ICAPS 2010 Tutorial

Planning and Scheduling for Traffic Control

Scott Sanner

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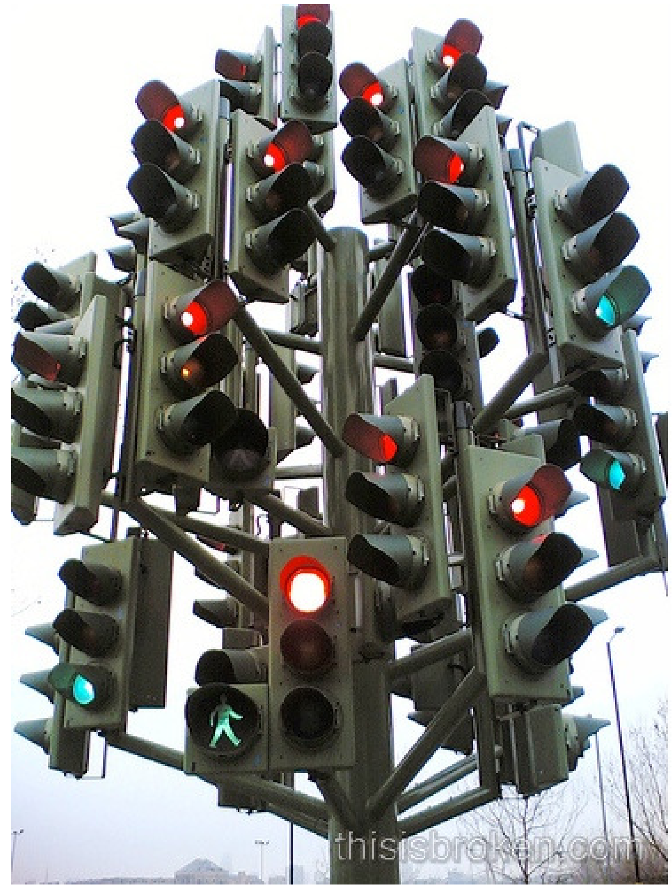
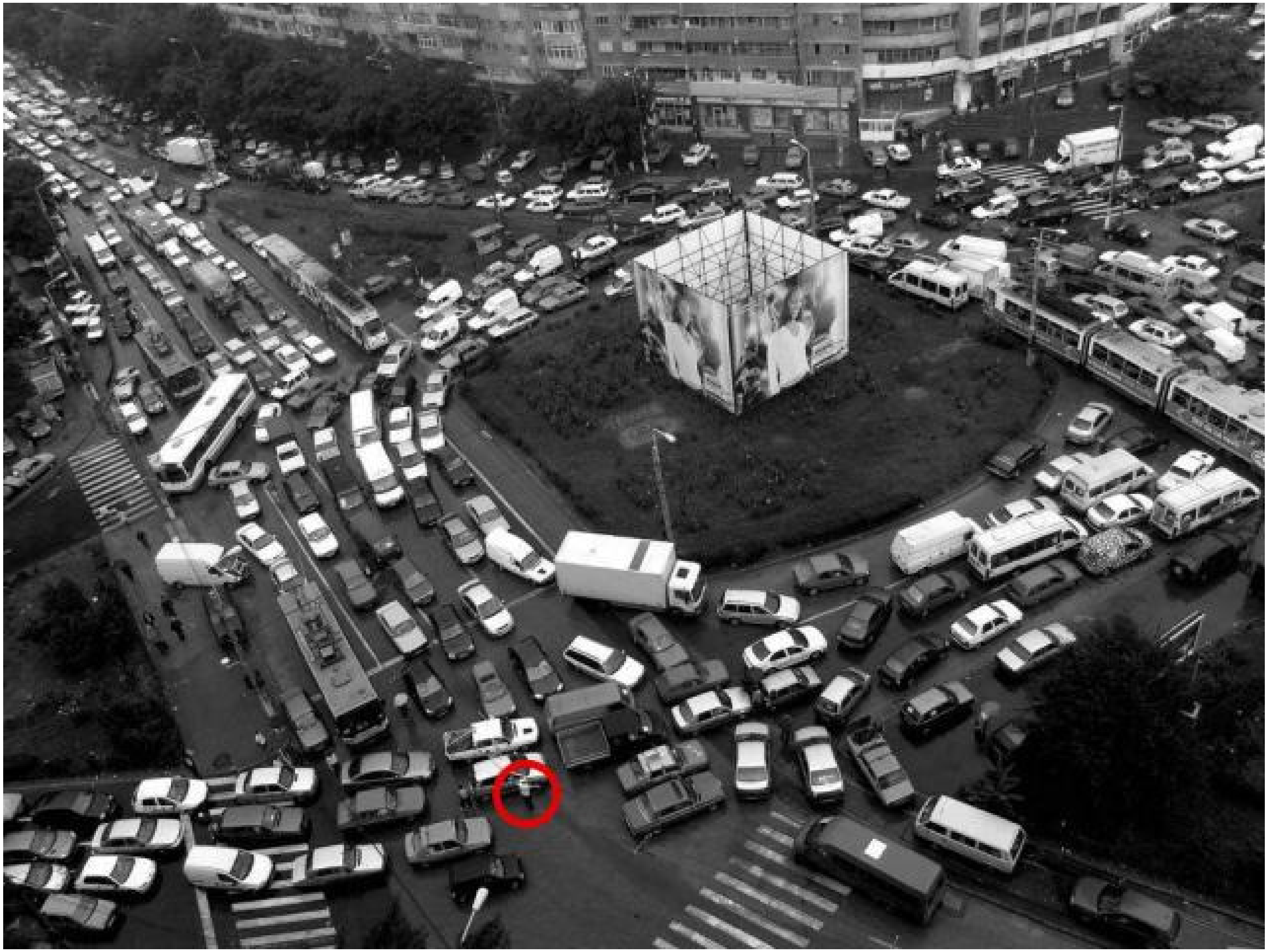
Outline

- Motivation
- History
- Fundamentals
- Simulation
- Control
  - Single Intersection
  - Multiple Intersection
- Future

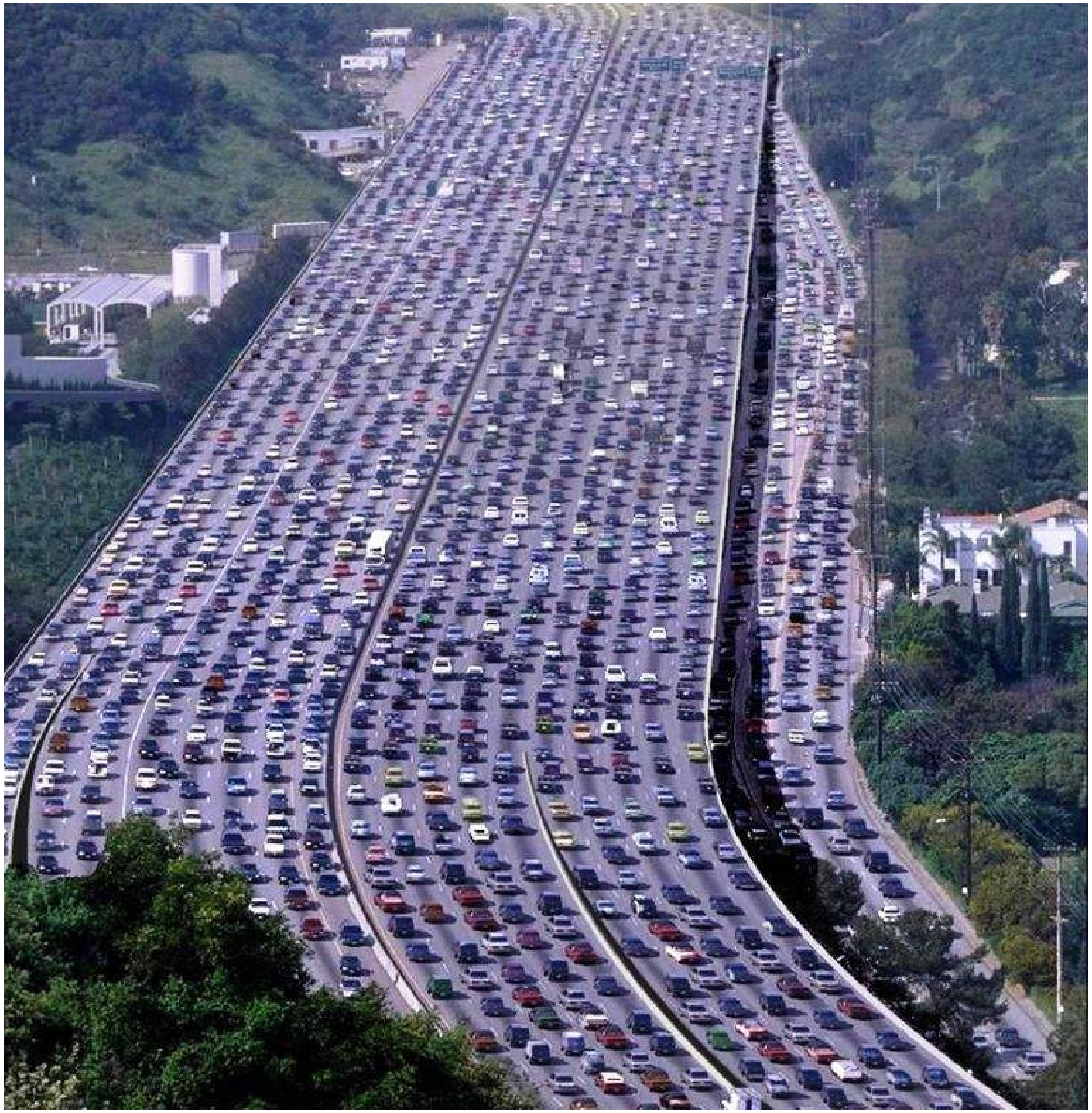


Motivation

More Motivation



Unreal Motivation



Traffic Impacts Everyone

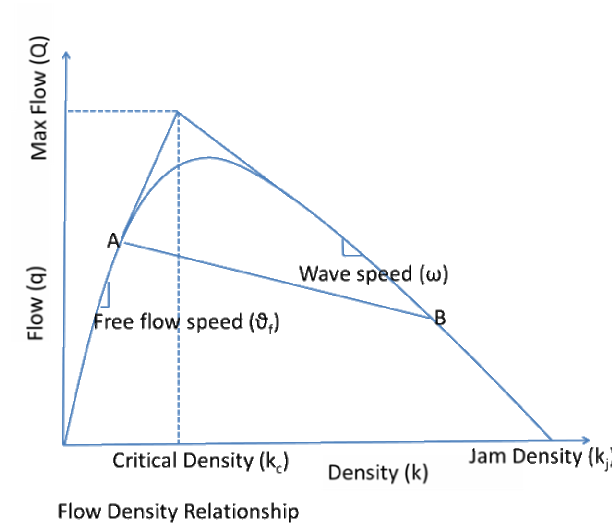
- Not a problem I have to motivate
  - Economically, impact of better control is in billions of $$$ for large cities!
- Real & unsolved problem
  - Multidimensional state (integer / continuous)
  - Multidimensional concurrent actions
  - Stochastic
  - Building a high fidelity model is difficult

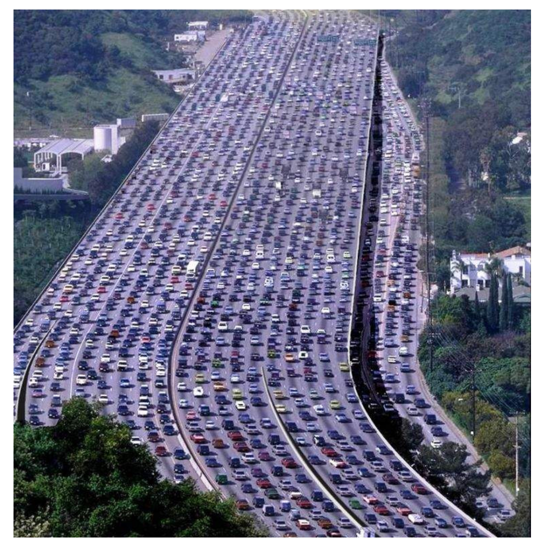
Theory vs. Practice

- Theory
  - Idealized
  - Models major phenomena
  - Good analytical techniques

Need a stronger connection!

