Using network science and data visualization to assess the potential of urban sharing economies

Technical University of Denmark, Copenhagen, Apr 4, 2017

Michael Szell

@mszll

Research with: P. Santi, G. Resta, R. Tachet, O. Sagarra, S. Sobolevsky, S.H. Strogatz, C. Ratti

Visualizations with: S. Bogner, B. Gross, J. Lee, T. Lauer, et al.

Hungarian Acad Sci I Northeastern University I MIT Senseable City Lab I Central European University I moovel lab

Urban transportation is facing serious issues

Pollution

3.7 Mio.

Traffic jams

Fatalities

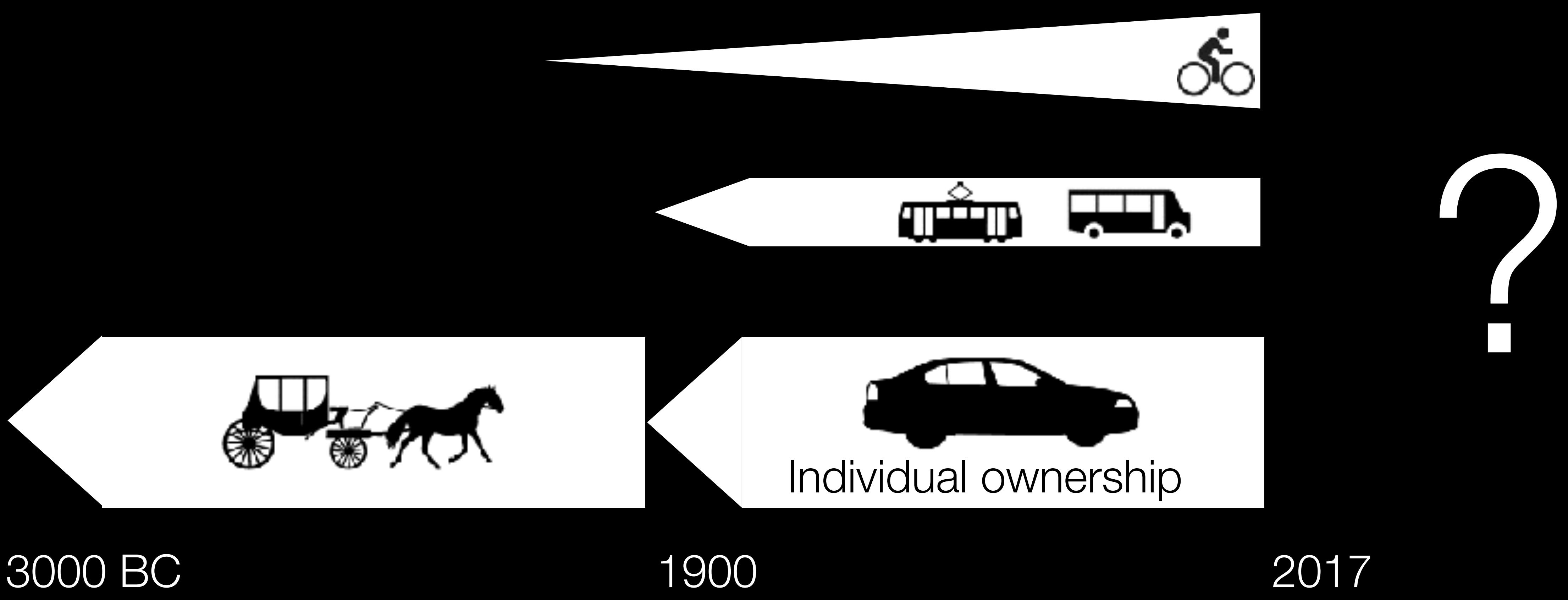
1.2 Mio.

How efficient is urban transport?

We don’t know.

Caiazzo et al, Atmosph Env 79 (2013)
WHO statistics (2011)

Urban transportation is at a turning point



Warner, S.B. Harvard Univ. Press (1978)

Urban transportation is changing

Vehicle sharing

Ownership ⟶ Accessibility

Botsman, R. and Rogers, R. HarperCollins, New York (2010)
Eckhardt, G.M. and Bardhi, F. Harvard Business Review (2015)

Urban transportation is changing

Algorithms and mobile technology
to improve existing services

Ownership ⟶ Accessibility

Botsman, R. and Rogers, R. HarperCollins, New York (2010)
Eckhardt, G.M. and Bardhi, F. Harvard Business Review (2015)

Urban transportation is changing

Self-driving cars

Lack of driver further motivates giving up ownership

Botsman, R. and Rogers, R. HarperCollins, New York (2010)
Eckhardt, G.M. and Bardhi, F. Harvard Business Review (2015)

The taxi system is inefficient

High emissions, cost, waiting times

Real-time data sets are available

NYC
Taxi & Limousine Commission

Freedom of Information Act

Real-time data sets are available

Can we use realtime data and mobile technology to

1) Quantify existing taxi systems
2) Design an improved system?

NYC
13,500 cabs

Real-time data sets are available

Can we use realtime data and mobile technology to

1) Quantify existing taxi systems
2) Design an improved system?

Goals
- more efficient
- less emissions
- affordable alternative

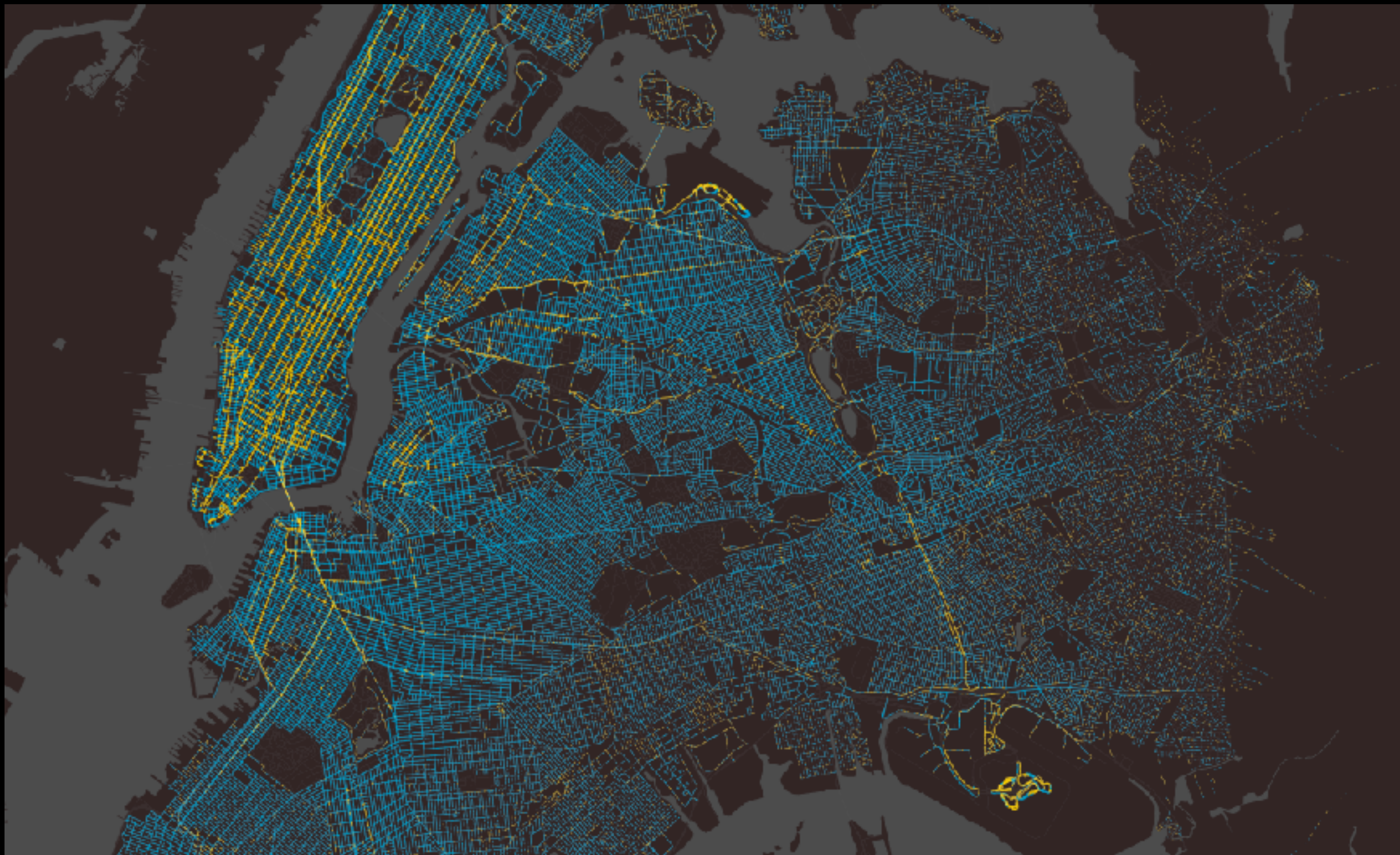
NYC
13,500 cabs

PAPER 1

Santi, P., Resta, G., Szell, M., Sobolevsky, S., Strogatz, S.H. and Ratti, C. PNAS 111 (2014)

Step 1: Analyze data

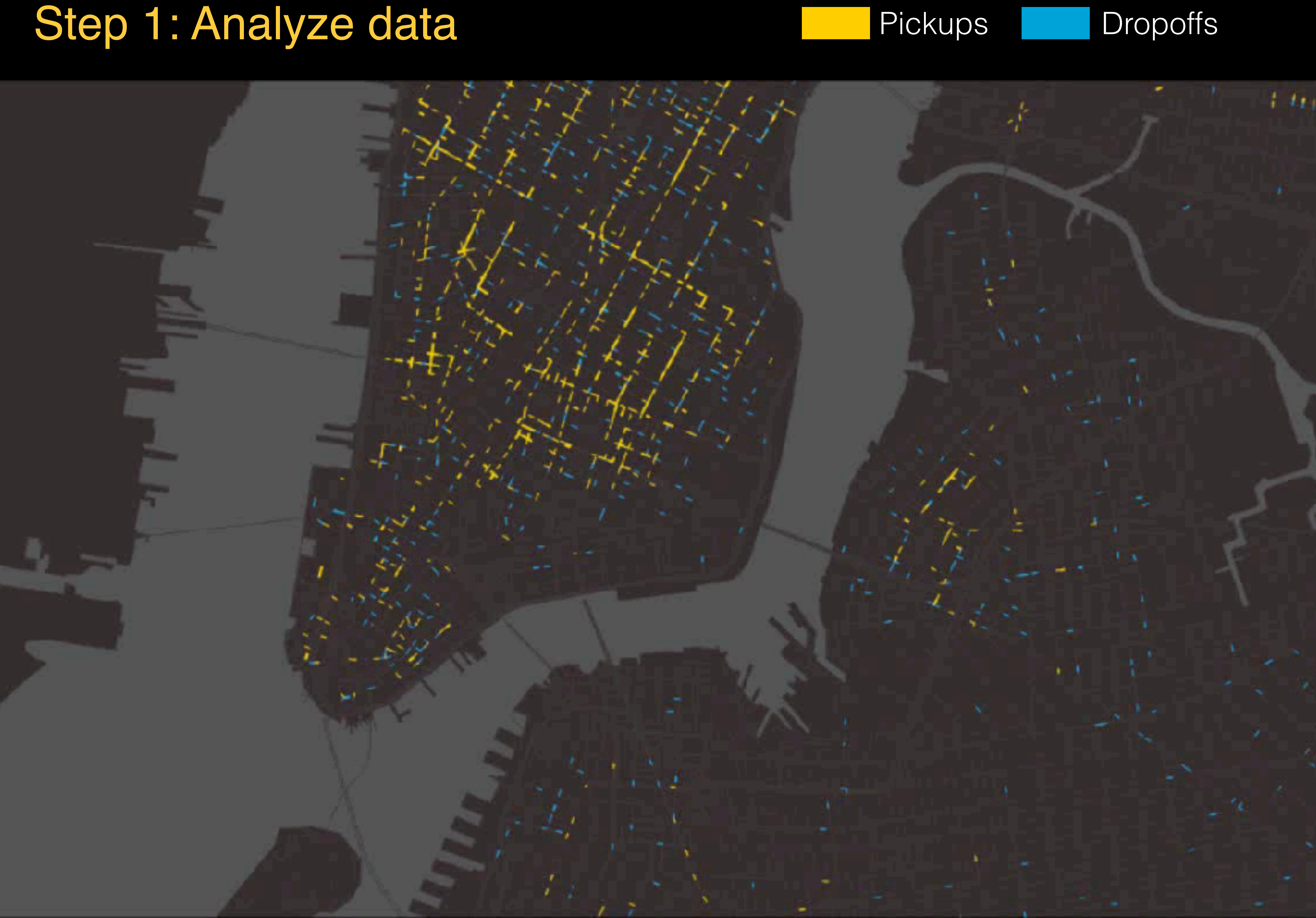
NYC taxi trips in 2011



13500 cabs
150 million trips ~400.000 per day

Pickups Dropoffs

Step 1: Analyze data



Step 1: Analyze data

Destinations

Origins

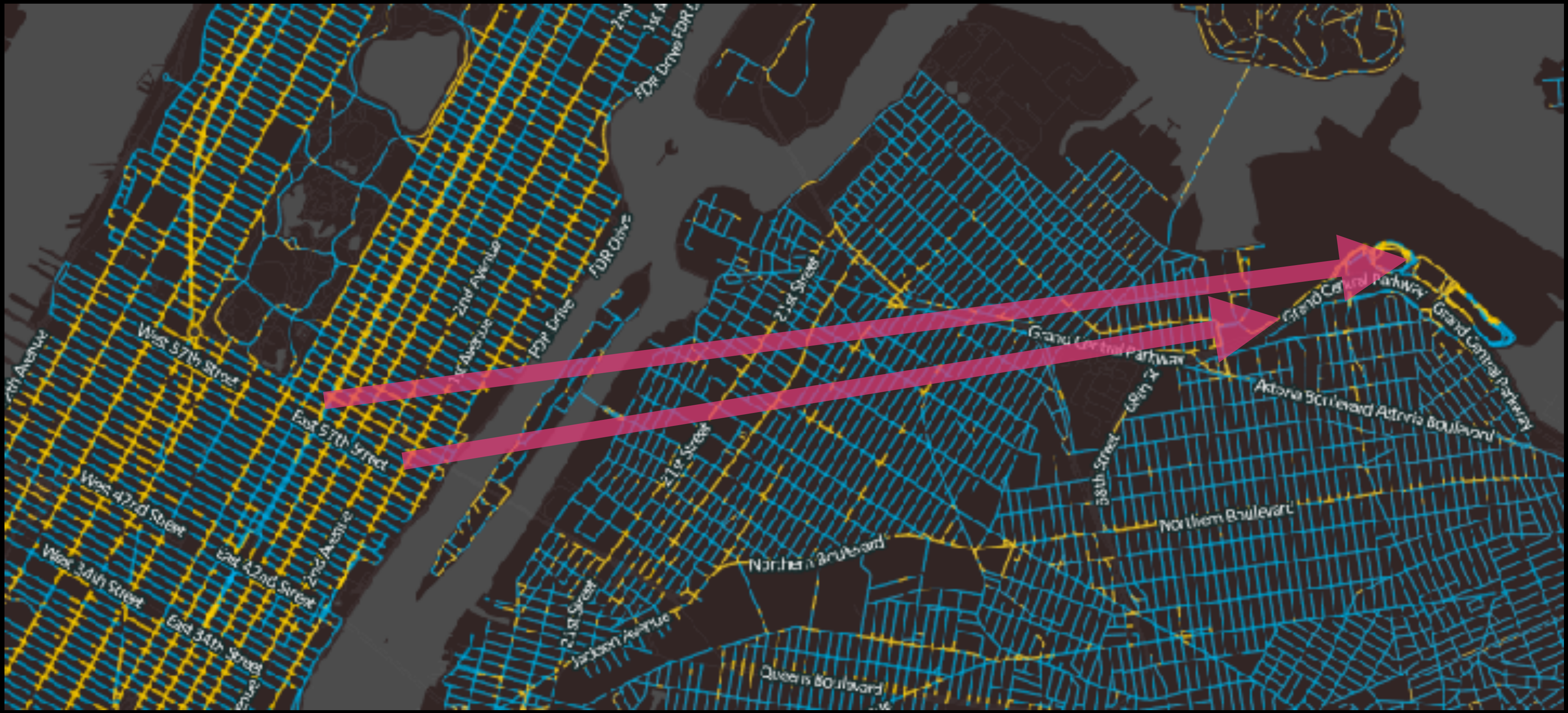
Pickups Dropoffs

Trips can be combined

Pickups Dropoffs

Step 2 : A new dispatch process

Combine 2 trips



Step 2 : A new dispatch process

Combine k trips

Oestreicher-Singer and Sundararajan, MIS Quarterly 36 (2012)

