

Urban dashboardistics

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Wardrop modelled route choice by drivers in a traffic network.

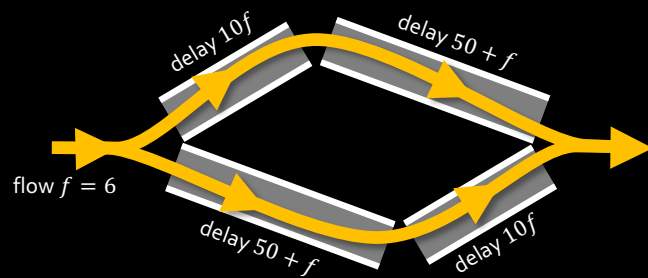
Braess discovered paradoxical outcomes
(which can be overcome by setting appropriate tolls).

DRIVERS

- can choose which route to take
- want the fastest travel time

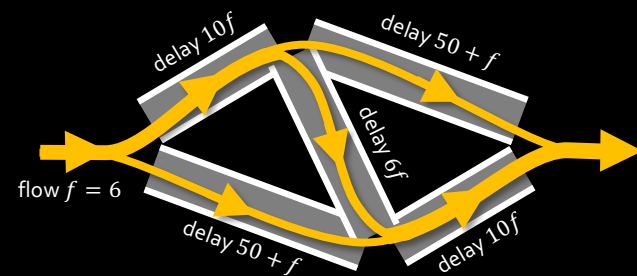
CITY

- provides infrastructure
- wants to maximize total utility over all drivers



travel time 83

*city builds
a new road*



travel time 92

Towards a multimodal Wardrop equilibrium model:

Let's consider three main agents, each with their own objectives.

USERS

- can choose mode of transport
- want low price, low travel time, etc.

- prompt, cheap deliveries

many uncoordinated individuals

RIDESHARE FLEET

- can choose its pricing model
- needs to rebalance its fleet
- wants profit

DELIVERY FLEETS

- and assorted other fleets, in competition

a few large operators, with direct user contact and real-time backends

CITY

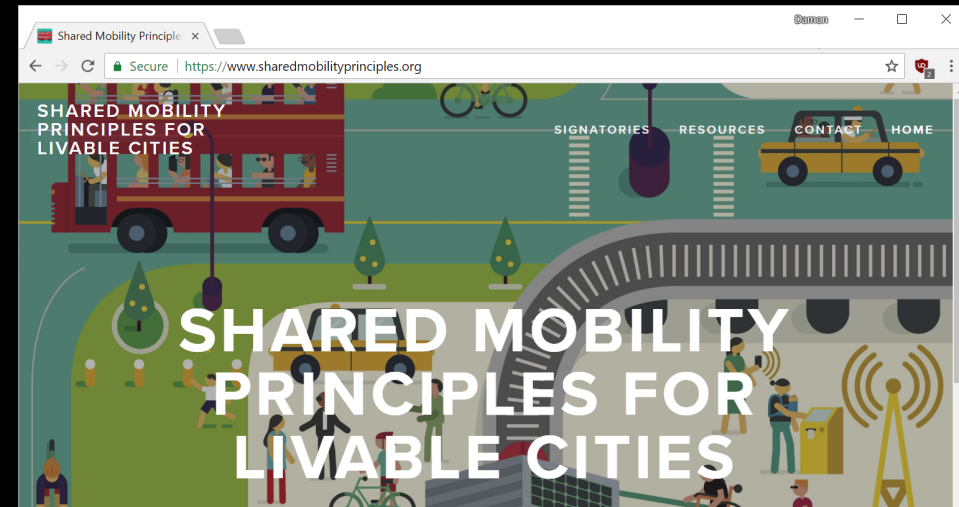
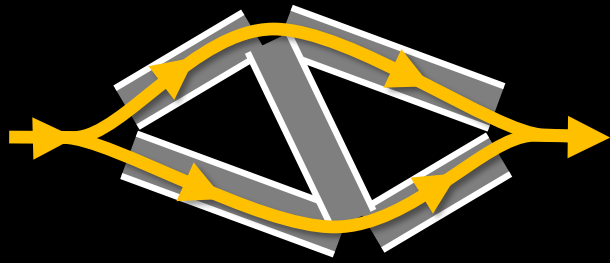
- wants to maximize total utility over all users
- provides public transport, and sets prices

- wants universal service
- responsible for environmental externalities etc.

REGULATORY POWER

How should cities relate to fleets?

1. A fleet operator, if it's a dominant player, can avoid Braess's paradox by internalizing the cost of congestion.



10. WE SUPPORT THAT AUTONOMOUS VEHICLES (AVS) IN DENSE URBAN AREAS SHOULD BE OPERATED ONLY IN SHARED FLEETS.

Due to the transformational potential of autonomous vehicle technology, it is critical that all AVs are part of shared fleets, well-regulated, and zero emission. Shared fleets can provide more affordable access to all, maximize public safety and emissions benefits, ensure that maintenance and software upgrades are managed by professionals, and actualize the promise of reductions in vehicles, parking, and congestion, in line with broader policy trends to reduce the use of personal cars in dense urban areas.