- Practice
  - Every case is different
  - Control is principled
    - but over-constrained
  - Manually tuned





Integrating into the Food-chain

- Important to understand what exists theoretically
  - Entire field devoted to transportation research
- And how **your research** can integrate practically
  - Billions of $$$ in **legacy** infrastructure
  - Hardware is limited (e.g., **1970's** era)
    - But still more integrated than you think
  - Systems are **safety verified**
    - Difficult and expensive to replace
    - Figure out where to fit in for lowest cost

Tutorial Objectives

- Main tutorial objective
  - Understand major areas of traffic research
  - Understand basic theory and practice

- At the end of this tutorial you should know….
  - The *fundamental diagram of traffic flow*
  - How to dissipate shockwaves in your arteries
  - The importance of platoons
  - Main differences between SCOOT and SCATS

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Traffic Control: History

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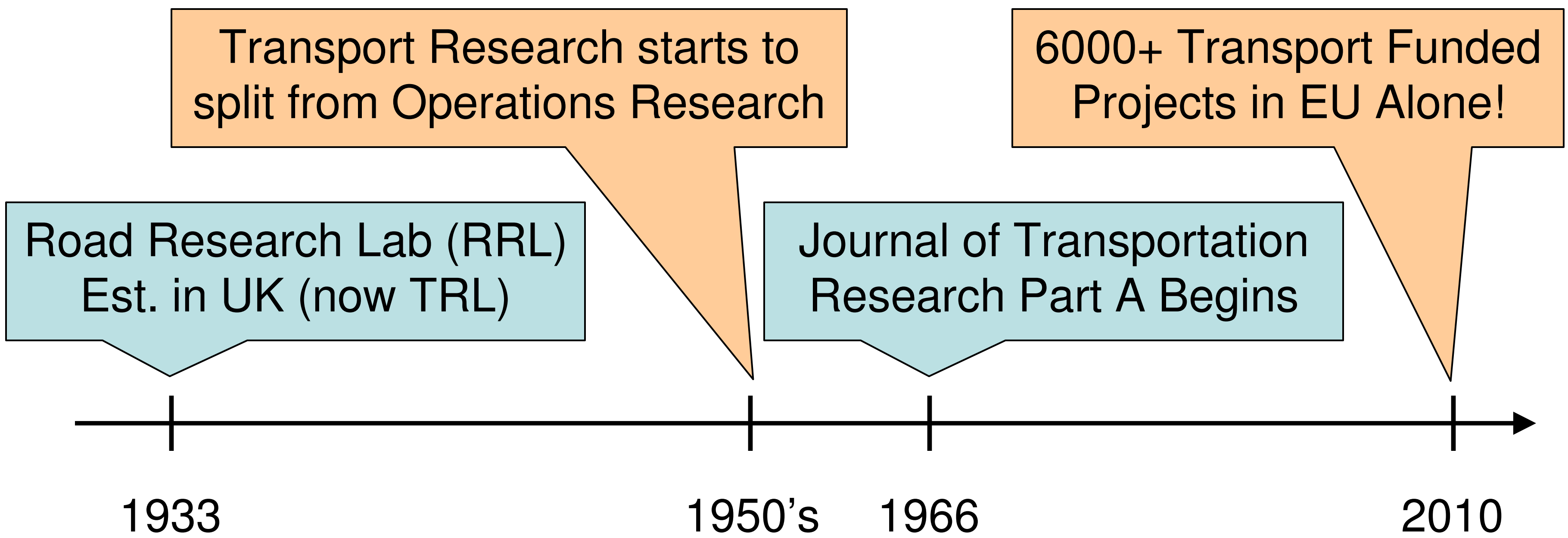
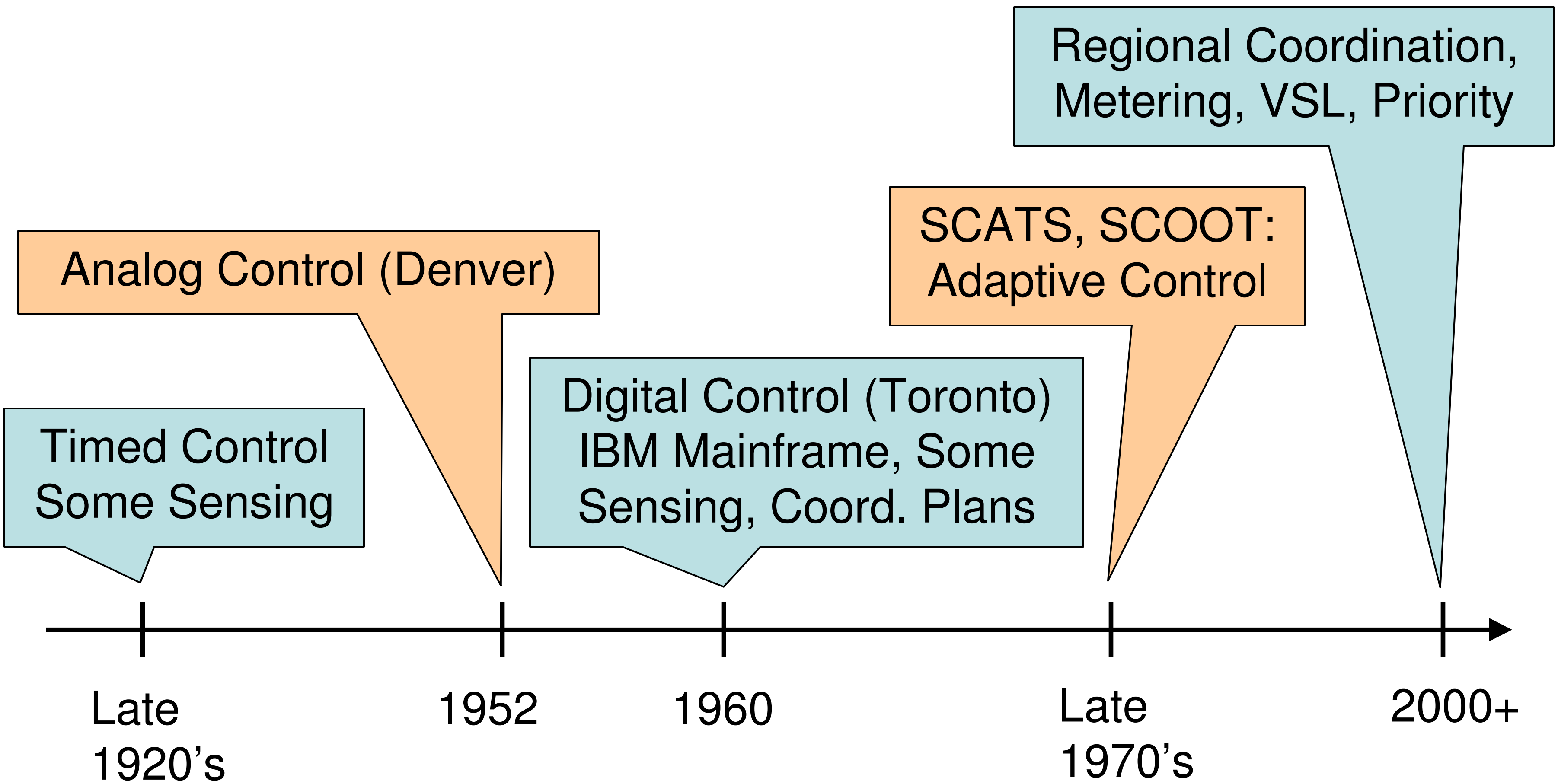
Minimalist Research Timeline

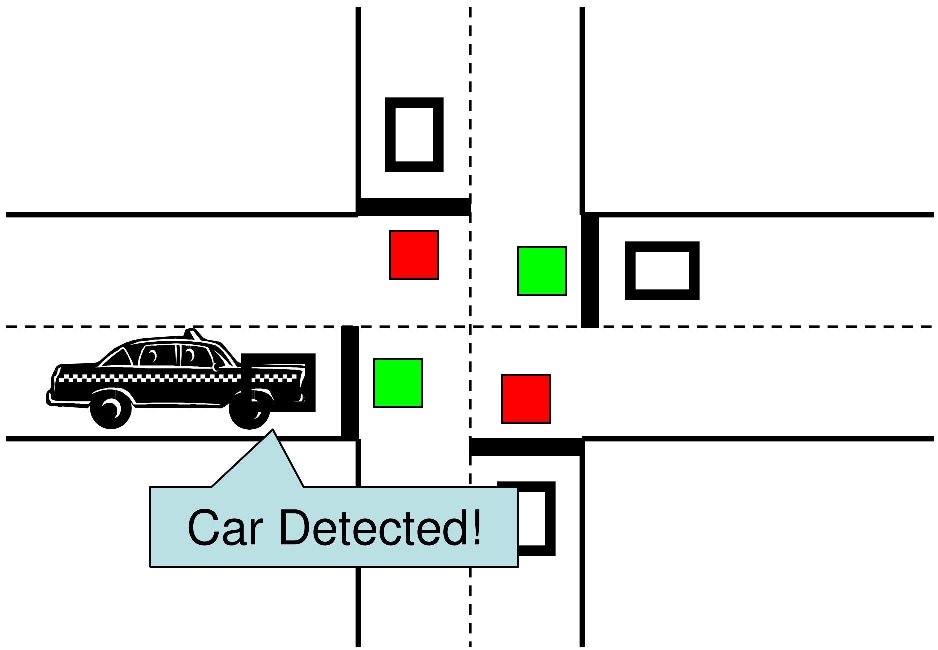


Signalized Control Timeline



SCATS

- Sydney Coordinated Adaptive Traffic System



- Stopline detectors

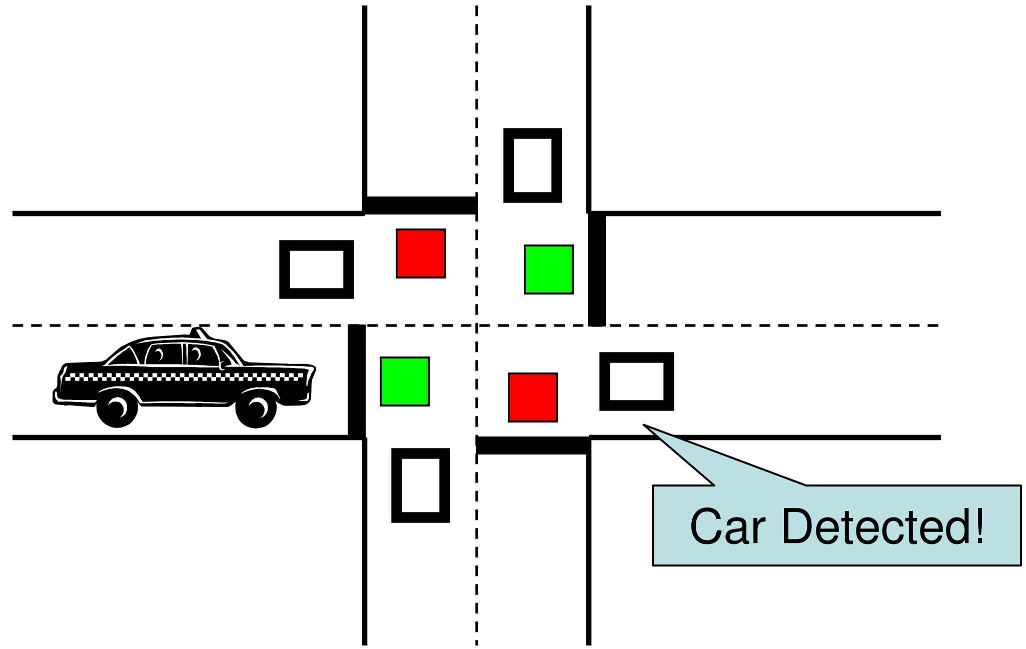
- Coordinated decentralized control

SCOOT

- Split, Cycle, & Offset Optimization Technique

- Centralized controller

- Some predictive feedforward control



  – Loops after intersection
    - No need to predict turn probabilities
    - Optimize lights before they arrive

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Traffic Control: Fundamentals

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Fundamental Diagram of Traffic Flow