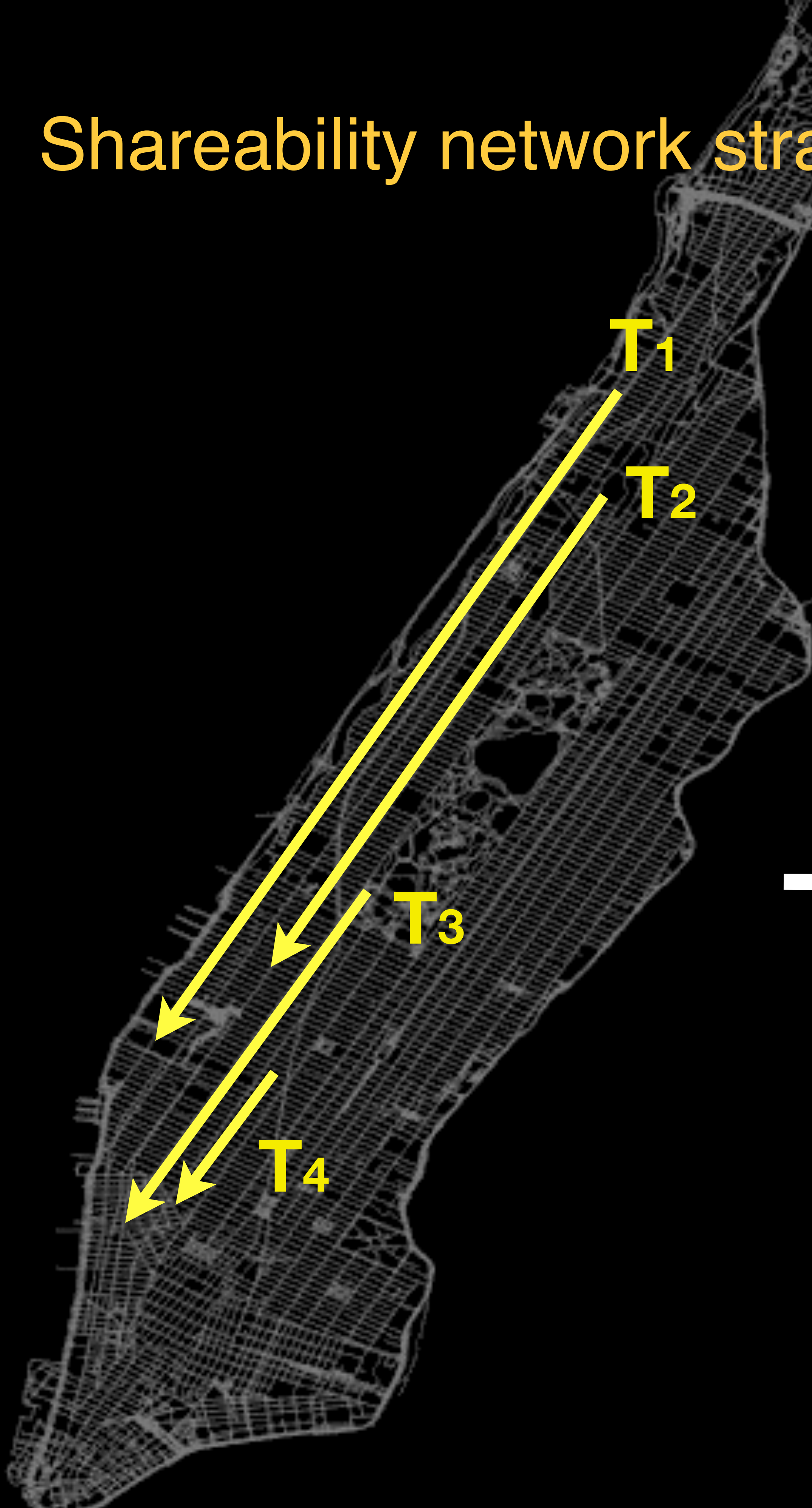
Street network

Extraction from OpenStreetMap

9000 street segments

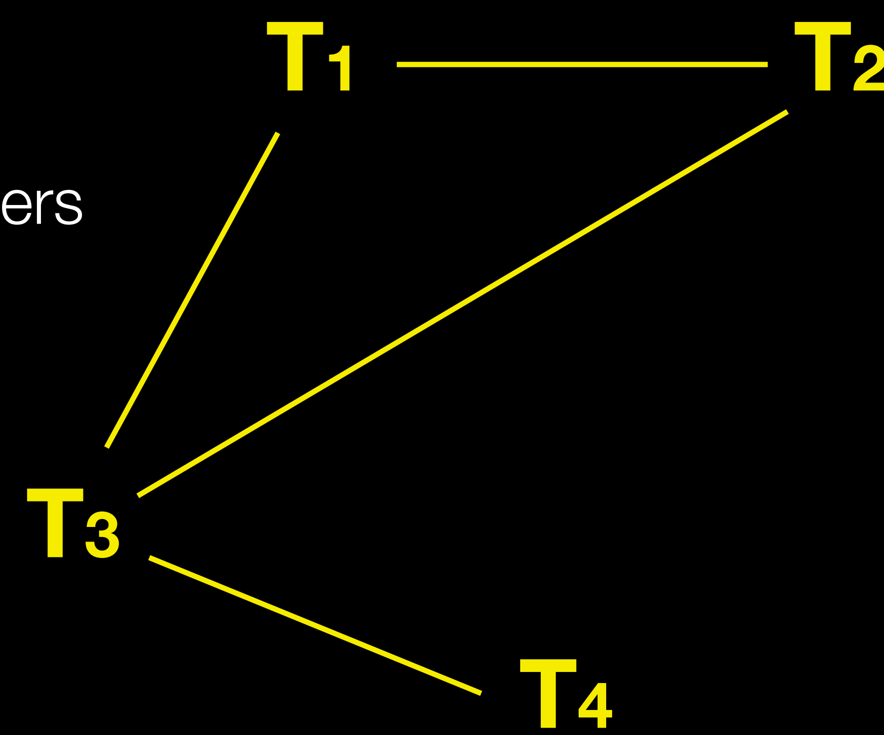
Matching GPS-coordinates

Shareability network strategy



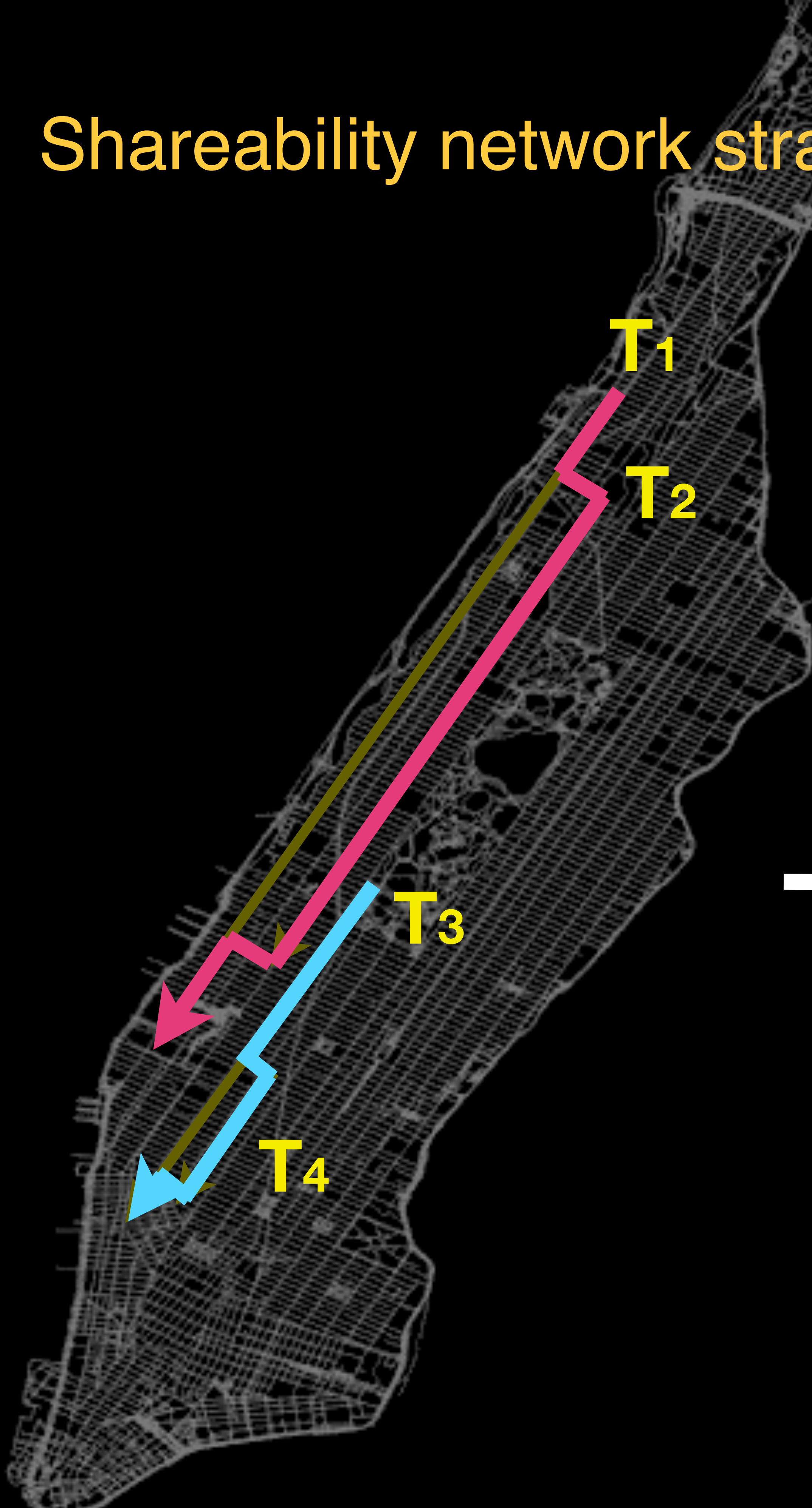
Mapping

\# of passengers
k = 2



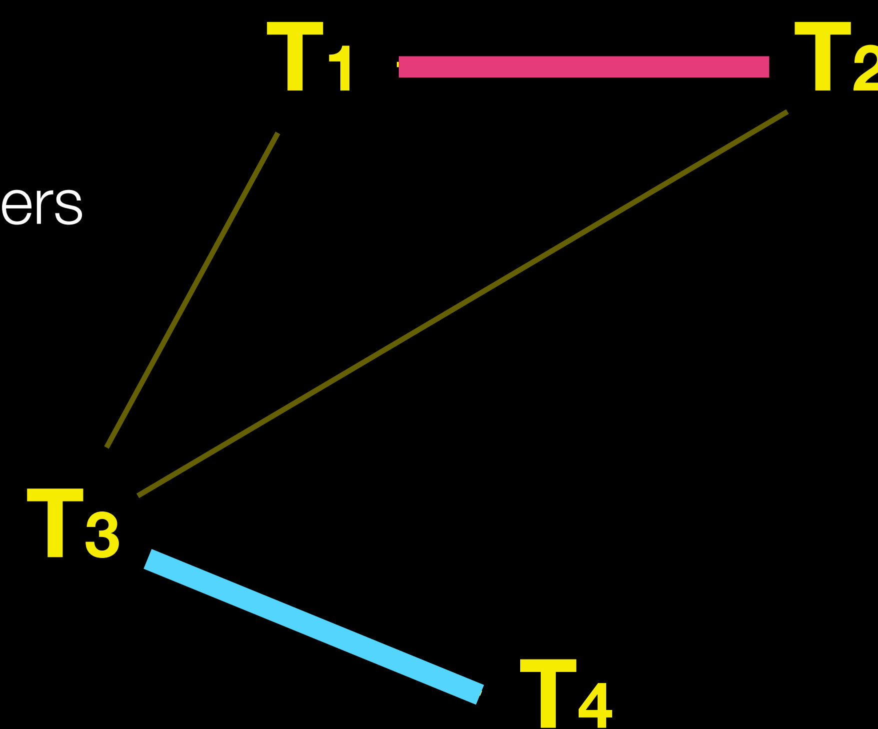
Chandra and Halldorsson, J Alg 39 (2001)

Shareability network strategy



# of passengers
k = 2

Maximum matching

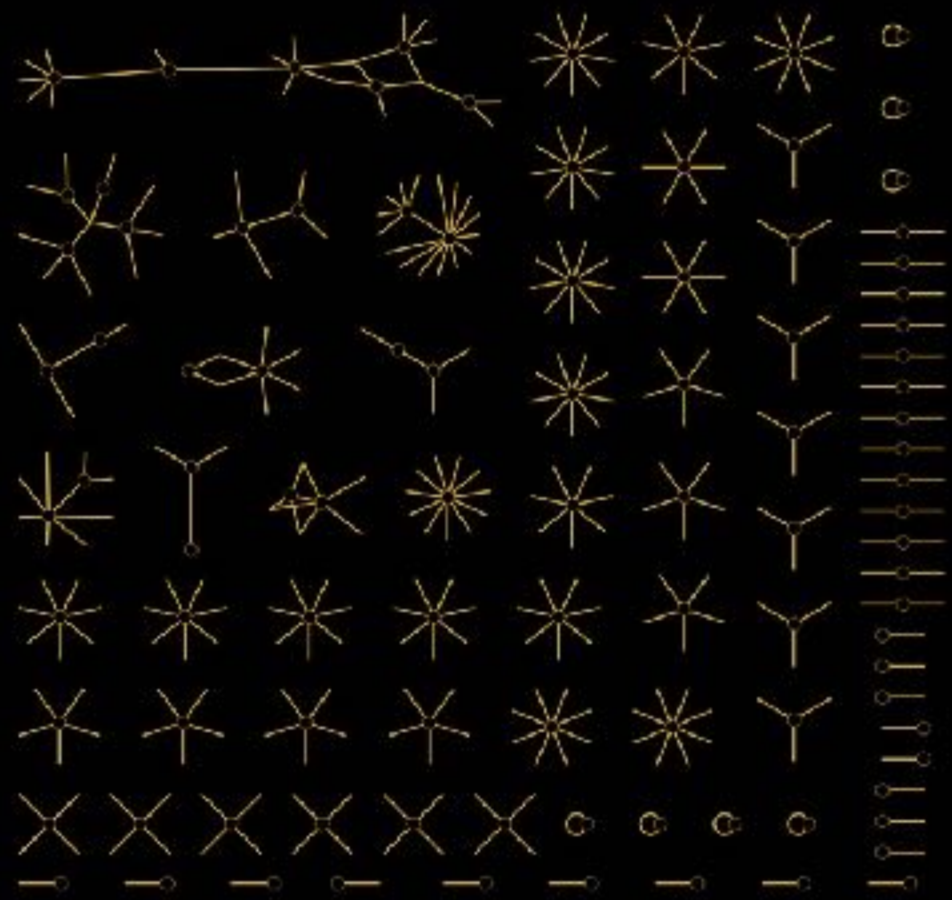


Chandra and Halldorsson, J Alg 39 (2001)

