Towards Digital Democracies and Societal Resilience: Upgrading Smart Cities with Collective Intelligence, and More

Prof. Dr.rer.nat. Dr.h.c. Dirk Helbing, ETH Zurich, Computational Social Science with Anders Johansson, Martin Treiber, Arne Kesting, Stefan Lämmer, Martin Schönhof, Mark Ballandies, Marcus Dapp, Regula Hänggli, Stefan Klauser, Marcin Korecki, Renato Kurz, Sachit Mahajan, Richard Mann, Heinrich Nax, Evangelos Pournaras, Javier Argota Sanchez-Vaquerizo, and others
Complex Behavior of Traffic Flow

Perturbing traffic flows and, paradoxically, even decreasing them may sometimes cause congestion.
Phase Diagram of Congested Traffic States
Congested Traffic States Simulated with a Traffic Model

Similar congested traffic states are found for several other traffic models, including “microscopic” car-following models.
Theoretical Phase Diagram of Traffic States and Universality Classes

Phase diagrams are not only important to understand the conditions under which certain traffic states emerge. They also allow one to categorize the more than 100 traffic models into different universality classes. From the universality class that reproduces the empirically observed stylized facts, one may choose any representative, e.g. the simplest or the most accurate one, depending on the purpose.
A scaling by the outflow, that varies from day to day, gives a clearer picture.
Traffic Congestion is Predictable
An Analytical Theory of Traffic Flow

D. Helbing

Derivation of non-local macroscopic traffic equations and consistent traffic pressures from microscopic car-following models
DOI: 10.1140/epjb/e2009-00192-5

D. Helbing and A.F. Johansson

On the controversy around Daganzo’s requiem for and Aw-Rascle’s resurrection of second-order traffic flow models
DOI: 10.1140/epjb/e2009-00182-7

D. Helbing and M. Moussaid

Analytical calculation of critical perturbation amplitudes and critical densities by non-linear stability analysis of a simple traffic flow model
DOI: 10.1140/epjb/e2009-00090-6


Theoretical vs. empirical classification and prediction of congested traffic states
DOI: 10.1140/epjb/e2009-00082-0

M. Treiber and D. Helbing

Hamilton–Jacobi statistics in one dimensional driven dissipative many-particle systems
DOI: 10.1140/epjb/e2009-00077-7

D. Helbing and B. Tilch

A power law for the duration of high-flow states and its interpretation from a heterogeneous traffic flow perspective
DOI: 10.1140/epjb/e2009-00082-0

D. Helbing

Derivation of a fundamental diagram for urban traffic flow
DOI: 10.1140/epjb/e2009-00082-0

D. Helbing and A. Mashhar

Operation regimes and slower-is-faster effect in the control of traffic intersections
DOI: 10.1140/epjb/e2009-00082-0
Freeway Traffic Control
Cooperative Driving Based on Autonomous Vehicle Interactions

- On-board data acquisition („perception“)
- Inter-vehicle communication
- Cooperative traffic state determination („cognition“)
- Adaptive choice of driving strategy („decision-making“)
- Driver information
- Traffic assistance (higher stability and capacity of traffic flow)

In: Transportation Research Record (2007)
Overcoming Congestion by Real-Time Feedback
Enhancing Traffic Performance by Adaptive Cruise Control

- Traffic breakdowns delayed
- Faster recovery to free traffic
- High impact on travel times
- Reduced fuel consumption and emissions

$p(\text{veh./km/lane})$

10% Equipped Vehicles

"Mechanism design"
Internet of Things

Data is the new oil – Clive Humby

… but models are the new gold

… and participation means social capital!
Mechanism Design: Modify Interactions with Real-Time-Measurements and -Feedback
With the Internet of Things, we can now make self-organization work, 300 years after Adam Smith’s “invisible hand” concept!
Urban Planning vs. Enabling Self-Organization
The Noble Goals of Traffic Planning

- Better mobility
- Less pollution
- Less noise
- Less traffic
But This Is Often the Reality …
... and This: Urban Gridlock
Can We Fix Traffic Congestion with Big Data and Super-AI?
The AI Revolution Is on Its Way

Exponential growth of computing. 20th through 21st century.