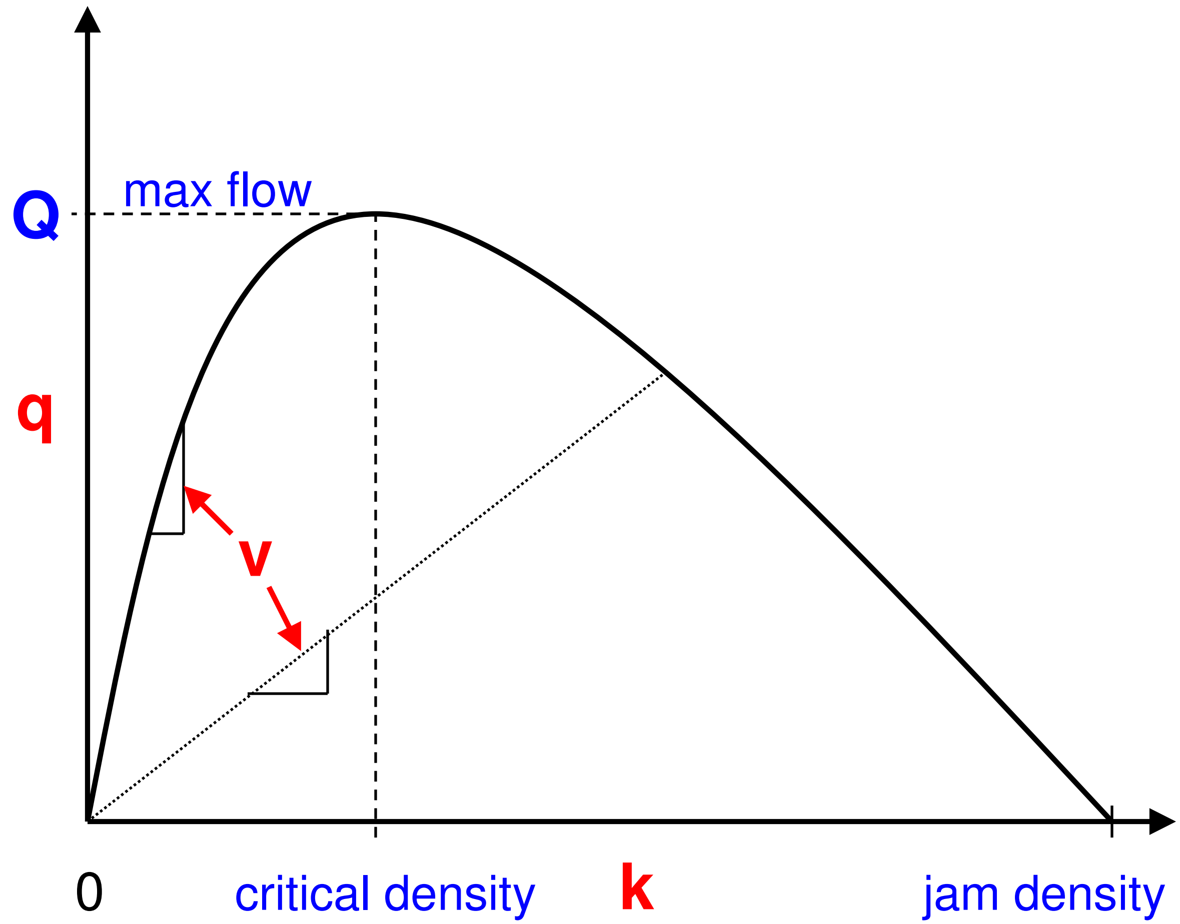
Flow q: cars/s

Density k: cars/m

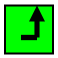
Velocity v: m/s

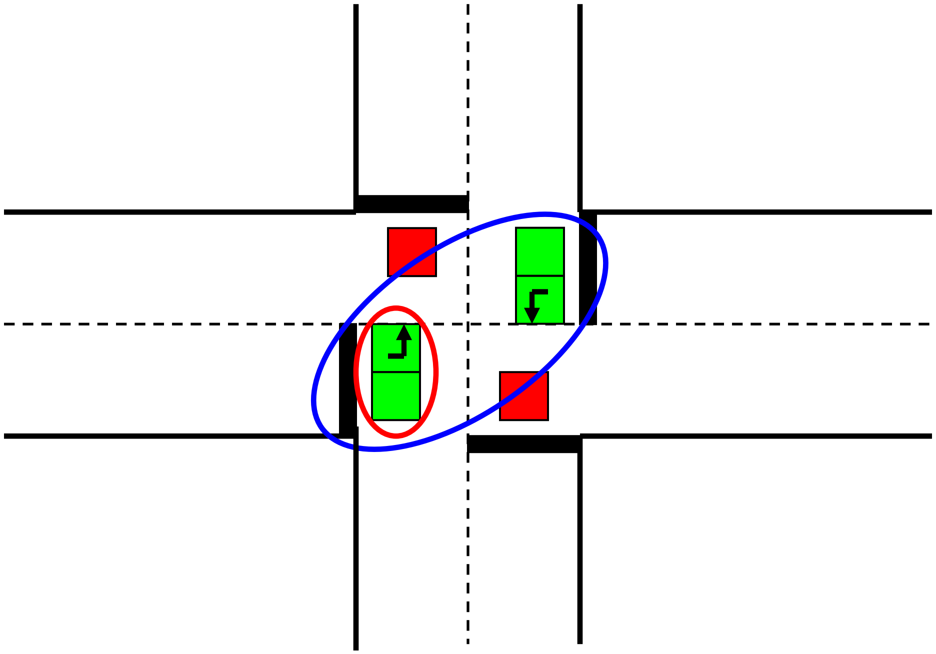
q = kv

v = q/k



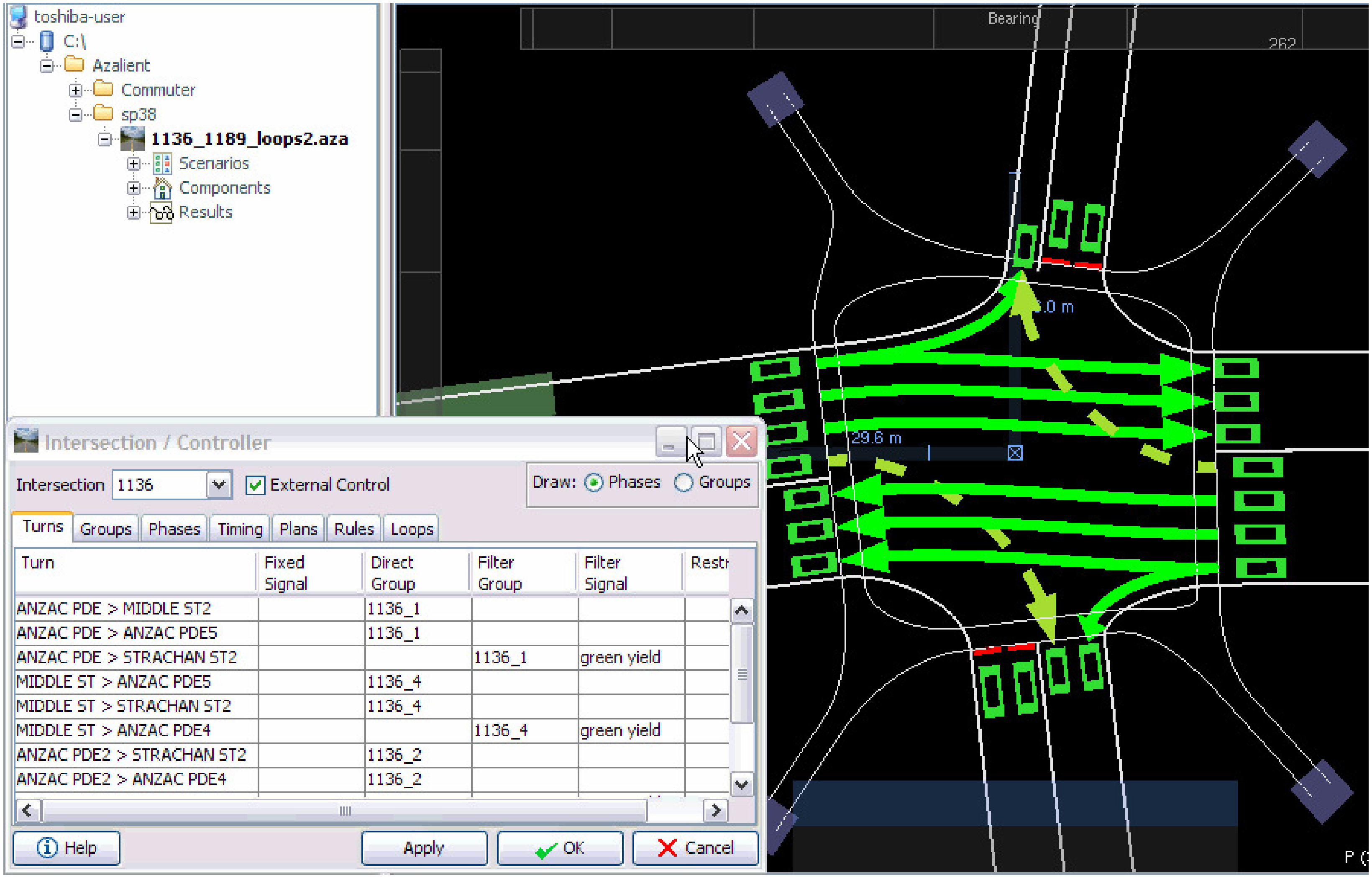
Terminology

- Signal, e.g., 
- Signal Group
- Phase
- Turns
  - Protected Turn
  - Filter Turn
    - unprotected



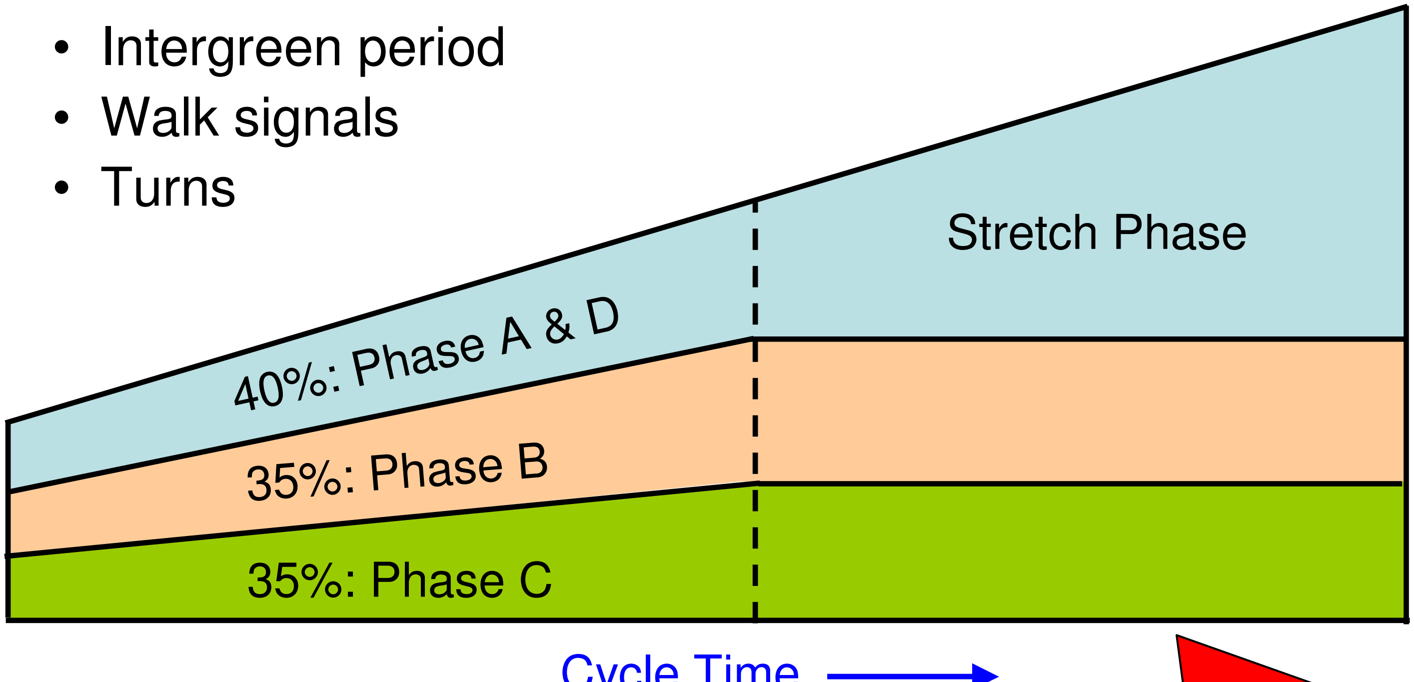
Terminology Illustration: Azalient Commuter

•



Phase Plans

- Each intersection has one or more **phase plans**
  - Time percentage of **cycle time** is **phase split**
  - Some absolute or variable times
    - Intergreen period
    - Walk signals
    - Turns



- Typically four plans per intersection
  - Heavy inbound / outbound, balanced, & light

Now just choose a plan and cycle time for one intersection!