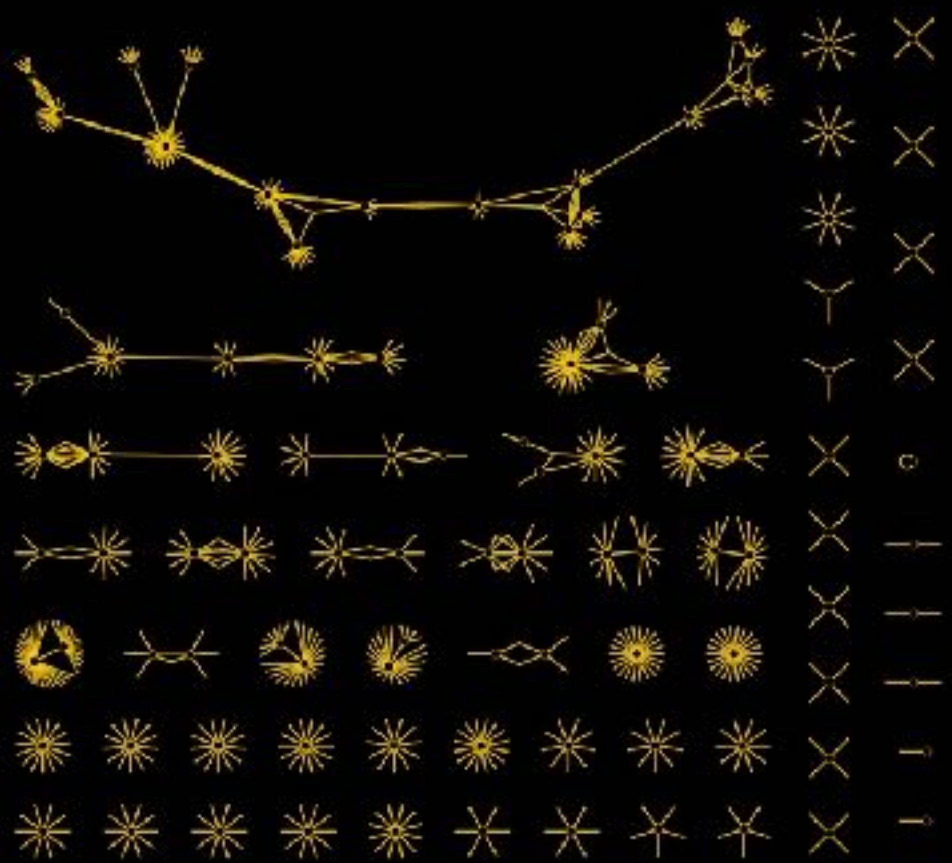
Shareability network densification

Maximum time delay Δ

Δ = 30 sec



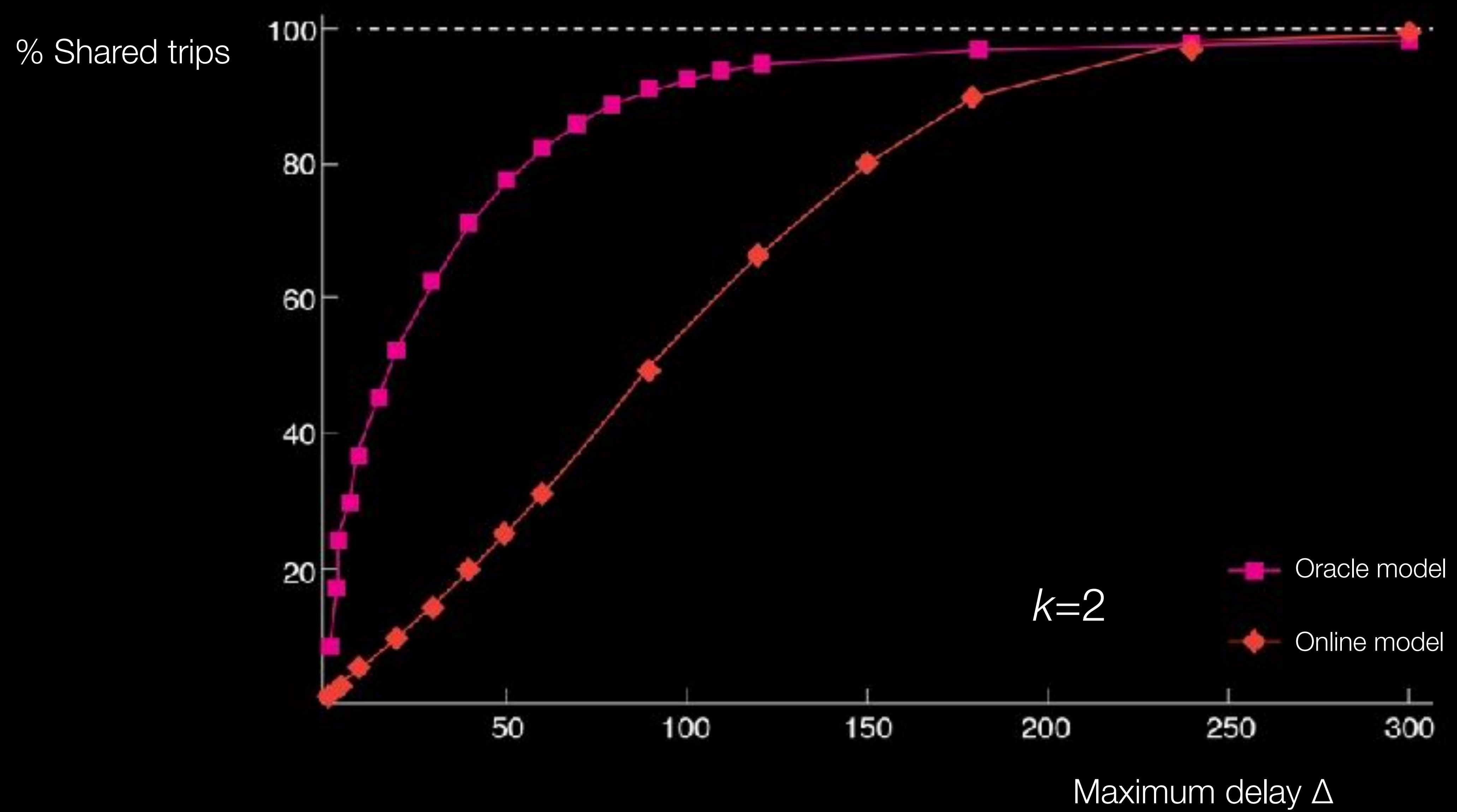
Δ = 60 sec



More tolerance = denser network = more sharing opportunities

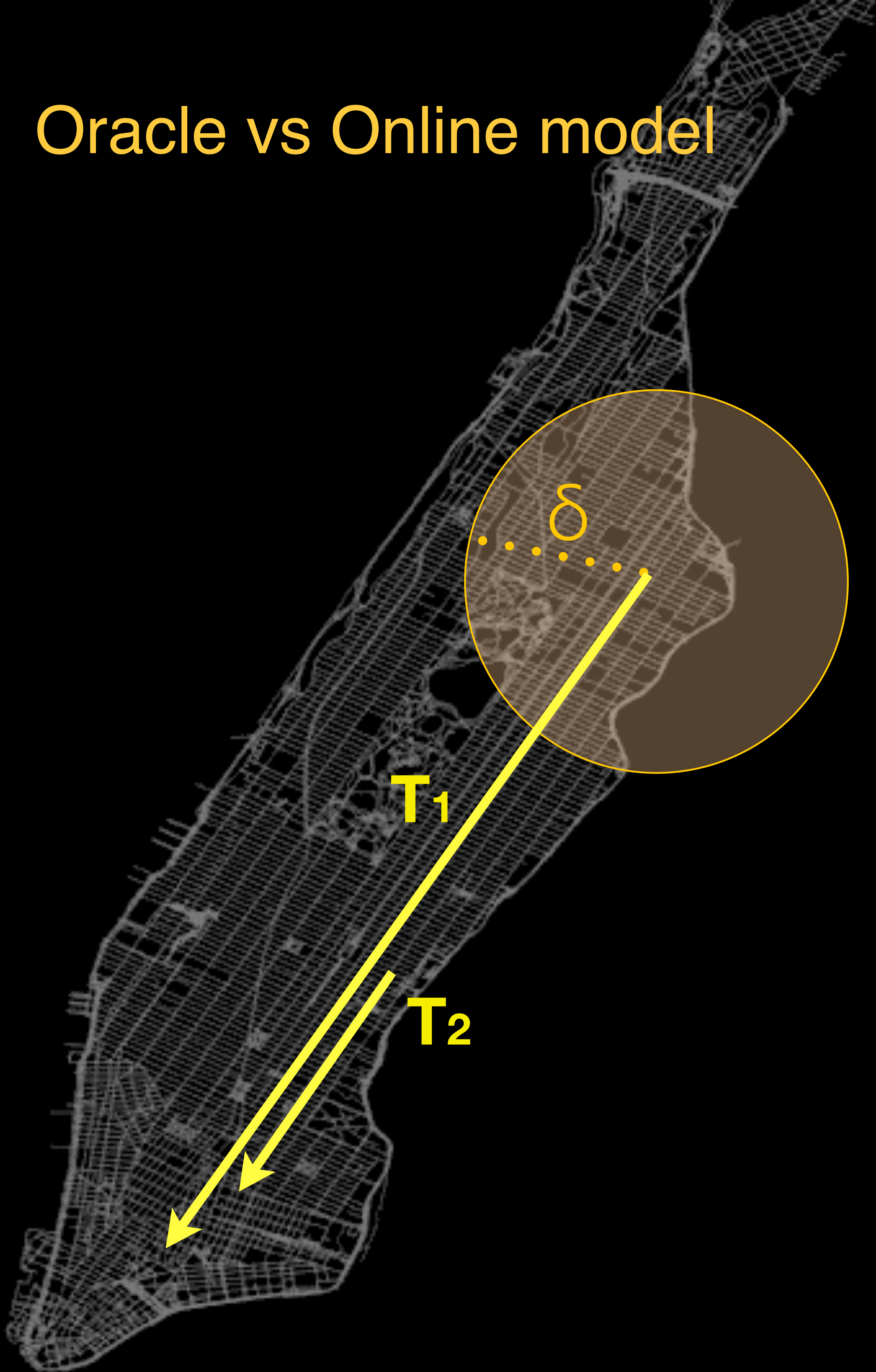
Krings et al, EPJ Data Sci 1 (2012)

The majority of trips is shareable!