How should cities relate to fleets?

2. Fleets have the effect of *coupling* parts of the transport network in new ways. This might lead to paradoxical behaviour.

USERS

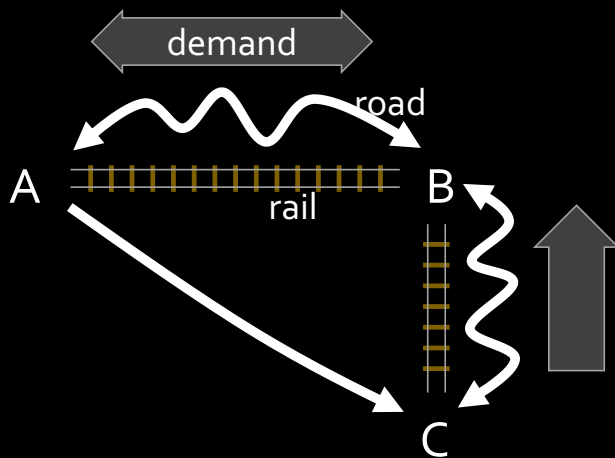
- can choose mode of transport
- wants lowest price

RIDESHARE FLEET

- can set origin-based 'surge' multipliers
- needs to rebalance the fleet
- has to balance cost and revenue

CITY

- sets public transit fares



Let c_{ij} be the base cost of a road trip from i to j , and f_{ij} the rail fare

Let μ_i be the surge multiplier at location i , so passenger pays $\mu_i c_{ij}$

Let $\alpha_{ij} = \alpha_{ij}(\mu_i)$ be the demand for rideshare trips

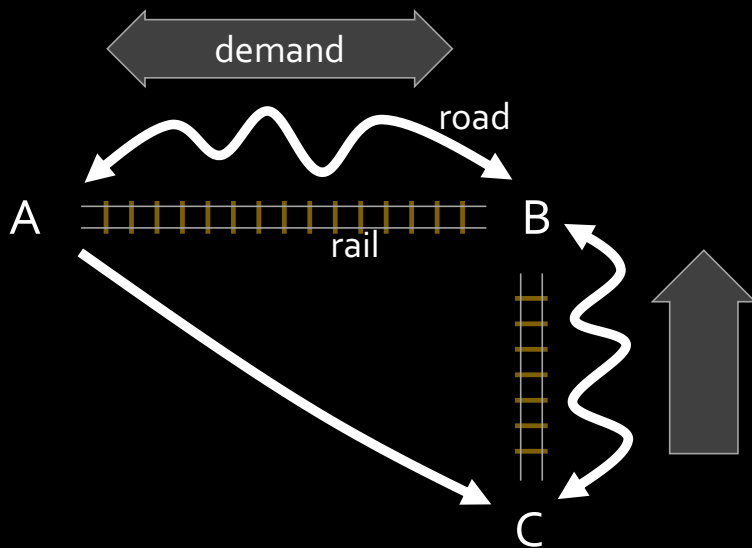
[measured in trips per unit time, and depending on c and f]

The fleet picks rebalancing rates β_{ij} such that for all i , $\sum_j (\alpha_{ij} + \beta_{ij}) = 0$ and adjusts μ to achieve budget balance:

$$\sum_{i,j} (\alpha_{ij} + \beta_{ij}) c_{ij} = \sum_{i,j} \alpha_{ij} \mu_i c_{ij}$$

How should cities relate to fleets?

2. Fleets have the effect of *coupling* parts of the transport network in new ways. This might lead to paradoxical behaviour.



If the city reduces the rail fare A→B

- some A→B passengers will shift to rail
- the fleet operator still wants to get cars to B, maybe via C
- it might as well discount rides C→B
- this takes C→B passengers off rail
- there might even be a net decrease in rail trips [Sid's paradox]

How should cities relate to fleets?

3. Cooperate with fleets, so that we don't use streets as parking lots.



How should cities relate to fleets?

3. Cooperate with fleets, so that we don't use streets as parking lots.

- The city simulates a *virtual road network* whose capacity is 95% of what's really there, and measures congestion
- Fleet operators agree to set routes and prices according to virtual congestion
- The city sends real-time virtual congestion signals, and the fleets send enough data that the city can verify compliance
- The streets are kept free-flowing
- In return, the fleets are permitted special access to restricted zones

Can't this all be done with congestion charges?