Coutesy of Ray Kurzweil and Kurzweil Technologies, Inc. License: CC-BY 1.0.
Smart Cities: **Artificial Intelligence As Opportunity!**

How Will Mobility and Logistics Change with AI?
Self-Driving Vehicles, Autonomous Cars
Automated Traffic Flow
Hybrid Traffic and Logistics of the Future
Could Cities Be Run Like Giant Machines?
The World's Sensor Network is Growing Quickly

THE INTERNET OF THINGS
AN EXPLOSION OF CONNECTED POSSIBILITY

BILLIONS OF DEVICES

YEAR

2002 0.5 BILLION

2005 1.000.000

2009 4.8 BILLION

2011 14.4 BILLION

2013 26.4 BILLION

2015 34.8 BILLION

2017 42.1 BILLION

2019 50.1 BILLION

2020

1980 60

1990 40

2000 30

2010 20

2020 10

YEAR


DGESS
Quantum Computers
D-Wave Systems, Inc. is a quantum computing company, based in Burnaby, British Columbia, Canada. D-Wave is the first company in the world to sell quantum computers.

<table>
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<td>January 2017</td>
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<tr>
<td>Power consumption</td>
<td>15.5 kW</td>
<td>25 kW</td>
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</table>

Buyers

- Lockheed Martin
- Google/NASA/USRA
- Los Alamos National Laboratory
- Lockheed Martin
- Google/NASA/USRA
- Temporal Defense Systems Inc.
- Volkswagen Group
- Virginia Tech
Google says its quantum computer is 100 million times faster than PC

Controversial D-Wave system gets thumbs up

By Iain Thomson in San Francisco 9 Dec 2015 at 01:31

Two years ago Google and NASA bought a D-Wave 2X quantum computing system and the Chocolate Factory has now pronounced itself very pleased with the results.
Googles smarte Stadt, ein digitaler Alptraum

Von Henryk M. Broder | Veröffentlicht am 28.10.2017 | Lesedauer: 3 Minuten

Google will in Toronto ein voll vernetztes Testfeld für das Leben von morgen errichten: Eine Stadt vom Reißbrett, total vernetzt und überwacht wie eine moderne Justizvollzugsanstalt. Unserem Autor gruselt es.
<table>
<thead>
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<th>City</th>
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<td>Sydney</td>
<td>Australia</td>
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</tbody>
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Exponential vs. Factorial Growth, Dark Data, Loss of Centralized Control

- X doubles every 18 months
- X doubles every 12 months
- X grows as a factorial with the number of years

Loss of top-down control: Distributed control

Big Data: Evidence-based decision-making

Data volume

Processing power

Systemic complexity

Not enough data to take good decisions
Cause and Effect in Networked Systems

- Intended effect
- Side effect
- Feedback effect
- Cascading effect
Complex Systems Cannot Be Steered Like A Car!
Systemic Instabilities Causing Unwanted Traffic Jams – and Many Other Problems!
Engineered Breaking Points to Stop Cascades
The Sustainability Challenges Call for A More Resilient Society

Cities and regions are relevant organizational units for a resilient society.

- Redundancy
- Diversity
- Decentralization
- Distributed Control
- Subsidiarity
- Modular Design
- Participatory Resilience
- Solidarity
- Digital Assistance
- Self-Organization
New paradigm: From top-down power and control to empowerment and coordination

Co-creation, co-evolution, collective intelligence
Traffic Light Control
Comparing 3 Ways to Organize a Complex System

Optimal top-down regulation
- Central control, “benevolent dictator”

Bottom-up self-organization
- Travel time minimization, “homo economicus”

Bottom-up self-regulation
- Same, but other-regarding coordination with neighbors
Decentralized Concept of Self-Organized Traffic Light Control

Inspiration: Self-organized oscillations at bottlenecks

Optimal compromise between coordination and local flexibility

Published in JSTAT (2008)
Bottom-Up Self-Regulation Can Outsmart Optimal Top-Down Control

Queue length vs. Capacity utilization graph showing the comparison between top-down regulation and clearing the longest queue.
Bottom-Up Self-Regulation Can Outsmart Optimal Top-Down Control

Stefan Lämmer and Dirk Helbing
Bottom-Up Self-Regulation Can Outsmart Optimal Top-Down Control

Adam Smith’s invisible hand works

Top-down regulation

Selfish optimization, self-organization

Clearing longest queue
Bottom-Up Self-Regulation Can Outsmart Optimal Top-Down Control

Adam Smith’s invisible hand fails

Top-down regulation

Selfish optimization, self-organization

Clearing longest queue
Bottom-Up Self-Regulation Can Outsmart Optimal Top-Down Control

- Top-down regulation
- Clearing longest queue
- Selfish optimization, self-organization
- Other-regarding optimization, self-regulation

Stefan Lämmer and Dirk Helbing
Bottom-Up Self-Regulation Can Outsmart Optimal Top-Down Control

Stefan Lämmer and Dirk Helbing
Towards Self-Organized Traffic Light Control in Dresden
The Measurement and Control Area
Disturbance of Traffic Coordination by Bus and Tram Lines
Synchronize Traffic by Green Waves or Use Gaps as Opportunities?