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Traffic Control: Simulation

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Types of Simulation

- Macrosimulation
  - Model aggregate properties of traffic
  - Average flow, density, velocity of cells
- Microsimulation
  - Model individual cars
  - Typically cellullar automata
- Nanosimulation
  - Model people (inside & outside of cars)

Human Factors in Microsimulation

- Microsimulation often involves driver choice:
  - Filter turns
  - Turns into flowing traffic
  - Lane merges
  - Lane changes
- Theories such as gap acceptance theory
  - Attempt to explain driver choices
  - e.g., gap size willing to accept on filter turn $\propto$ 1/time
- See Ch. 3 of Traffic-Flow Theory, Henry Lieu

Microsimulation Turn Models

Two ways to model turns:

1. Turn probabilities at each intersection

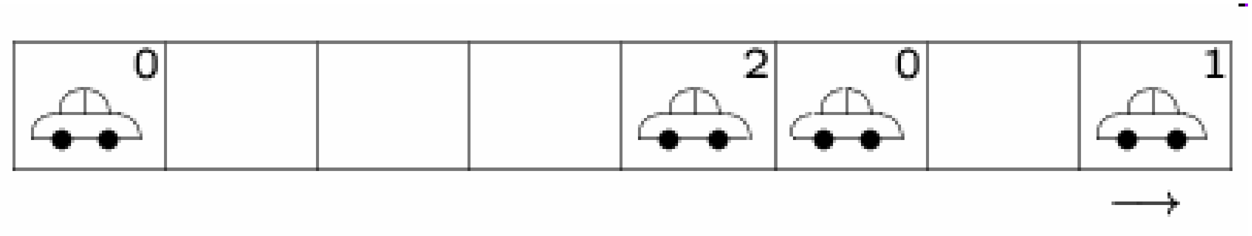
2. Frequencies in origin-destination (OD) matrix
   (routes predetermined for each OD pair)

Which is better?

Car may go in loops
for 1, more realistic
to choose 2!

Microsimulation

- Nagle-Schreckenberg
  - Cellular Automata Model
    - nominally each cell is 7.5m in length



  - Simplest model that reproduces realistic traffic behavior

Image and description from: http://www.thp.uni-koeln.de/~as/Mypage/traffic.html

Car Following in Microsimulation

- Nagel-Schreckenberg
- 4 Rules
  - Acceleration:
    $v_i := \min(v_i + 1, v_{max})$
  - Safety Distance:
    $v_i := \min(v_i, d)$
  - Randomization:
    prob p: $v_i := v_i - 1$
  - Driving:
    $x_i' = x_i + v_i$

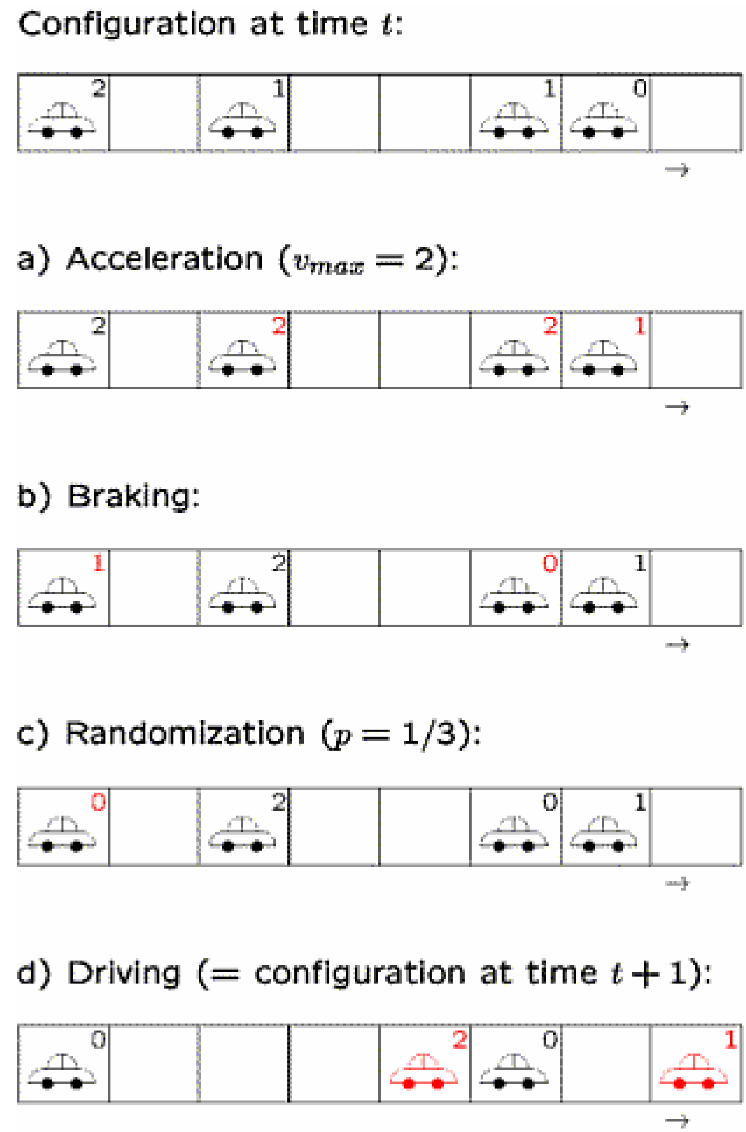


Image and description from: http://www.thp.uni-koeln.de/~as/Mypage/traffic.html

Car Following Microsimulation

- Continuous traffic flow example:
  - Upper plot is space/time diagram
  - Lower plot is actual traffic

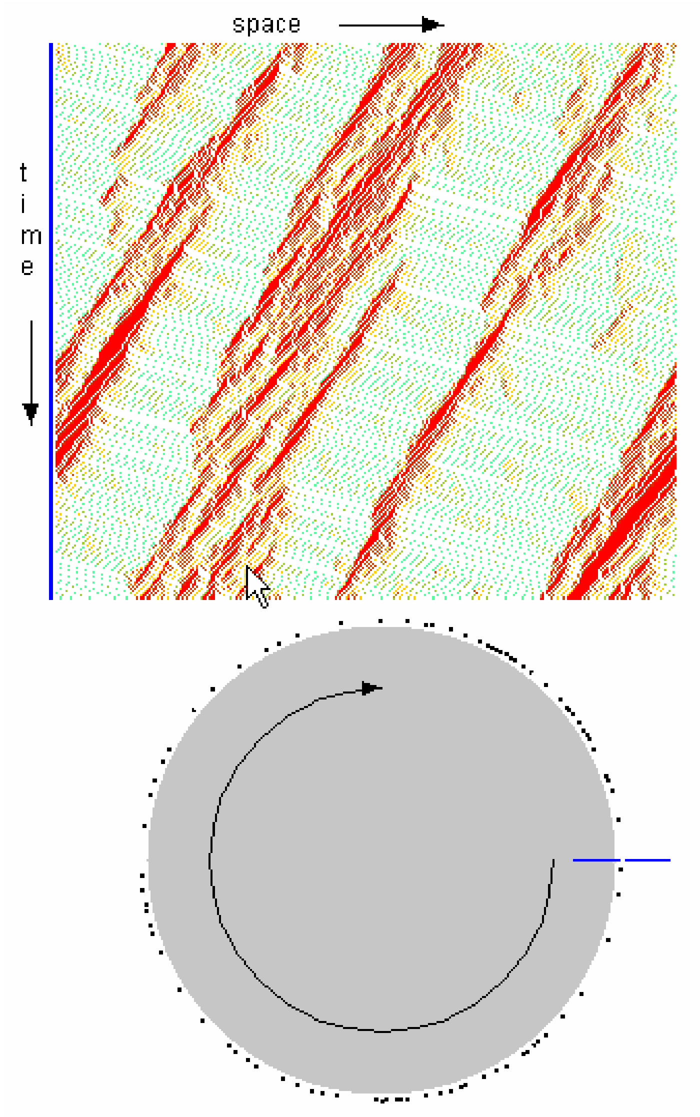
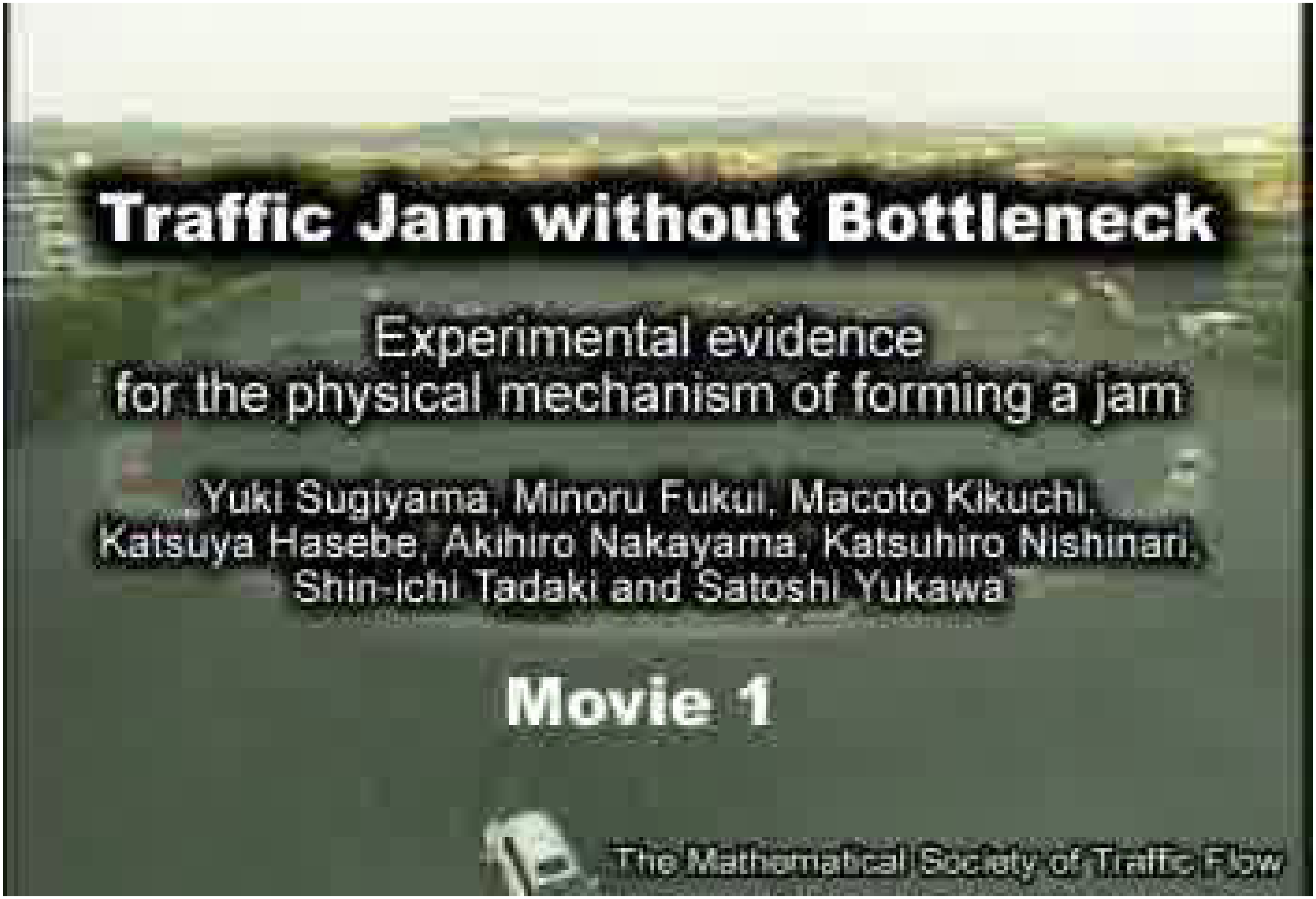


Image and description from: http://www.thp.uni-koeln.de/~as/Mypage/simulation.html