*Singapore's
Electronic Road Pricing*

DIGRESSION

The full story of Internet
congestion control theory

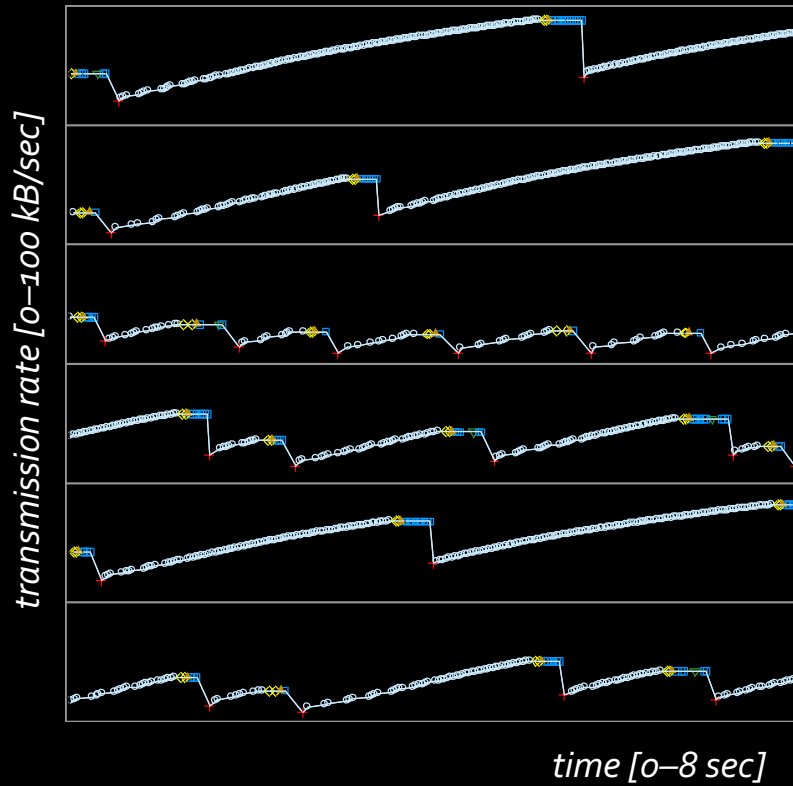


*Lawrence Berkeley
National Lab*

“In October of '86, the Internet had the first of what became a series of 'congestion collapses'. During this period, the data throughput from LBL to UC Berkeley (sites separated by 400 yards and two IMP hops) dropped from 32 Kbps to 40 bps. We were fascinated by this sudden factor-of-thousand drop in bandwidth and embarked on an investigation of why things had gotten so bad. In particular, we wondered if the 4.3BSD (Berkeley UNIX) TCP was misbehaving or if it could be tuned to work better under abysmal network conditions.”

Van Jacobson, “Congestion avoidance and control”, 1988

Jacobson's TCP algorithm



```
if (seqno > _last_acked) {
    if (!_in_fast_recovery) {
        _last_acked = seqno;
        _dupacks = 0;
        inflate_window();
        send_packets(now);
        _last_sent_time = now;
        return;
    }
    if (seqno < _recover) {
        uint32_t new_data = seqno - _last_acked;
        _last_acked = seqno;
        if (new_data < _cwnd) _cwnd -= new_data;
        else _cwnd=0;
        _cwnd += _mss;
        retransmit_packet(now);
        send_packets(now);
        return;
    }
    uint32_t flightsize = _highest_sent - seqno;
    _cwnd = min(_ssthresh, flightsize + _mss);
    _last_acked = seqno;
    _dupacks = 0;
    _in_fast_recovery = false;
    send_packets(now);
    return;
}
if (_in_fast_recovery) {
    _cwnd += _mss;
    send_packets(now);
    return;
}
_dupacks++;
if (_dupacks!=3) {
    send_packets(now);
    return;
}
_ssthresh = max(_cwnd/2, (uint32_t)(2 * _mss));
retransmit_packet(now);
_cwnd = _ssthresh + 3 * _mss;
_in_fast_recovery = true;
_recover = _highest_sent;
}
```

- 1974 Packet-switched Internet invented (Kahn, Cerf)
- 1986 congestion collapse
- 1988 TCP congestion control designed (Jacobson)
- 1998 mathematical model (Kelly)
- 2002 control theory solved (Vinnicombe)
- 2011 standardization of TCP-friendly multipath (Handley)
- 2013 Apple's Siri is using multipath TCP

Kelly's model for Internet congestion control

x_r = transmission rate of user / route r

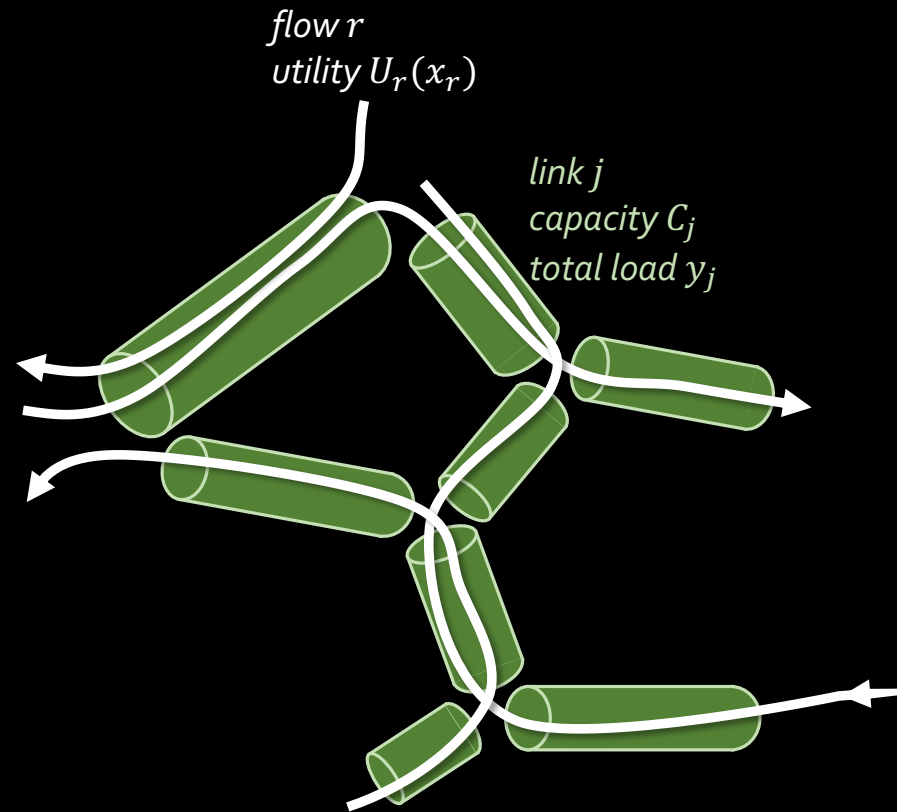
$U_r(x_r)$ = utility associated with user r

