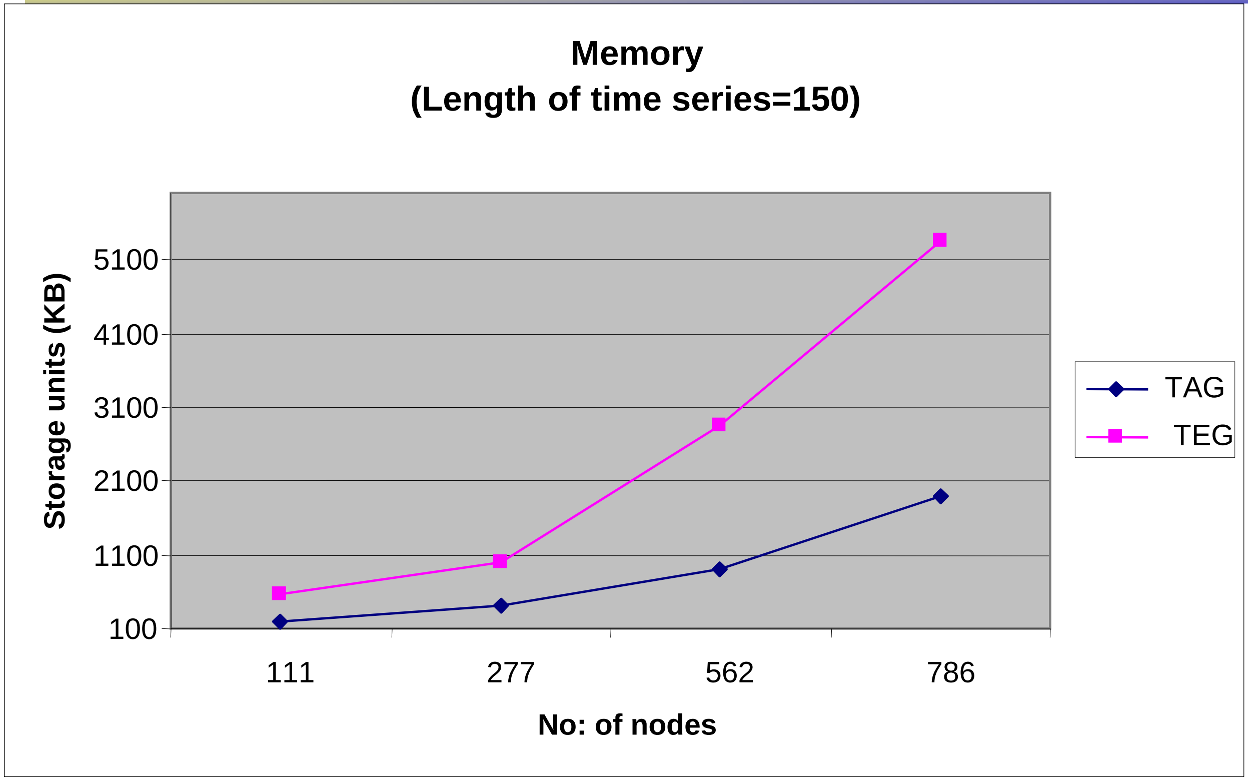
(3) Time Aggregated Graph (TAG) [Our Approach]

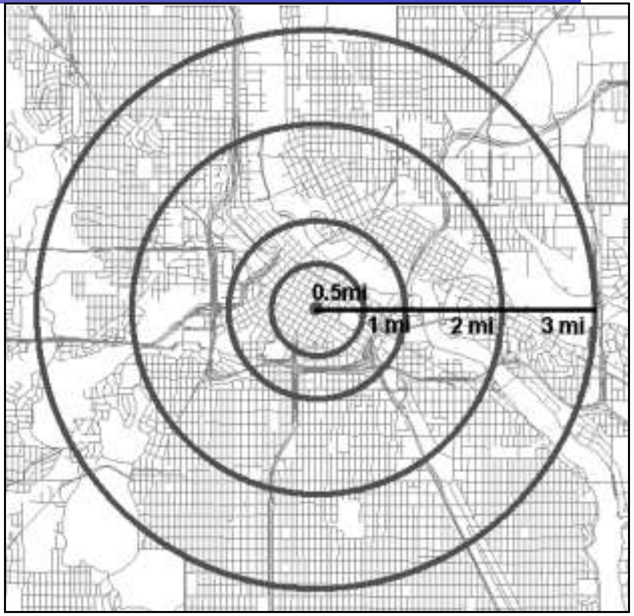
¤ Attributes aggregated over edges and nodes.



