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Infrastructure adaptation and emergence of loops in network routing with time-dependent loads

Alessandro Lonardi

Physics for Inference and Optimization
Max Planck Institute for Intelligent Systems

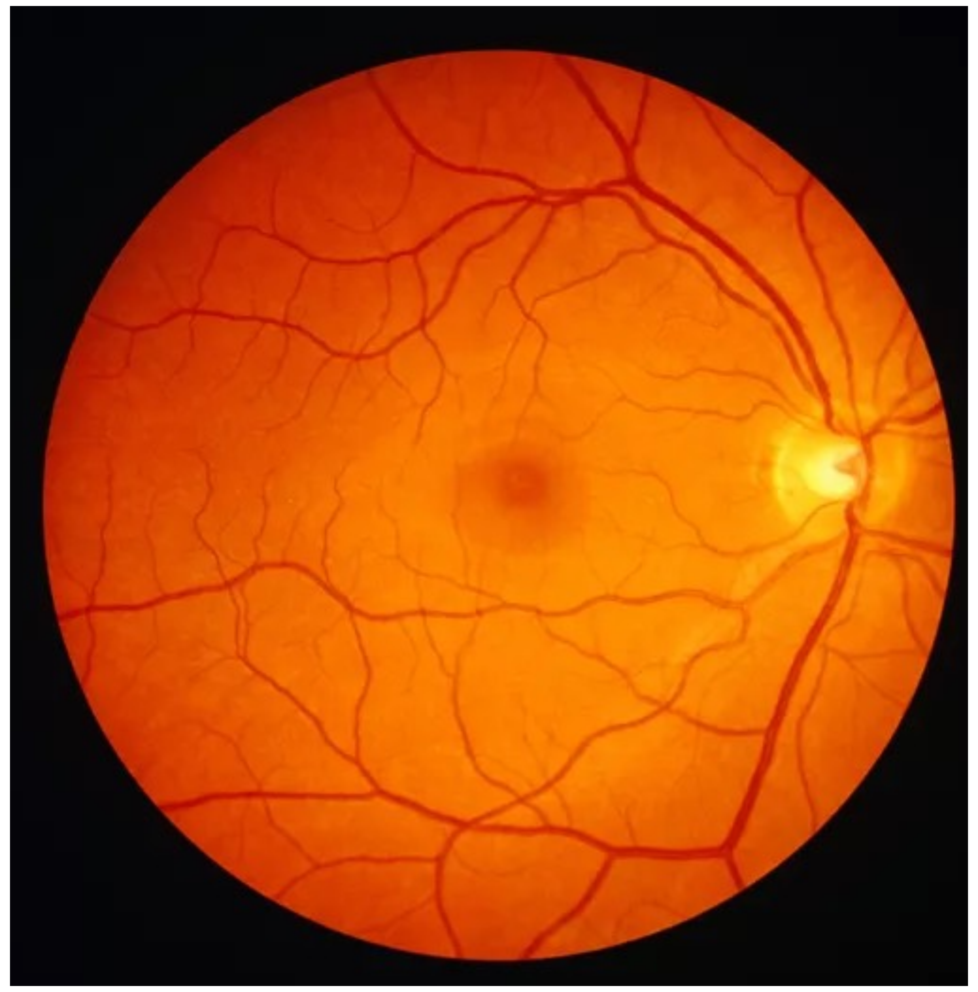
MAX-PLANCK-GESELLSCHAFT

imprs-is

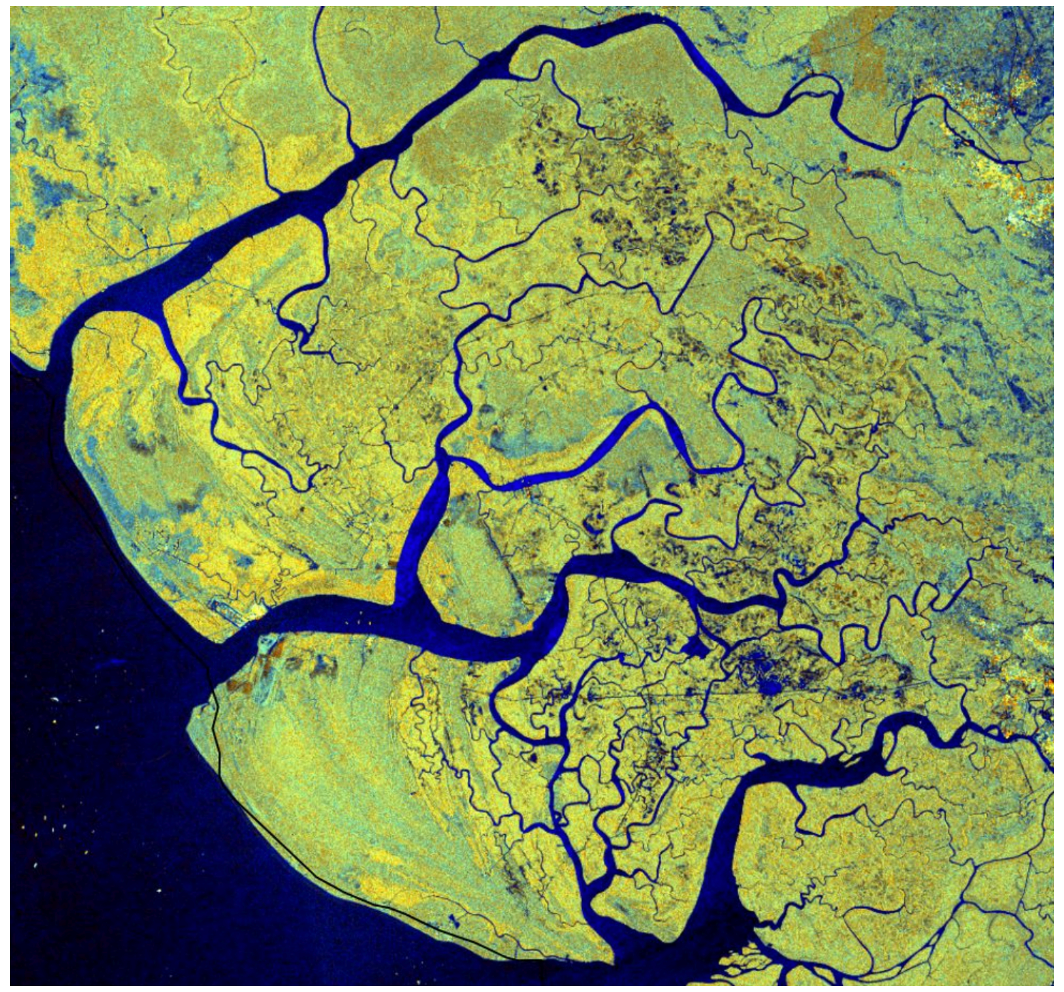
Cyber Valley

Motivation

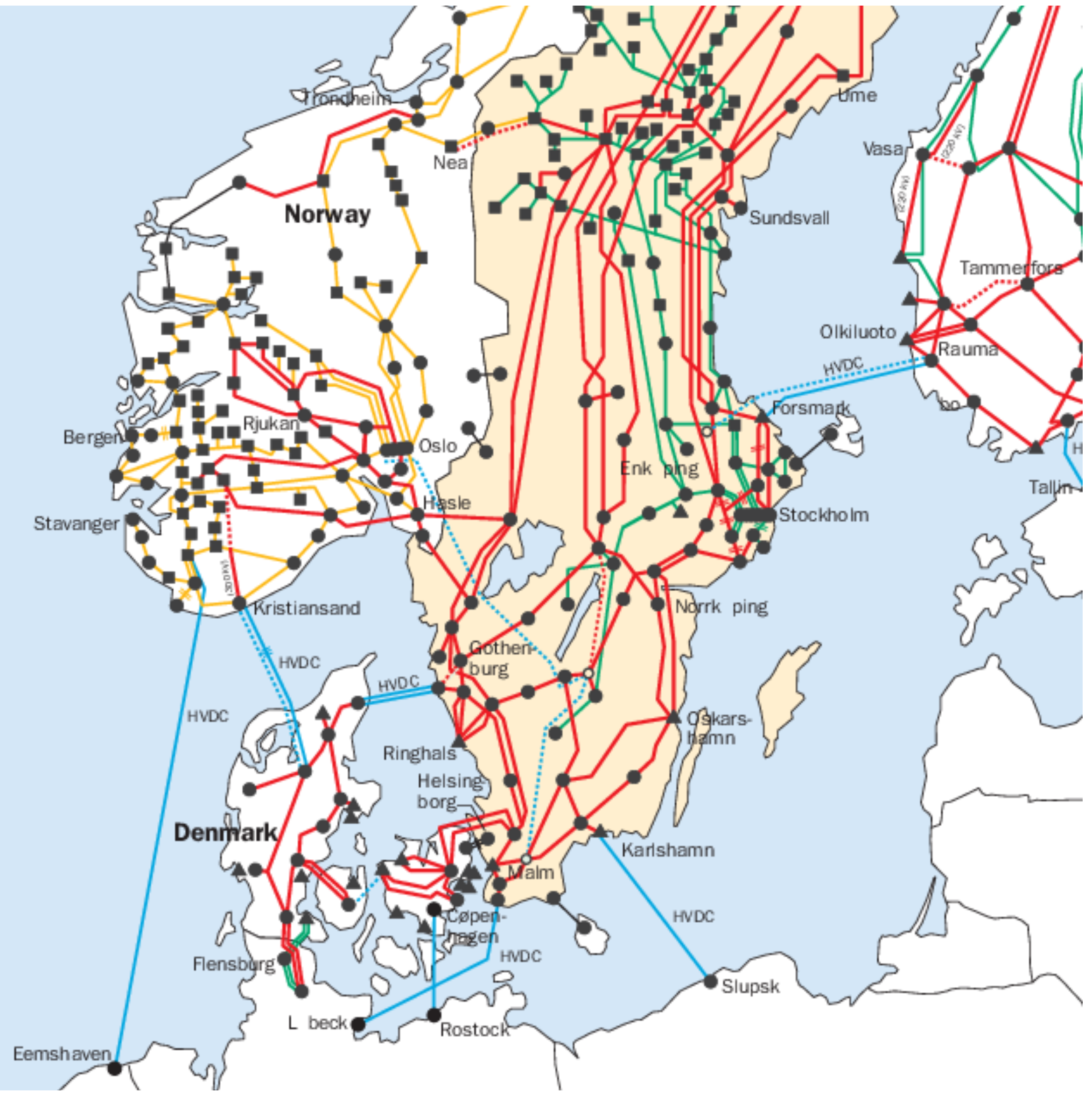
Transport networks are pervasive at different scales



UHB Trust

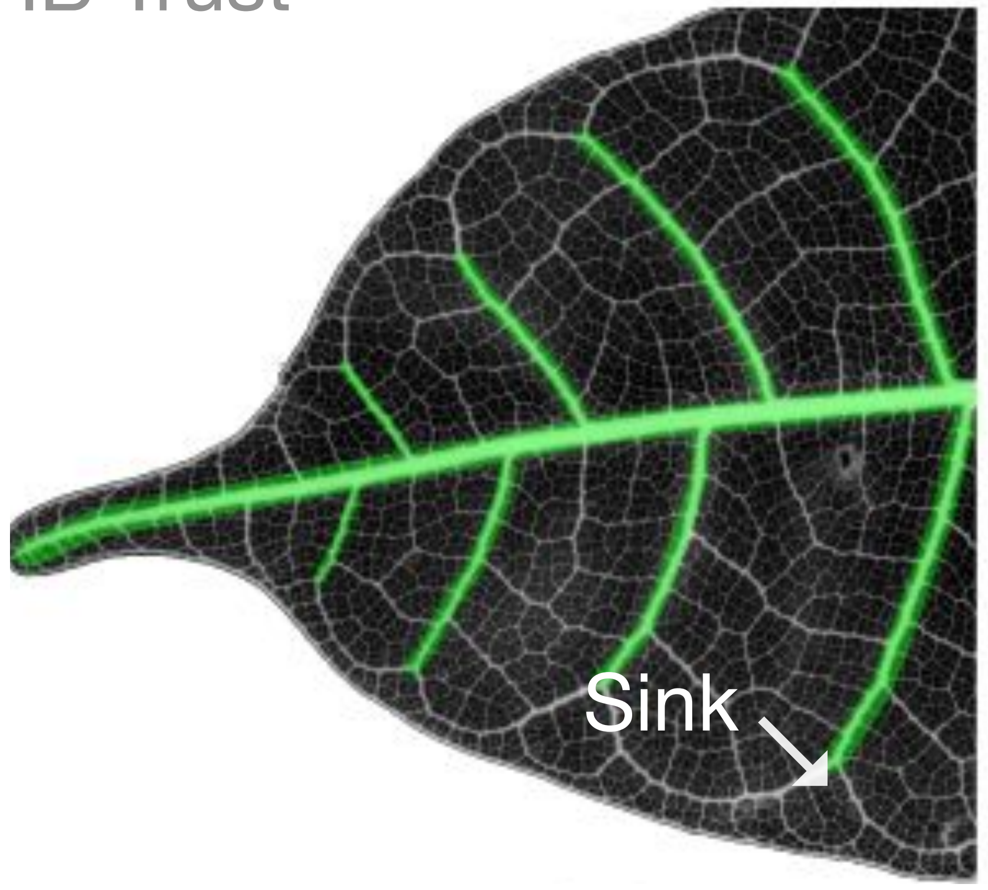


ESA



Perninge
KTH (2011)