y_j = total rate on link $j = \sum_r A_{jr} x_r$

C_j = capacity of link j

Consider the optimization problem

maximize $\sum_r U_r(x_r)$
over $x_r \geq 0, y_j \geq 0$
such that $y = Ax$ and $y \leq C$



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embodies the utility function implicit in Jacobson's TCP, including the round trip time for route r , RTT_r

Consider the optimization problem:

maximize $\sum_r U_r(x_r)$
over $x_r \geq 0, y_j \geq 0$
such that $y = Ax$ and $y \leq C$

A dynamical system for a relaxed version:

$$\frac{dx_r(t)}{dt} = \frac{1}{RTT_r^2} - p_r(t) \frac{x_r(t)^2}{2}$$

$$p_r(t) = \sum_j A_{jr} \left(1 - \frac{C_j}{y_j(t)}\right)^+$$

a cost / dual variable incurred by the flow on each congested link it uses, corresponding to packet drop rate

Kelly's model for Internet congestion control

	A	B	C	D
1	C	3		
2	RTT	0.1		
3				
4	t	x	p	dx/dt
5	0	0.1	=MAX(1-B\$1/B5,0)	=1/B\$2^2-C5*B5^2/2
6	0.01	=B5+D5*(A6-A5)		
7				
8				

embodies the utility function implicit in Jacobson's TCP, including the round trip time for route r , RTT_r

A dynamical system for a relaxed version:

$$\frac{dx_r(t)}{dt} = \frac{1}{RTT_r^2} - p_r(t) \frac{x_r(t)^2}{2}$$

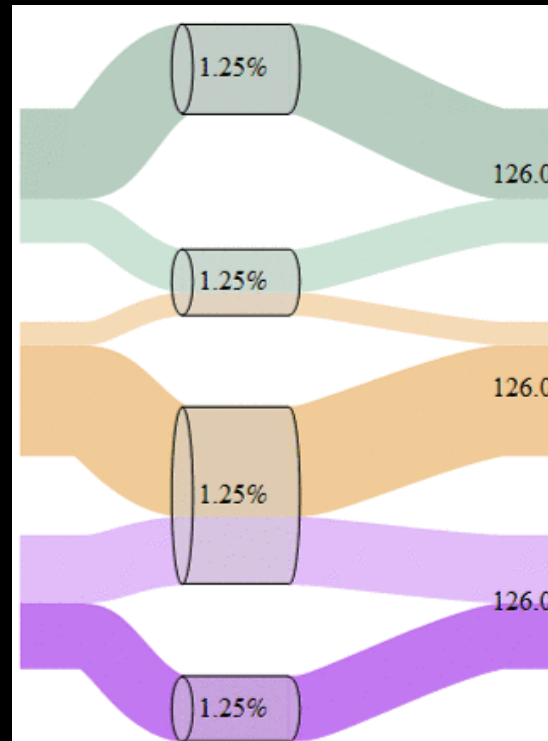
$$p_r(t) = \sum_j A_{jr} \left(1 - \frac{c_j}{y_j(t)}\right)^+$$

a cost / dual variable incurred by the flow on each congested link it uses, corresponding to packet drop rate

The congestion control algorithm extends naturally to multipath settings.

Each end system balances its traffic on the paths it has available, and the overall result is complete resource pooling (when there is sufficient diversity of paths).