Edge $\xrightarrow{[m_1,\ldots,(m_T]}$ m_i- travel time at t=i

TAG vs. TEG: Storage Cost Comparison





Minneapolis CBD
[1/2, 1, 2, 3 miles radii]

Dataset	# Nodes	# Edges
(MPLS -1/2)	111	287
(MPLS -1 mi)	277	674
(MPLS - 2 mi)	562	1443
(MPLS - 3 mi)	786	2106

Trend: TAG better than TEG
on storage overhead!

TAG compared to Related Work

- TAG has lower storage cost
  - No replication of nodes and edges across time-frames
  - Allows sharing/compression of time-series
- TAG leads to faster and scalable algorithms
  - Smaller representation
  - TAG transformations, partitions, …
- Relative to TEG,
  - Provides logical-physical independence
  - Can model properties beyond travel-time

Problem 2: ST Shortest Path Algorithms

- **Input** :
  a) A Spatial Network
  b) Time-series edge-weights.
  c) An (origin, destination) pair
  d) A start time
- **Output** : A spatio-temporal route (and schedule)
- **Objective** : Minimize route cost (e.g., travel-time or fuel consumed)
- **Constraints** :
  (i) Predictable future
  (ii) Changes occur at discrete instants of time,

Challenges

Non Stationary ranking of paths

Time	Preferred Routes
7:30am	Via Hiawatha
8:30am	Via Hiawatha
9:30am	via 35W
10:30am	via 35W

➢ **Violation of stationary assumption dynamic programming**

Non FIFO Behavior

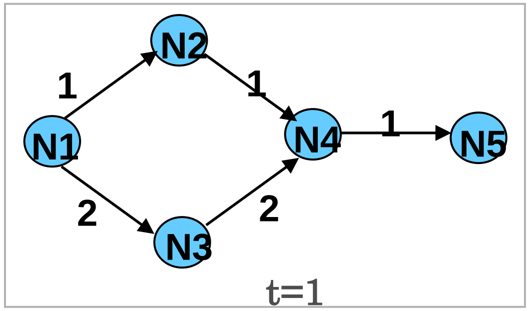
Time	Route	Flight Time
8:30am	via Detroit	6 hrs 31 mins
9:10am	direct flight	2 hrs 51 mins
11:00am	via Memphis	4 hrs 38mins
11:30am	via Atlanta	6 hrs 28 mins
2:30pm	direct flight	2 hrs 51 mins

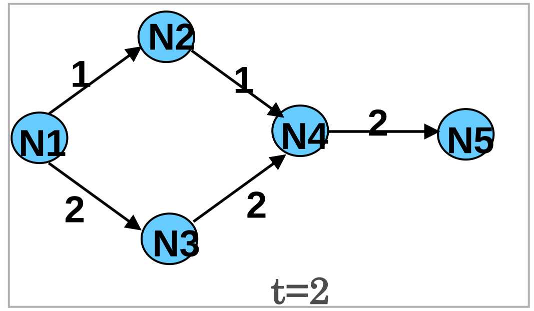
***Flight schedule between Minneapolis and Austin (TX)**

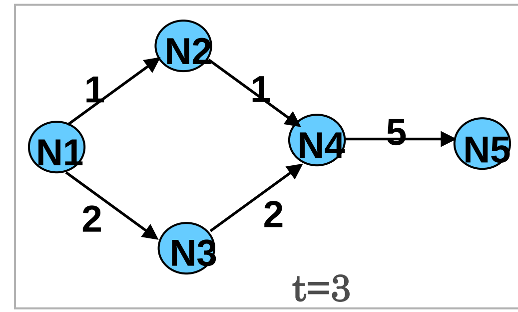
➢ **Violates the no wait assumption of Dijkstra/A***