The majority of trips is sharable with minimal passenger inconvenience

Oracle vs Online model

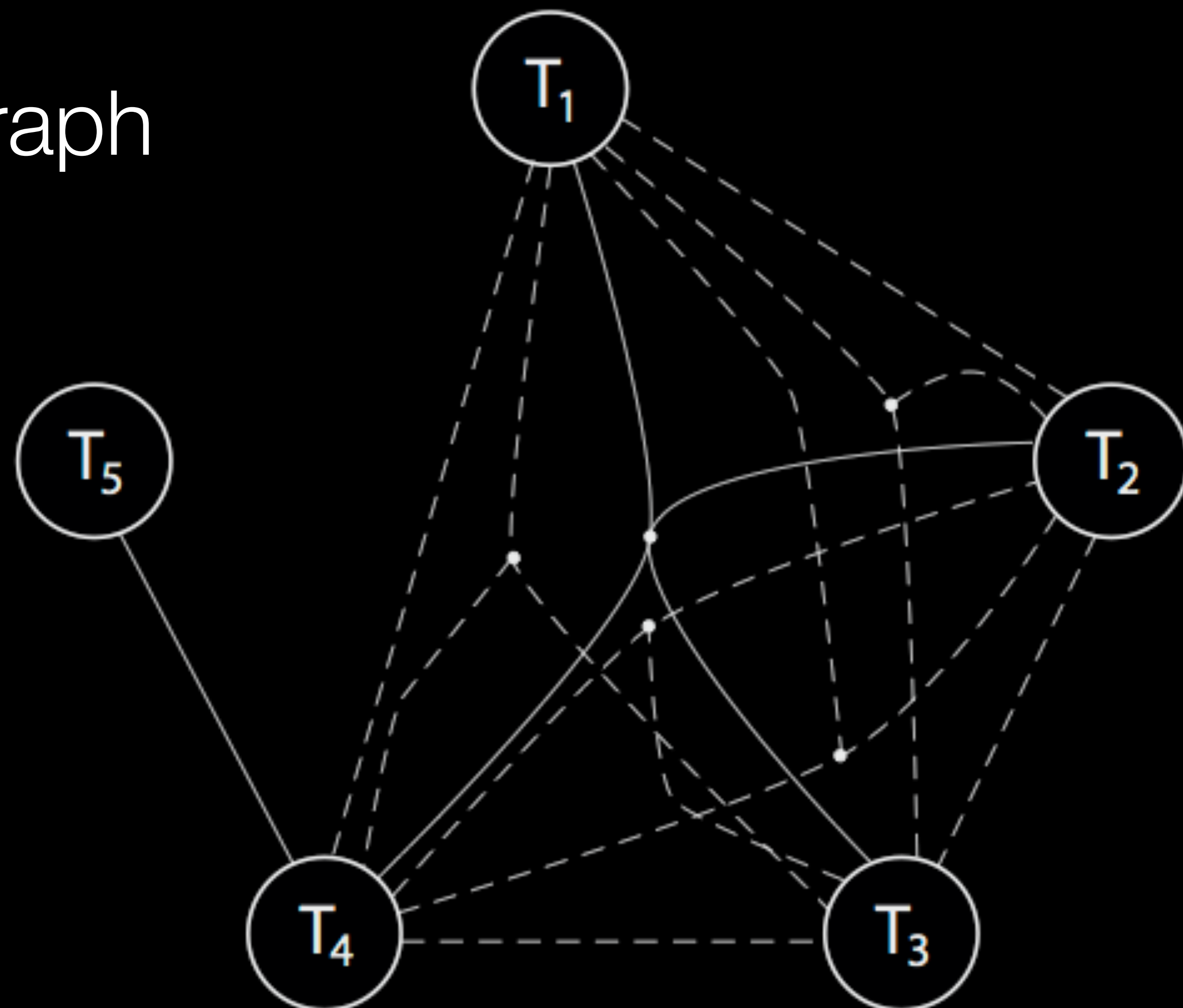


Oracle: omniscient

Online: realistic, constrained by time window $\delta = 1$ min

Approach can be extended to higher dimensions

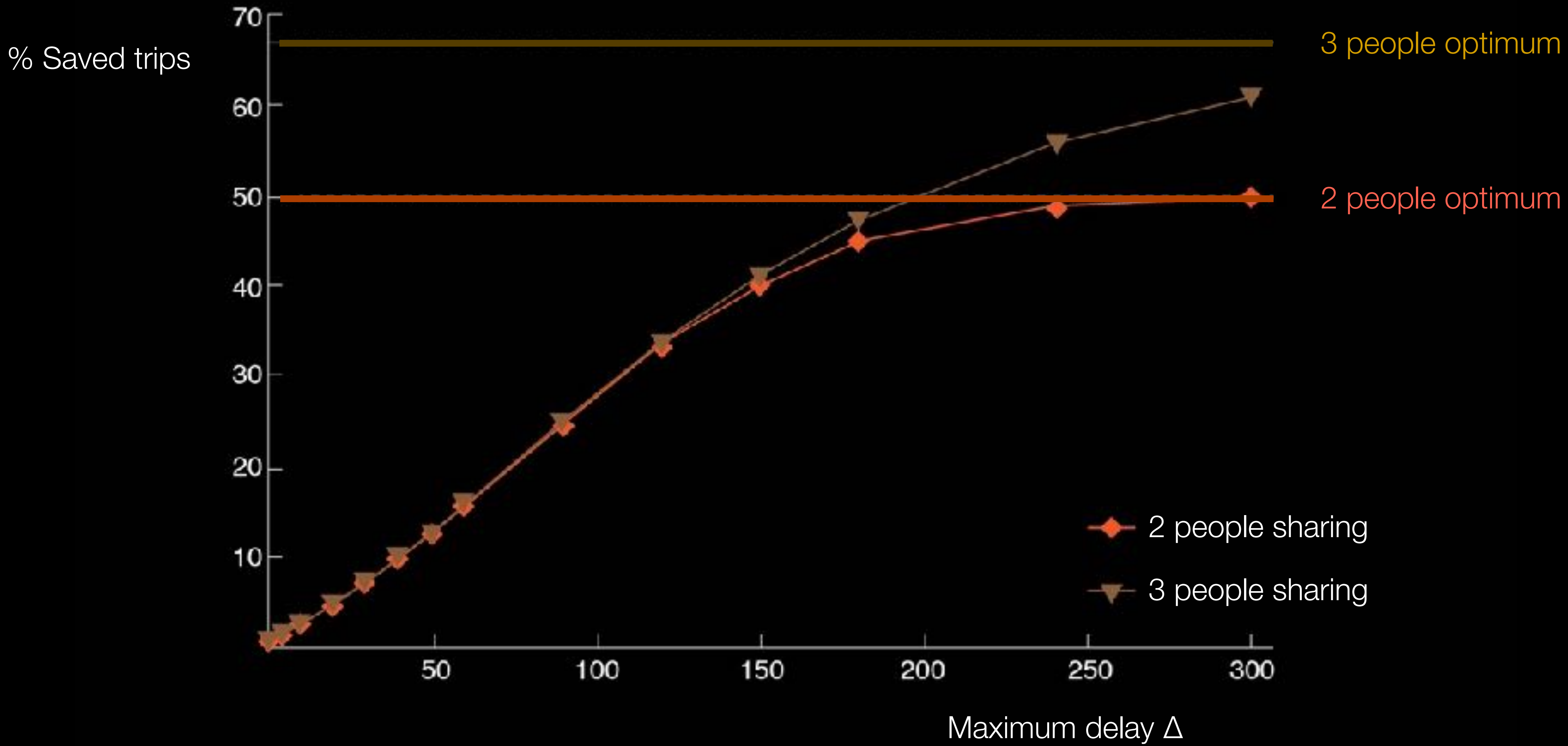
Trip hypergraph



Approximation in O(n log n)

Chandra and Halldorsson, J Alg 39 (2001)

From 2 to 3 people sharing



In NYC, benefits of 3 people sharing increase only slightly

Consequences of trip-sharing

- More efficient use of vehicles: 40% decrease

- Decreased pollution and deaths

- Blurring line between private and public transportation

- New design of fare system

Online tool hubcab for interactive exploration of sharing benefits

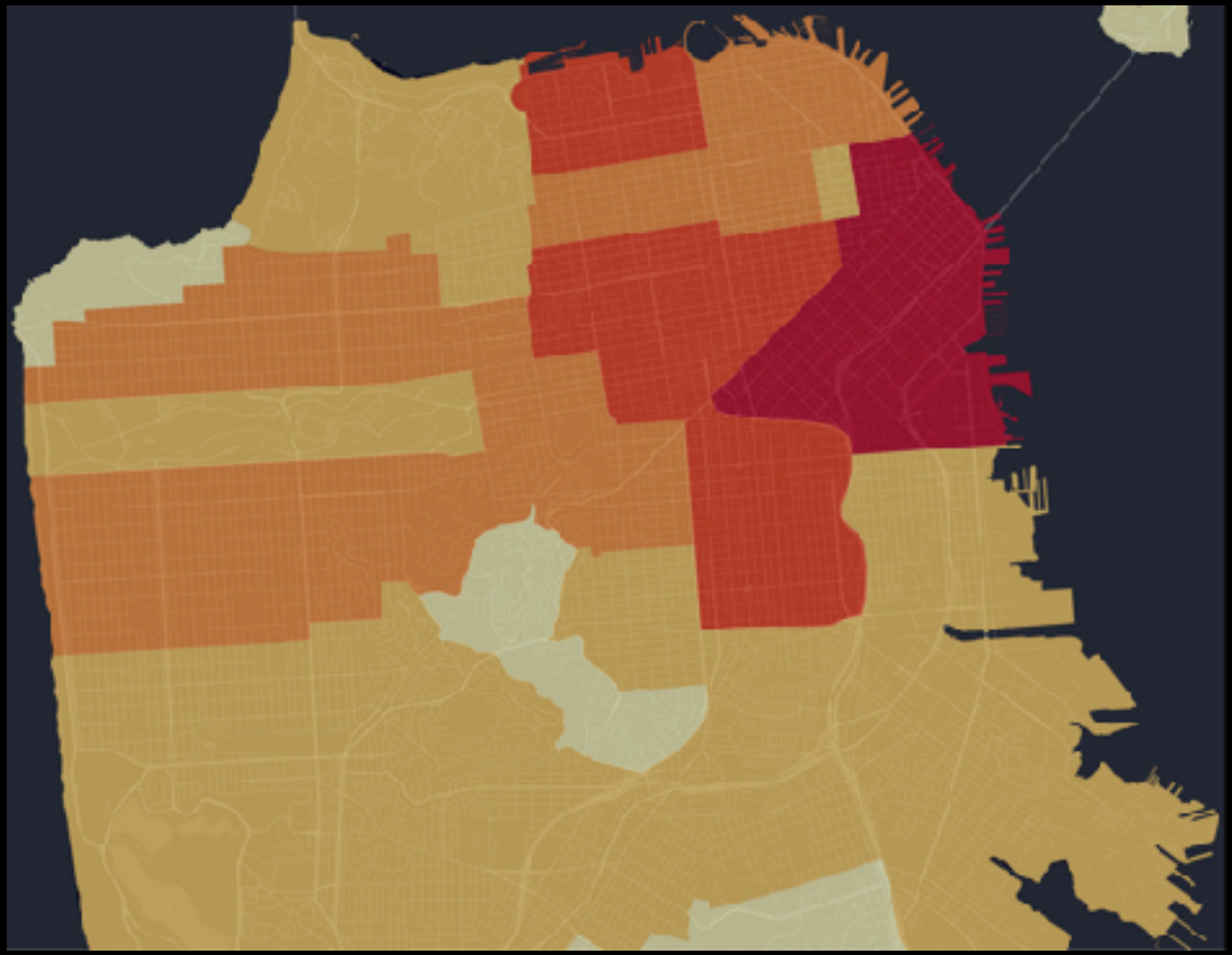
http://www.hubcab.org

Zoom into the data, flow exploration, time selection

Trip-sharing is now implemented!

Trip-sharing is now implemented!

So far, uberPOOL saved 674,000 miles in San Francisco!



Source: http://blog.uber.com/uberpool-update

Beware of unintended consequences!

Cars become more attractive

↓

Cities invest less in public infrastructure

↓

MORE cars on the road = MORE problems

Sustainable implementation of sharing requires understanding systemic effects

Lopez et al., PNAS 111.51, E5488 (2014)
Santi, Resta, Szell, Sobolevski, Strogatz, Ratti, PNAS 111.51, E5489 (2014)

PAPER 2


www.nature.com/scientificreports

SCIENTIFIC REPORTS

OPEN

Scaling Law of Urban Ride Sharing

Tachet, Sagarra, Santi, Resta, Szell, Strogatz, Ratti, Scientific Reports 7 (2017)

New York is special - What about other cities?

NYC 13,500 cabs

San Fran 1,500 cabs

Singapore 26,000 cabs

Vienna 5,000 cabs

New York is special - What about other cities?

NYC 13,500 cabs

25,846/km²

San Fran 1,500 cabs

6,659/km²

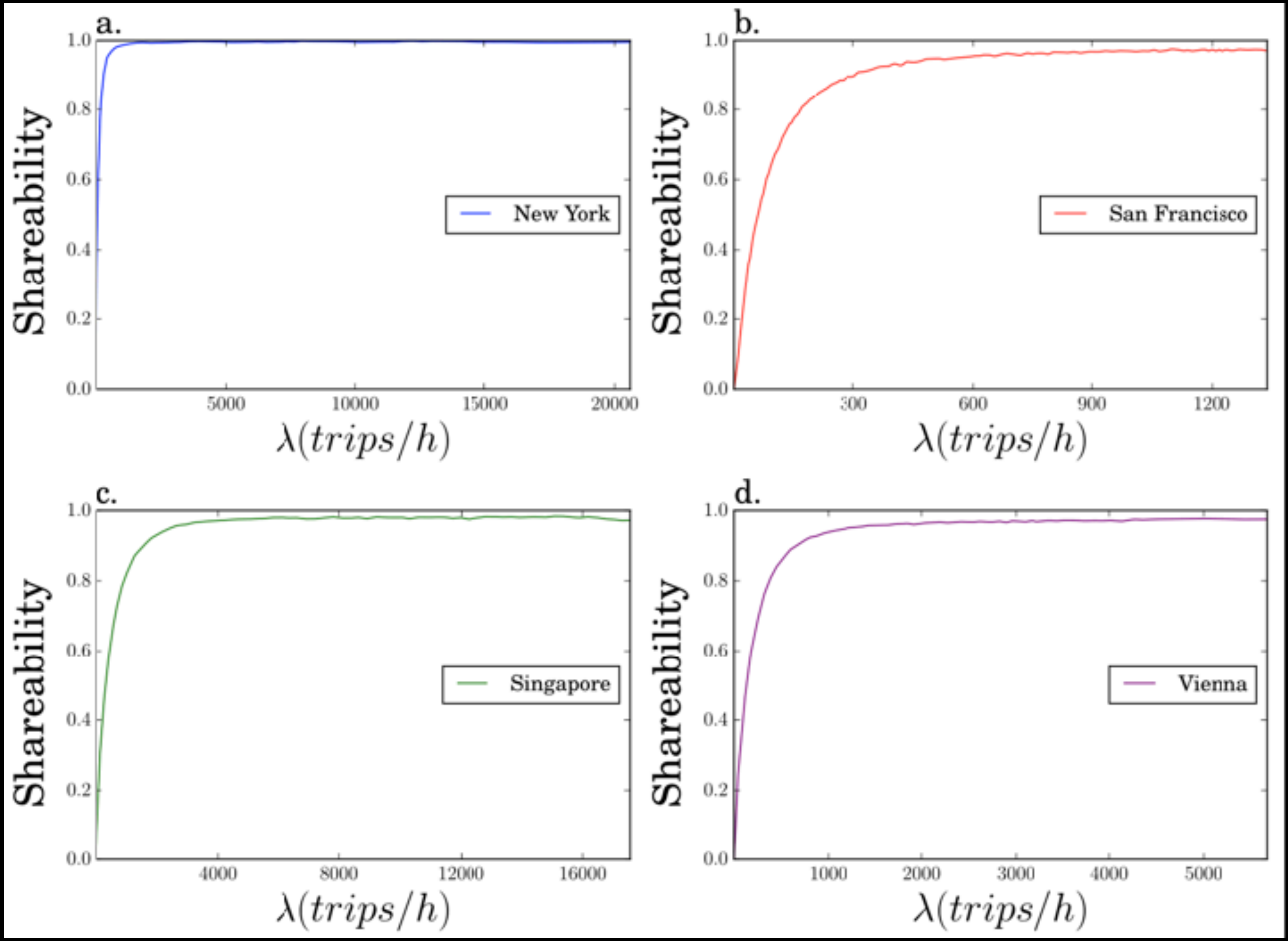
Singapore 26,000 cabs

7,988/km²

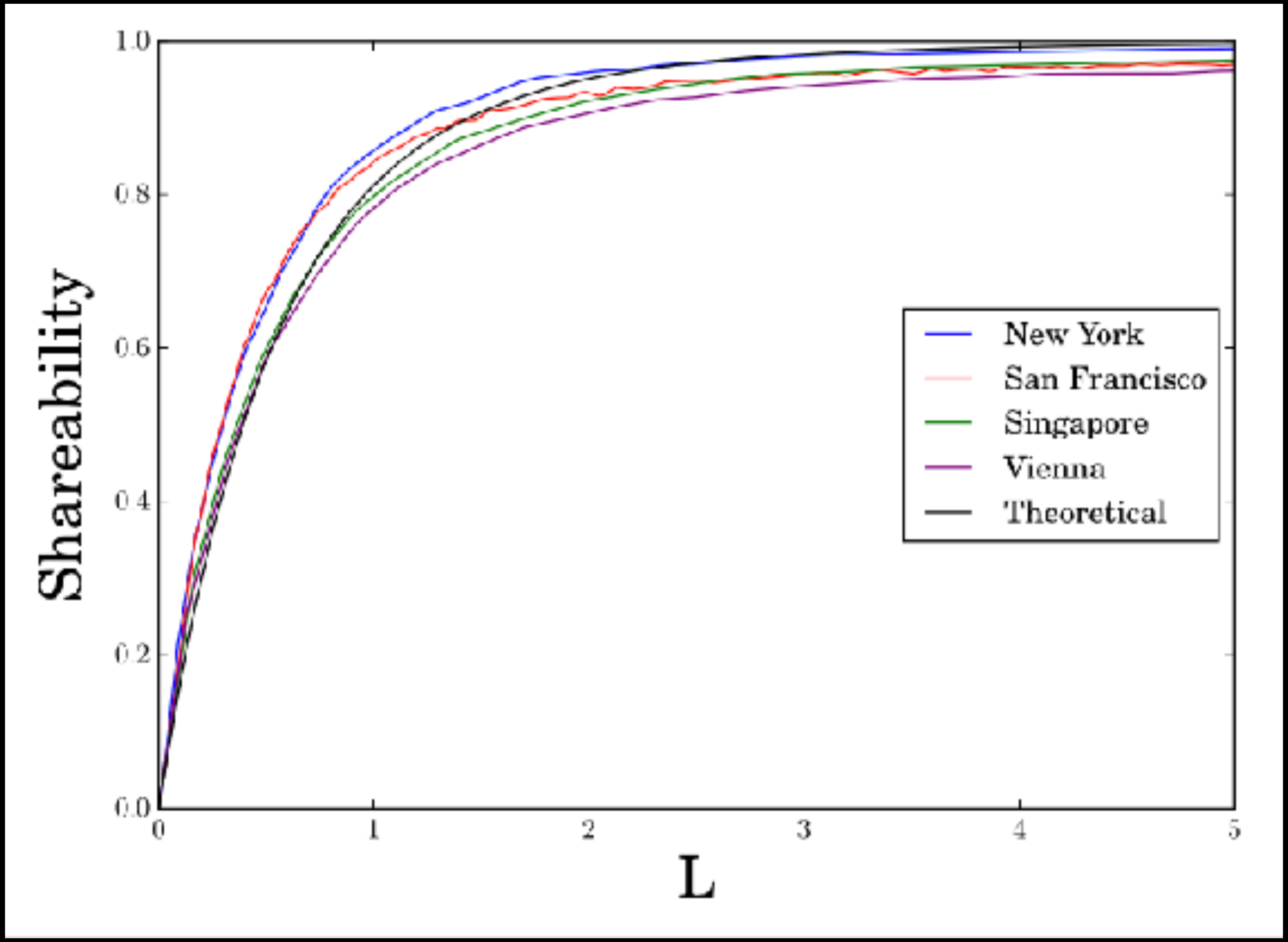
Vienna 5,000 cabs

4,002/km²

Different cities have similar shareability curves



All curves collapse onto a universal curve!