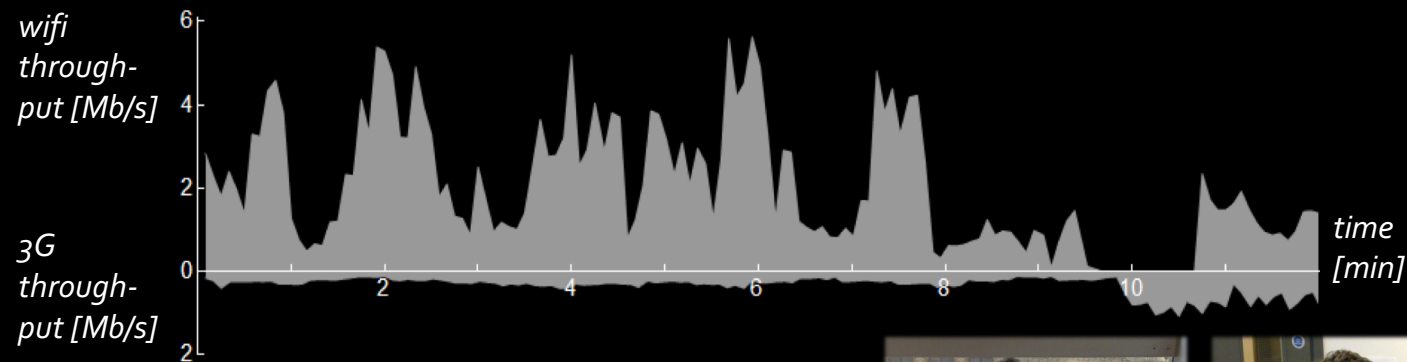
Three flows share four resources, as though the network were made up of a single resource.



Mark Handley et al. implemented MPTCP, and ensured it played nicely with middleboxes in the Internet.

Internet Engineering Task Force (IETF)
Request for Comments: 6356
Category: Experimental
ISSN: 2070-1721

C. Raiciu
Univ. Politehnica of Bucharest
M. Handley, D. Wischik
Univ. College London
October 2011



*User in his office,
using wifi and 3G*



Going downstairs

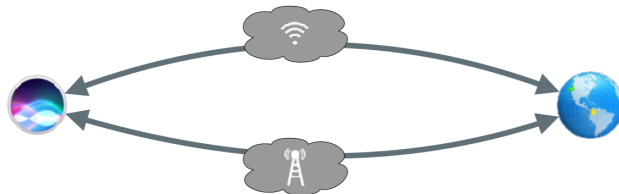


In the kitchen

Christoph Paasch, Apple IETF meeting in Prague 2017

MPTCP at Apple

- Implemented since iOS 7 for Siri



User-feedback (Time-to-First-Word) 20% faster in the 95th percentile

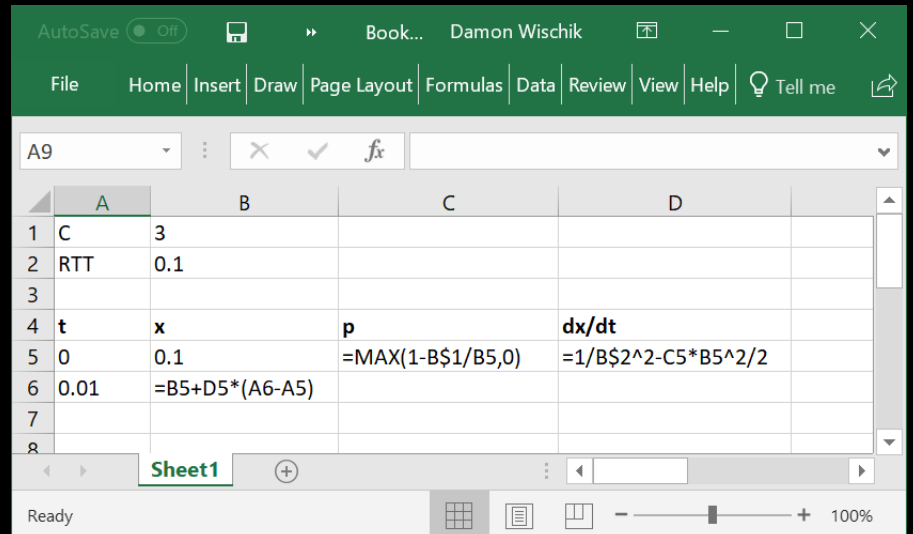
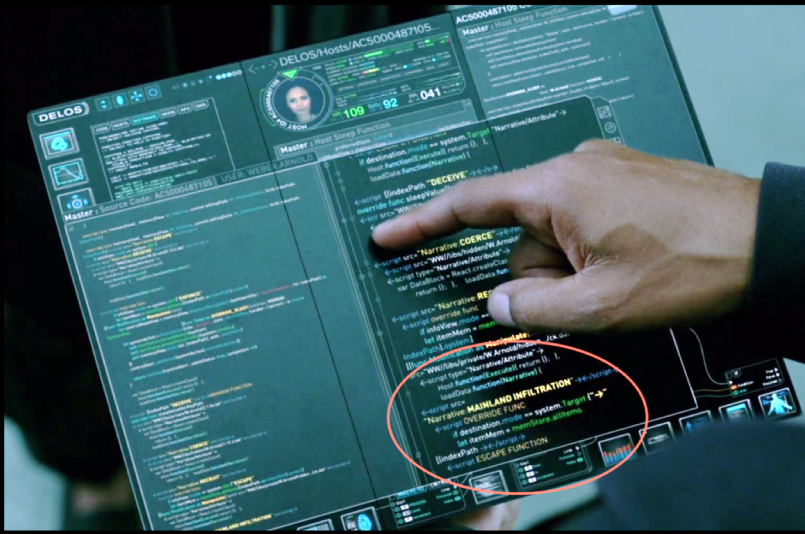
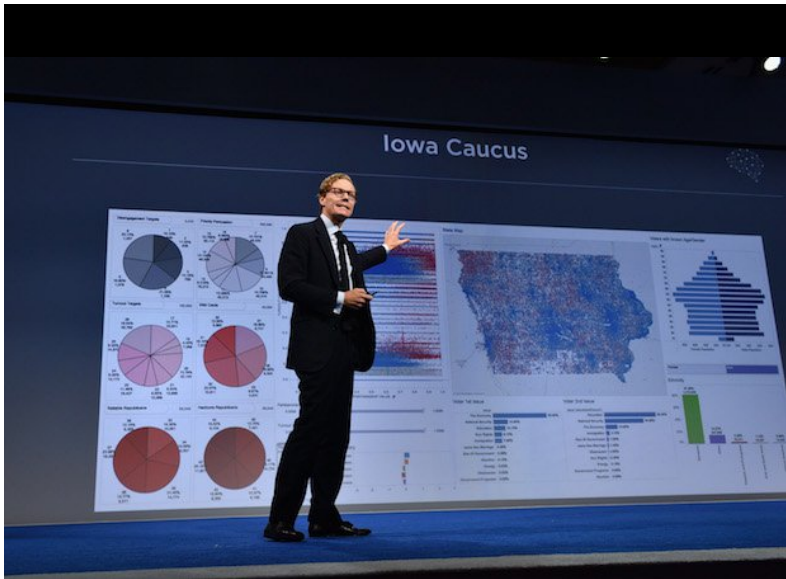
5x reduction of network failures