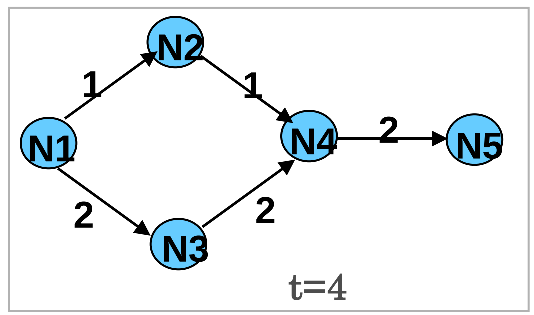
Dealing with non-FIFO edges using Waits

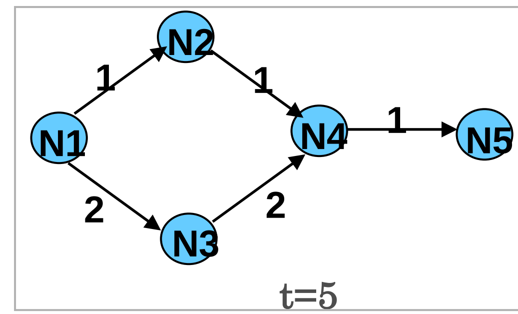
Find the shortest path travel time from N1 to N5 for start time t = 1.











	N1	N2	N3	N4	N5
1	~~1~~	∞	∞	∞	∞
2	1	~~2~~	3	∞	∞
3	1	2	~~3~~	3	∞
4	1	2	3	~~3~~	∞
5	1	2	3	3	8

Optimal path: Reach N4 at t=3;

Wait for t=4;