Transport for
London

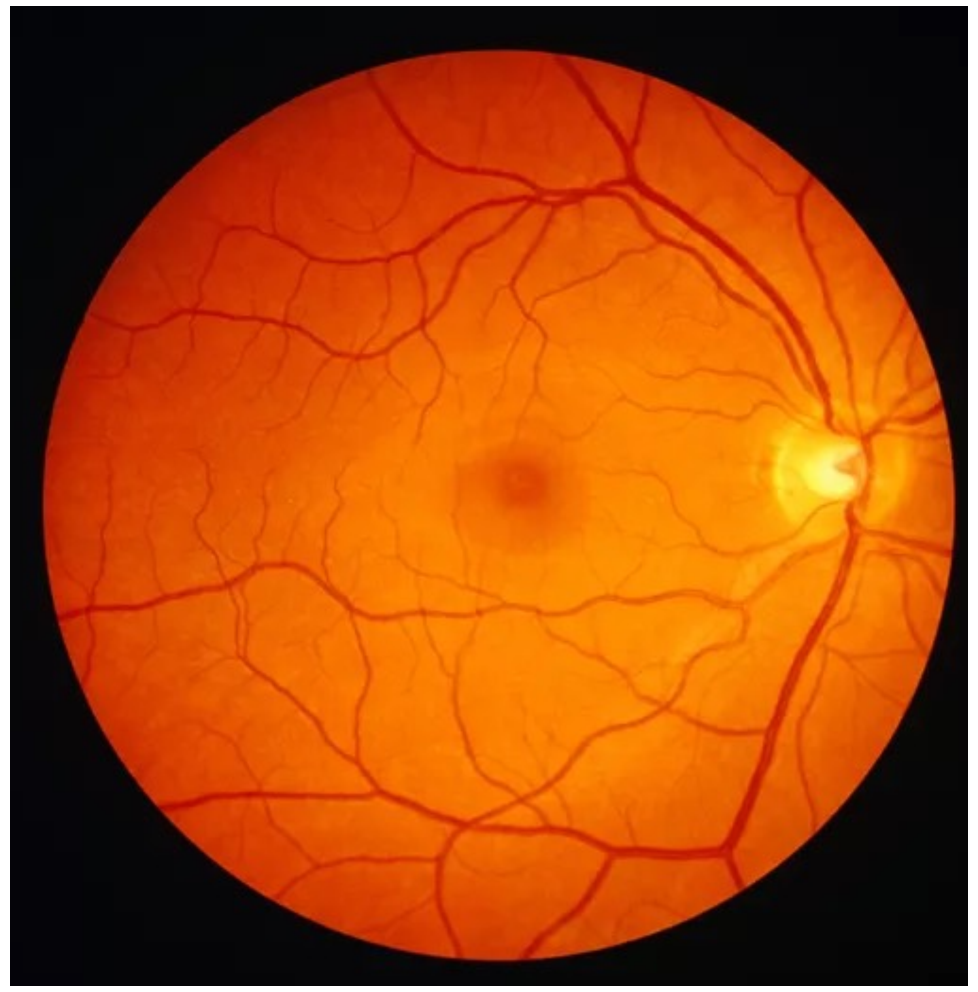


Ronellenfitsch and Katifori
PRL (2016)

Motivation

Transport networks are pervasive at different scales

Natural systems



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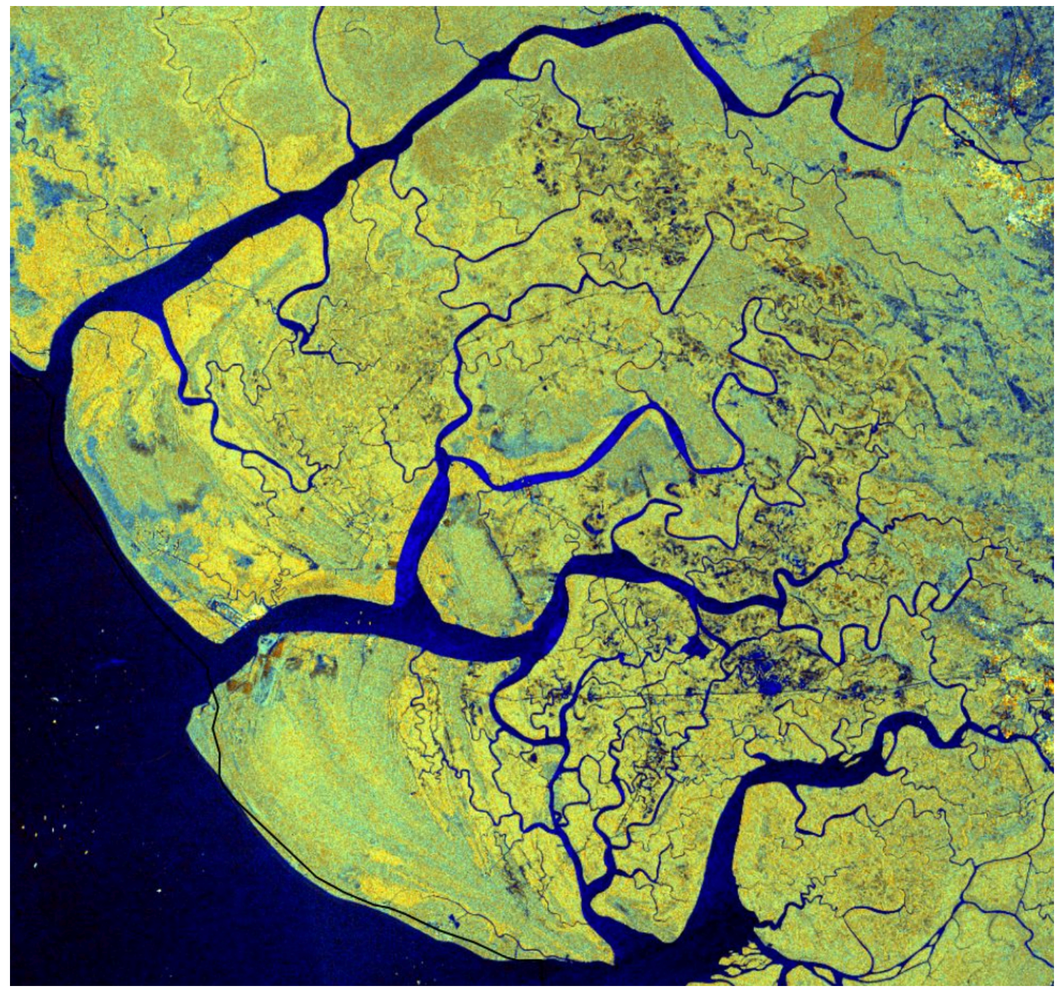
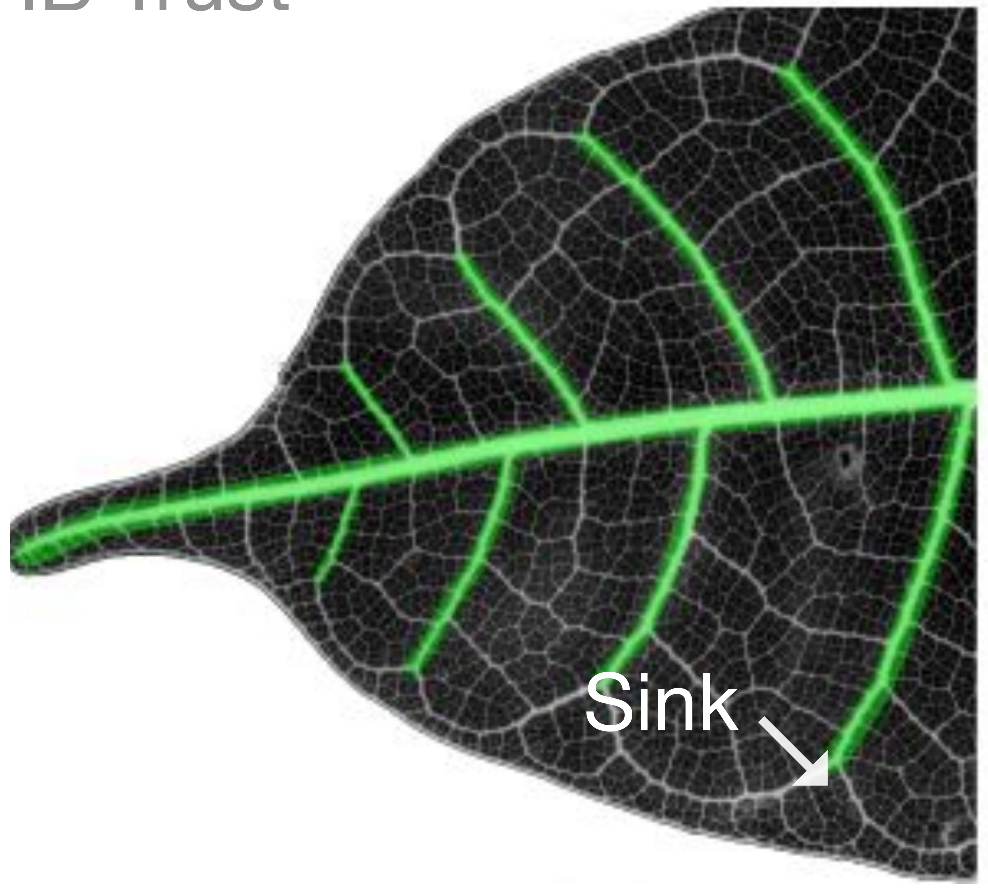


ESA

Source →



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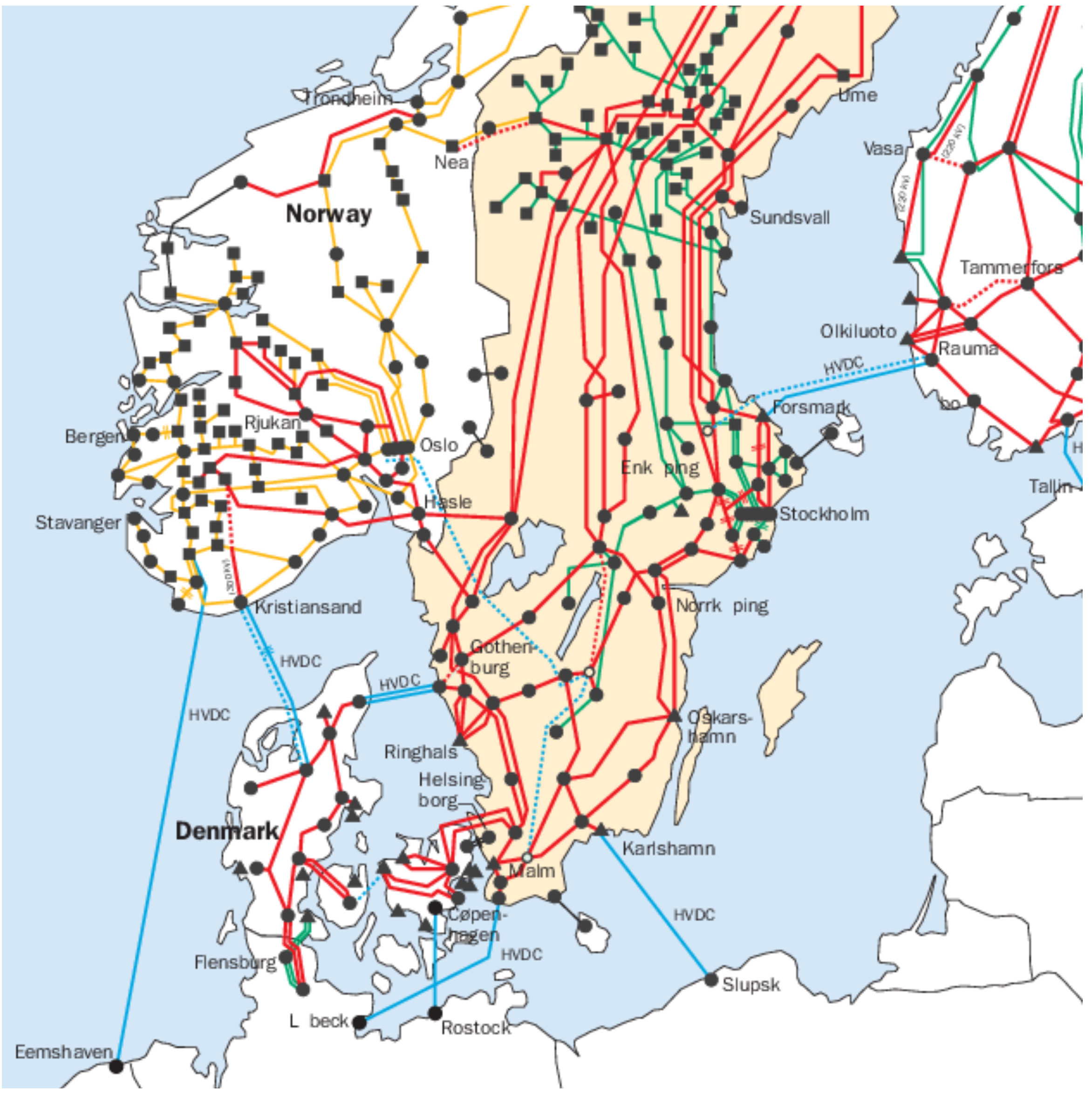


Perninge
KTH (2011)