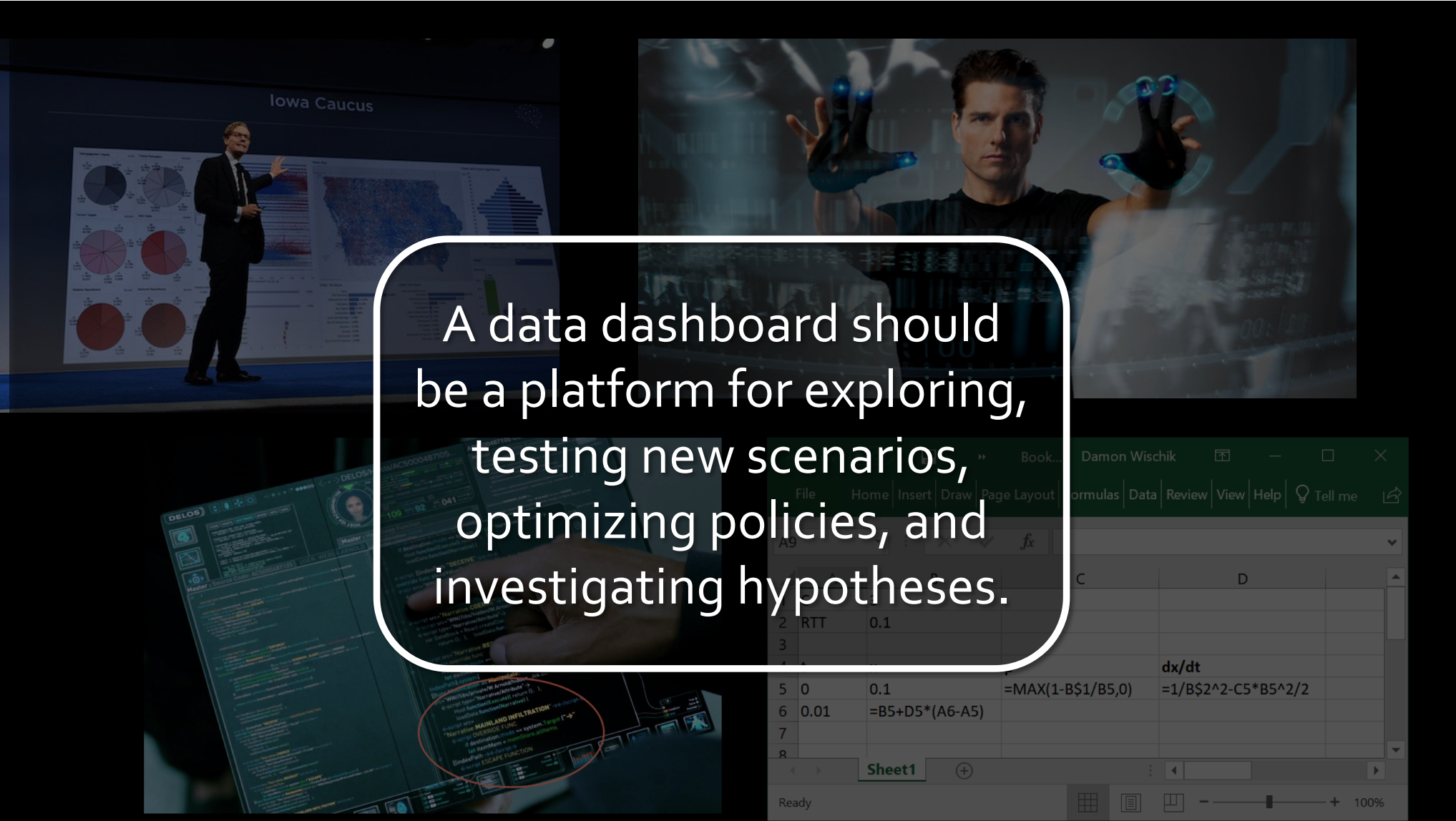
— but Apple discarded the multipath congestion controller,
and simply sends each packet on both interfaces!