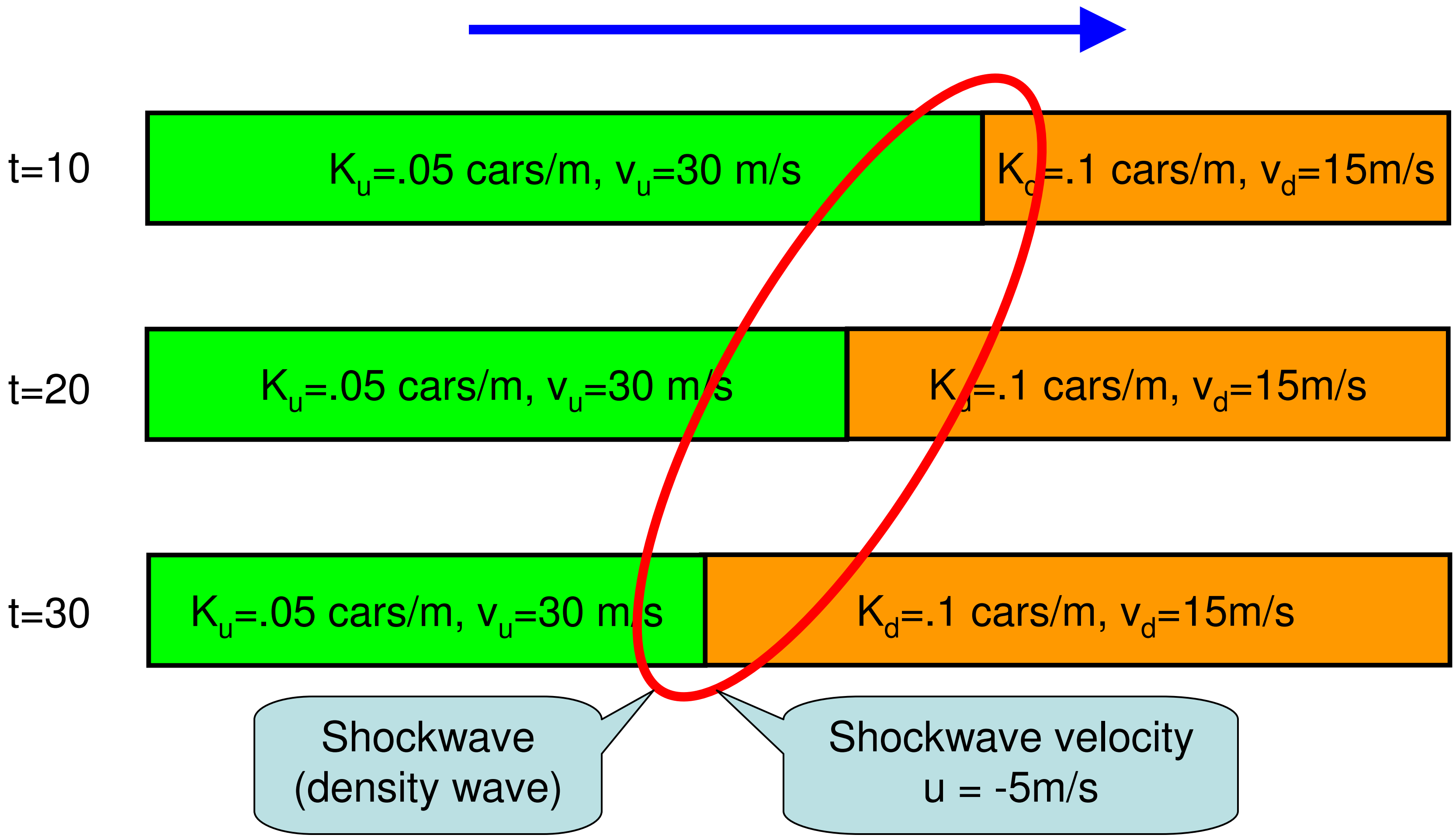
An Even Better Microsimulator



http://news.sciencemag.org/sciencenow/2008/03/28-01.html

Shockwaves

- Low density traffic meets high density traffic…



Calculation of Shockwave Speed

- Law of conservation of cars:
  - “Cars can neither be created nor destroyed”

- Traffic flows in/out of shockwave at rate:

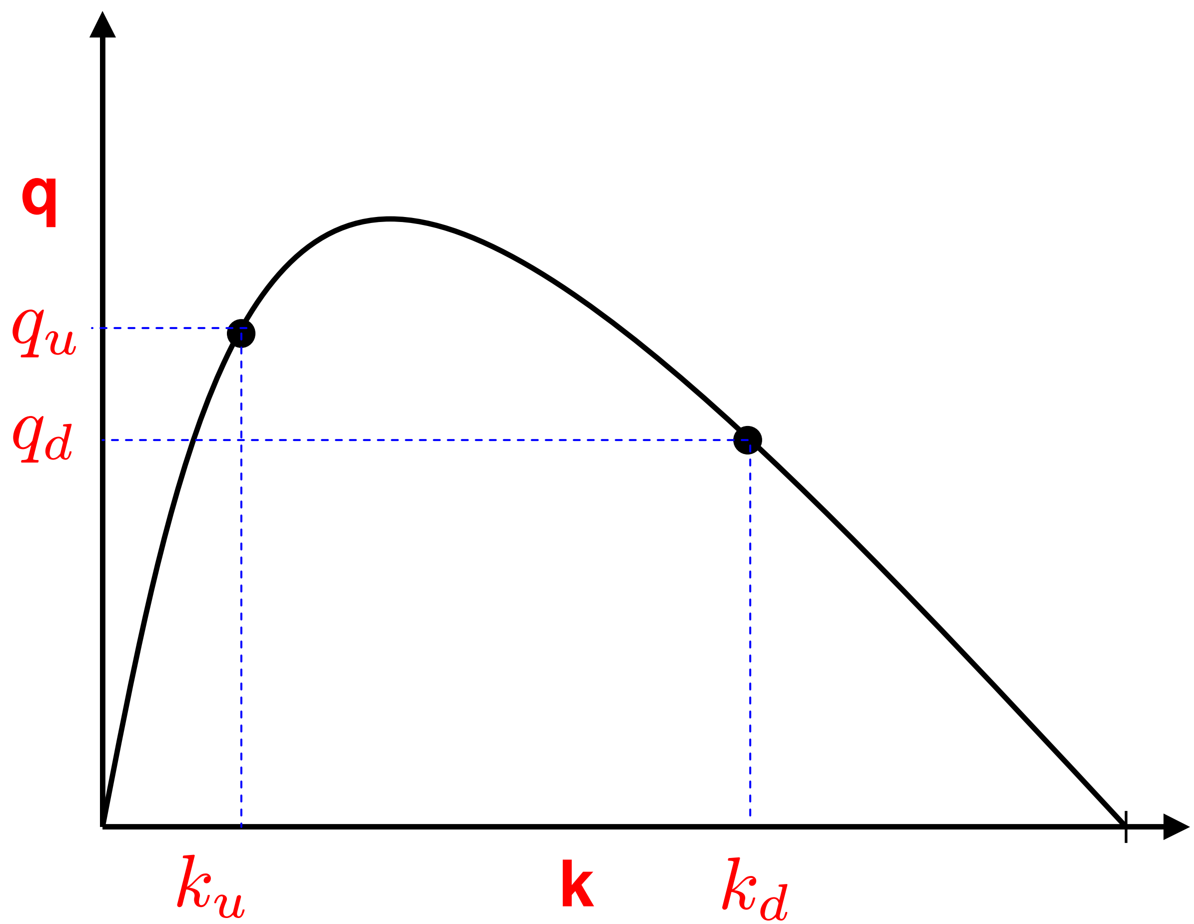
$$q_{enter} = k_u(v_u - u)$$

$$q_{exit} = k_d(v_d - u)$$

$$q_{exit} = q_{exit} \Rightarrow u = \frac{k_d v_d - k_u v_u}{k_d - k_u} = \frac{q_d - q_u}{k_d - k_u} = \frac{\Delta q}{\Delta k}$$

Theory of Shockwaves

Determine shockwave speed u from diagram:



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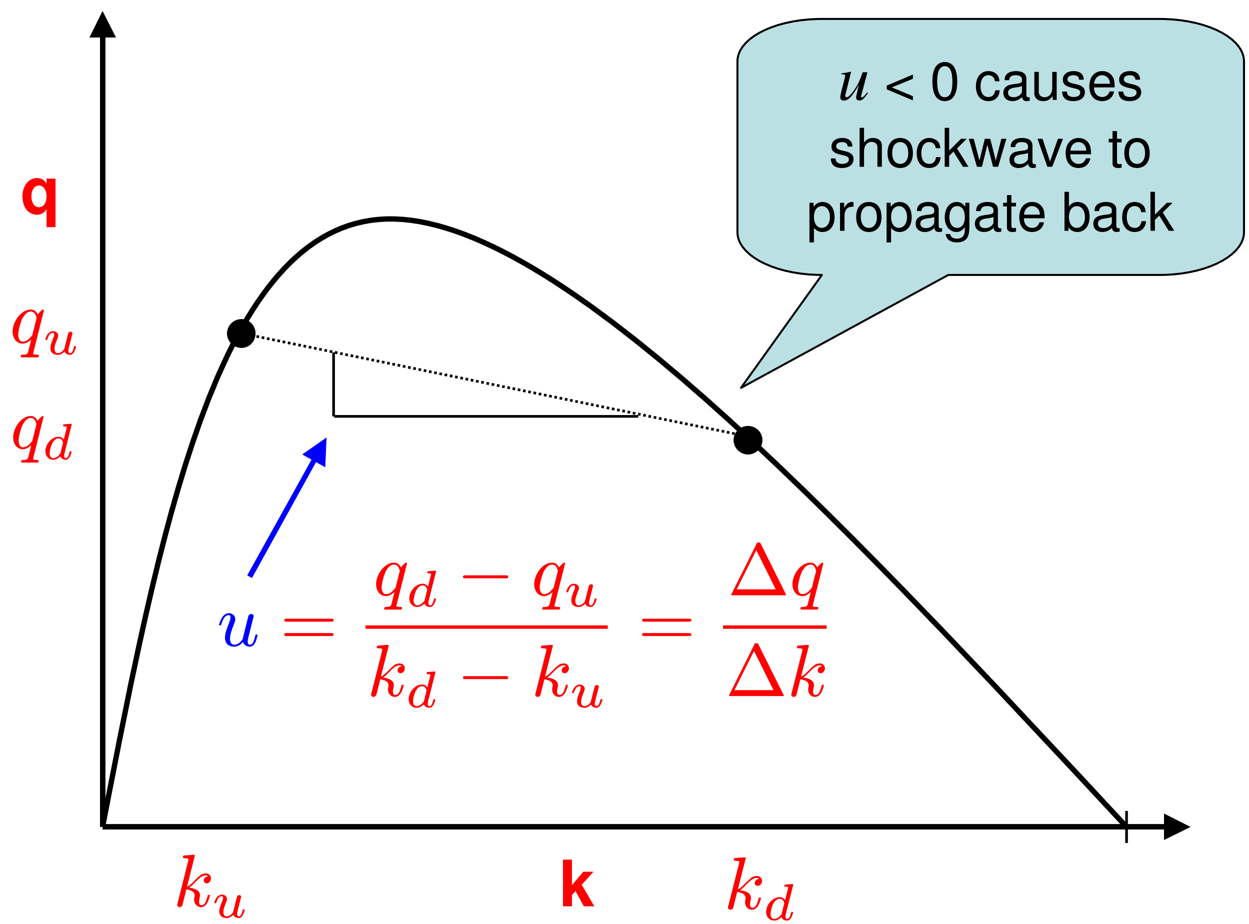