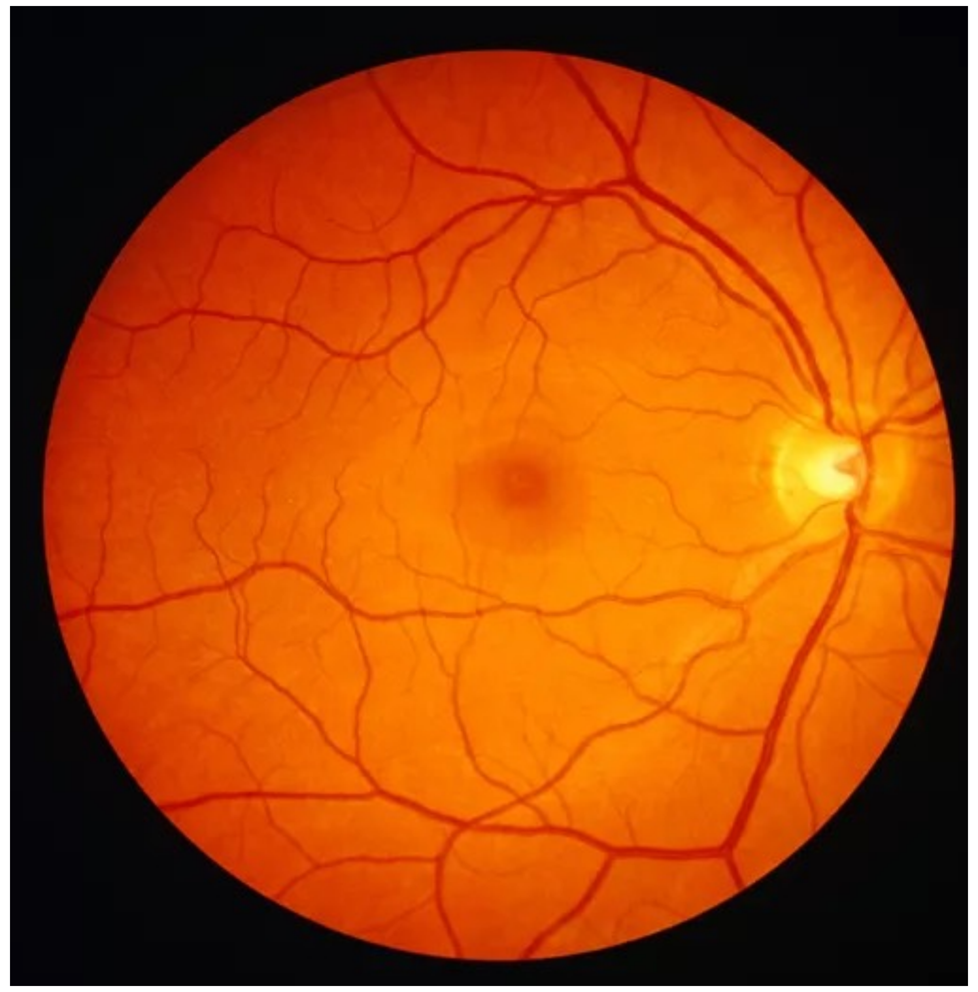
Transport for
London

Adaptation leads to the emergence of macroscopic properties

Motivation

Transport networks are pervasive at different scales

Natural systems



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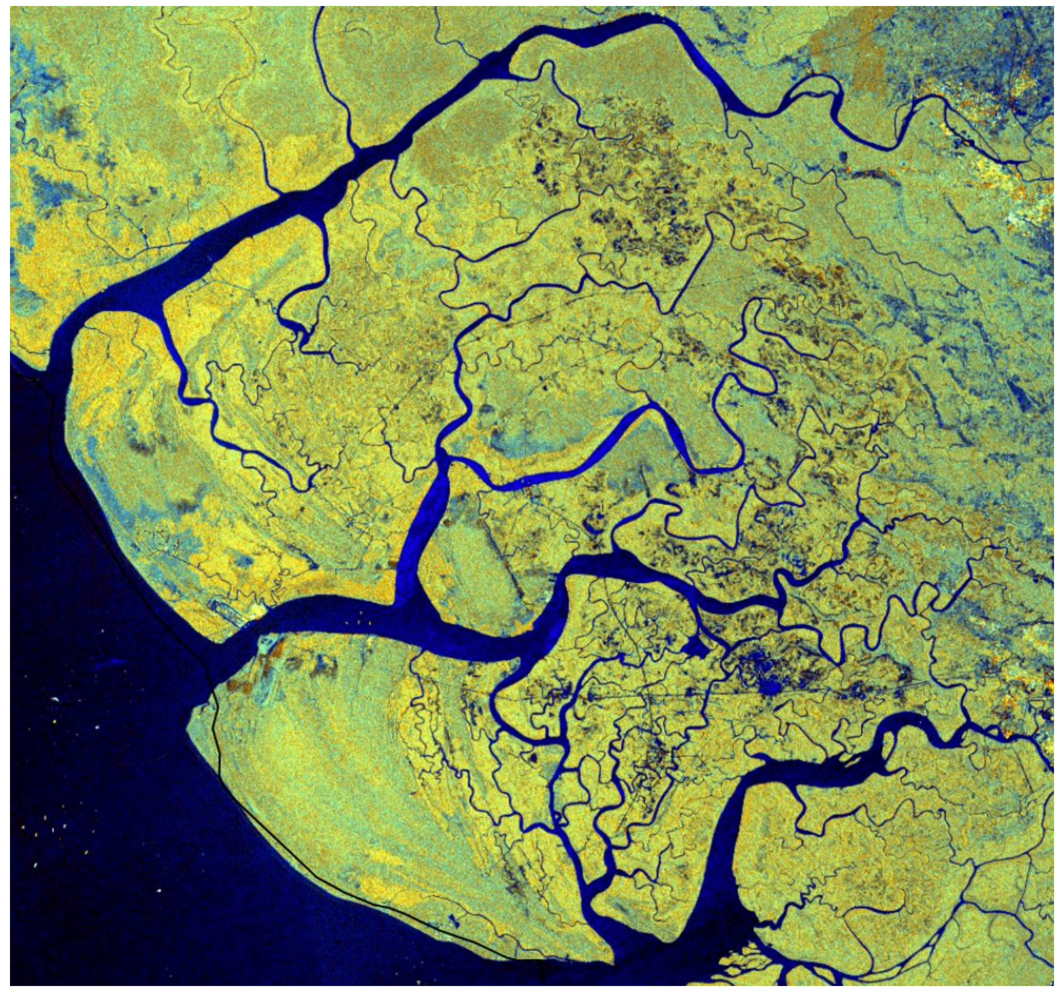

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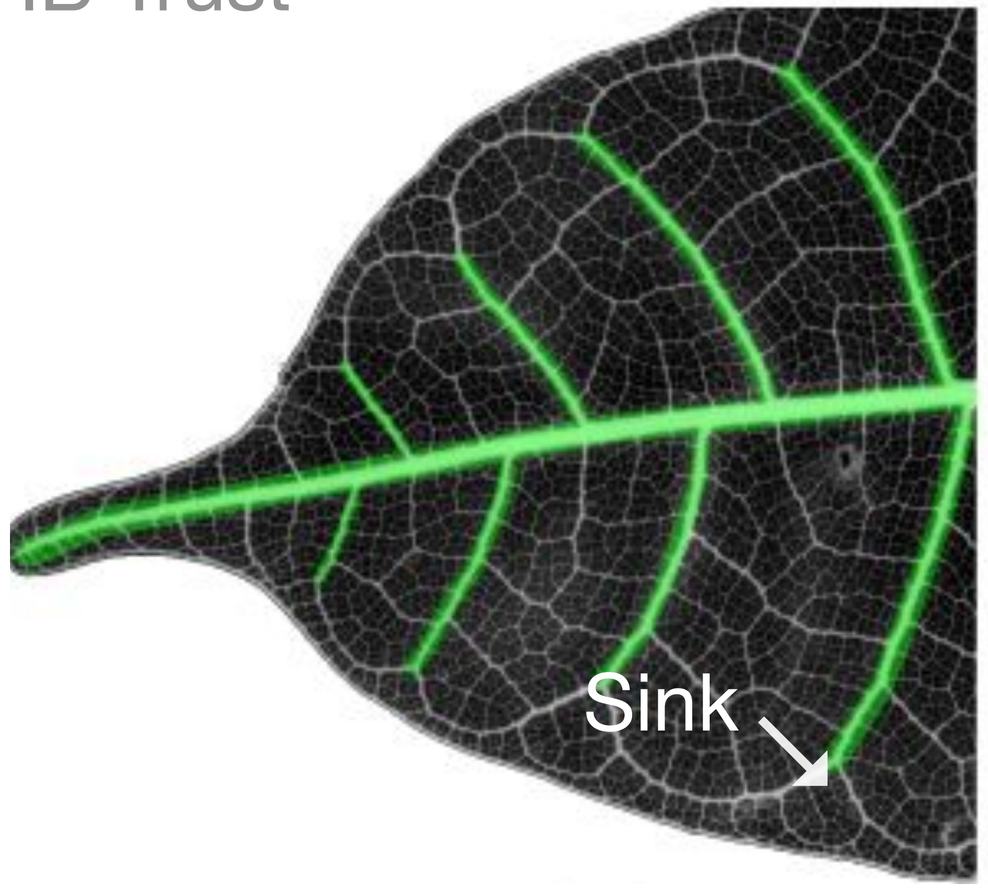
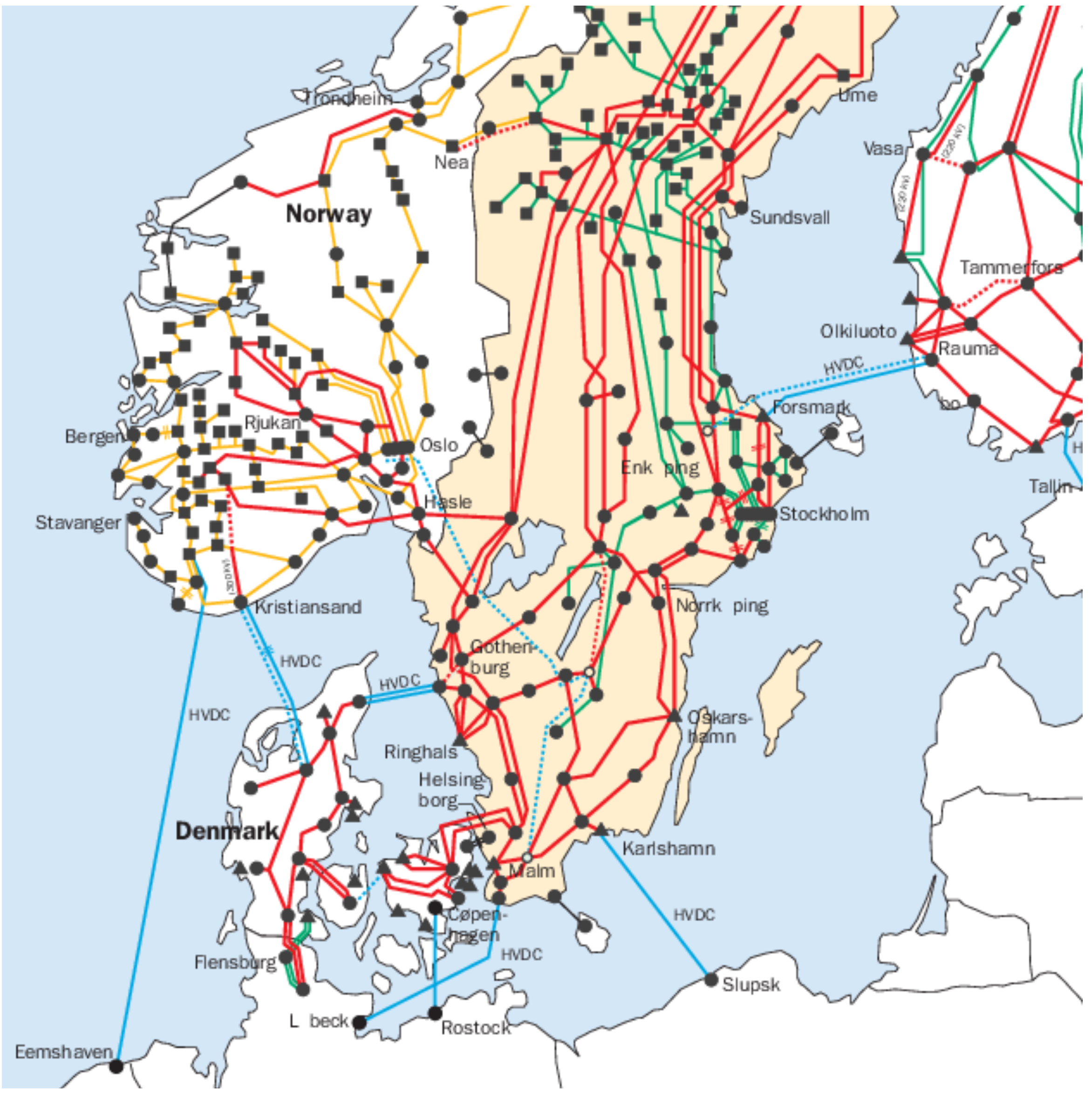


Ronellenfitsch and Katifori PRL (2016)

Artificial systems



Perninge KTH (2011)