All models are wrong,
but some are useful.

George Box, 1978

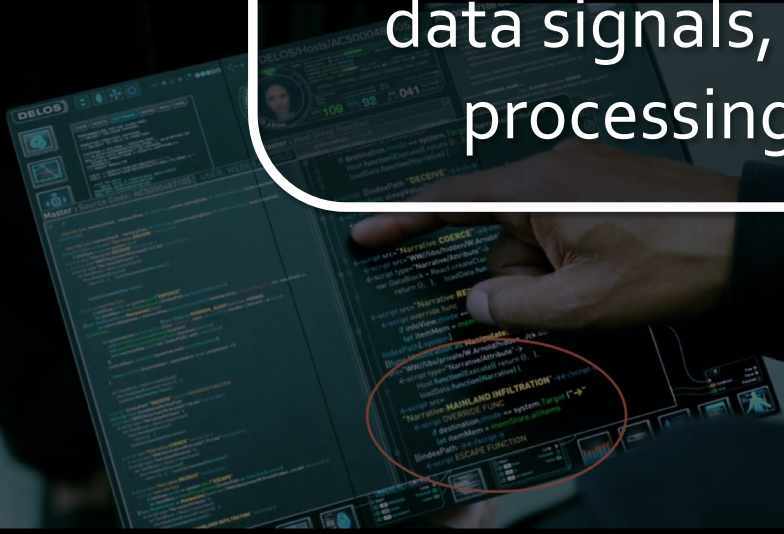
What makes a model useful?





Iowa Caucus

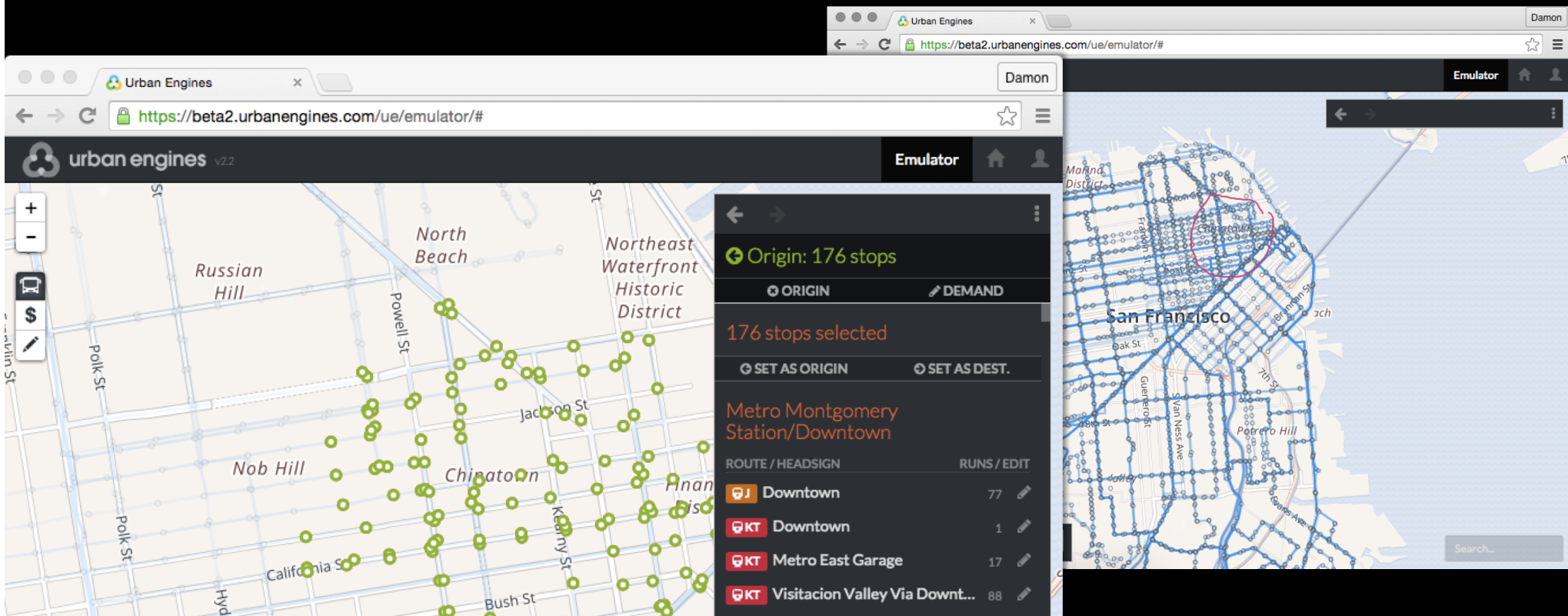
Good design comes from understanding robustly the space of control problems: their data signals, and their data processing operations