Theory of Shockwaves

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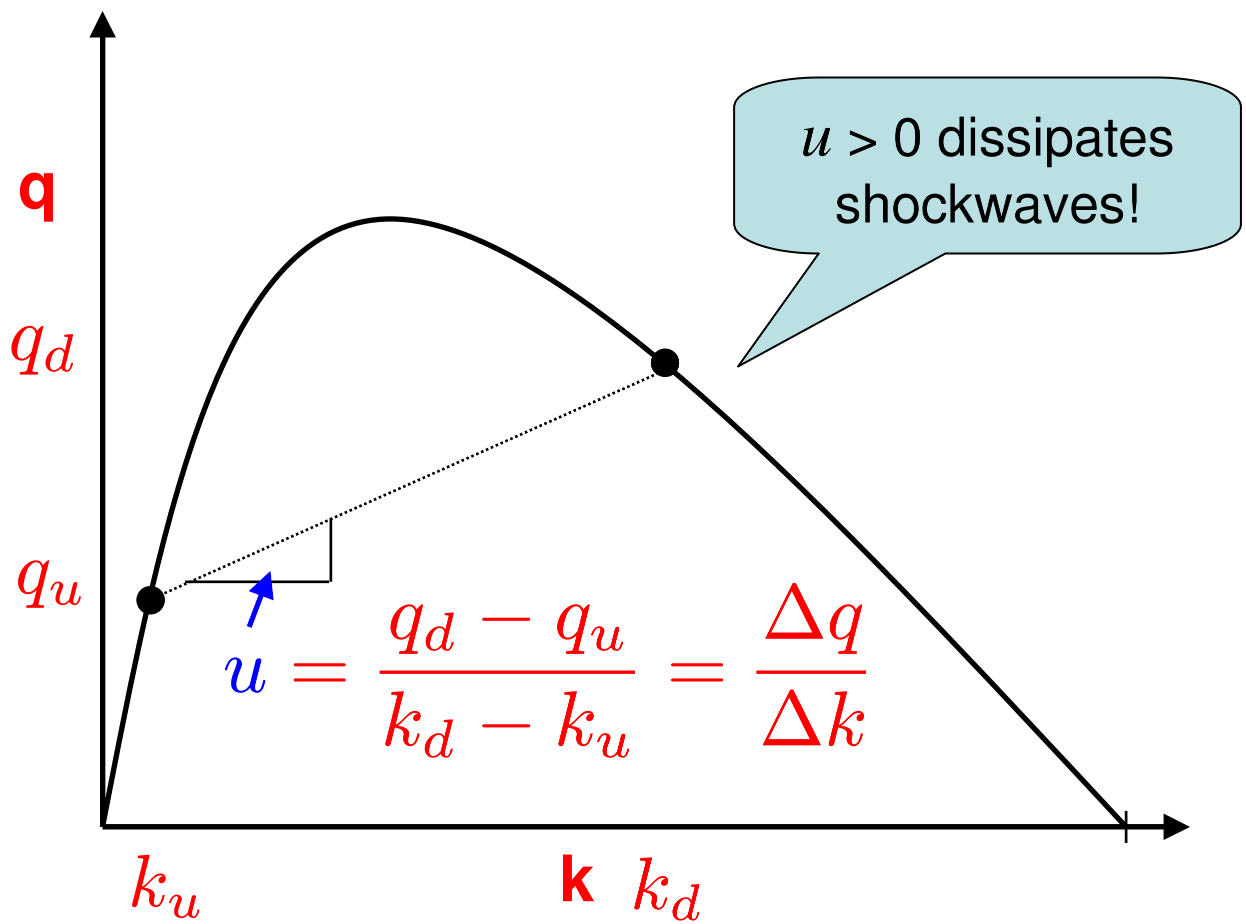
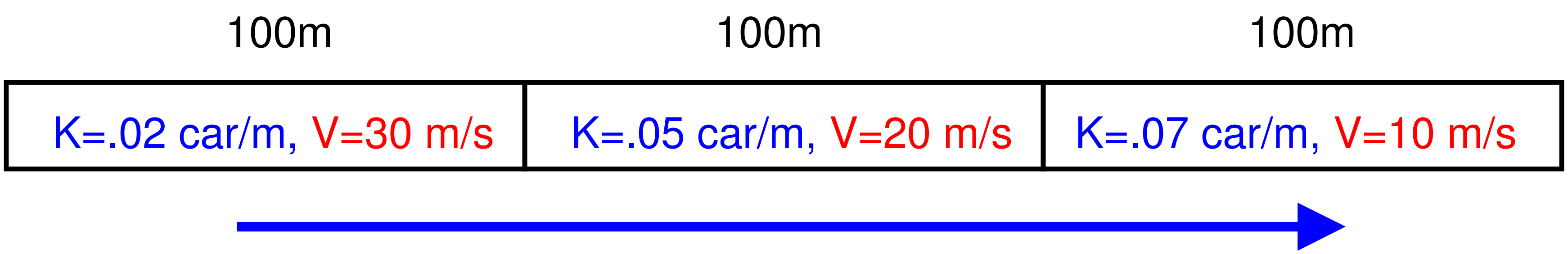


Macro Simulation

- Cell Transition Model
  - Model **aggregate properties** of traffic
  - Average flow, density, velocity over **segments**



  - Nonlinear difference equation transition model
  - **Recreates shockwave phenomena**

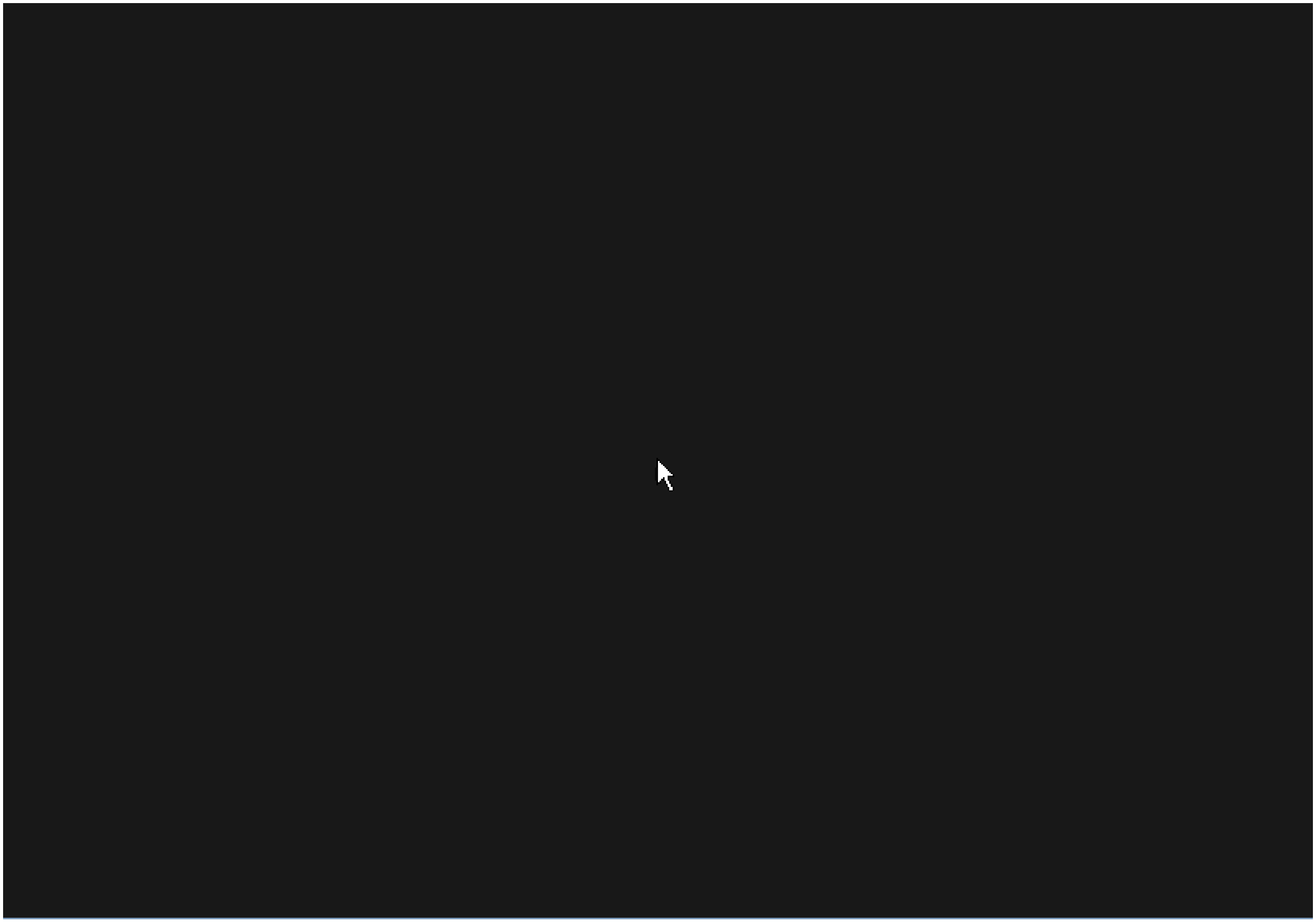
Carlos F. Daganzo, 1994. “The Cell Transmission Model: Network Traffic’
http://www.path.berkeley.edu/path/publications/pdf/PWP/94/PWP-94-12.pdf

Simulation Software

- Quadstone Paramics (microsimulation)
  - Largest market share
  - Industrial strength
  - Expensive

- Azalient Commuter (micro- and nano-simulation)
  - Relatively recent startup
  - Intuitive 3D GUI
  - Java API for external control and evaluation
  - More economical for academia

Azalient Commuter



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Traffic Control: Single & Multi-intersection

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Optimization Objective

- Can minimize
  - Delays,
  - Stops,
  - Fuel consumption,
  - Emission of pollutants,
  - Accidents

- Here we focus on delays in car-seconds

  (and implicitly stops, fuel, emissions)

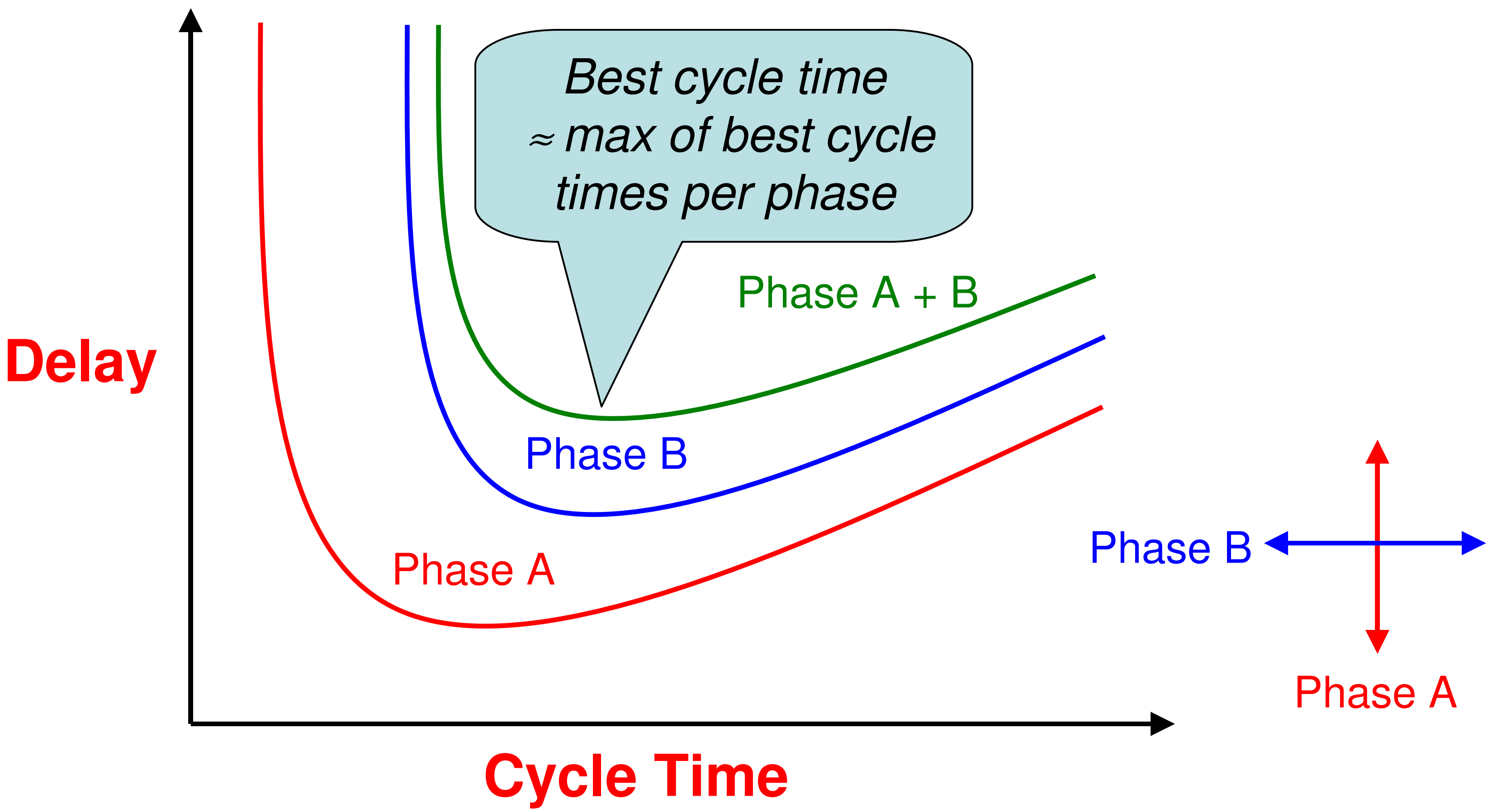
Coordinated Control

- Unconstrained policy space (state $\rightarrow$ action) is large / ∞!
- **One intersection:** multidimensional state and action
  - Changing demand observations & predictions
  - Demand-based protected turns & walk signals
  - Min/max cycle, phase, & intergreen times
- **Coordinated Intersections:** multidimensional action
  - 10x10 grid = 100 intersections
  - Simplest model: 2 decisions per intersection (NS or EW)