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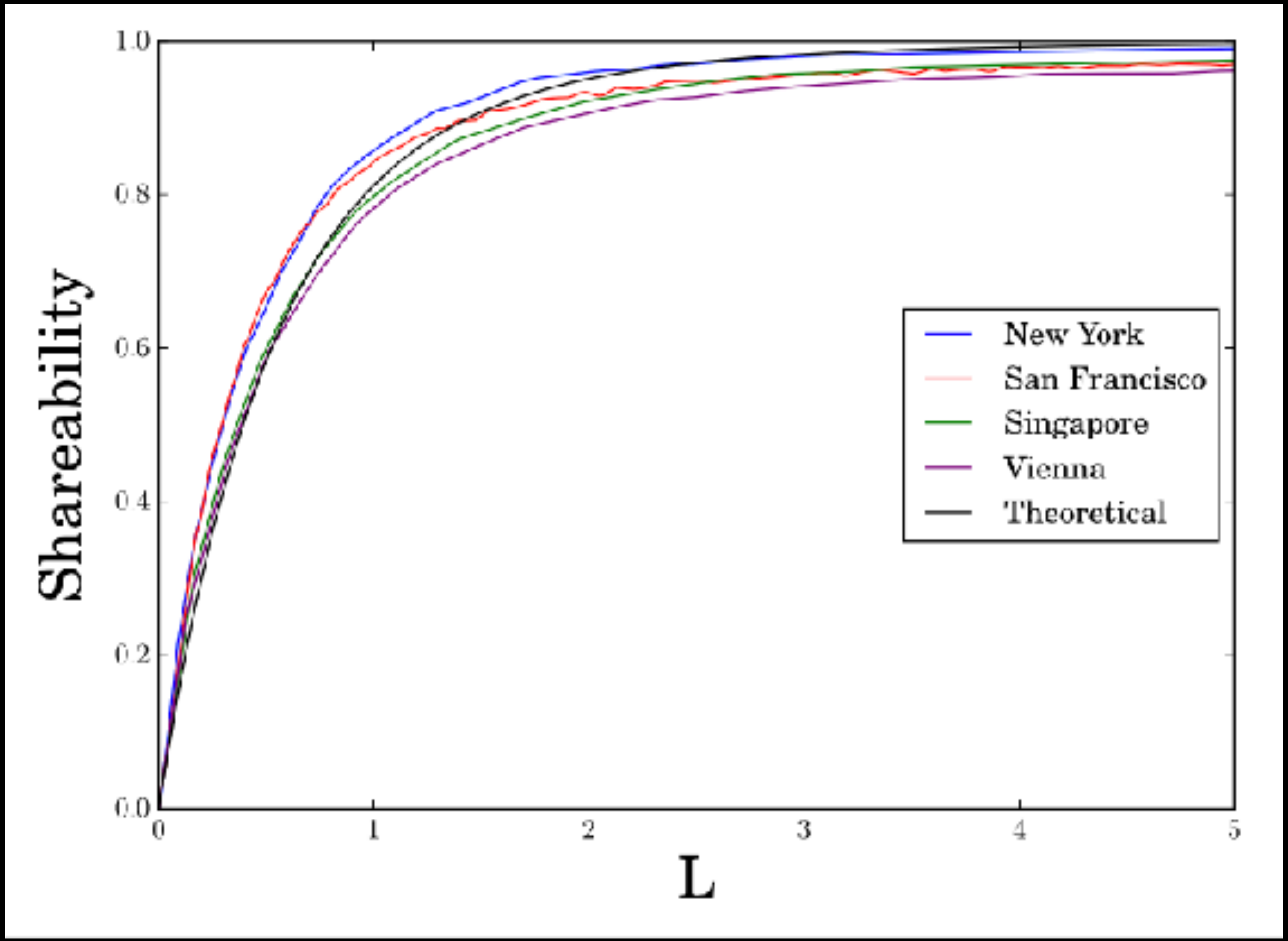


What is L?

Rescaling through L

$$L = \lambda \Delta^3 \frac{v^2}{|\Omega|}$$

Rescaling through L

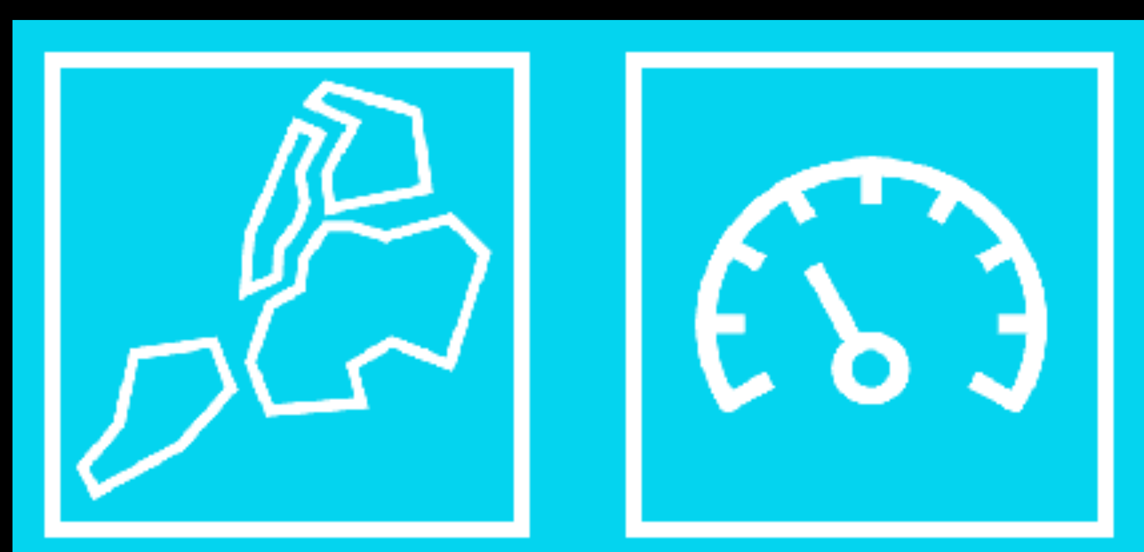
$$L = \lambda \Delta^3 \frac{v^2}{|\Omega|}$$

City area

Rescaling through L

$$L = \lambda \Delta^3 \frac{v^2}{|\Omega|}$$

Avg speed



Rescaling through L

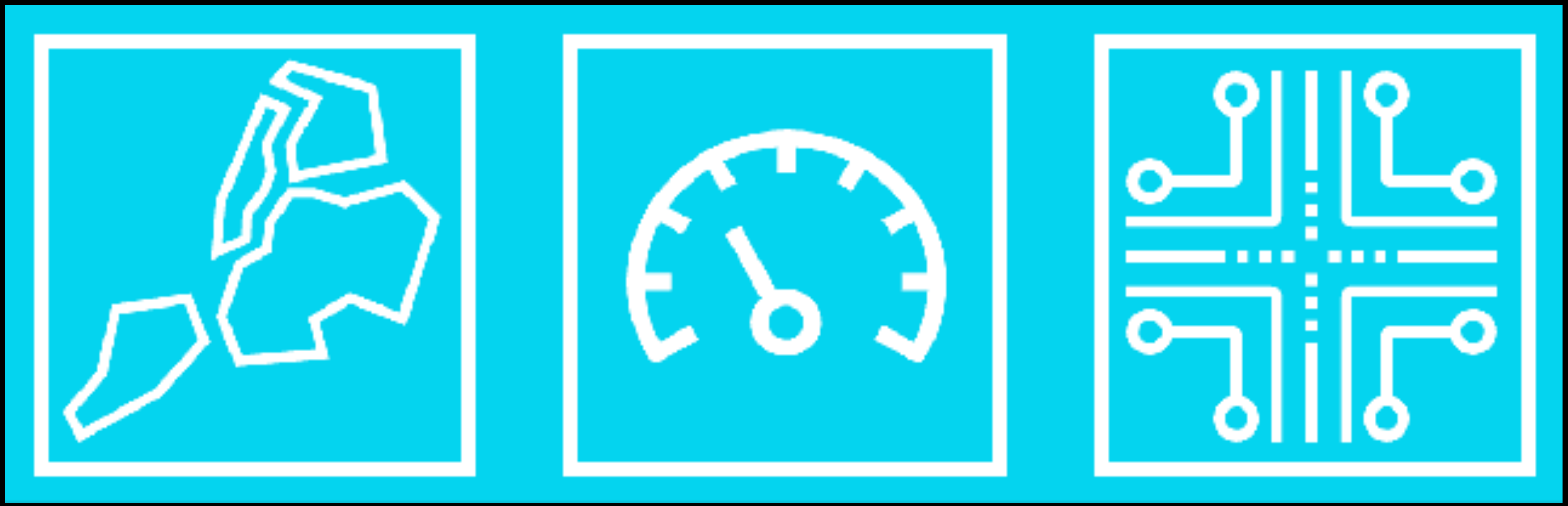
$$L = \lambda \Delta^3 \frac{v^2}{|\Omega|}$$

Trip density

Rescaling through L

$$L = \lambda \Delta^3 \frac{v^2}{|\Omega|}$$

City area **Avg speed** **Trip density**



L is dimensionless

$$L = \lambda \Delta^3 \frac{v^2}{|\Omega|}$$

Trip density	λ	[T^{-1}]	$\nearrow$
Max delay	Δ	[T]	$\nearrow$
Avg speed	v	[L / T]	$\nearrow$
City area	$\lvert\Omega\rvert$	[L^2]	$\searrow$

L is a ratio between two timescales

$$L = \lambda\Delta^3 \frac{v^2}{|\Omega|}$$

Tolerable delay time	Δ
vs	
Expected waiting time	t_{wait}

L is a ratio between two timescales

$$L = \lambda \Delta^3 \frac{v^2}{|\Omega|}$$

$$\frac{\text{Tolerable delay time} \qquad \Delta}{\text{Expected waiting time} \qquad t_{\mathrm{wait}} = \frac{1}{\lambda} \times \frac{|\Omega|}{(v\Delta)^2}}$$

vs

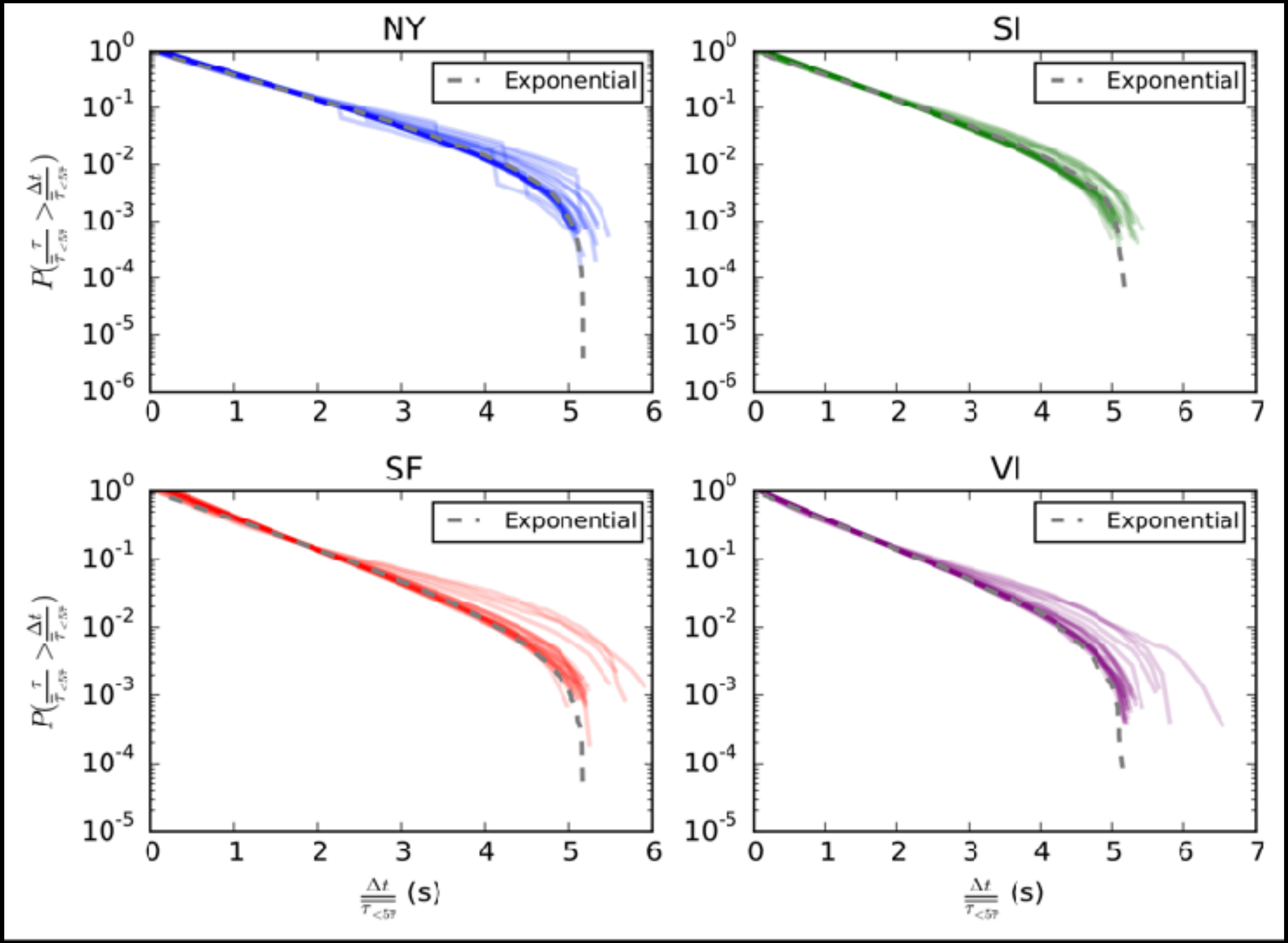
L is a ratio between two timescales

$$L = \lambda \Delta^3 \frac{v^2}{|\Omega|}$$

Characteristic time for new trip

Tolerable delay time		Δ
vs		
Expected waiting time		$t_{\text{wait}} = \frac{1}{\lambda} \times \frac{|\Omega|}{(v\Delta)^2}$

Trip generation is poissonian



L is a ratio between two timescales

$$L = \lambda\Delta^3 \frac{v^2}{|\Omega|}$$

Tolerable delay time Δ

vs

Expected waiting time $t_{\mathrm{wait}} = \frac{1}{\lambda} \times \frac{|\Omega|}{(v\Delta)^2}$