A screenshot of a Microsoft Excel spreadsheet. The table has columns labeled C, RTT, x, p, and dx/dt. The data is as follows:

	C	RTT	x	p	dx/dt
1	C	3			
2	RTT	0.1			
3					
4	t	x		p	dx/dt
5	0	0.1		=MAX(1-B\$1/B5,0)	=1/B\$2^2-C5*B5^2/2
6	0.01		=B5+D5*(A6-A5)		
7					
8					

City dashboards we've prototyped:

- GUI interface for modifying trace data, to test out new scenarios
- Novelty: see simulation output in the same environment as your original datasets
- Downside: too clunky to explore the scenario space



City dashboards we've prototyped:

- Like Excel pivot tables, but including set-valued columns / factorized database queries
- Novelty: break down a simulator into functional expressions on data, e.g. $=\text{TSP}(\$B\$3)$
- Downside: a confusing way to express simulations

The image shows two overlapping browser windows of the Urban Engines v2.2 application. The background window displays a 'Chart settings' dialog with the following configuration:

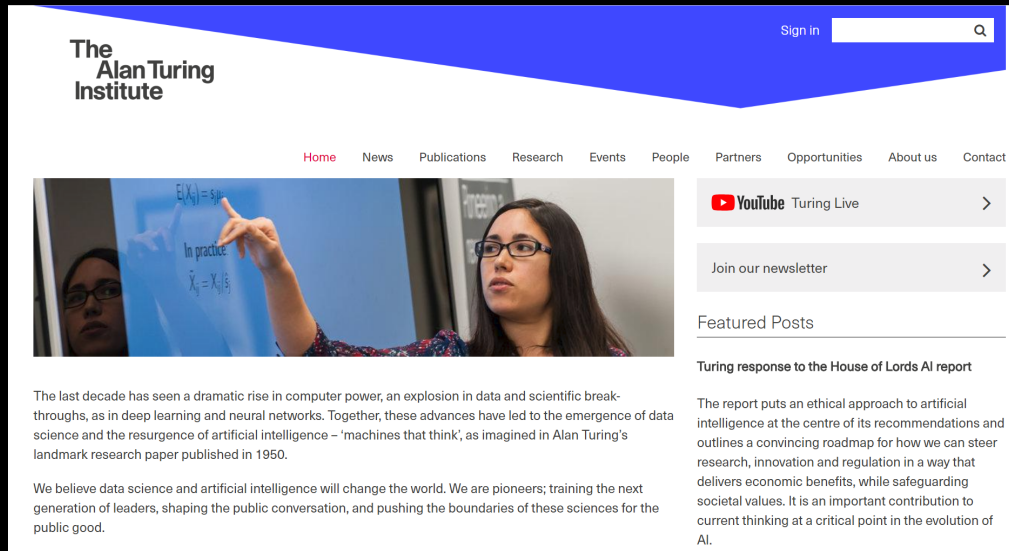
- main selection:** deliveries on 12 - 18 Oct 2015
- Filter by:** (empty)
- values:**
 - show deliveries
 - $=\text{TSP}([\text{show deliveries}])$
- row variables:**
 - date
 - individual drivers

The foreground window displays a 'Table' view for the same data. The table has four columns: 'date', 'individual drivers', 'show deliveries', and '= TSP([show deliveries])'. Each row contains a date, a count of drivers, a map showing delivery points, and a map showing the Traveling Salesman Problem (TSP) route connecting those points.

date	individual drivers	show deliveries	= TSP([show deliveries])
2015-10-11	≡(2)		
2015-10-11	≡(4)		
2015-10-16	≡(2)		
2015-10-13	≡(6)		

*The Alan Turing Institute in London is hiring!
We want a postdoc for two years, to join 3 faculty, 1 PhD, 1 software engineer*

- explore user+fleet+city interaction
→ dashboard design → regulatory policy discussion
- study traffic signal control, using reinforcement learning
→ integrate ML with data dashboards



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Turing response to the House of Lords AI report

The report puts an ethical approach to artificial intelligence at the centre of its recommendations and outlines a convincing roadmap for how we can steer research, innovation and regulation in a way that delivers economic benefits, while safeguarding societal values. It is an important contribution to current thinking at a critical point in the evolution of AI.

The last decade has seen a dramatic rise in computer power, an explosion in data and scientific breakthroughs, as in deep learning and neural networks. Together, these advances have led to the emergence of data science and the resurgence of artificial intelligence – ‘machines that think’, as imagined in Alan Turing’s landmark research paper published in 1950.

We believe data science and artificial intelligence will change the world. We are pioneers; training the next generation of leaders, shaping the public conversation, and pushing the boundaries of these sciences for the public good.

