Spatial Modeling Of Urban Road Traffic Using Graph Theory

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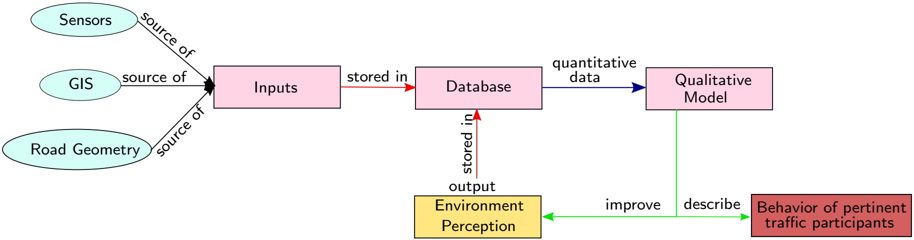
Outline

Introduction

- Why do we need a model?
  - Integrate different kinds of **data** to understand road traffic
  - Easy visualization of the road traffic at **different levels of detail**
- Quantitative data? Qualitative knowledge? **Both?**
- Microscopic model? Macroscopic model? **Both?**
- **Spatio-Temporal** (but as of now it is spatial)
- **Graph based**: abstract representation of the world, incorporate dynamics of road traffic, graph structure based analysis



Previous Work

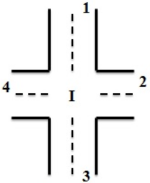
Model Categories	Microscopic/ Macroscopic	Qualitative/ Quantitative	Time	Physical Object Classes
Probabilistic	Microscopic	Quantitative	Yes	Random variables $\neq$ physical objects
Object Oriented (segmentation based)	Microscopic/ Macroscopic	Quantitative	Yes	Multiple
Graph based	Macroscopic	Quantitative & Qualitative	No	Vehicles and Road Lanes
Proposed Model	Microscopic & Macroscopic	Quantitative & Qualitative	Yes	Multiple

Kuhnt et al. 2015.
Rieken, Matthaei, and Maurer 2015; Sengupta et al. 2013.
Knaup and Homeier 2010; Ulbrich et al. 2014.

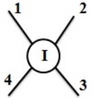
Previous Work

Representation of Road Networks

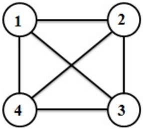
- Primal Graphs
- Dual Graphs



Road Network with an intersection



Primal Graph



Dual Graph

Porta, Crucitti, and Latora 2006b.
Porta, Crucitti, and Latora 2006a.

Contributions of the model

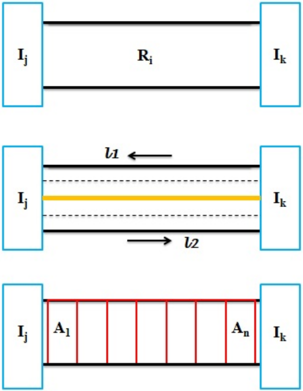
- Includes spatial relations between real world objects
- Visualizes the environment at different levels of detail
- Avoids quantitative errors
- Ideal for implementation in an urban traffic data center

Spatial Graphical Model

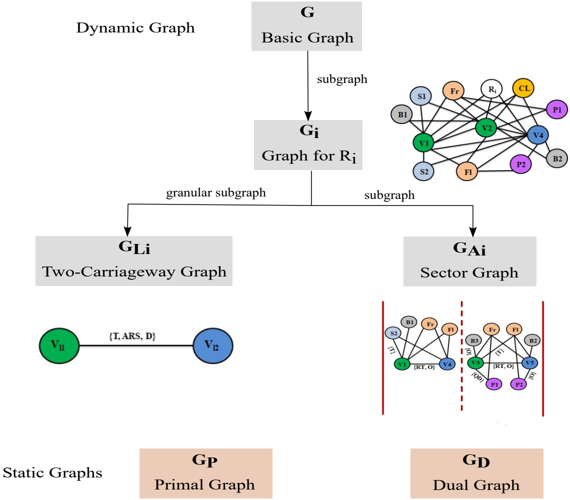
- A graph model is $G = (X, E)$, where X: set of nodes and E: set of edges
- **Spatial relations**: Topological (overlap, proper-part etc.), Orientation (left, right-front etc.), Qualitative Distance (close, very far etc.), Order, Directional (cardinal directions), Relative Trajectory (towards, follow etc.), Relative Speed, Average Relative Speed, Accessibility, Relative Orientation