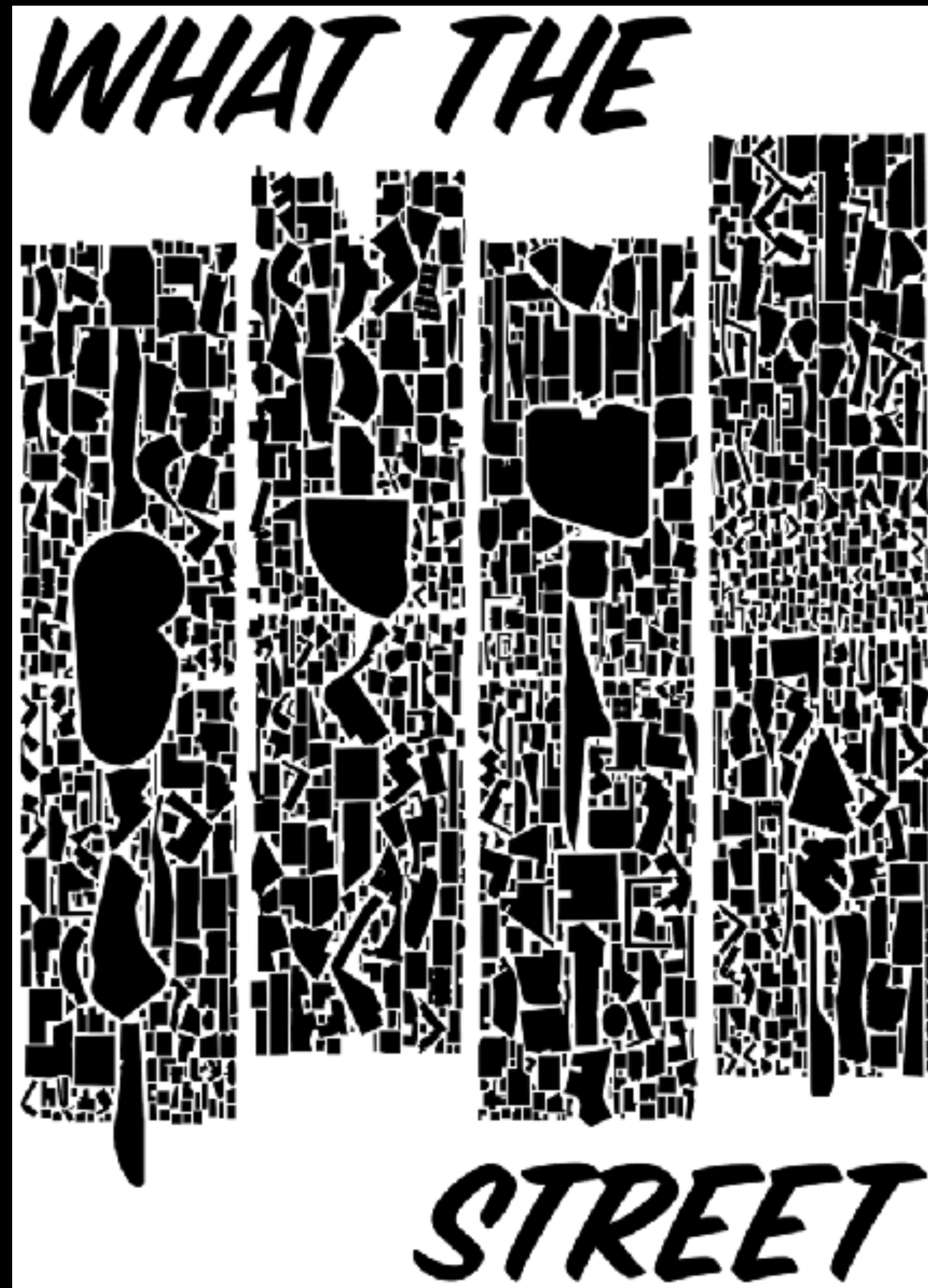
Characteristic scale of a vicinity

Sure, cities are different…

…but ride-sharing works well almost everywhere

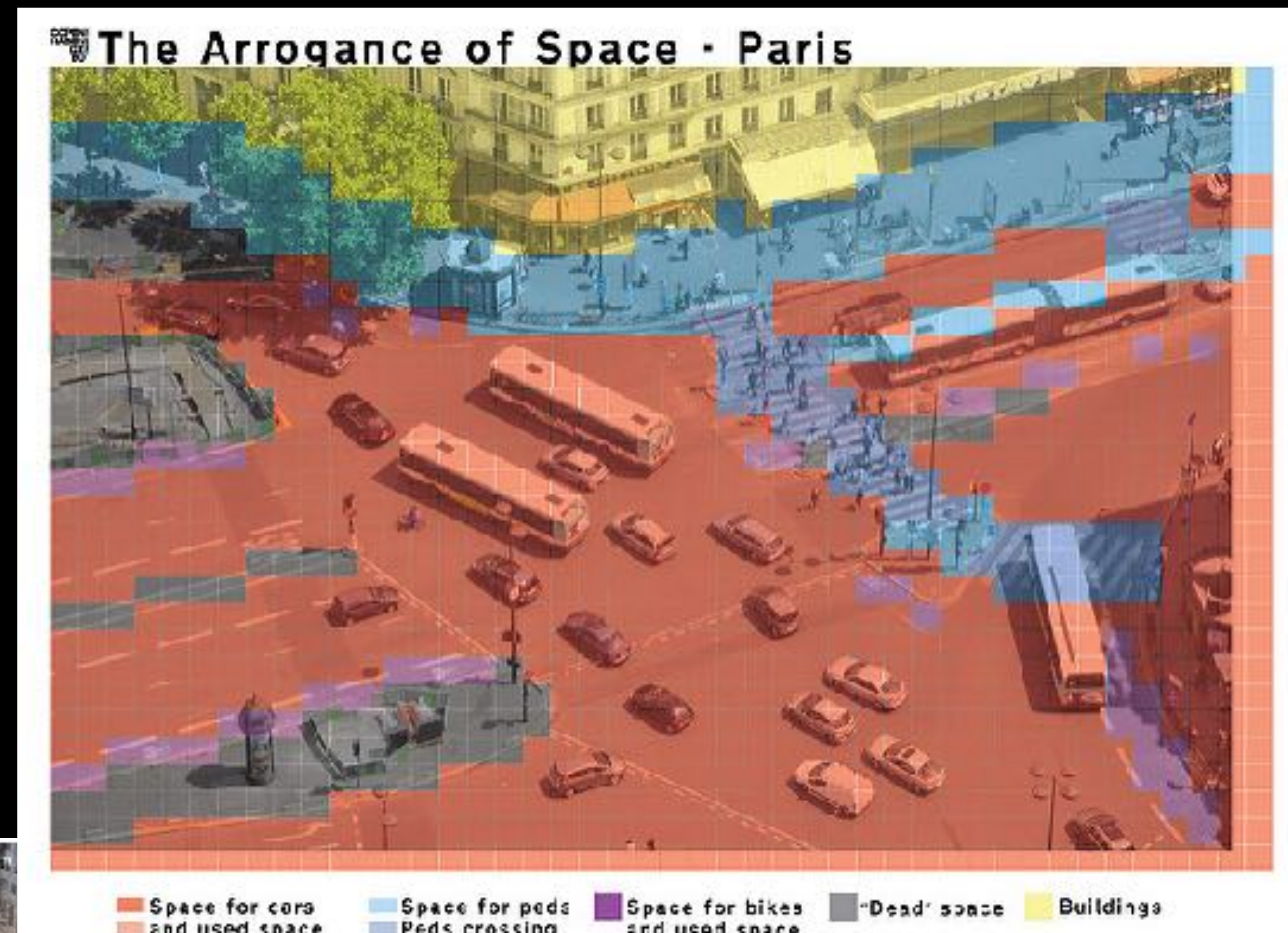
http://senseable.mit.edu/shareable-cities/

moovellab



Szell, Bogner, Groß, Lauer, Hauser, Reimann, Schmid, Lee, Wachs & Anagrama, zoom7

Exploring "The Arrogance of Space"



http://www.copenhagenize.com/2014/09/the-arrogance-of-space-paris-calgary.html

Cars are used 36 min per day

They stand around 1404 min per day

civity (2016)

Cars are used 36 min per day

They stand around 1404 min per day

A typical snapshot of Berlin
from space shows:

30,000 cars moving

1,200,000 cars parked

civity (2016)

Cars are used 36 min per day

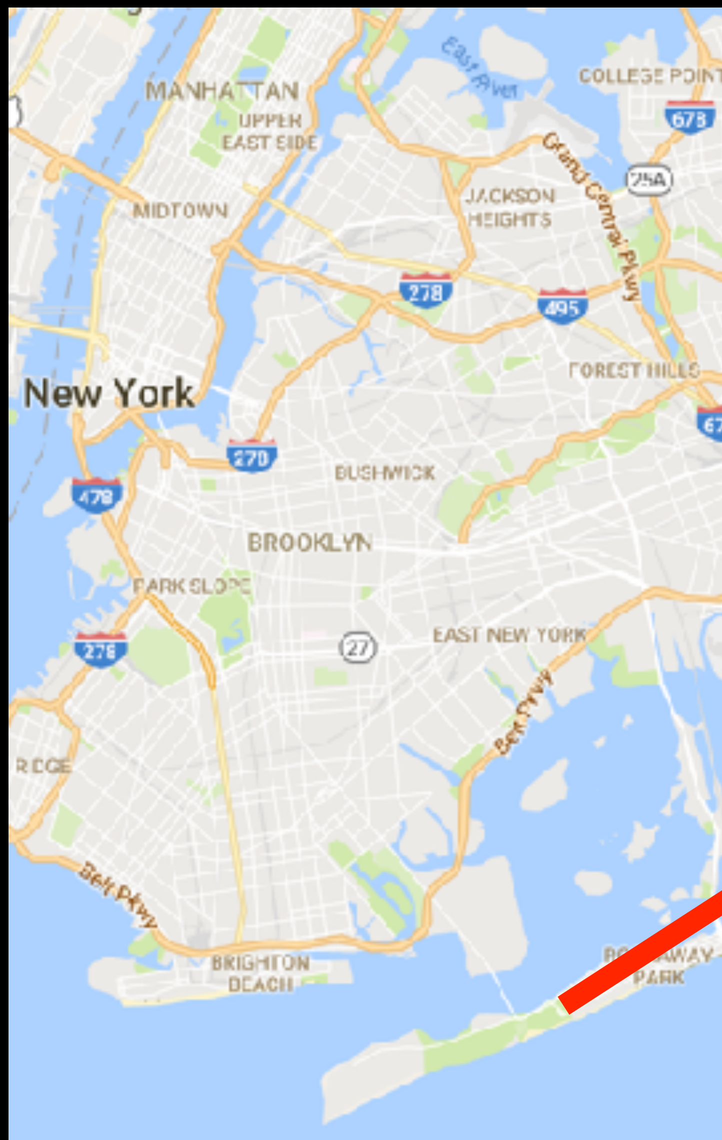
They stand around 1404 min per day

A typical snapshot of Berlin
from space shows:

30,000 cars moving

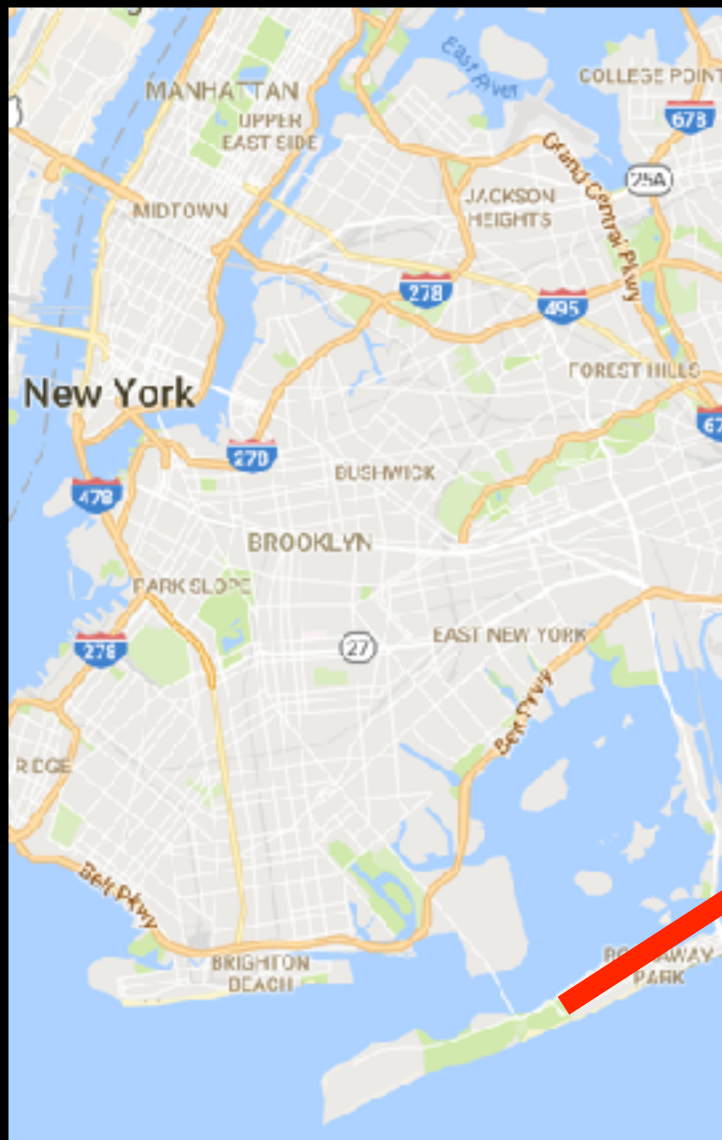
1,200,000 cars parked = 4 Central Parks
= 64,000 playgrounds

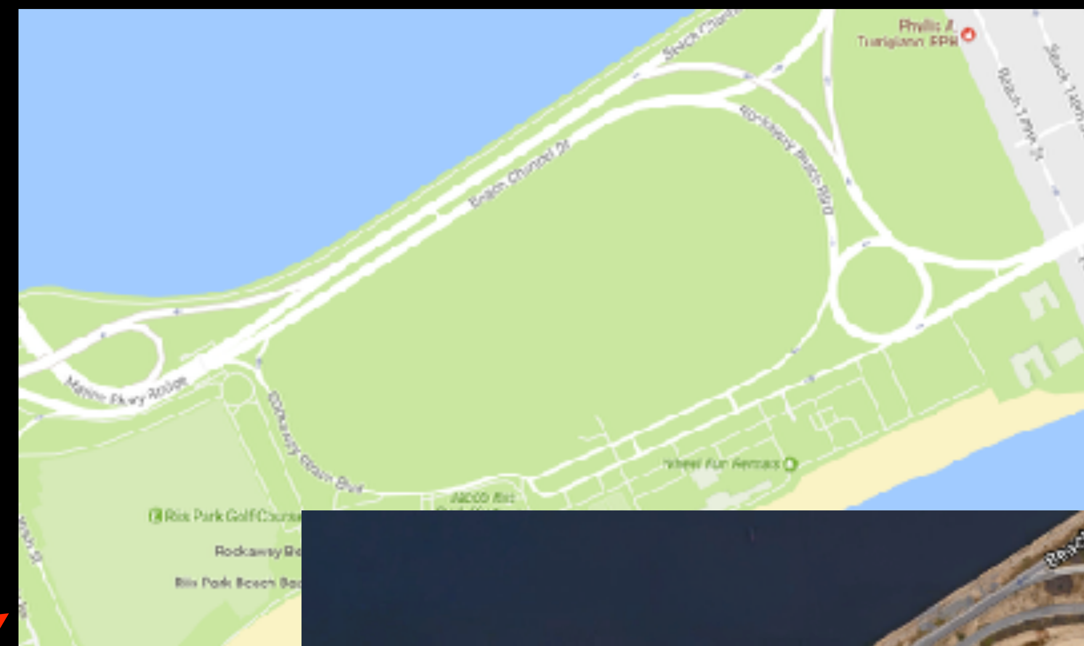
civity (2016)