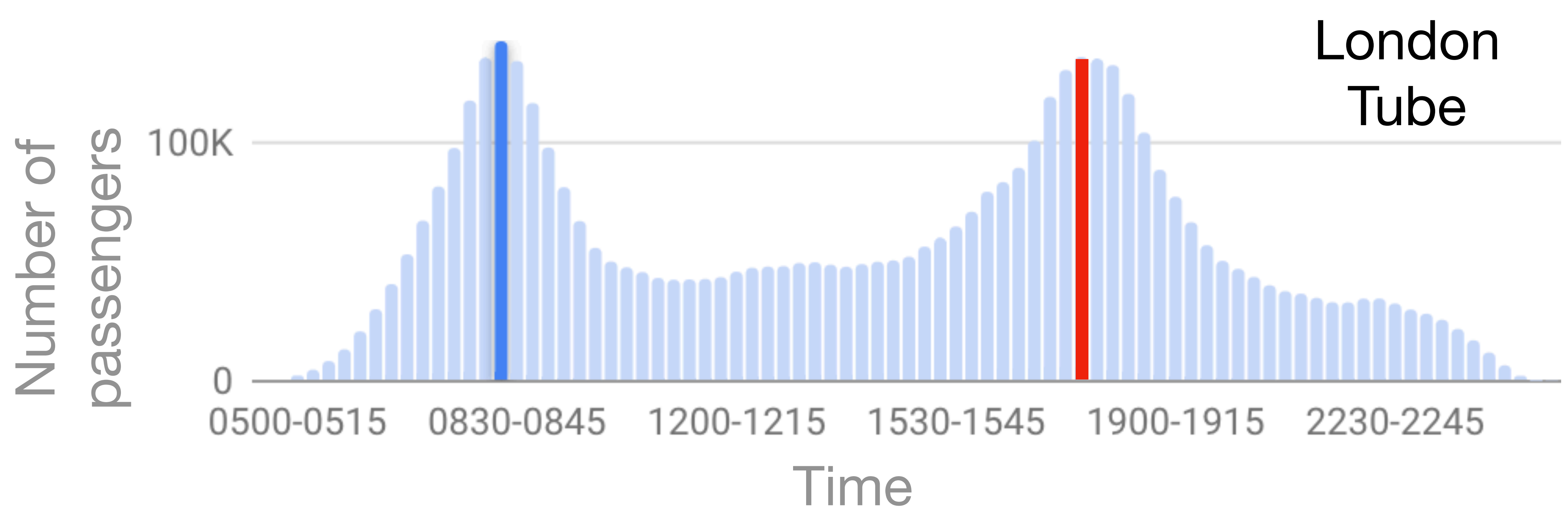
Transport for London

➡ Adaptation leads to the emergence of macroscopic properties

➡ Idea: leverage adaptation to design urban transportation

Modeling assumption

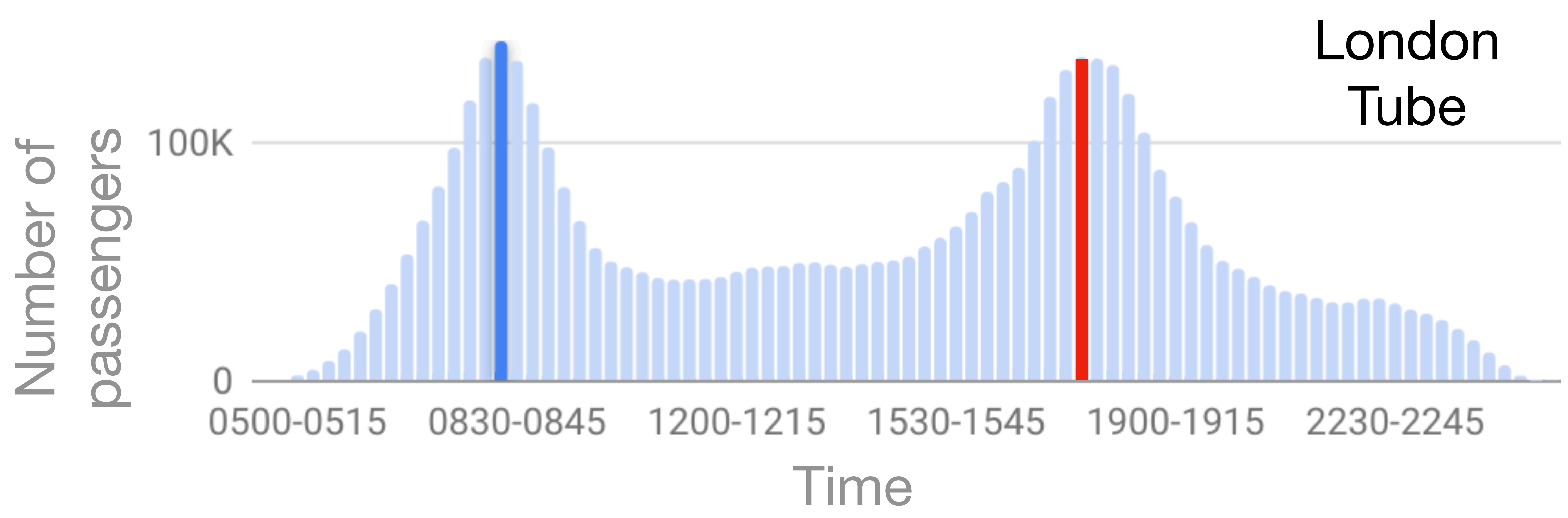
Node loads are dynamic!



Oliver O'Brien,
Transport for London

Modeling assumption

Node loads are dynamic!



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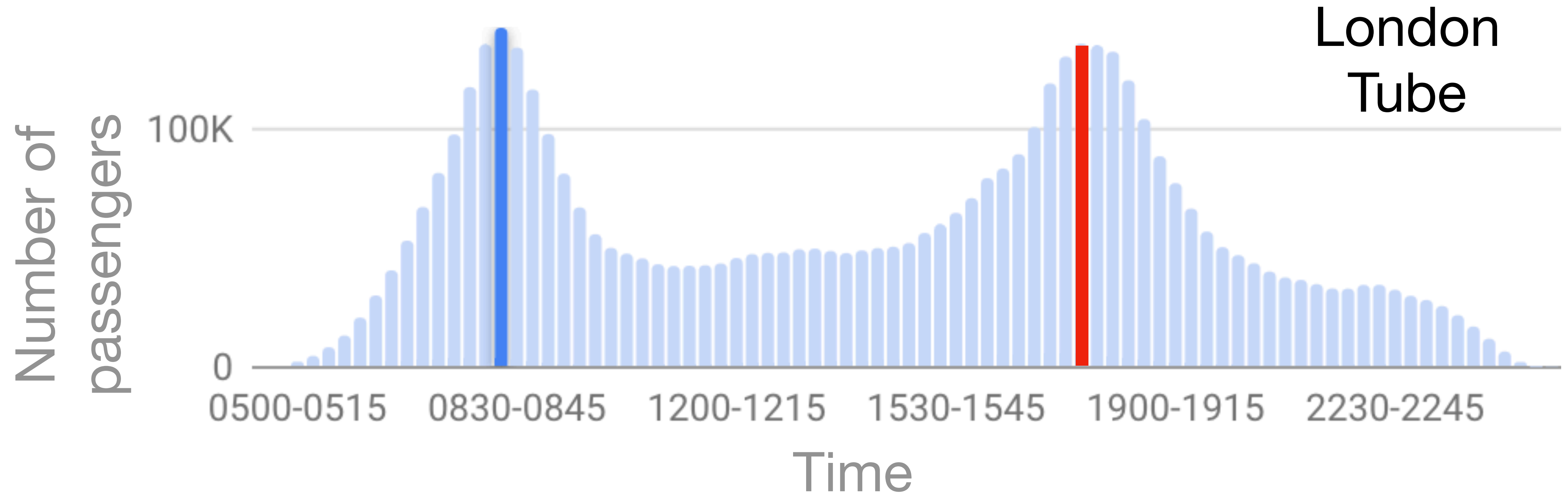
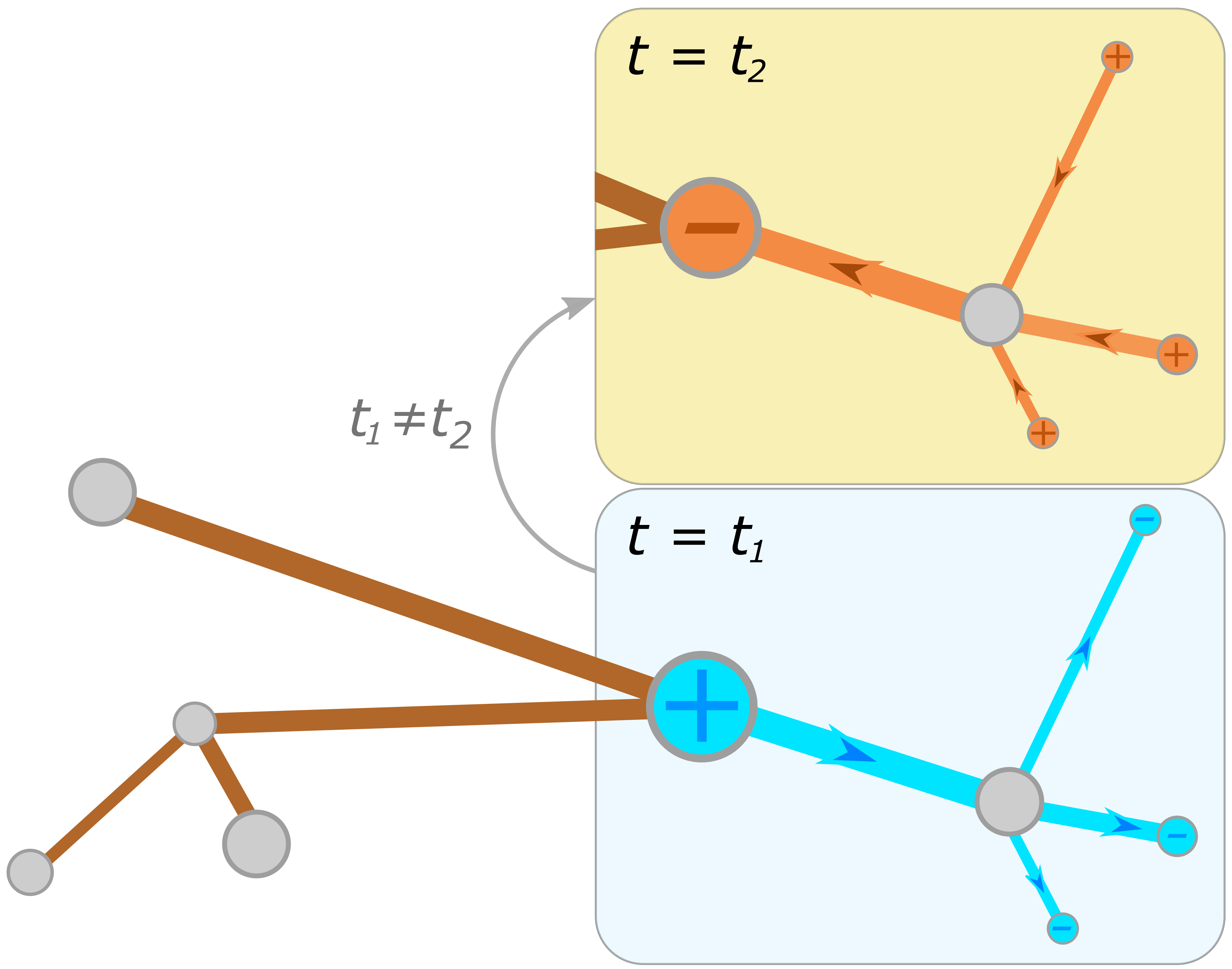


Often neglected by adaptation models!

Oliver O'Brien,
Transport for London

Research questions

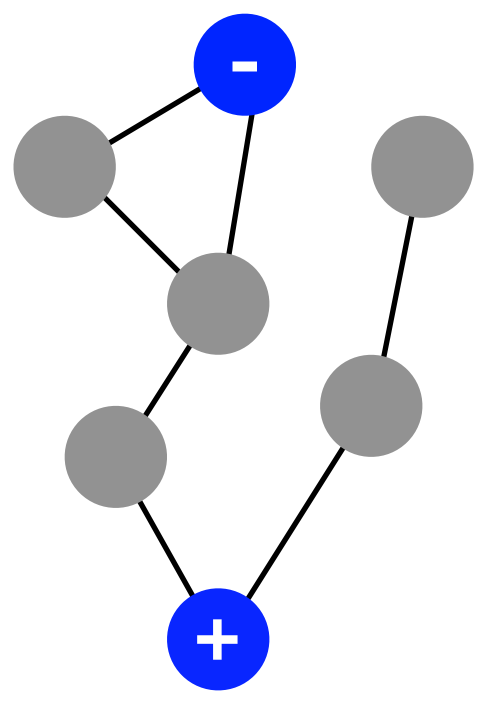


Adapted from
Lonardi PRE (2023)

1) Can we find adaptation rules for time-dependent node loads?

2) Does adaptation shed light on transport network properties?

Background



μ_e : road capacity

F_e : load displacement

$$\begin{cases} \dfrac{d\mu_e}{dt} = \dfrac{f(|F_e|)}{w_e} - \mu_e \\ \text{Kirchhoff's law} \end{cases}$$

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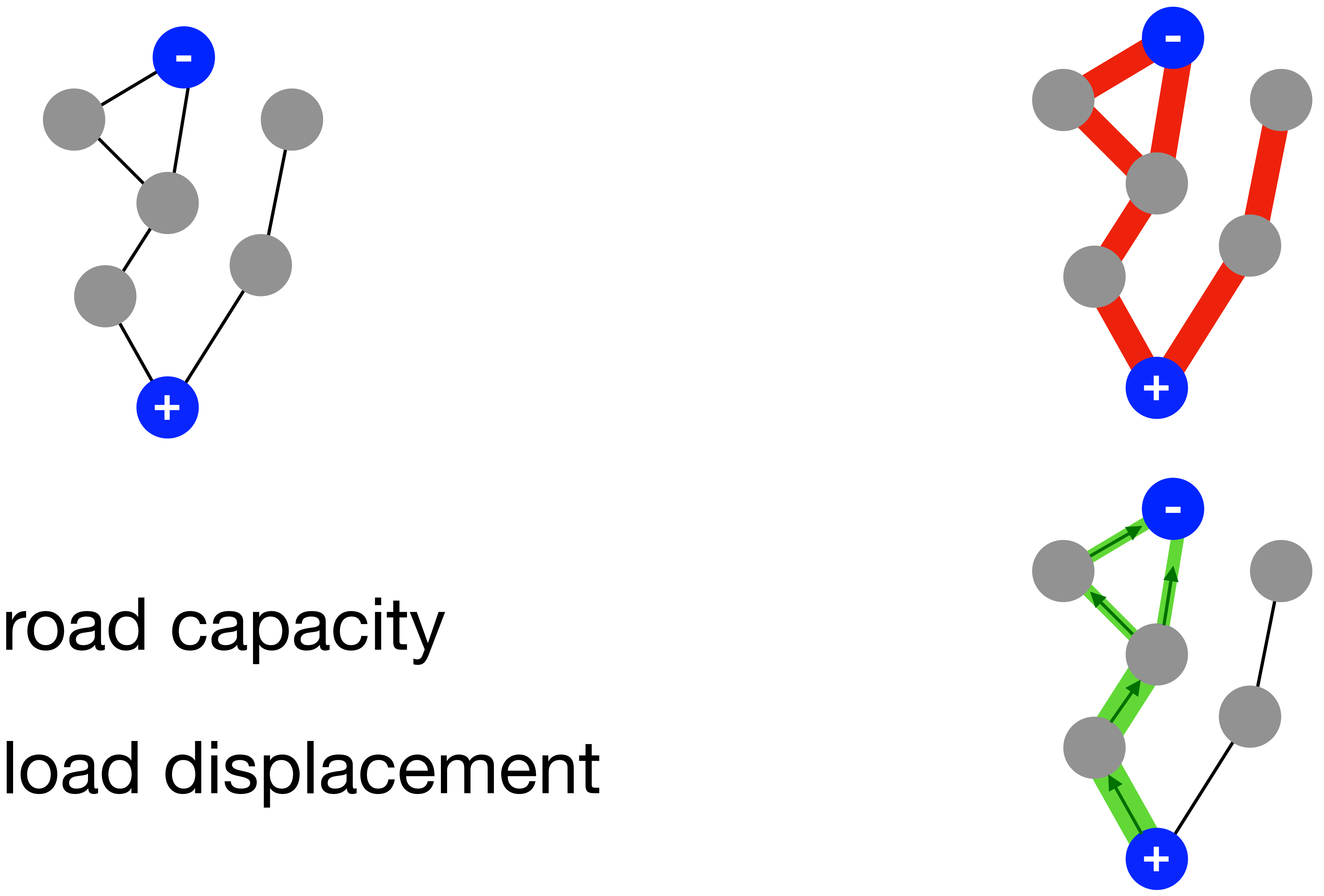