Reach N5 at t=6

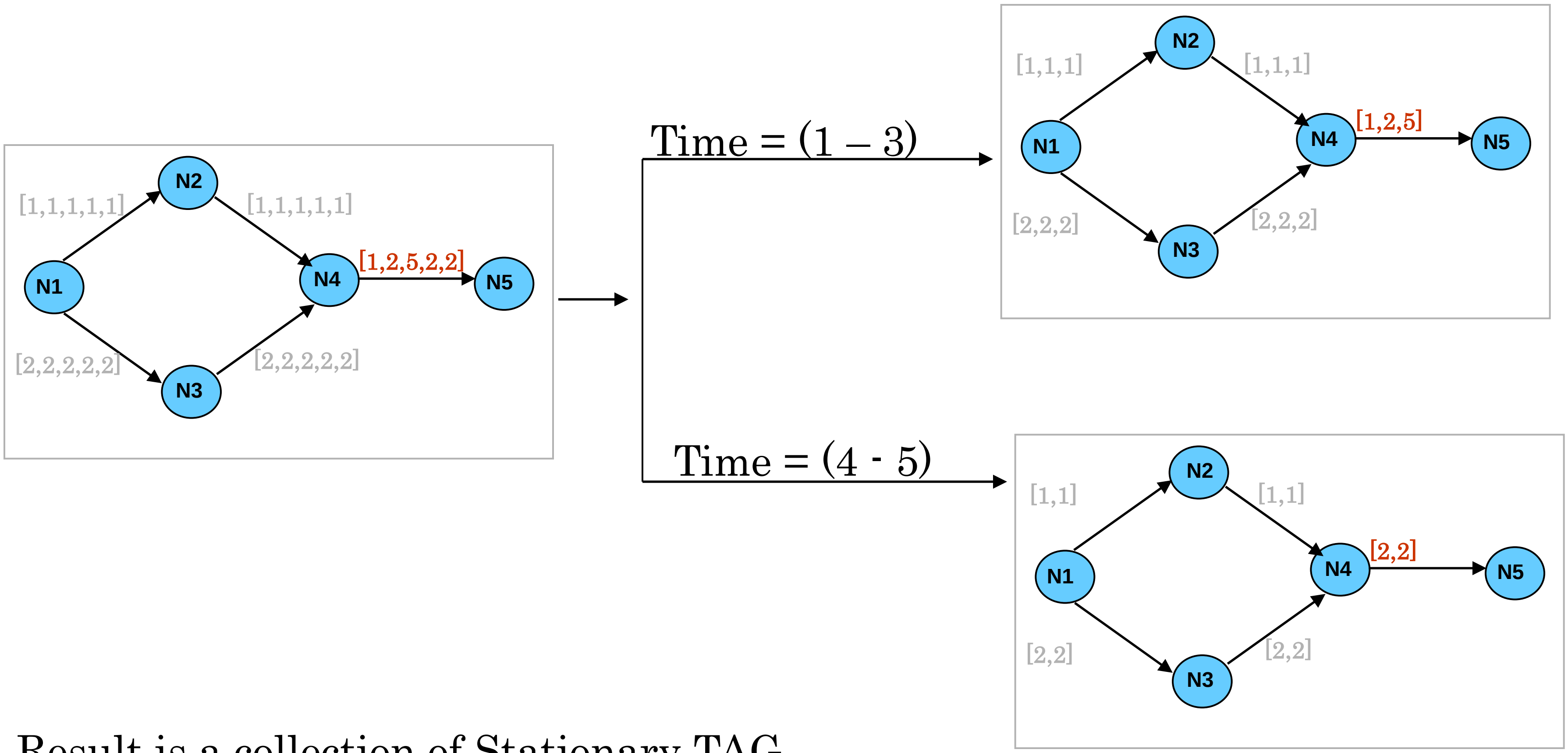
Total time = 5

Dijktra's algo.: Reaches N5 at t=8.

Total time = 7

Dealing with non-stationary ranking of routes

Idea: Divide into time-intervals with stationary ranking of routes



Result is a collection of Stationary TAG.

Dynamic programming may be used within each sub-TAG !

Summary: ST Routing Algorithms

Predictable Future → Stationary — Dijkstra's, A*….

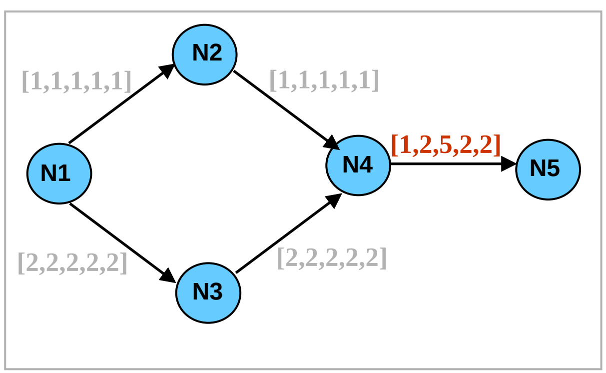
Predictable Future → Non-stationary → Special case (FIFO)

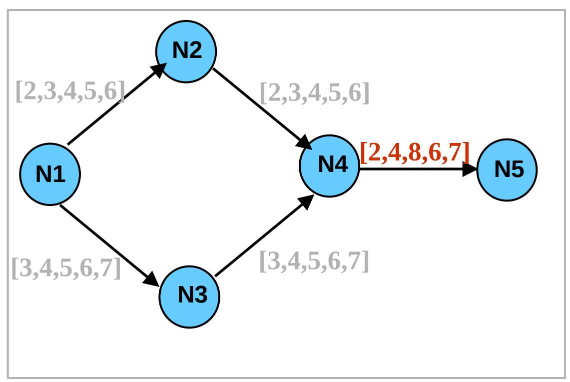
Predictable Future → Non-stationary → General Case — TEG: LP, Label-correcting