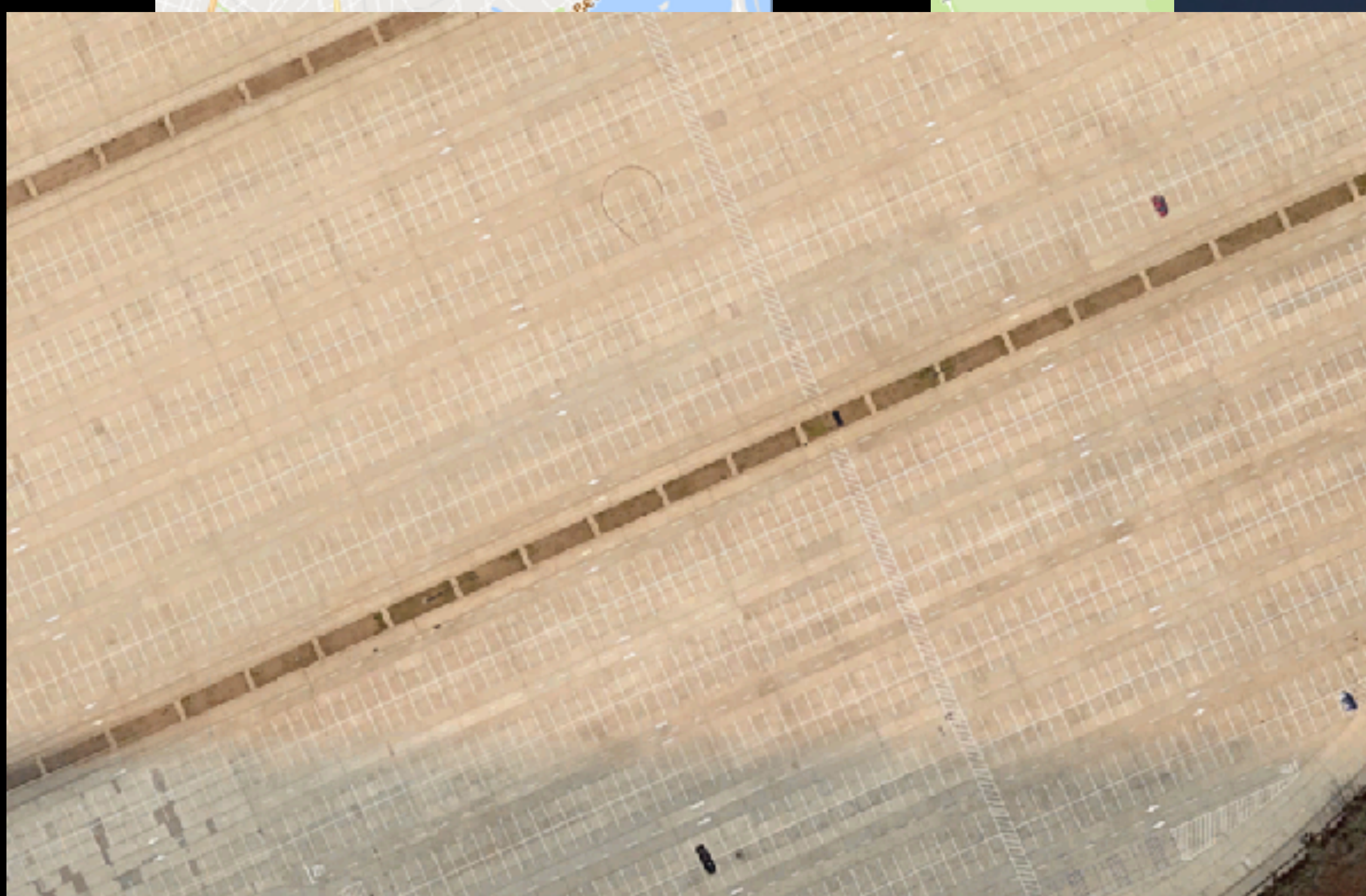
What a lovely green..

What a lovely ~~green~~..



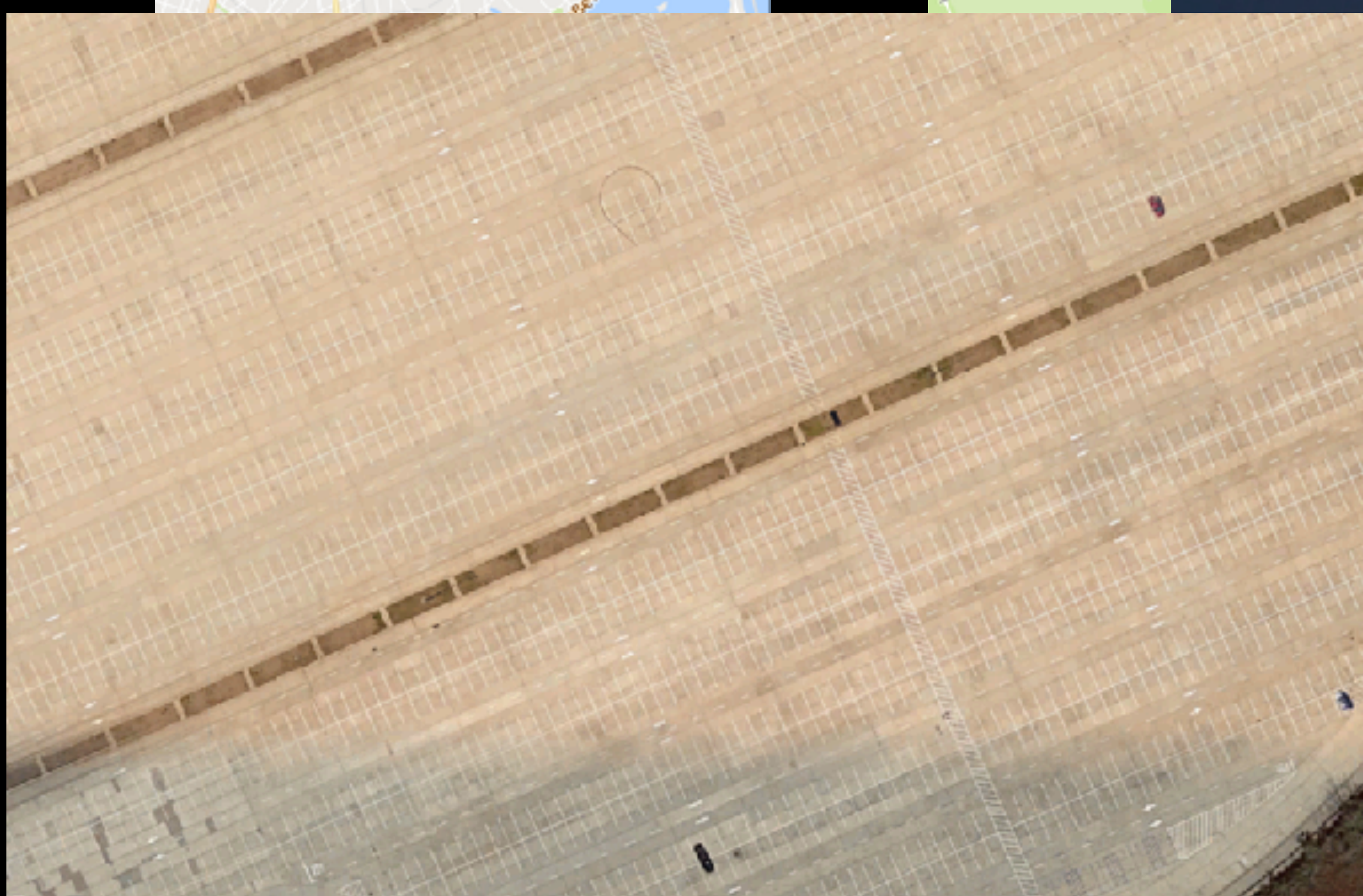


What a ~~lovely green~~.. MONSTER




MANHATTAN
UPPER EAST SIDE
MIDTOWN
New York
East River
COLLEGE POINT
678
25A
JACKSON HEIGHTS
Grand Central Pkwy
278
495
FOREST HILLS
278
478
BUSHWICK
BROOKLYN
PARK SLOPE
276
27
EAST NEW YORK