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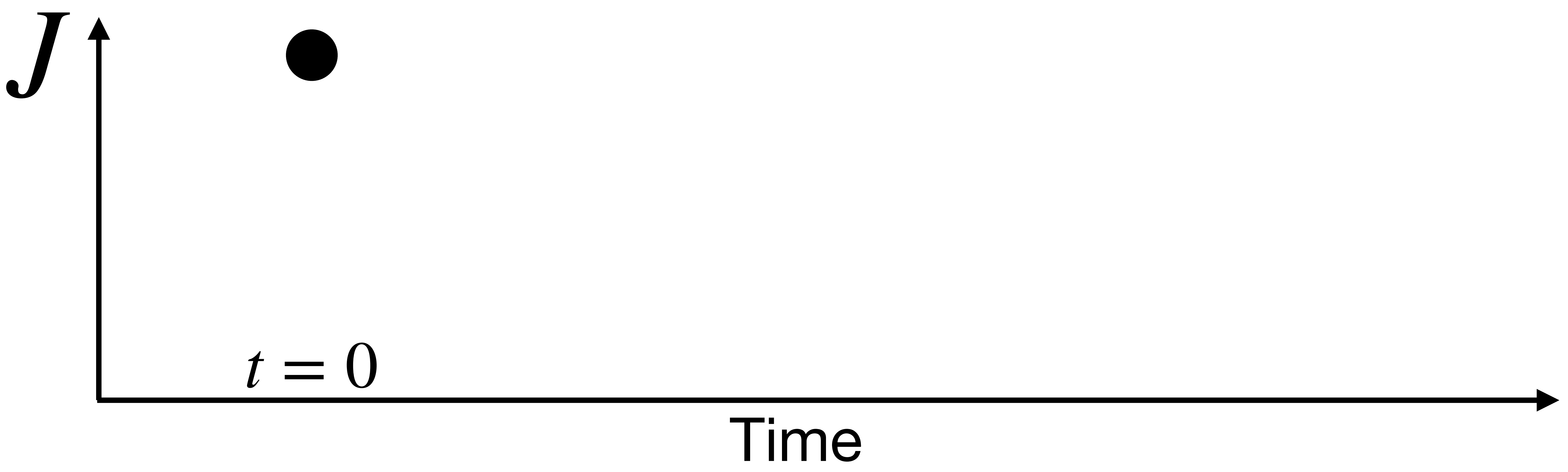

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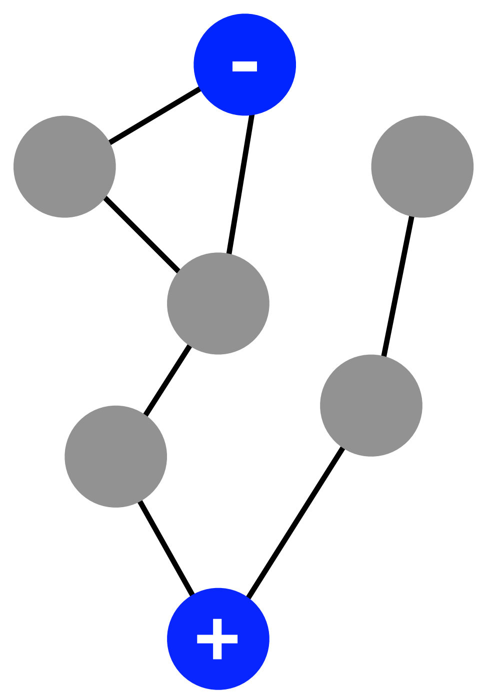

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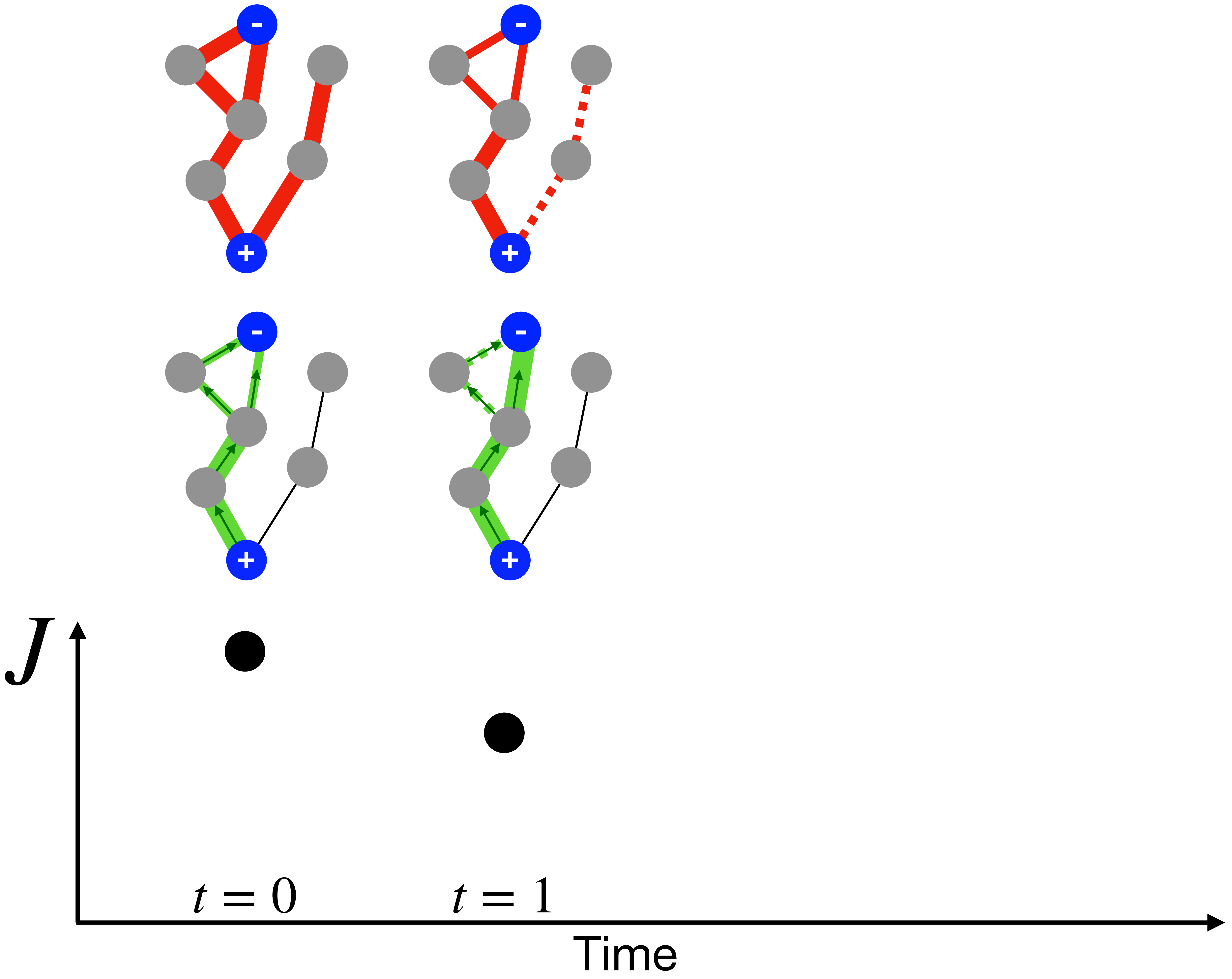

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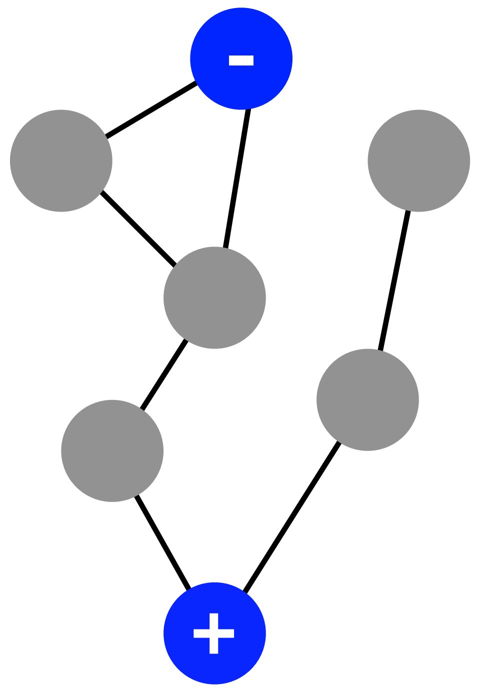

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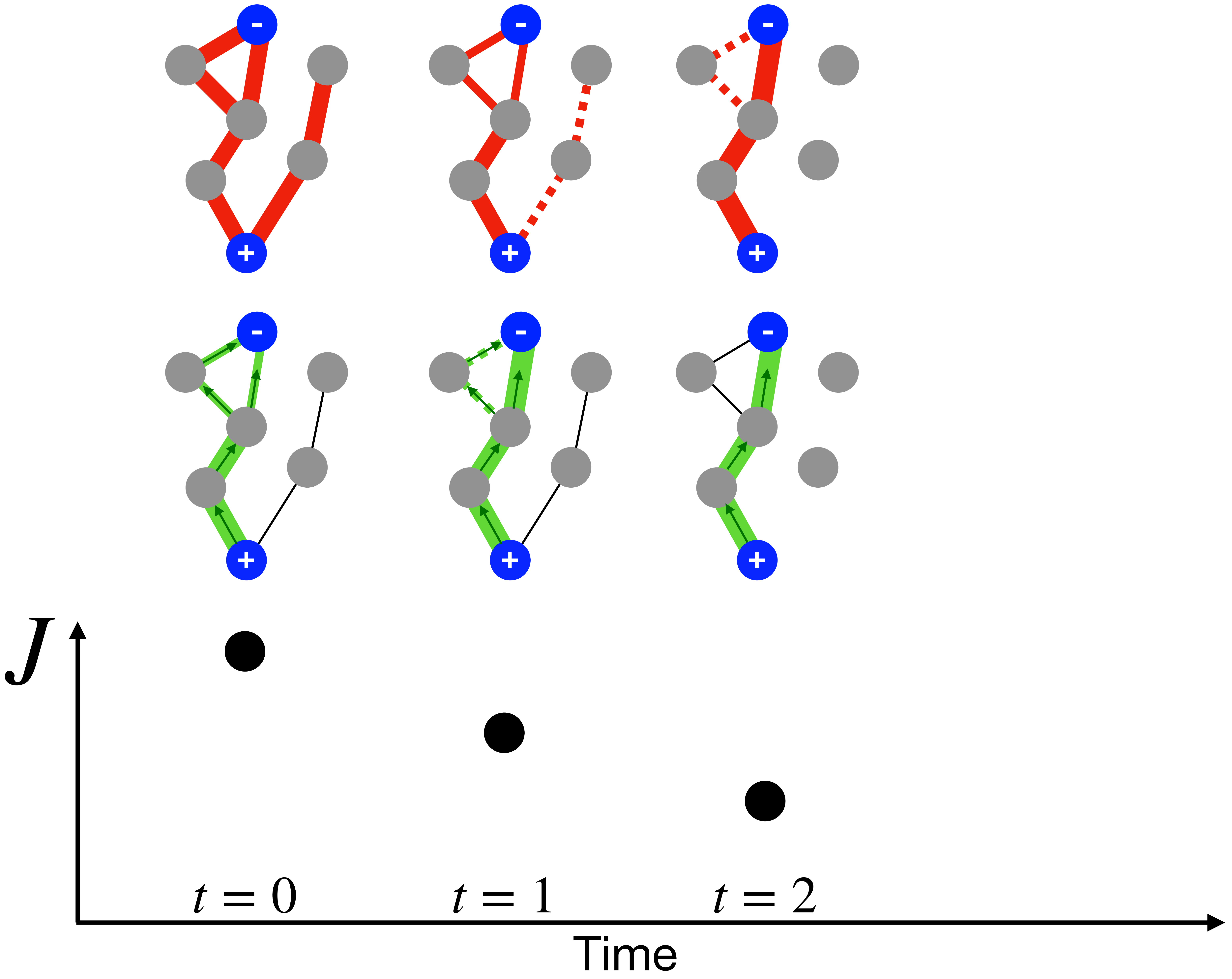

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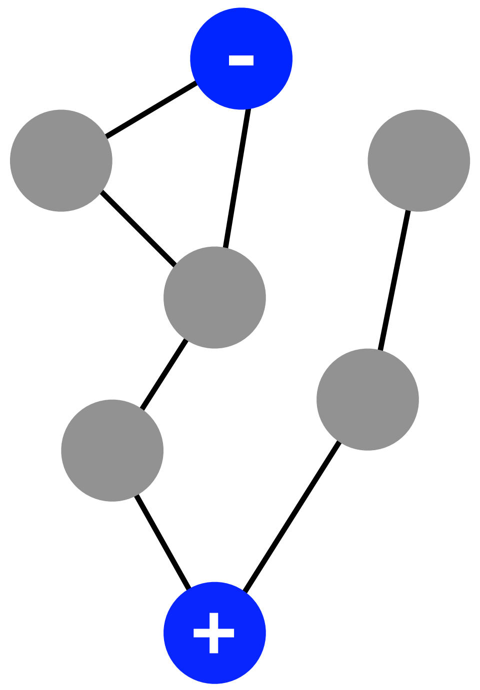

