Nonlinear Modeling of the Internet Delay Structure

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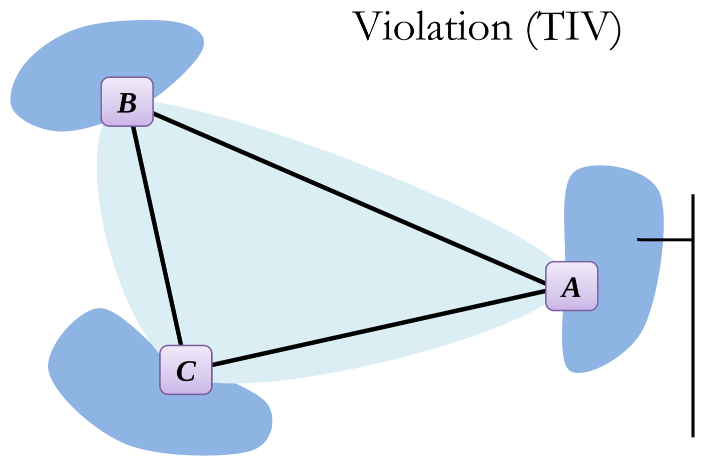
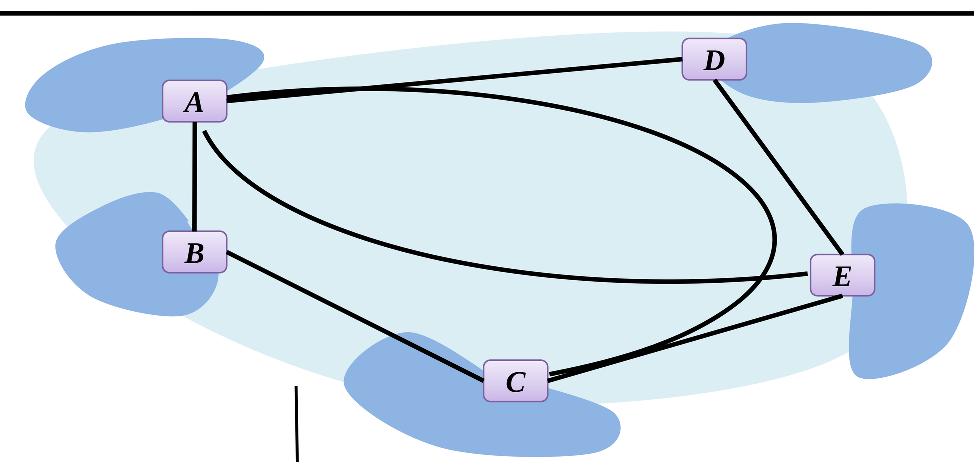
1. Motivation

- **Why model the Internet delay structure?**
  - Large-scale distributed systems applications:
    - overlay multicast
    - server selection
    - distributed query optimization
    - file-sharing via BitTorrent
    - compact routing

- **Typical models – Euclidean**
  - Existing systems: GNP, NPS, Vivaldi
  - A serious problem: Triangle Inequality Violation (TIV)





Euclidean modeling
- Conform to Triangle Inequality
- d(A,C) ≤d(A,B) + d(B,C)

Real Internet delay Structure
-Triangle Inequality Violation
- d(A,C) >d(A,B) + d(B,C)

2. Solution: Kernel Methods (KM)

- **What are Kernel Methods?**
  - A class of algorithms for pattern analysis (e.g. Support Vector Machine (SVM)).
  - **General task**: to find and study general types of relations in general types of data.

  Model the Internet delay structure

  - **Types of relations**: clusters, rankings, principal components, correlations, classifications

  Models

  - **Types of data**: sequences, text documents, sets of points, vectors, images, etc.

  Internet delays

- **Kernel**
  - What is kernel?
    - instead of using a mapping $\phi : \mathcal{X} \rightarrow \mathcal{F}$ to represent $\mathbf{x} \in \mathcal{X}$ by $\phi(\mathbf{x}) \in \mathcal{F}$
    - using $k : \mathcal{X} \times \mathcal{X} \rightarrow \mathbb{R}$ to represent Internet delay matrix by $k(\mathbf{x}_i, \mathbf{x}_j)$
  - Interpretation: a mapping exerted on Internet delay matrix
    - Isotropic stationary kernel: $K(\vec{x}, \vec{z}) = K_S(\|\vec{x} - \vec{z}\|)$
    - Euclidean norms: $K(\vec{x}, \vec{z}) = \|\vec{x} - \vec{z}\|$
    - The mapping: $K_S(\cdot)$
  - Typical kernels:
    - Polynomial kernel, Gaussian kernel, exponential kernel, etc.

3. Methodology

- **How to choose kernels?**
  - We define:
    - Measured Internet delay matrix: D_{MS}
    - Kernel: $K_S(\cdot)$
    - Mapped matrix in feature space: D_K, thus $D_{MS} = K_S(D_K)$
  - Current assumption: If there are less TIVs in D_K, such kernel $K_S(\cdot)$ is a good kernel, since Euclidean models can be embedded in D_K.
  - Example: a Euclidean based Network Coordinate system