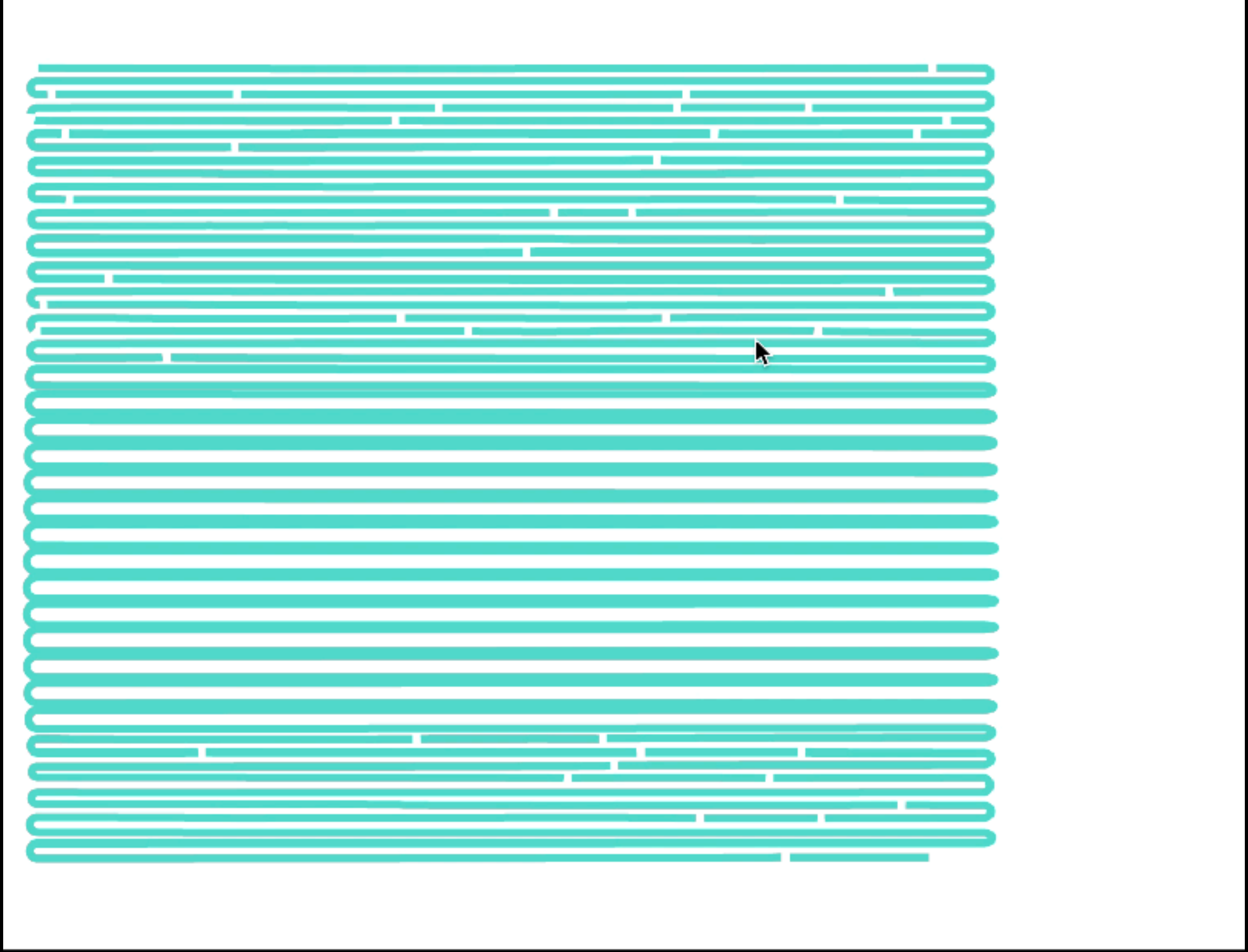

Beach Channel Dr




Beach Channel Dr

Use polygon packing to visualize ALL parking spaces

Use graph algorithms to roll up ALL streets and rails

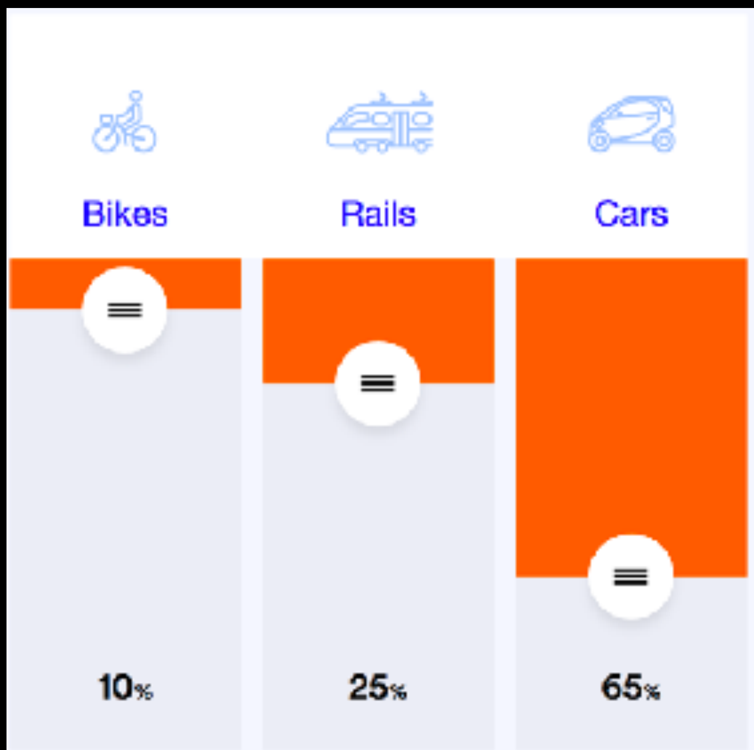


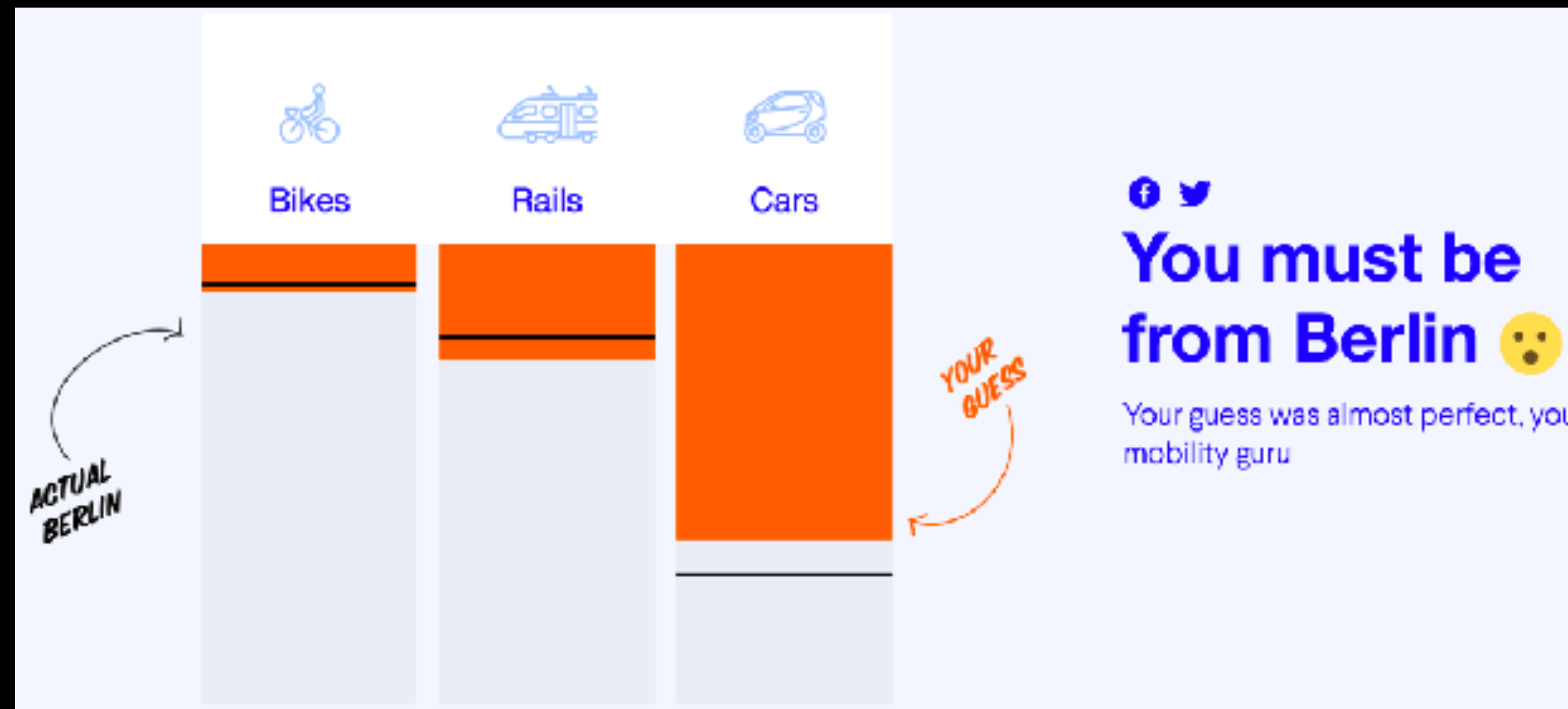
Shared self-driving cars

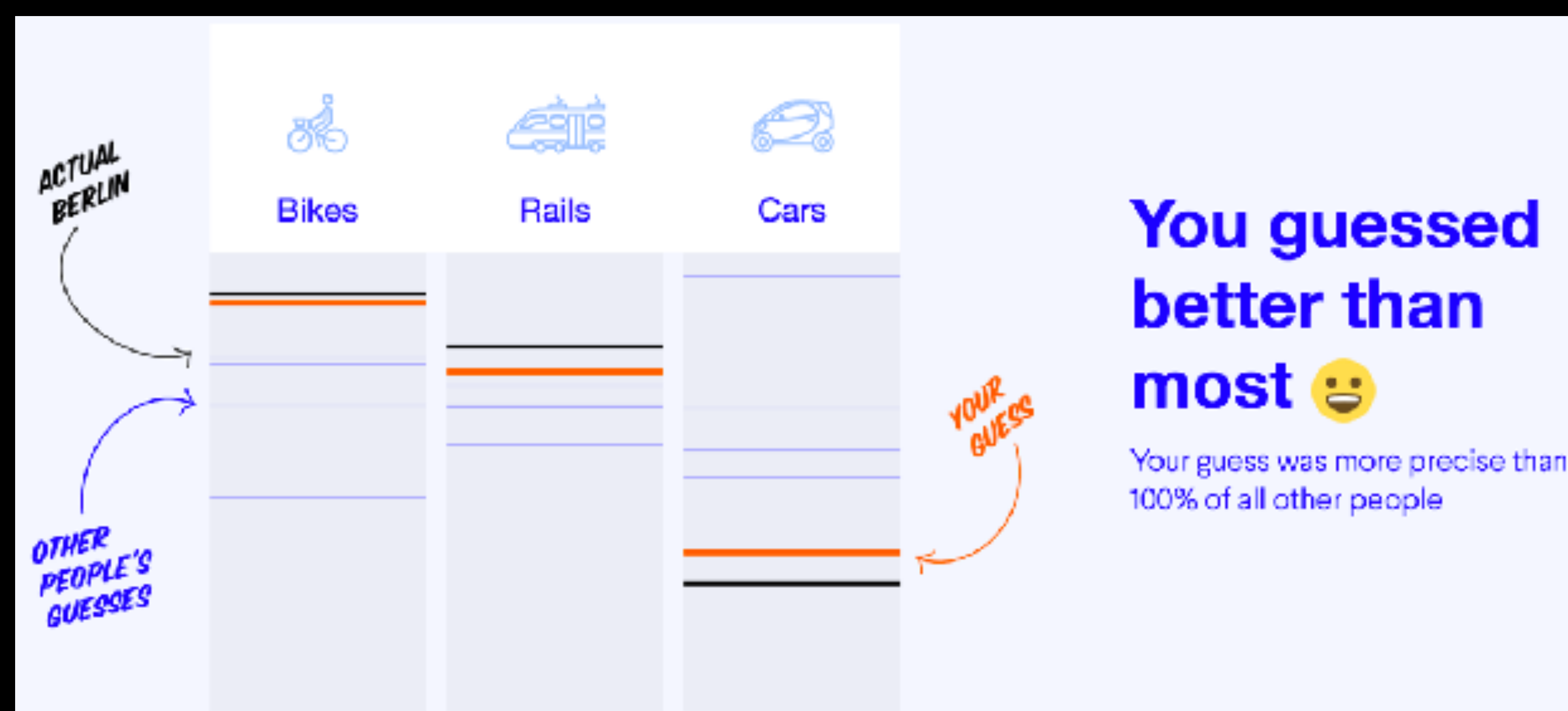
Same mobility can be delivered with 10% of cars

OECD, International Transport Forum (2015)
Friedrich, Hartl, Univ. Stuttgart (2016)

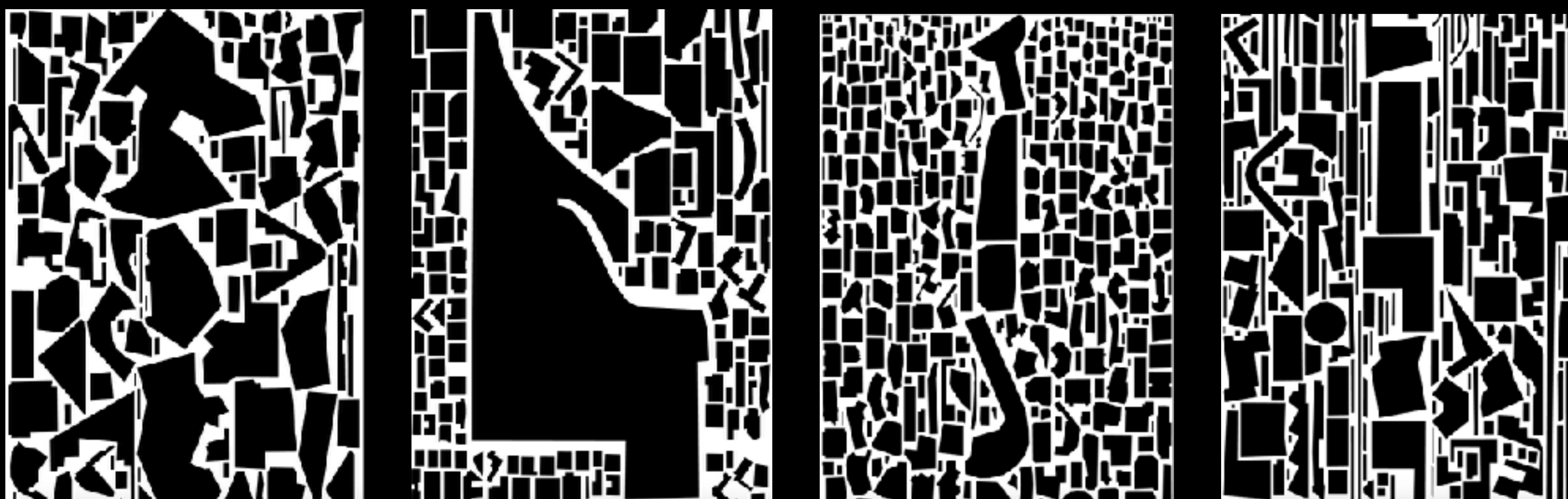
Exploring "The Arrogance of Space" interactively







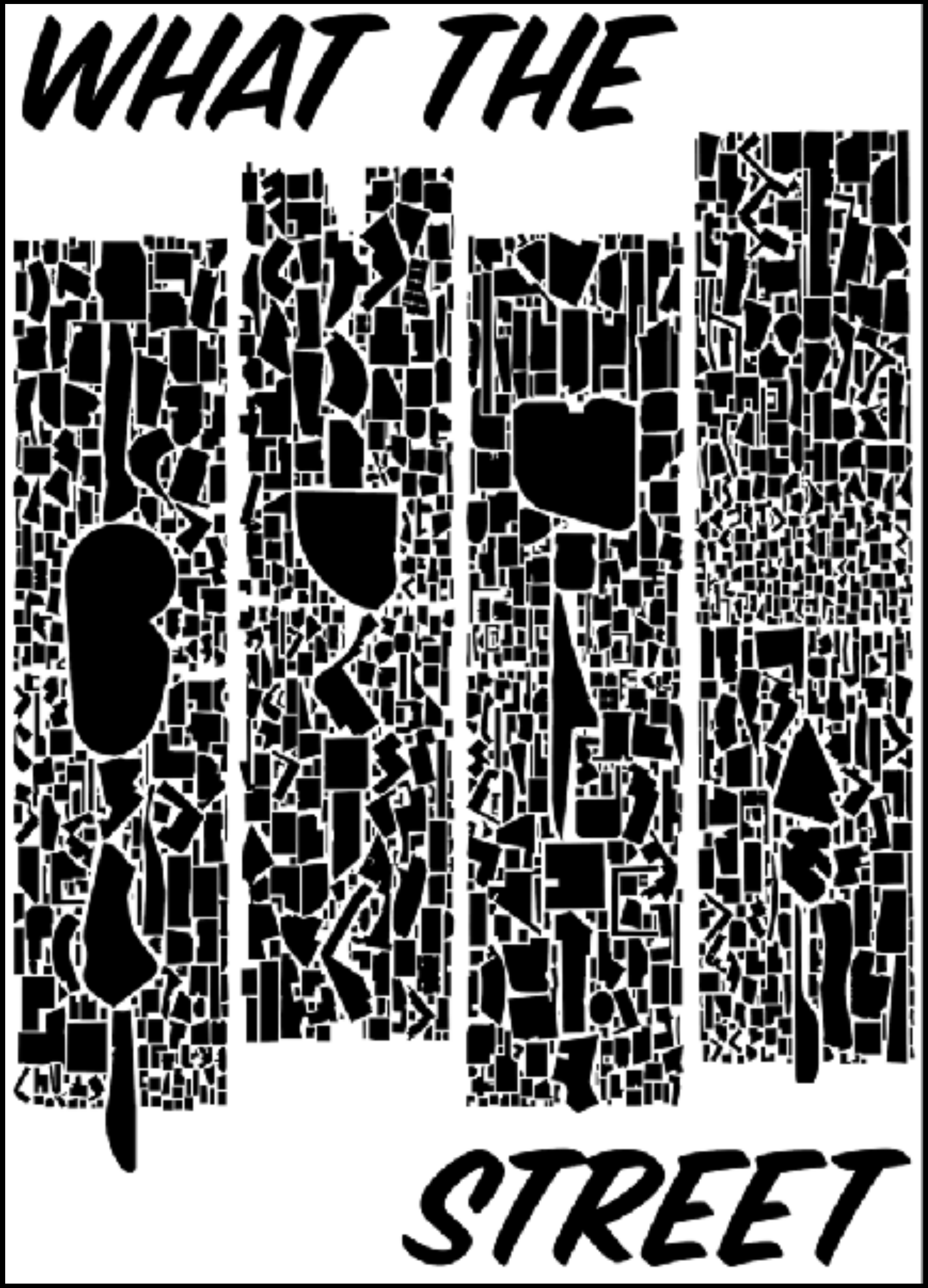
Cities have unique patterns



Which one is Copenhagen, and why?

Launching April 19, whatthestreet.com

moovel lab



Let us prioritize + incentivize what works best for society

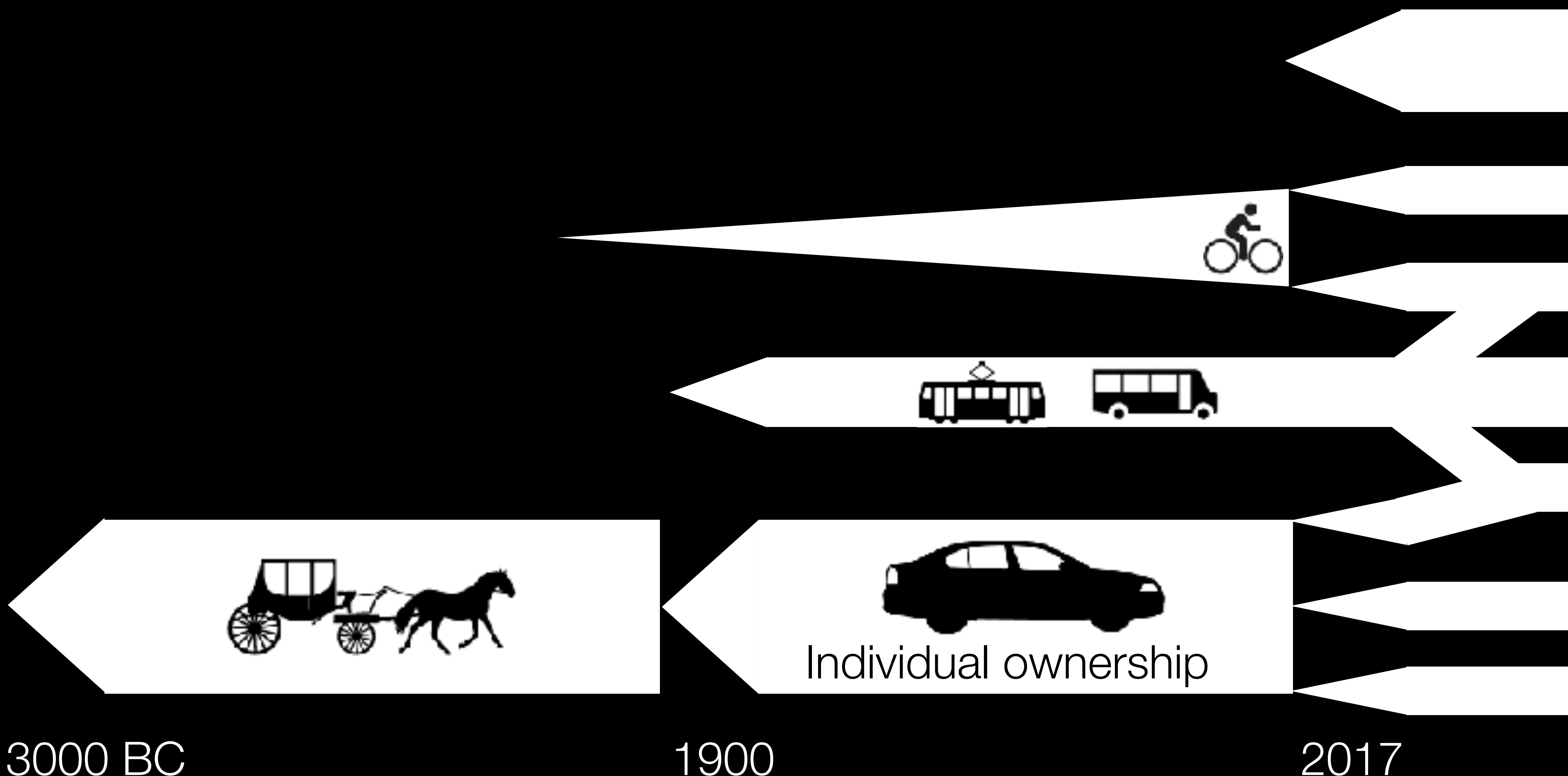
1. Bike
2. Metro, rail, tram
3. Bus

If cars needed, let them be shared and autonomous, to not waste space

Good scaling arguments why car-centric cities are not sustainable

Gossling and Choi, Ecol Econ 113 (2015)
Louf and Barthelemy, PRL 111.19 (2013)

Let us understand these developments towards sustainable solutions for living together



Warner, S.B. Harvard Univ. Press (1978)

<u>Research</u>

Paolo Santi
Giovanni Resta
Remi Tachet
Oleguer Sagarra
S. Sobolevsky
Carlo Ratti
Steven Strogatz

<u>Visualizations</u>

Benedikt Groß
Joey Lee
Eric Baczuk
Carlo Ratti
Andi Weiß
Stefan Landsbeck
Pierrick Thebault

Stephan Bogner
Tobias Lauer
Tilman Hauser
Raphael Reimann
Daniel Schmid
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