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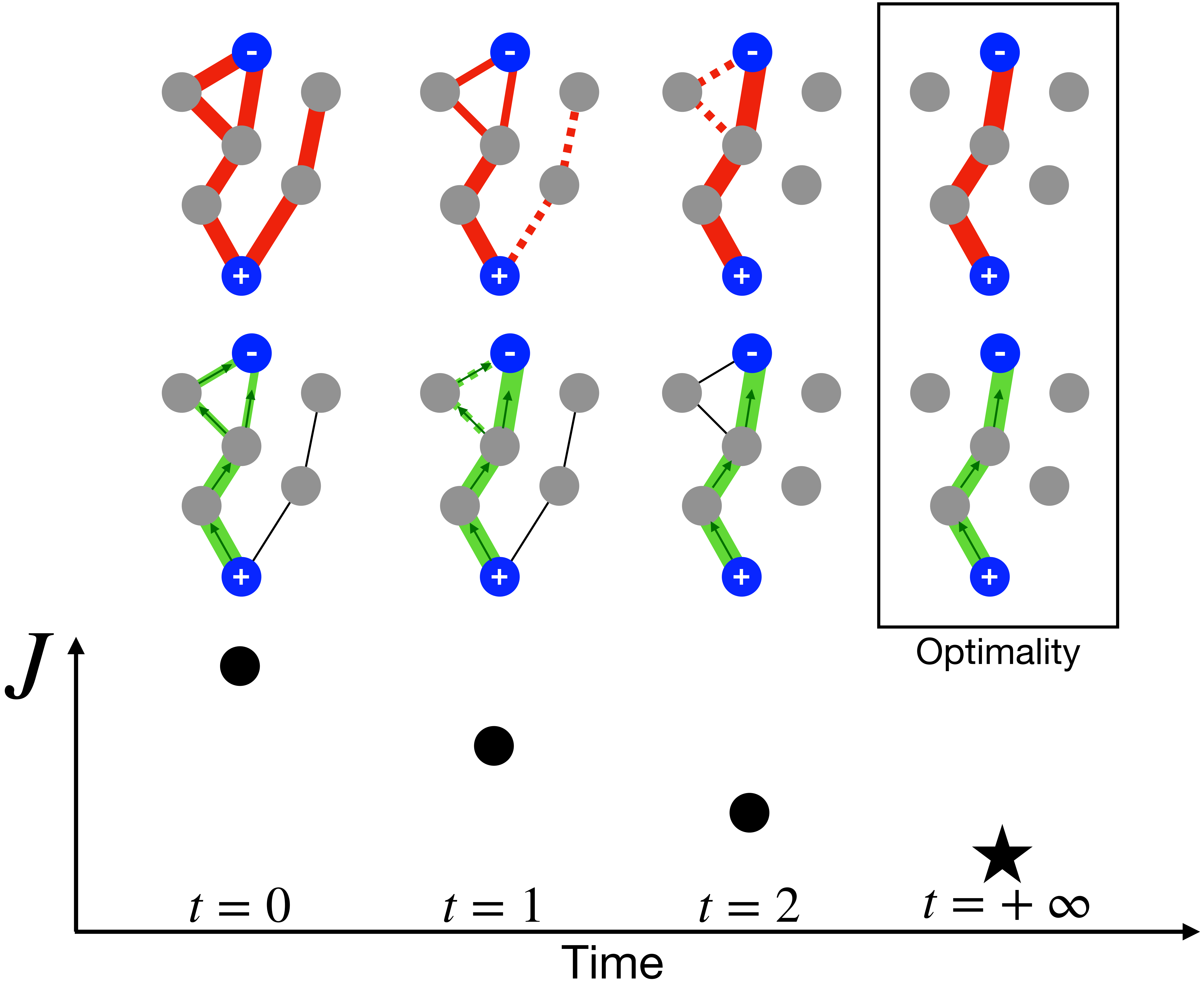
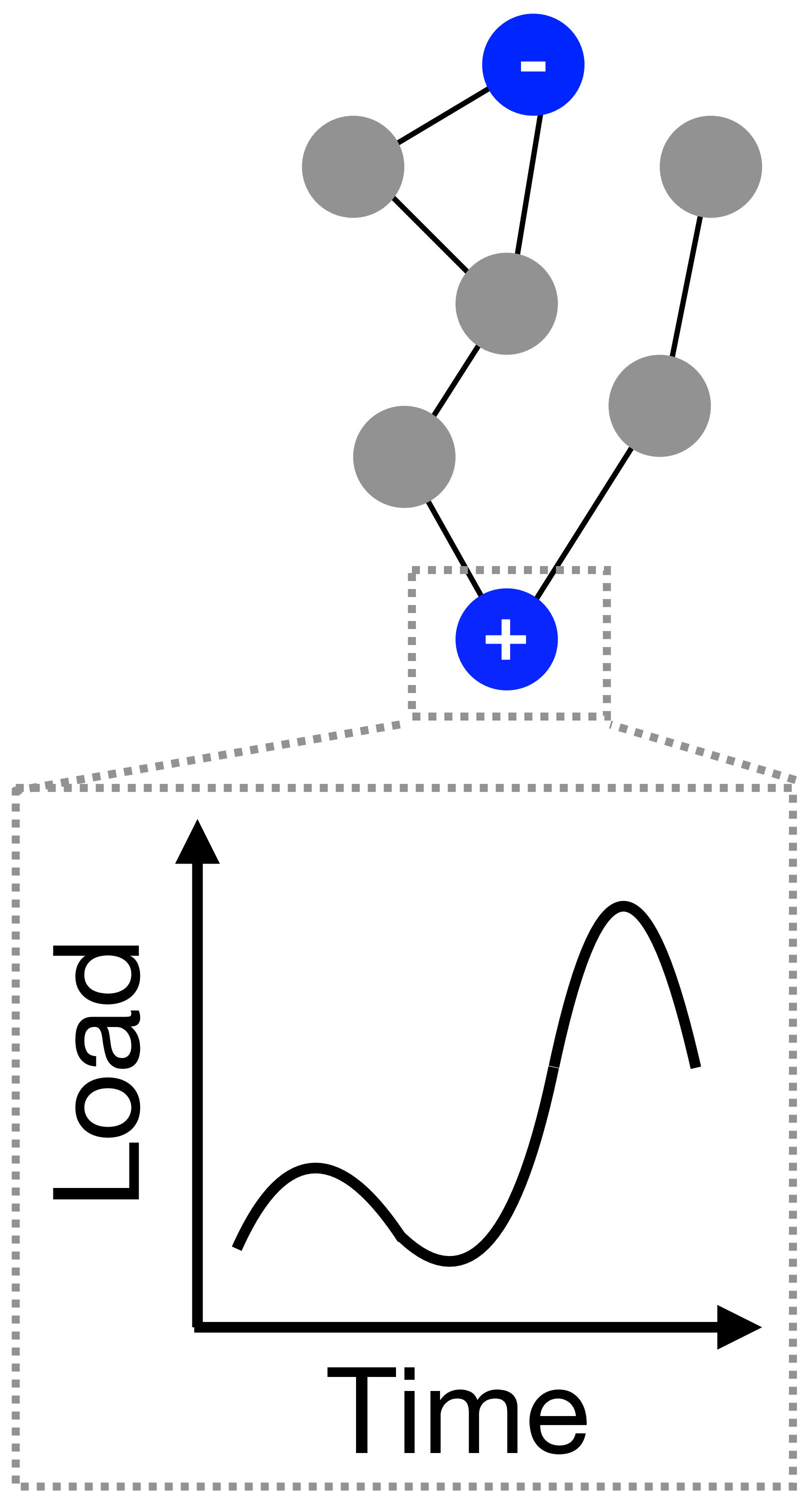
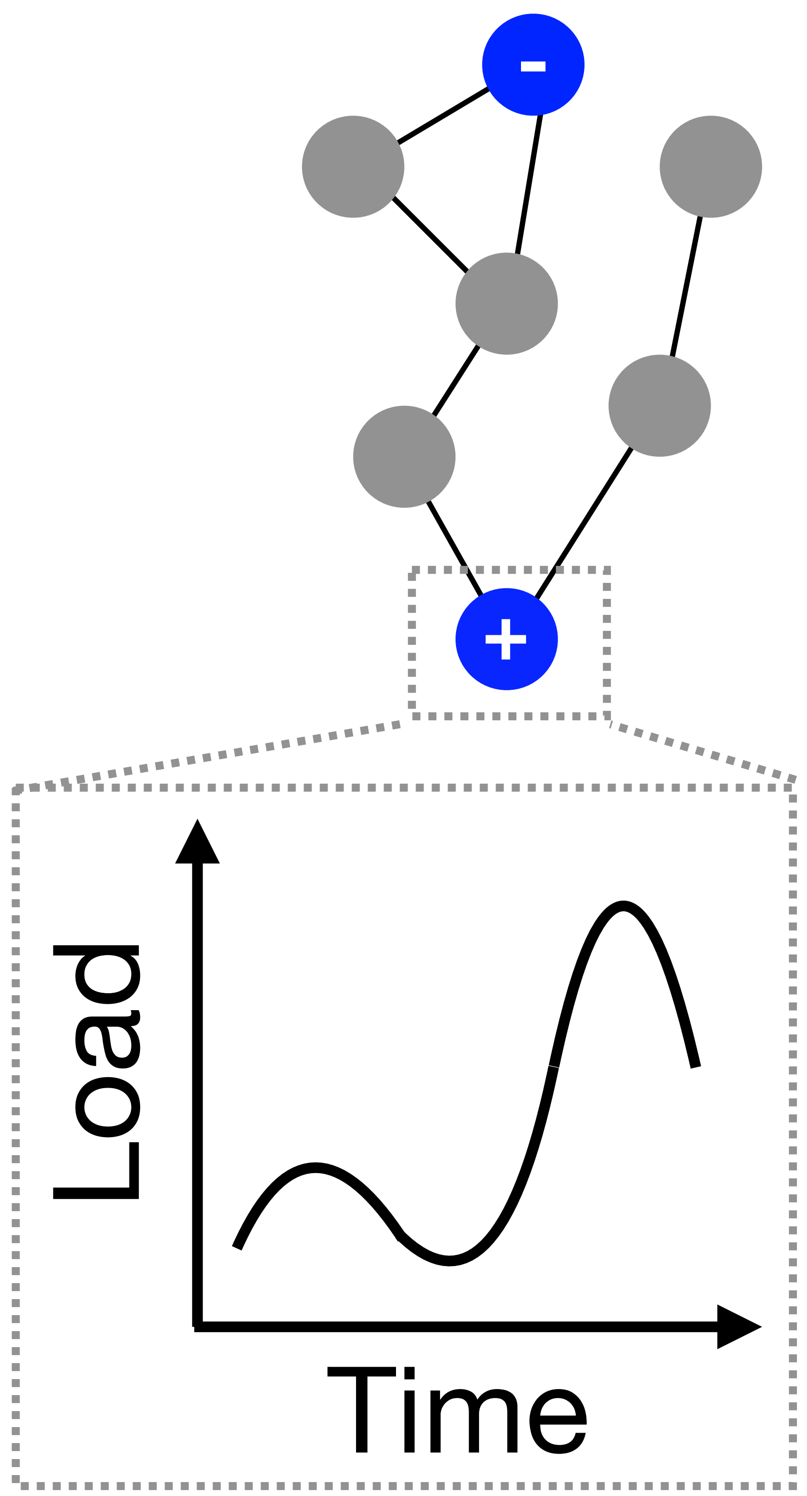