Some Definitions

- Road Segment
- Road Carriageways: Set of carriageways, $L = \{l1, l2\}$
- Road Sectors: Set of sectors, $A = \{A_1, ..., A_n\}$



Hierarchy of Graphs

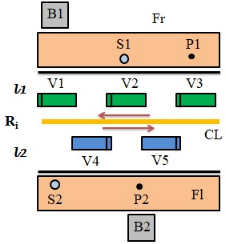


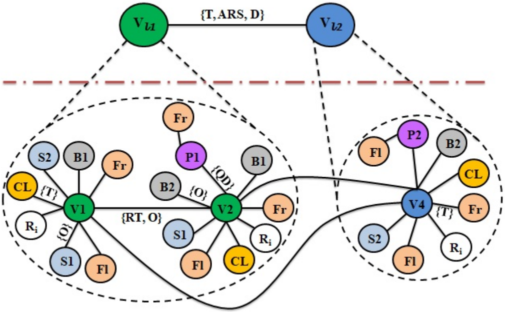
Stell 1999.

Granularity

The levels of detail/abstraction at which a model can be understood define the **granularity** for that model.

- Carriageway-based Granularity

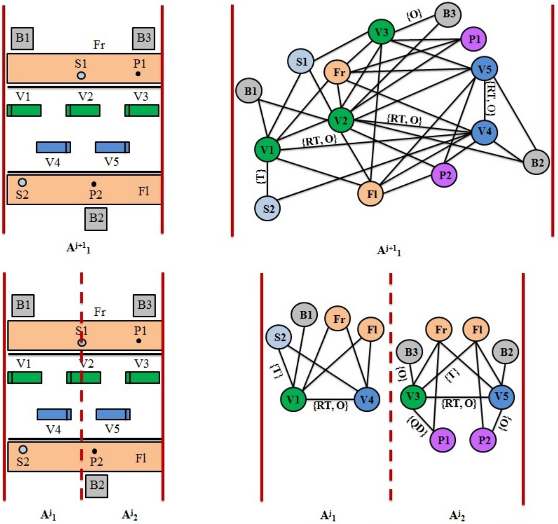




Keet 2006.