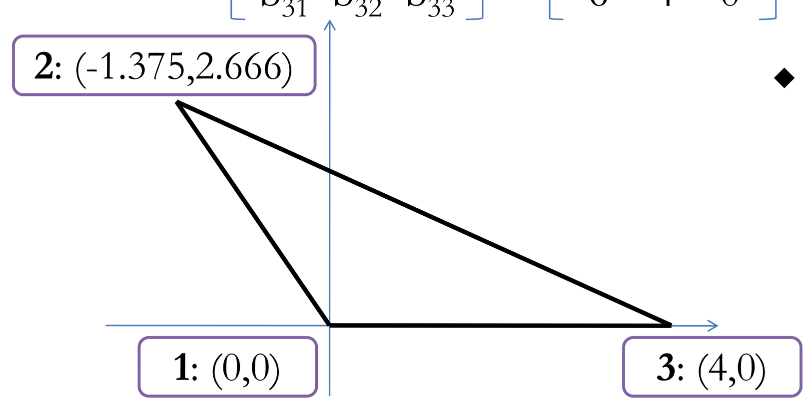
    Suppose: $K_S(\cdot) = (\cdot)^2$

$$D_{MS} = \begin{bmatrix} a_{11} & a_{12} & a_{13} \\ a_{21} & a_{22} & a_{23} \\ a_{31} & a_{32} & a_{33} \end{bmatrix} = \begin{bmatrix} 0 & 9 & 36 \\ 9 & 0 & 16 \\ 36 & 16 & 0 \end{bmatrix}$$

, here $a_{31} > a_{21} + a_{32}$ **TIV**

$$D_K = \begin{bmatrix} b_{11} & b_{12} & b_{13} \\ b_{21} & b_{22} & b_{23} \\ b_{31} & b_{32} & b_{33} \end{bmatrix} = \begin{bmatrix} 0 & 3 & 6 \\ 3 & 0 & 4 \\ 6 & 4 & 0 \end{bmatrix}$$

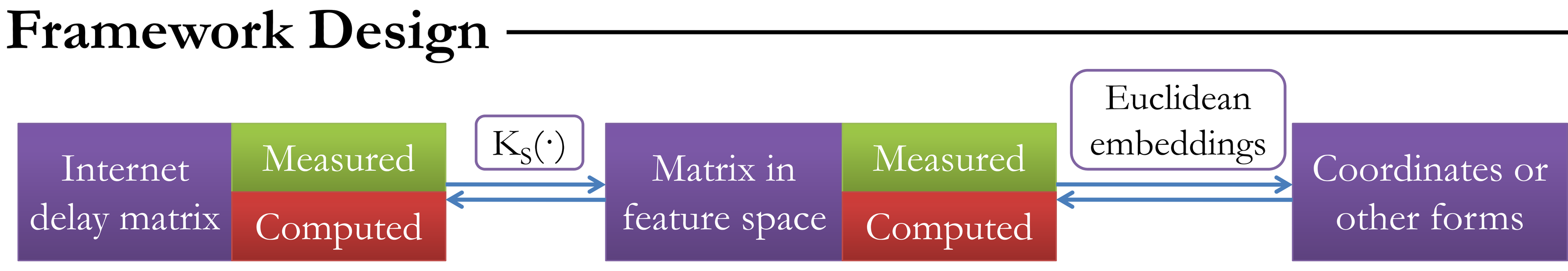
, here $b_{31} < b_{21} + b_{32}$ **no TIV**



- **2-D coordinates of 1,2,3:**
  - 1: (0,0)
  - 2: (-1.375,2.666)
  - 3: (4,0)

Can be embedded!

4. Framework Design



5. Evaluation

- **Data sets:**
  - **PlanetLab**: 226 nodes
  - **Meridian**: 2500 nodes
- **Metrics:**
  - **TIV ratios**: the number of triples of nodes violating triangle inequality to the proportion of all triples
  - **TIV severity** of edge AC:

$$\frac{\sum d(A,C)/(d(A,B)+d(B,C))}{|S|}$$

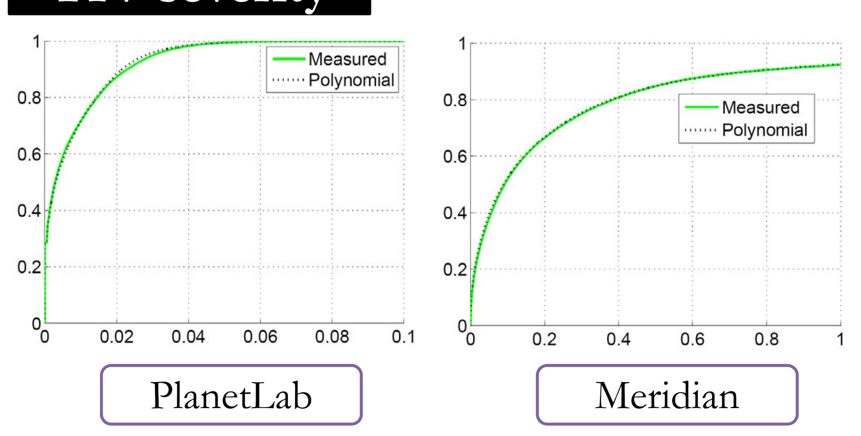
$B \in S$ and $d(A,C) > d(A,B) + d(B,C)$

S: the set of all nodes

TIV ratios

Data set	Real Internet	Euclidean systems	Poly Kernel
PlanetLab	0.2501	0	0.2745
Meridian	0.2350	0	0.2557

TIV severity



6. Further Works

- **Delay prediction performance:**
  - Current results: not steady among different data sets;
  - Future work: tune adaptive parameters
- **How to search for good kernels:**
  - Current kernel: polynomial kernel
  - Current methodology:
    - less TIVs in mapped matrix, better kernel.
    - But no guarantee: "if there is no TIV, Euclidean space can be embed"
  - Future work: need further exploration
- **Benefits: only Euclidean models?**
  - Hyperbolic, spherical: add kernels on them
  - Dot-product: add kernels and guarantee non-negativity
  - Future work: need further exploration

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