Method

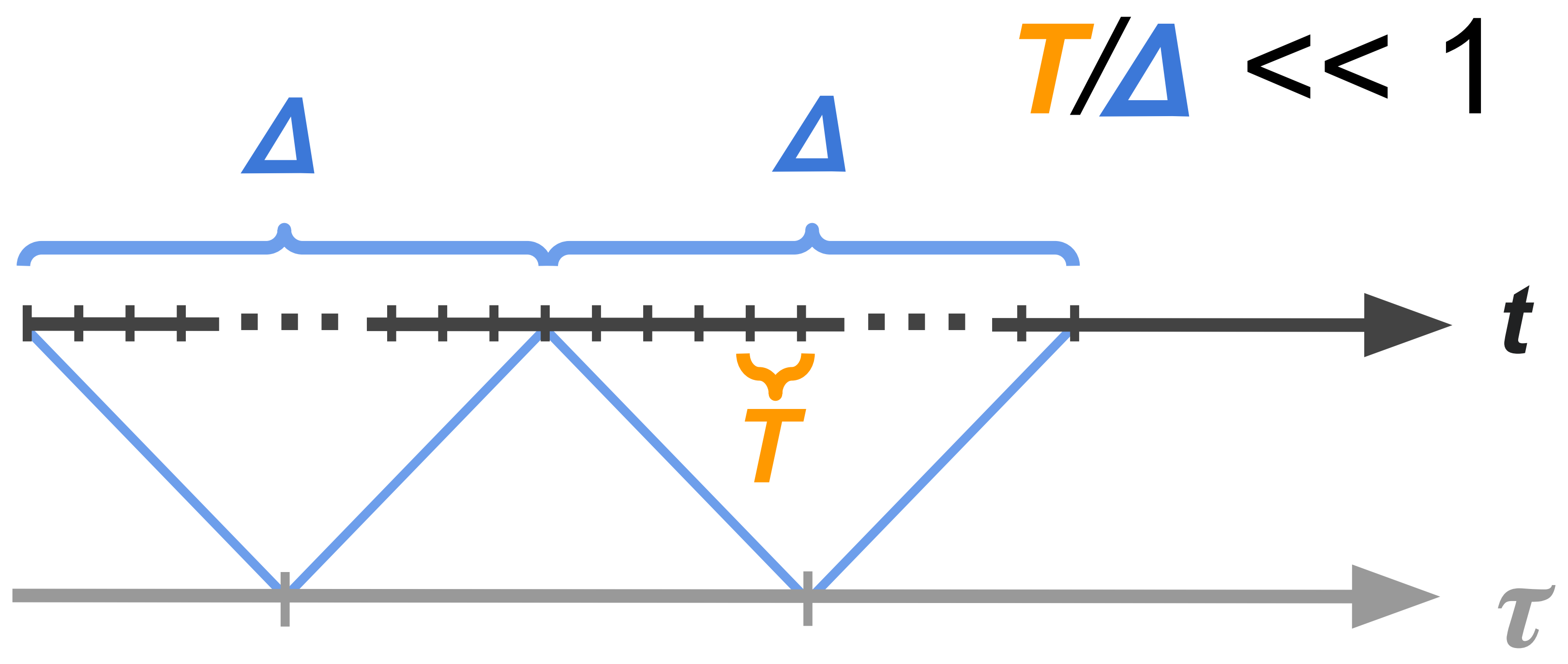


Method

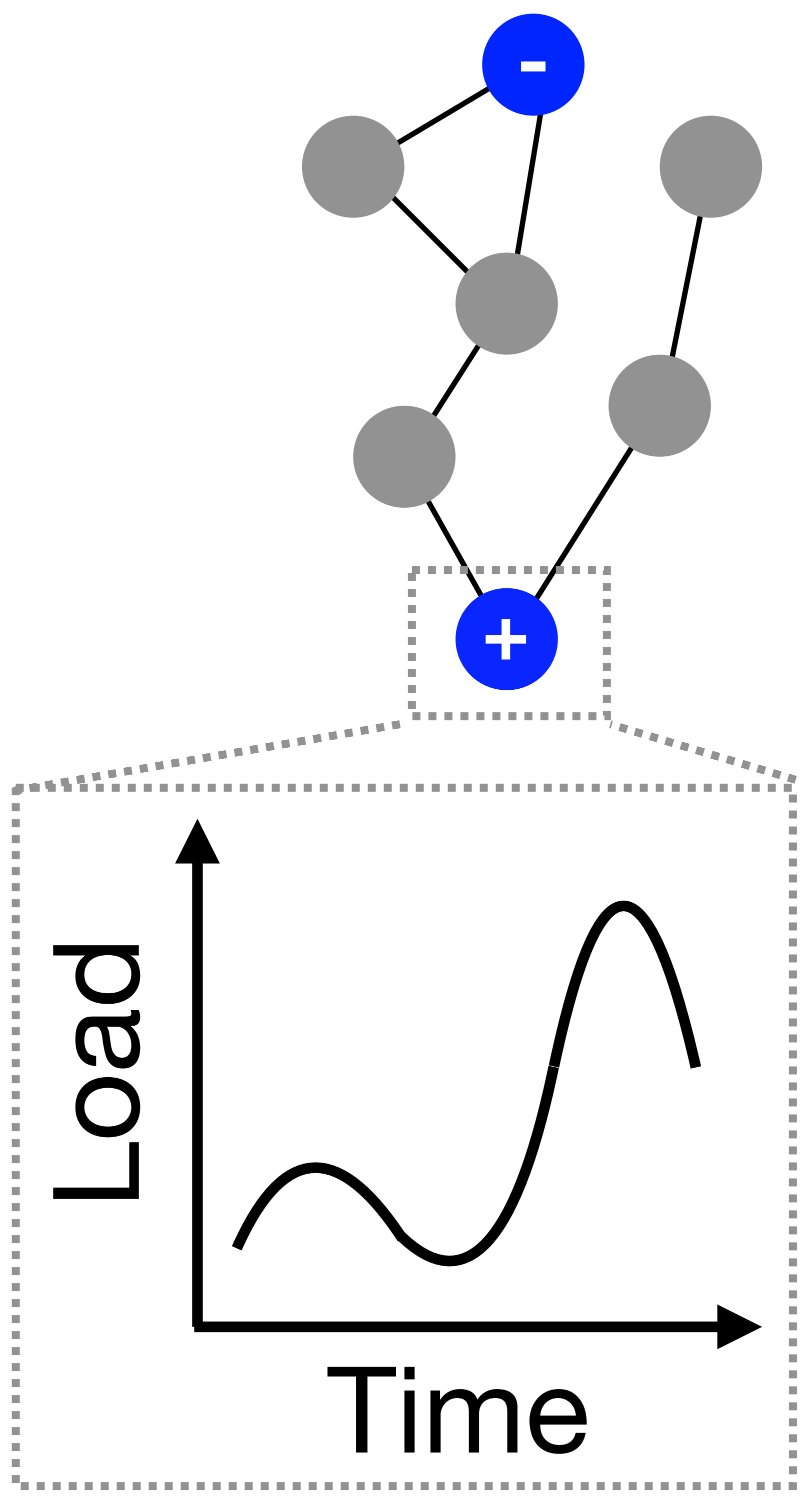


1) Slow time scale (τ) and coarse observation window (Δ) for the network manager

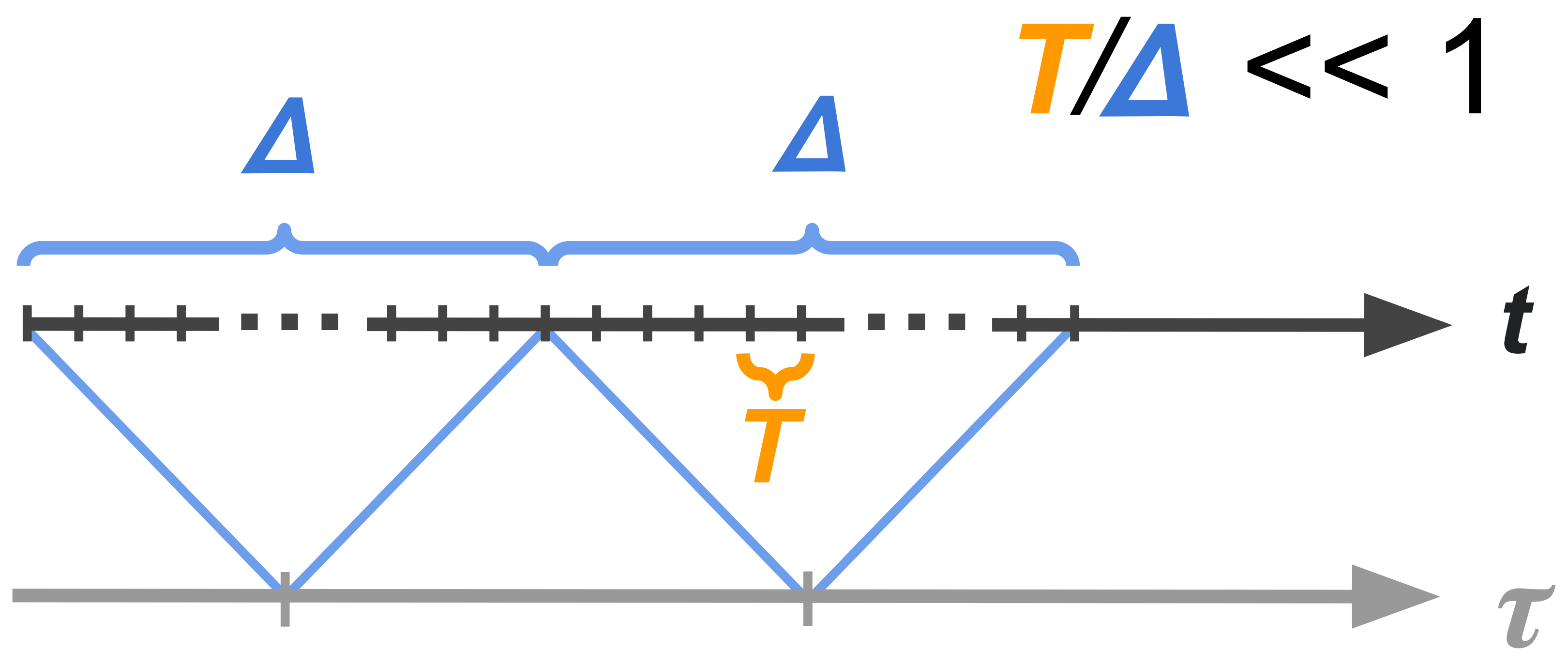
   Fast time scale (t) for the passengers



Method



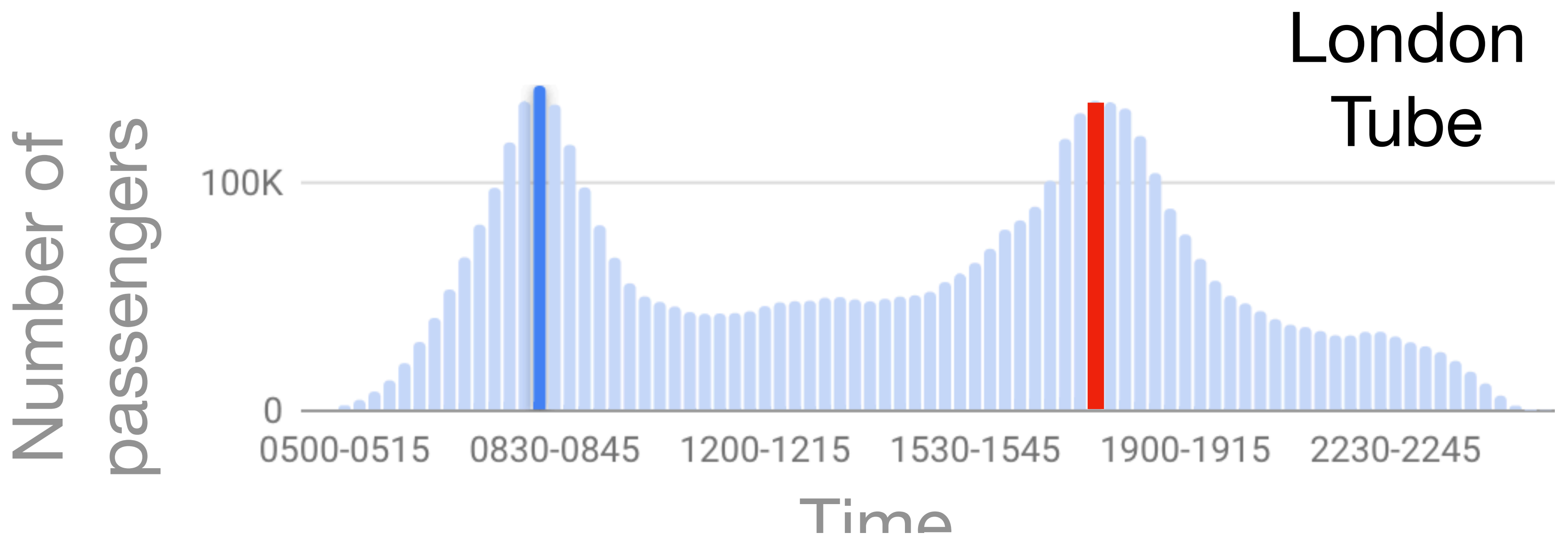
1) Slow time scale (τ) and coarse observation window (Δ) for the network manager



Fast time scale (t) for the passengers

2) Periodic fast time loads

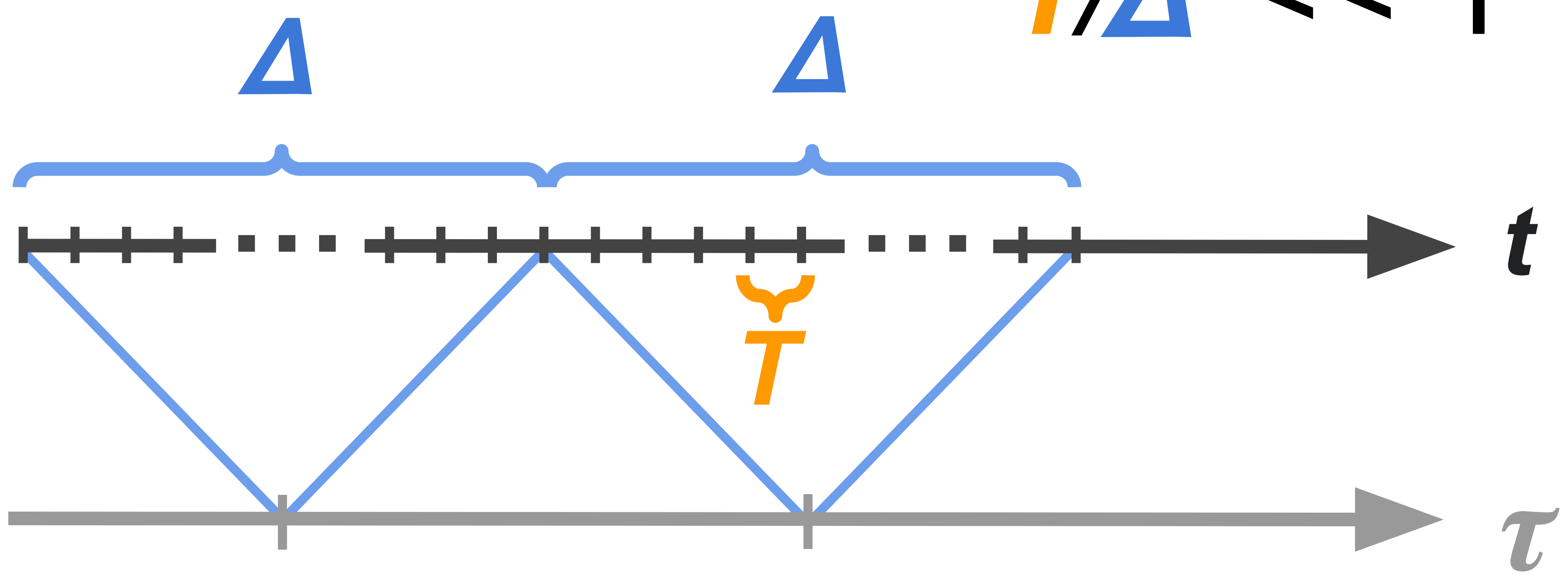
$$S(t) = S(t + T)$$



Results

Contribution 1: Closed-form adaptation rules

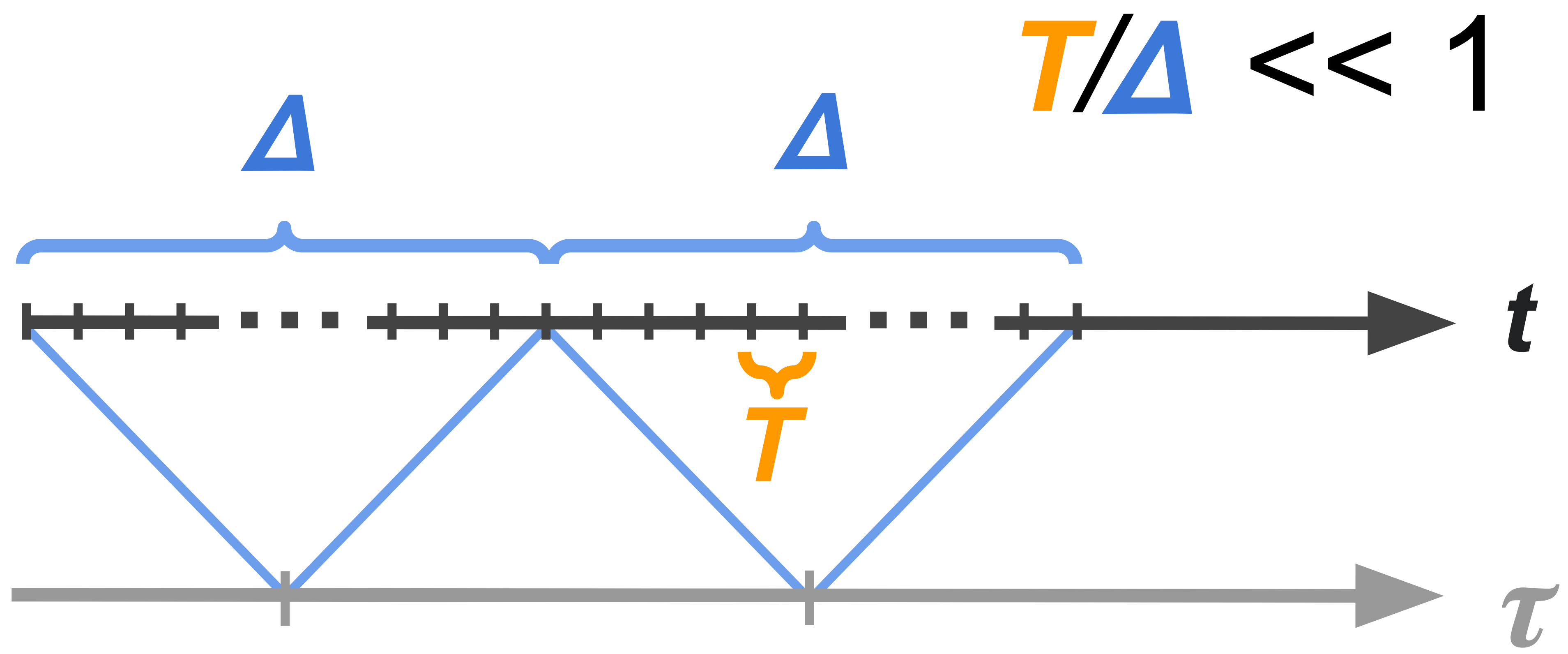
$T/\Delta \ll 1$



$$S_v(t) = \sum_{n_v} c_v^{n_v} \exp\left(\mathbf{i}\frac{2\pi}{T} n_v t\right)$$