State-of-the-Art Control

Flexible Self-Control
Performance in Dependence of the Traffic Volume

- **Public transport**
  - State-of-the-Art Control
  - Flexible Self-Control

- **Motorized traffic**
  - State-of-the-Art Control
  - Flexible Self-Control

Traffic volume (% of measured flow)
Gain in Performance

Public transport
- Total delay: 2.02 vh, -56%

Motorized traffic
- Total delay: 63.9 vh, -9%

Pedestrians and Cyclists
- Average red times: 59 s, -36%
Socio-Ecological Finance FIN4+: Participatory sustainability
THE INTERNET OF THINGS
AN EXPLOSION OF CONNECTED POSSIBILITY

BILLIONS OF DEVICES

YEAR

2019
11.2 BILLION
Internet of Things

2018
18.2 BILLION

2017
26.4 BILLION

2016
34.8 BILLION

2015
42.1 BILLION

2014
14.4 BILLION

2013
8.7 BILLION

2012
1.000.000

2002
0.5 BILLION

2000

1992
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2018
2019
2020

50.1 BILLION
Global population
Mapping Noise and Other Externalities
The No. 1 Principle

Increase positive externalities, reduce negative ones, and ensure fair compensation
Multi-Dimensional Reward System

Value exchange

- user-centric pluralistic reputation system
- Qualified Money
  - Transparent Money
    - some transaction transparency
      (publish some transaction features)
    - prints money
  - cash
    - payment
      - fee/tax \( t_1 \)
      - "inflation"
      - real investments
        - payment
          - products
        - shops
    - producing companies
      - + interest rate
      - fees/tax \( t_2 \)
      - stock markets
        - ± speculative wins/gains or losses
      - "transaction fee"

- central bank
- electronic money
  - transactions
    - \( m \)
    - \( r \)
  - loans
  - Virtual Electronic Money (VEM)
It is Now Possible to Create Such New Money(s), As BitCoin Has Shown
Circular Economy + Sharing Economy
A multi-dimensional approach is a paradigm change
So Many Goals...

- Prosperity
- Sustainability
- Health
- Education
- Culture
- ...

But optimization neglects all goals but one!
Finance 4.0: A Multi-Dimensional Finance System

More balanced accounts
With a multi-dimensional value (exchange) system, there are many more possibilities to find solutions that benefit all. The space of possible solutions is significantly increased.
Multi-Dimensional Feedback, Not One-Dimensional Control

We are living not just on one thing, say water.

We need
- carbohydrates
- proteins
- vitamins
- minerals
A Typical Supply Network Today
A Typical Metabolic Network
Symbiosis
Social self-organization
Self-Governance Is Efficient, Given Proper Design Principles Are Followed
Tragedies of the Commons

Border between Haiti and Dominican Republic
There are a number of decentralized mechanisms to promote cooperation and social order, and to overcome “tragedies of the commons”
Direct Reciprocity, Repeated Interactions
Reputation, Indirect Interactions
Emergence of “Networked Thinking”

From collective intelligence to digital democracy
A NEW YORK TIMES BUSINESS BESTSELLER

“As entertaining and thought-provoking as The Tipping Point by Malcolm Gladwell. . . . The Wisdom of Crowds ranges far and wide.”
—The Boston Globe

THE WISDOM OF CROWDS

JAMES SUROWIECKI

WITH A NEW AFTERWORD BY THE AUTHOR
Bring the Best Ideas of Many Minds Together, But How?
Massive Online Deliberation Platforms (MOODs)

We need to build suitable platforms to collect, share and integrate ideas
Combine Different Perspectives
Meeting of Minds

The performance of humans across a range of different kinds of cognitive tasks has been encapsulated as a common statistical factor called $g$ or general intelligence factor. What intelligence actually is, is unclear and hotly debated, yet there is a reproducible association of $g$ with performance outcomes, such as income and academic achievement. Woolley et al. (p. 686, published online 30 September) report a psychometric methodology for quantifying a factor termed “collective intelligence” (c), which reflects how well groups perform on a similarly diverse set of group problem-solving tasks. The primary contributors to c appear to be the $g$ factors of the group members, along with a propensity toward social sensitivity—in essence, how well individuals work with others.
Diversity Wins, Not the Best

Top-down and majority decisions obstruct collective intelligence

Wisdom of crowds requires independent exploration and then integration
Optimal Incentives: ”Minorities Report” Strategy Can Outperform Yes/No-Democracies and Markets!