  $\Rightarrow 2^{100}$ decisions

Delay vs. Optimal Cycle Times

- Use maximum best cycle time of any phase



Optimal Cycle Times vs. Flow

- Light traffic
  - Short cycle times
  - Minimize delay for individual cars
- Heavy traffic
  - Long cycle times
  - Maximize steady-state flow

Single Intersection Control

- Given cycle time, what is best phase split?
  - Webster's theory…

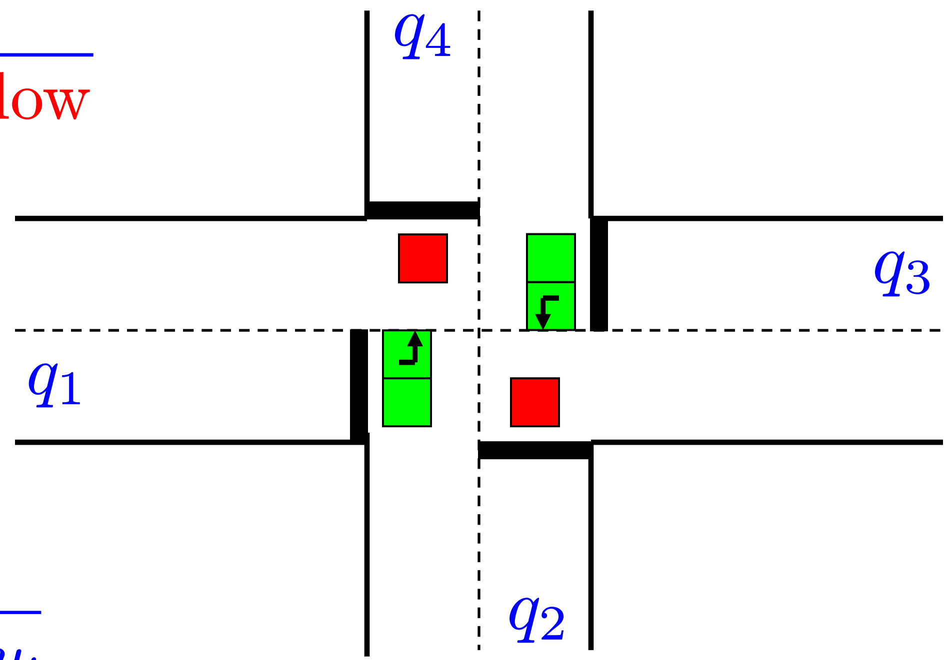
$$y_i = \frac{q_i \leftarrow \text{inflow}}{s_i \leftarrow \text{max outflow}}$$

  - Worst case?

any $y_i > 1$

  - Solution

$$\text{phase time } i \propto \frac{y_i}{\sum_i y_i}$$



Problems with Local Control

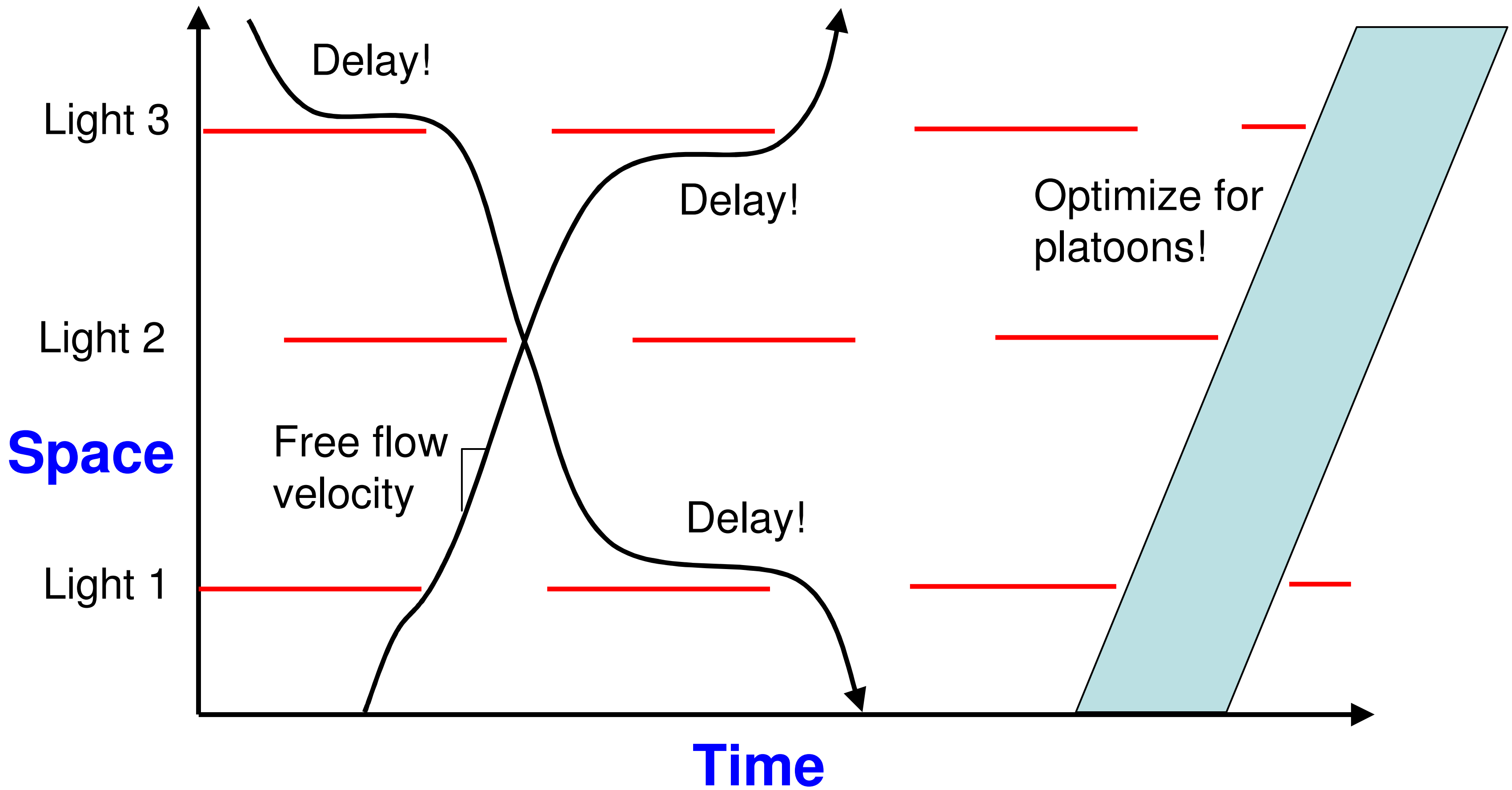
- Upstream or downstream intersections
  - Downstream queue saturated (s_i decreases)
  - In-flow of cars q_i is **not uniformly distributed!**
- **Platoons** 

AI papers tend to ignore

  - Cars tend to "clump" into platoons
    - Due to discharge from upstream queues
  - Best throughput with good platoon management
    - Careful timing needed

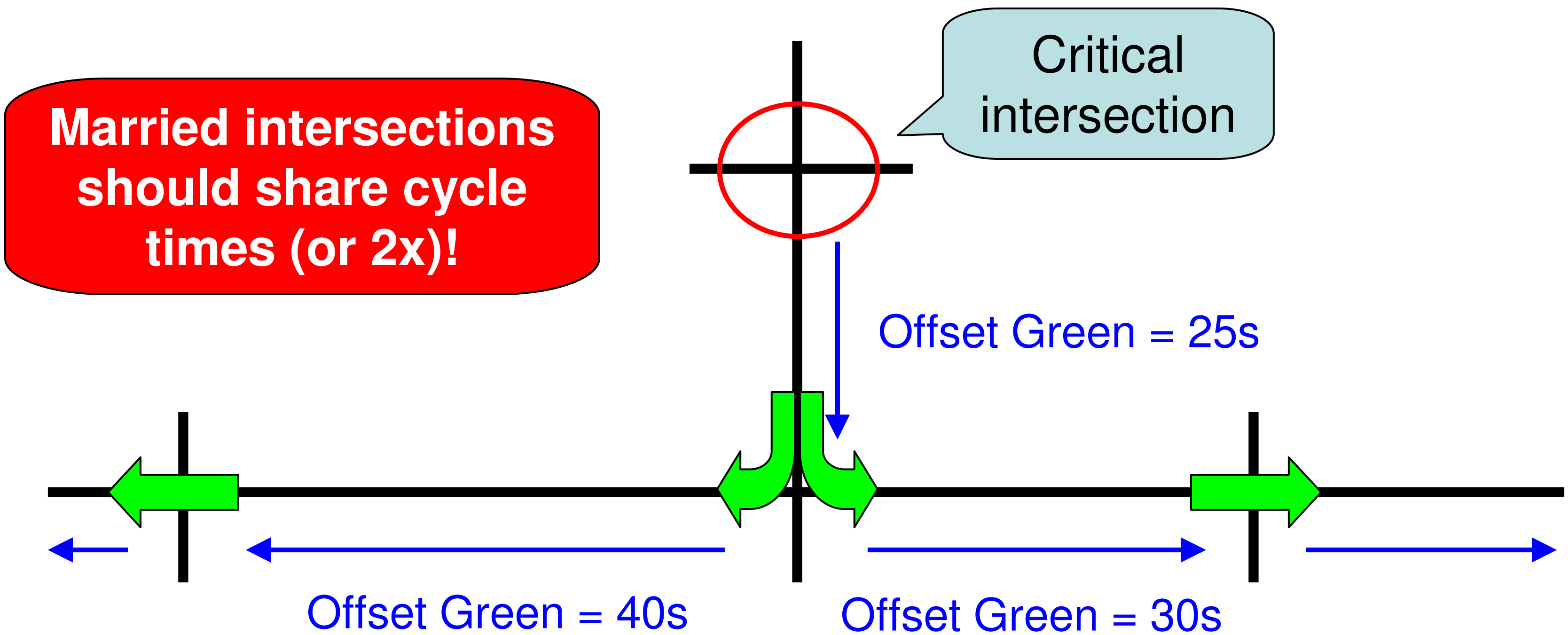
Multi-intersection Control

- Optimize phase offsets for platoon throughput:



Master/Slave Offset Control

- Fix timing offsets from critical intersections
  - Allows platoons to pass in dominant flow direction



Multi-intersection Control in Practice

- Split, Cycle, Offset Optimization (SCOOT, SCATS)
  - Decide on married intersections
  - Decide on intersection offsets
    - Based on dominant flow direction
  - Decide on phase splits
    - w.r.t. offset constraints

for end of phase!