Results

Contribution 1: Closed-form adaptation rules



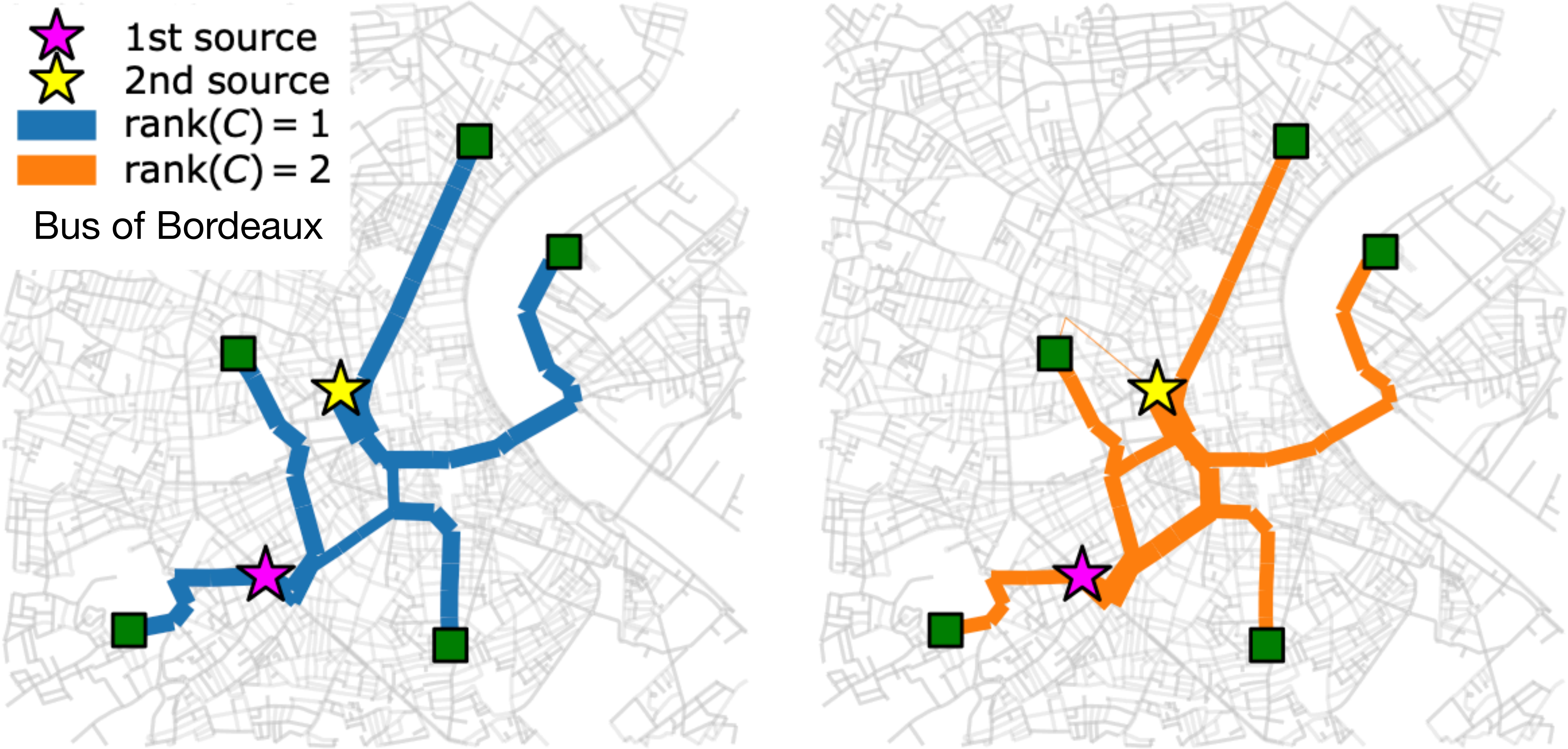
$$S_v(t) = \sum_{n_v} c_v^{n_v} \exp\left(\mathrm{i}\frac{2\pi}{T} n_v t\right)$$

$$\frac{d\mu_e}{d\tau} = \Psi(\mu_e, C) - \mu_e$$

C "$=$" combination of loads' Fourier coefficients over T

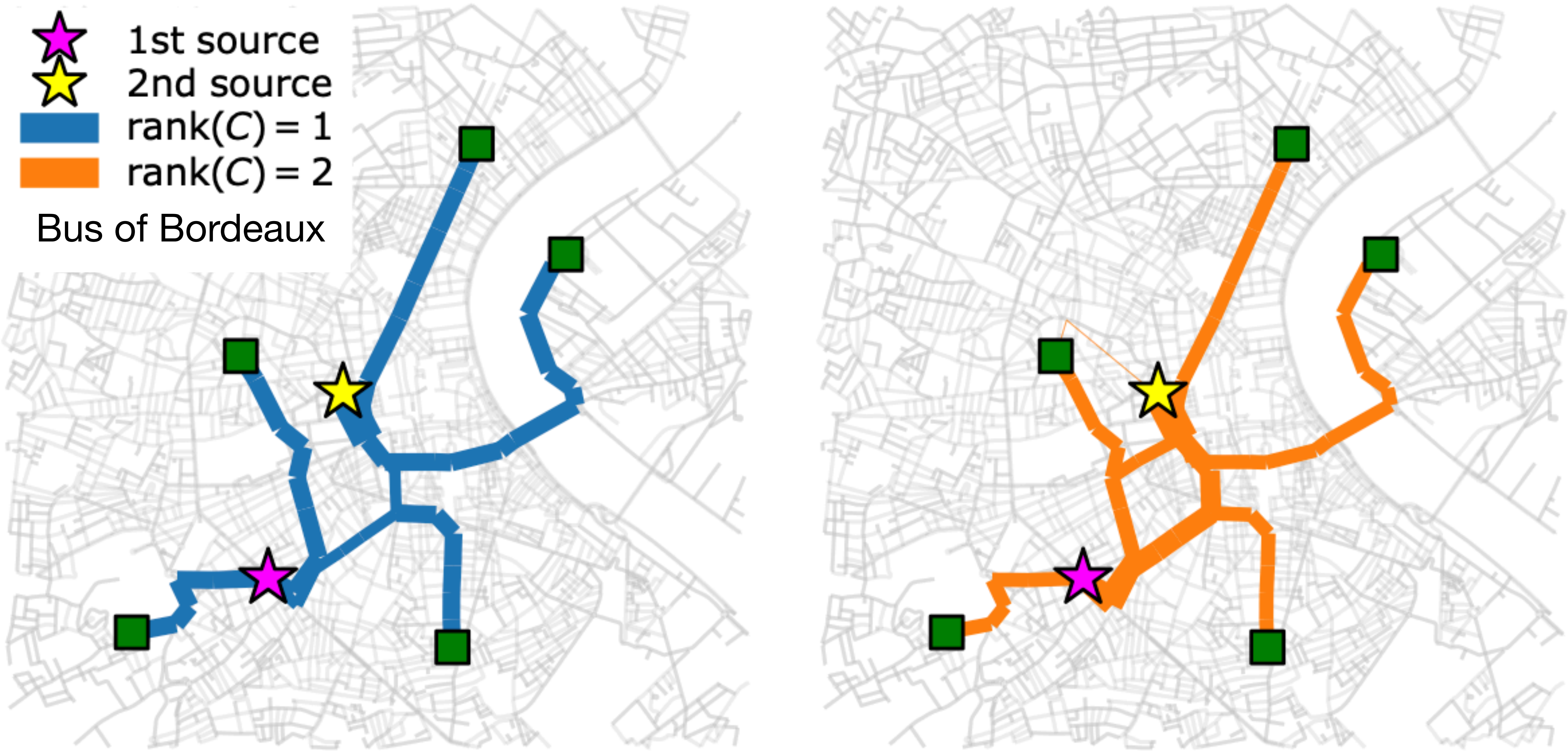
Results

Contribution 2: Proxy for robustness of networks



Results

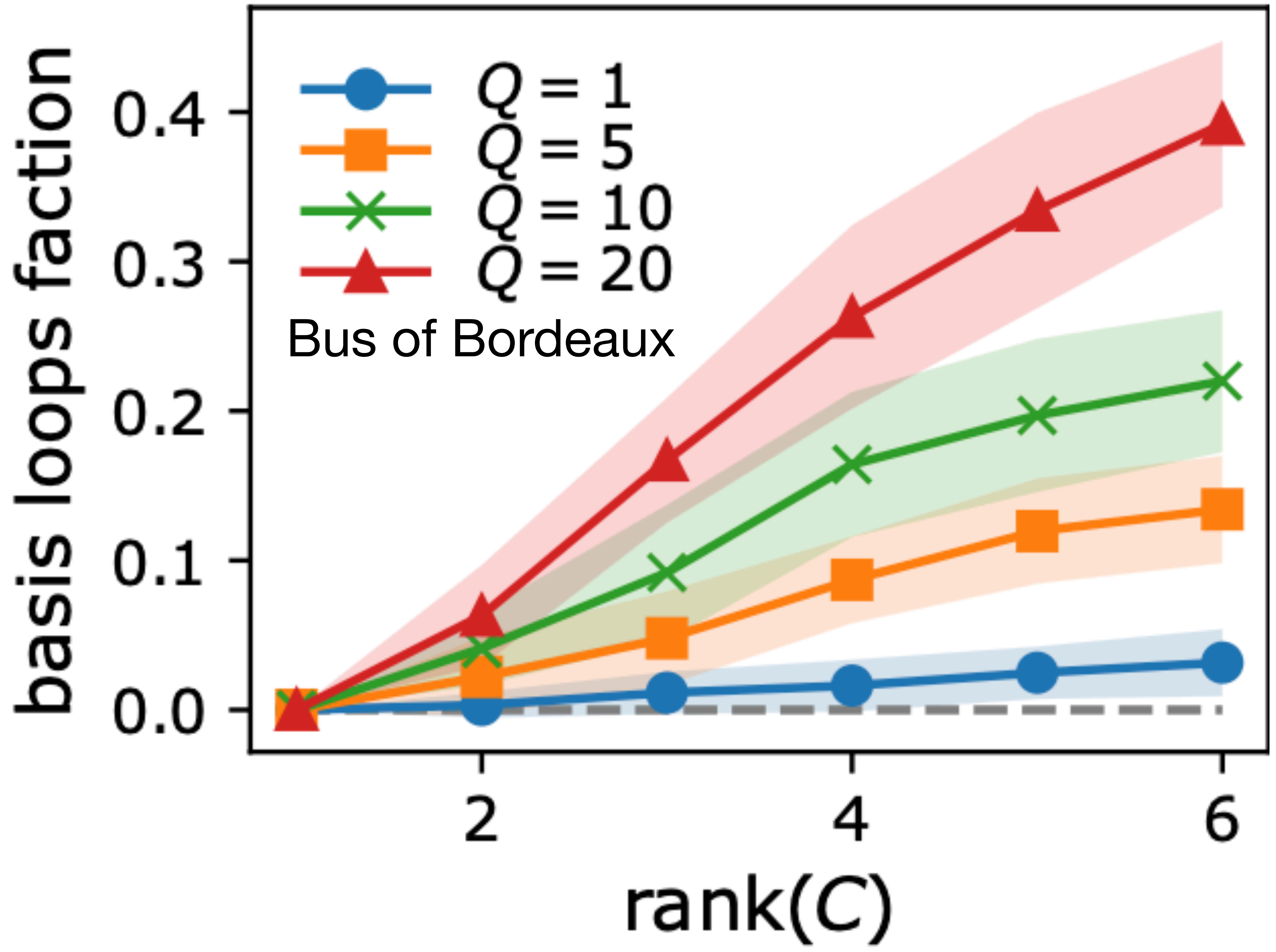
Contribution 2: Proxy for robustness of networks



Contribution 3: Scalable method → C is only computed once

Results

Contribution 2: Proxy for robustness of networks



Q = number of origins and destinations

Take aways

Questions

1) Can we find adaptation rules for time-dependent node loads?

2) Does adaptation shed light on transport network properties?

Answers

Contribution 1: Closed-form adaptation rules

Contribution 2: Proxy for robustness of networks

Contribution 3: Scalable method

Caterina De Bacco
(MPI IS)

Mario Putti
(Uni Padova)

Enrico Facca
(Uni Bergen)

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N-STARK

Thank you!

✉ alessandro.lonardi@tuebingen.mpg.de
🌐 aleable.github.io

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