R. Mann and DH: Optimal Incentives for Collective Intelligence, PNAS (2017)
Phase 1: Independent exploration

Phase 2: Information exchange

Phase 3: Integration

Phase 4. Voting

Notes: This is not about winning! It’s about finding solutions that work for many people.

Not everyone must do the same, in fact, shouldn’t!

Everybody can play a different role to achieve a good solution.
The New Paradigm
Centralized Control and Its Limits

- Advantage of centralized control is large-scale coordination
- Disadvantages are due to
  - vulnerability of the network
  - information overload
  - wrong selection of control parameters
  - delays in adaptive feedback control
- Decentralized control can perform better in complex systems with heterogeneous elements, large degree of fluctuations, and short-term predictability, because of greater flexibility to local conditions and greater robustness to perturbations

(Windt, Böse, Philipp, 2006)
The Sustainability Challenges Call for A More Resilient Society

Cities and regions are relevant organizational units for a resilient society.
Countering Global Problems Bottom-Up: City Olympics for Better Energy, Environmental and Climate Solutions
Competition Naturally Raises Everybody’s Effort

Joint work of Michael Mäs and Dirk Helbing
Combining Competition and Cooperation
Combining the Success Principles of Various Systems

- Competition (capitalism)
- Collective intelligence (democracy)
- Experimentation and selection (evolution, nature)
- Intelligent design (AI)
Climate City Cup
Let’s win together!
mobility
BIKE TO WORK
#Hack4Climate

#Hack4Climate 2017 was a success, with 100 hackers from 33 countries and 50 experts/partners. Check out the official -> after movie & -> best pictures. Get engaged by signing up for the newsletter, by contacting us per -> email and by following us on social media.

And stay tuned for #Hack4Climate 2018 at COP24.

Dates: 3-12/12/2018
Location: -> Katowice Poland
Presidency/more info: -> Polish Government

stay tuned with our newsletter:

[ newsletter.email ]
[ register ]

[ application closed ]  [ participant info ]
Glocalisation Rather than Globalisation

- Think global
- Act local (and diverse)
- Experiment
- Learn from each other
- Help each other
The Emerging Concept of Open Source Urbanism

Sergei Zhilin
PhD Candidate
TU Delft, The Netherlands
I see in Open Source a DNA that resonates strongly with how people make the city theirs or urbanize what might be an individual initiative. And yet, it stays so far away from the city. I think that it will require making. We need to push this urbanizing of technologies to strengthen horizontal practices and initiatives. (Saskia Sassen, 2011)
open source hardware

WIKIPEDIA
The Free Encyclopedia

open source architecture

GitHub
Openness
Collaboration
Modularity
Granularity
Low-cost integration
“Successful urban design requires the right combination of top-down and bottom-up involvement.”
I could not control anything, but I could influence everything
Cybernetics + Synergy = CyberSyn?
Synergy + Cybernetics = Synergetics!
Success Principles for A Complex World

- Co-learning
- Co-creation
- Co-ordination
- Co-operation
- Co-evolution
Upgrading Smart Cities with Collective Intelligence

The city in the hands of its citizens

28.02.2019 | Zukunftsblog | Digitalisierung
Von: Prof. Gerhard Schmitt

Dank moderner Technologie können Bürger stärker in die Stadtentwicklung einbezogen werden. Gerhard Schmitt spricht von einer «Responsive City», welche die Idee der «Smart City» ablöst.

Design for Values

- Privacy
- Self-determination
- Fairness
- Justice
- Dignity
- Happiness
- Wellbeing
- Safety
- Security

- Sustainability
- Health
- Friendship
- Solidarity
- Peace
- Usability
- Resilience
- Efficiency
- Flexibility

After Jeroen van den Hoven, with minor modifications by DH

Goals must be balanced (politically negotiated). Otherwise, the approach is oversimplified, inadequate.
Design for Democracy

- Human rights, human dignity
- Freedom
- Self-determination
- Pluralism
- Protection of minorities
- Division of power
- Checks and Balances
- Participation
- Transparency
- Fairness
- Justice
- Legitimacy

- Privacy
  - Protection from misuse/exposure
  - Right to be left alone

Design for values, value-sensitive design
Build digital democracy

Open sharing of data that are collected with smart devices would empower citizens and create jobs, say Dirk Helbing and Evangelos Pournaras.
Democracy by design
Food for thought

DISCUSSION PAPER