- Practical, but highly constrained
  - Room for more fine-grained optimization

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Traffic Control: Future

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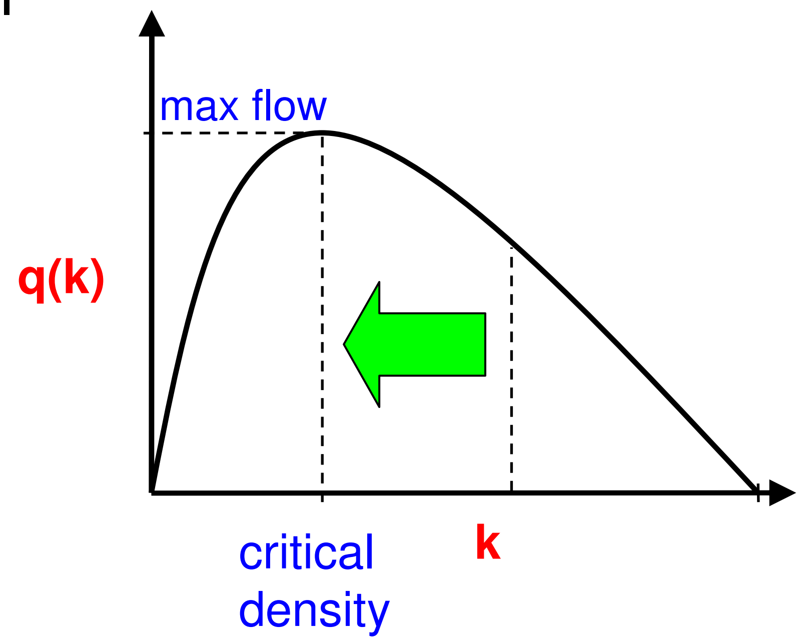
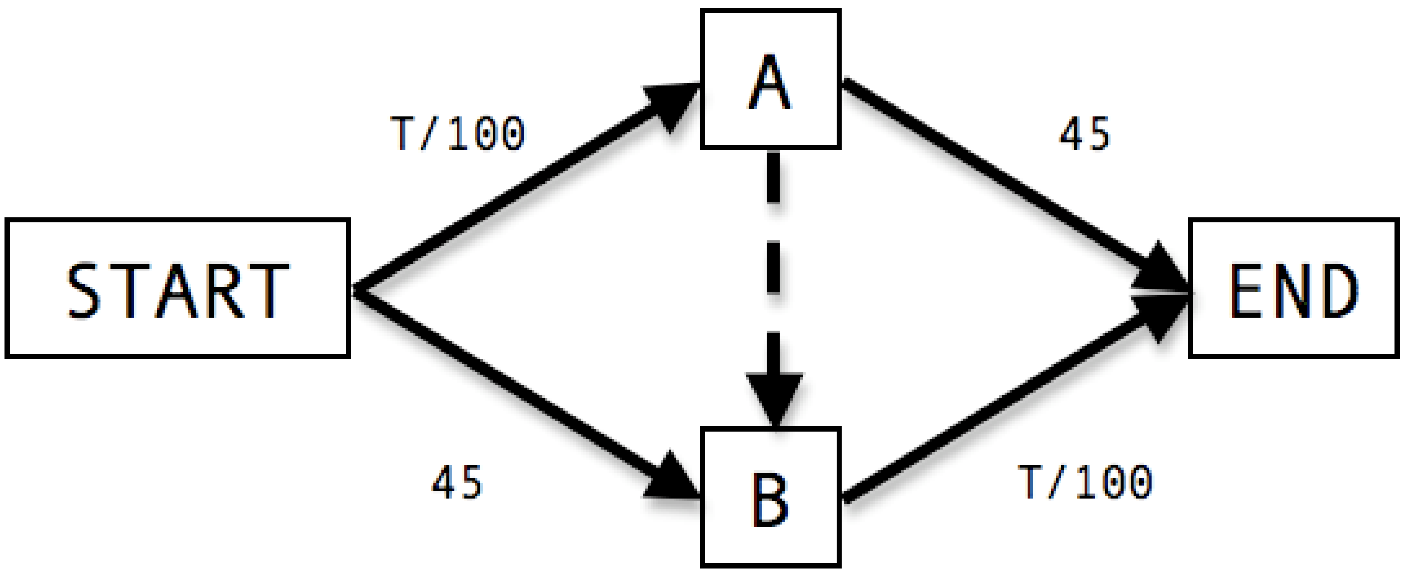
The Future of Traffic Control

- Priority (bus) control
  - Change objective to minimize delay in person-seconds
- Ramp metering & variable speed limits
  - Shockwave / density control
- Real-time selfish routing
- Better sensors
  - Cameras
- Better road topology…



Topology and Traffic I: Braess's Paradox

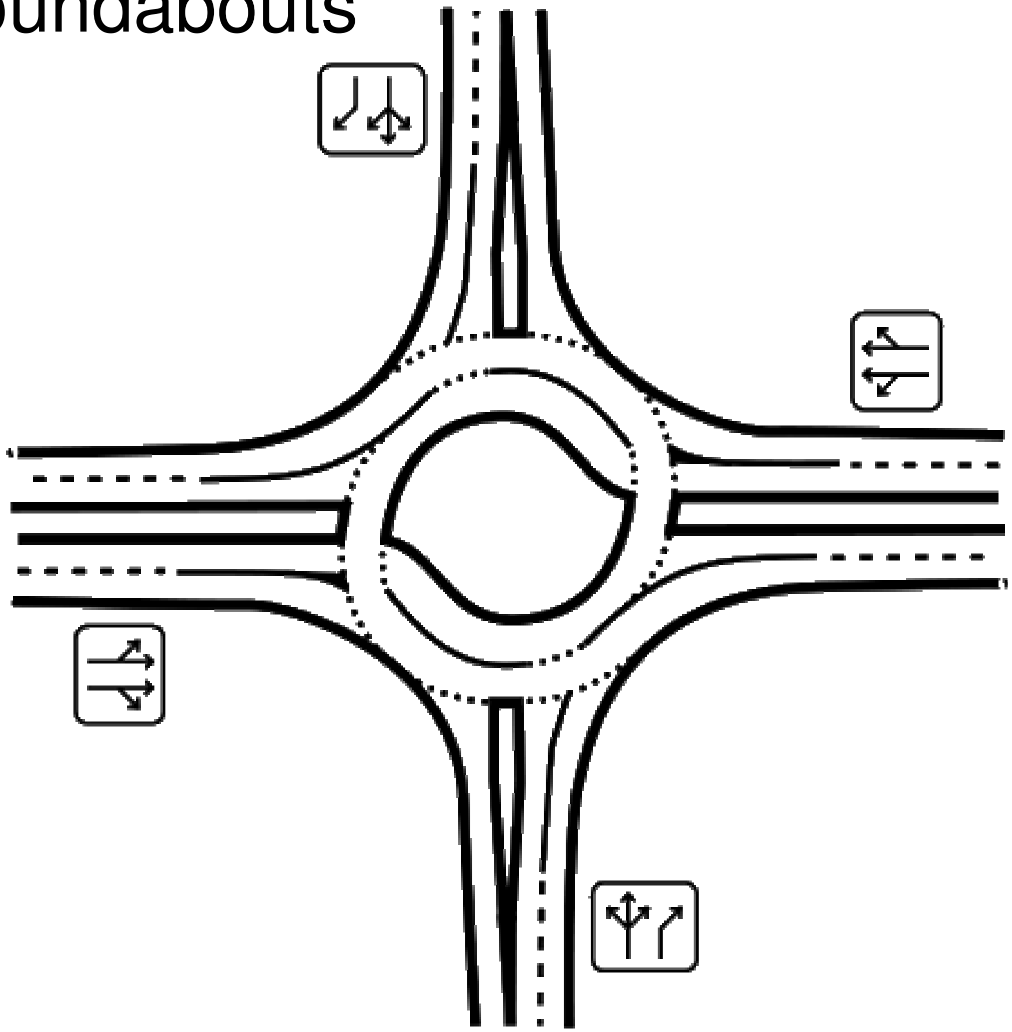
- Adding network capacity can reduce flow *if*
  - Local route choices based on observed flow



http://en.wikipedia.org/wiki/Braess%27s_paradox#How_rare_is_Braess.27s_paradox.3F

Topology and Traffic II

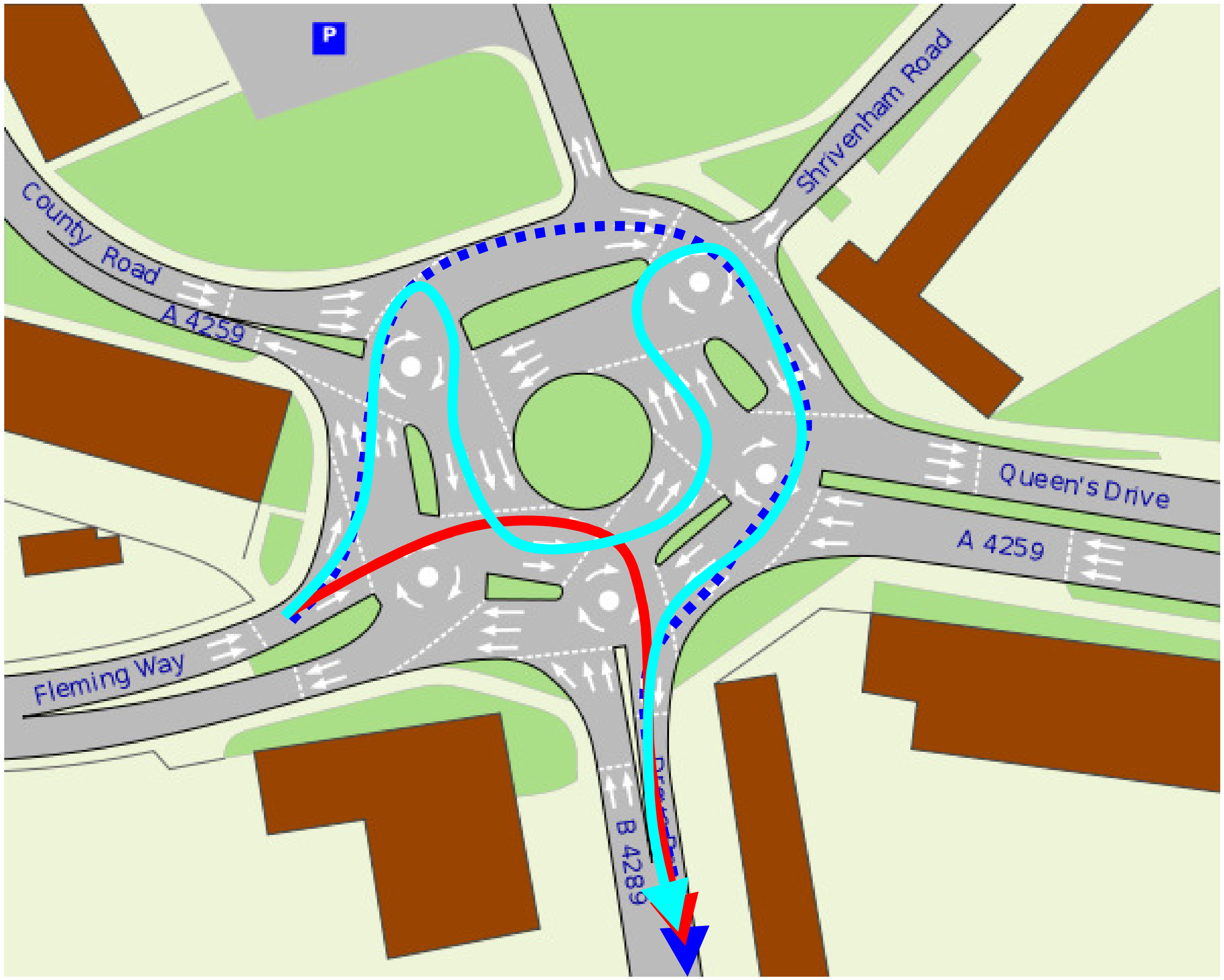
- Turbo Roundabouts



http://en.wikipedia.org/wiki/Roundabout_intersection#Turbo_roundabouts

Topology and Traffic III

- Magic Roundabouts



http://en.wikipedia.org/wiki/Magic_Roundabout_%28Swindon%29

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Traffic Control: Conclusions

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Advice

- Room for improvement in Traffic Control
  - State-of-the-art is principled, but ad-hoc
  - Could use better planning & scheduling
- If your traffic work draws on traditional AI P&S
  - Publish in ICAPS, AAAI, IJCAI, …
- If you really think you’re onto something
  - Go for a **journal** visible to traffic field…

Transportation Research
is a journal-oriented field

Publish in a Journal (bold top-rated)

- Transportation Research (TR)
  - **TR Part A: Policy and Practice**
  - **TR Part B: Methodological**
  - TR Part C: Emerging Technologies
  - TR Part D: Transport and Environment
  - TR Part E: Logistics and Transportation Review
  - TR Part F: Traffic Psychology and Behaviour
- **Transportation Science**
- **Journal of Transport Economics and Policy**
- **Environment and Planning**
- **Transportation**

Find a Research Collaborator

- Transport Research Laboratory (TRL)
  - Independent consultancy (500+ employees)
- University College London (UCL)
  - Center for Transport Studies
- UC Berkeley
  - Institute of Transportation Studies
- University of Minnesota
  - Center for Transportation Studies
- University of Texas, Austin
  - Center for Transportation Research
- University of Michigan
  - Transportation Research Institute
- National ICT Australia (NICTA)
  - STaR Project

Thank you!

Questions?