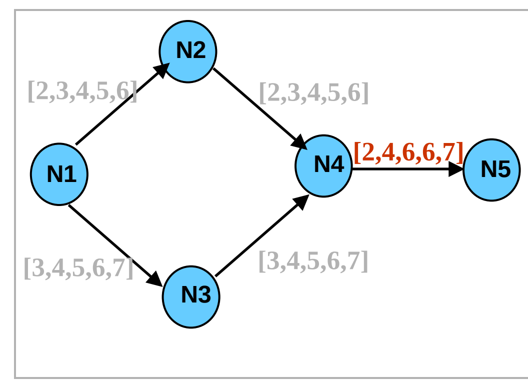
TAG: Transform to Stationary TAG

Unpredictable Future

travel times → arrival times at end node → Min. arrival time series







Non-stationary TAG → Stationary TAG

More ST Shortest Path Problems

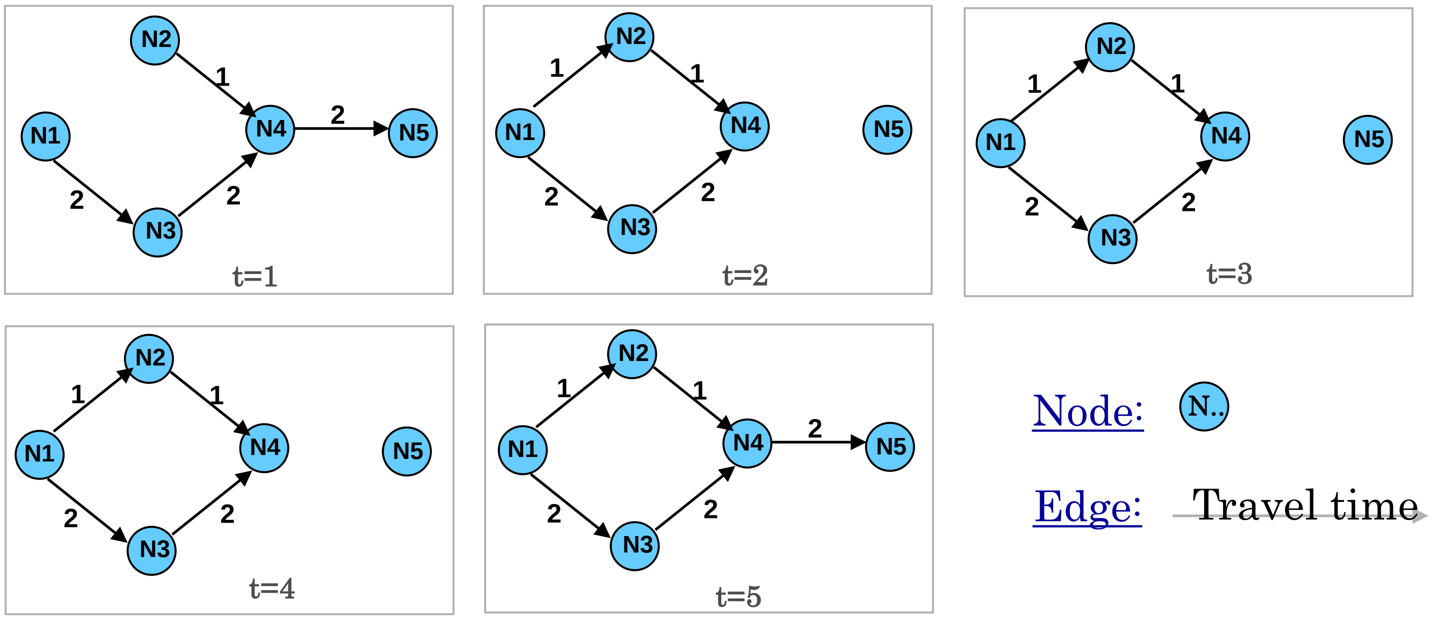
Static	Time-Variant
Which is the shortest travel time path from downtown Minneapolis to airport?	Which is the shortest travel time path from downtown Minneapolis to airport at different times of a work day?
What is the capacity of Twin-Cities freeway network to evacuate downtown Minneapolis ?	What is the capacity of Twin-Cities freeway network to evacuate downtown Minneapolis at different times in a work day?

- New Routing Questions
  - Best start time to minimize time spent on network
  - Account for delays at signals, rush hour, etc.

Dealing with new Semantics, e.g., Best start time

*Identify **best start-time** for travel from N1 to N5.,*

if Shortest Path is dependent on start time!!



Start at t=1:

Shortest Path is N1-N3-N4-N5;
Travel time is **6** units.

Start at t=3:
Shortest Path is N1-N2-N4-N5;
Travel time is **4** units.

Best Start Time is 3