Granularity

- Sector-based Granularity



Thesaurus of Objects

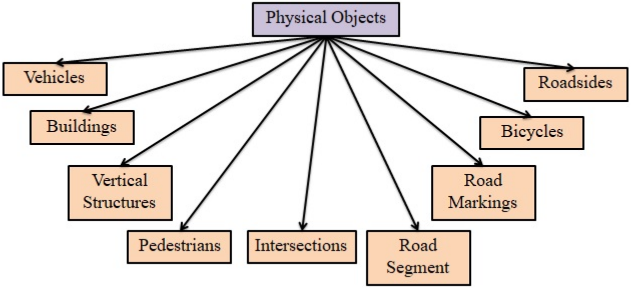


Figure: Object classes

Thesaurus of Objects

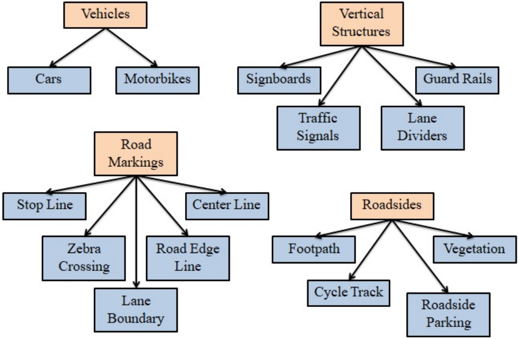


Figure: Types of objects in each class

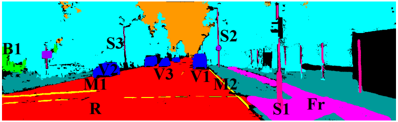
Thesaurus of Objects

Table: Spatial relations for different object classes

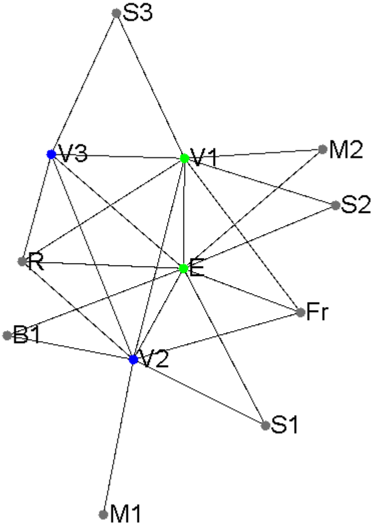
Object class	**Relation with class**	**Relations**
Vehicle	Vehicle	$\{T, O, RT, RS, QD, Ord\}$
Vehicle	Building	$\{T, O, QD\}$
Vehicle	Vertical Structure	$\{T, O, QD\}$
Vehicle	Road Marking	$\{T\}$
Vehicle	Roadside	$\{T, QD\}$
Vehicle	Road segment	$\{T\}$
Vehicle	Pedestrian	$\{T, O, RT, QD\}$
Vehicle	Bicycle	$\{T, O, RT, RS, QD\}$
Vehicle	Intersection	$\{T, QD, Ord\}$
Pedestrian	Roadside	$\{T\}$
Bicycle	Roadside	$\{T\}$

Real World Graph: RWTH KITTI Semantics Dataset

(a) input image



(b) (labeled) segmented image



Ošep et al. 2016.

Real World Graph: Cityscapes Dataset

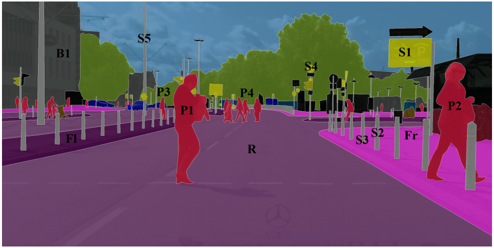
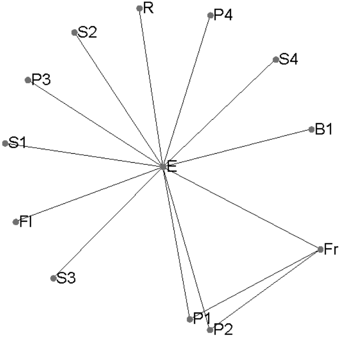


Figure: Ulm



Cordts et al. 2016.

Conclusion and Future Work

- A graph-based spatial model of the road traffic is presented
- The objective is to use qualitative knowledge along with quantitative data to avoid errors

Future Work

- Include time to make the model dynamic
- Include uncertainty of information
- Propose a dynamic graph for a single intersection
- Implementation (GraphStream, GraphML etc.)

Dutot et al. 2007.

THANK YOU FOR YOUR ATTENTION !!

QUESTIONS ?

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Appendix: Mathematical formalization of Graphs

Graph G at highest level of detail

$$G = (X, E)$$

$$X = V \ \cup \ B \ \cup \ VS \ \cup \ M \ \cup \ F \ \cup \ P \ \cup \ H \ \cup \ R \ \cup \ I$$

$$E = \{(x, y) \mid x \ \rho \ y\}, \ \rho \in \varrho,$$

$$\forall x, y \ ((x \in V \wedge y \in X) \vee (x \in F \wedge y \in P \cup H))$$

$$\varrho = \{T, \ O, \ RT, \ RS, \ QD, \ Ord\}$$

Appendix: Mathematical formalization of Graphs

Graph G_i for a single road segment $R_i \in R$

$$G_i = (X_i, E_i)$$

$$X_i \subseteq X \setminus (I \cup \{R_j \mid R_j \in R,\ j \neq i\}),\ \ i, j = 1, .., N_R$$

$$E_i \subseteq E$$

Two-carriageway graph G_{Li}

$$G_{Li} = (Y_i, E_{\omega i})$$

$$Y_i = \{V_{l1},\ V_{l2}\}$$

$$E_{\omega i} = \{(x, y) \mid x\ \omega\ y\},\ \omega \in \Omega,\ \forall x, y \in Y_i,\ x \neq y$$

$$\Omega = \{T,\ ARS,\ D\}$$

Appendix: Mathematical formalization of Graphs

Sector graph G_{Aij} for jth sector of $R_i \in R$

$$G_{Aij} = (U_{ij}, E_{ij})$$

$$U_{ij} \subseteq X_i,\ E_{ij} \subseteq E_i$$

Primal graph G_P

$$G_P = (I, E_\gamma)$$

$$E_\gamma = \{(x, y) \mid x\ \gamma\ y\},\ \gamma \in \Gamma,\ \forall x, y \in I,\ x \neq y,\ \Gamma = \{D\}$$

Dual graph G_D

$$G_D = (R, E_\psi)$$

$$E_\psi = \{(x, y) \mid x\ \psi\ y\},\ \psi \in \Psi,\ \forall x, y \in R,\ x \neq y,\ \Psi = \{AR,\ RO\}$$