Travel Demand Models, The Next Generation: Boldly Going Where No-One Has Gone Before

University of Toronto Transportation Research Day
Toronto, December 13, 2018

UNIVERSITY OF TORONTO
FACULTY OF APPLIED SCIENCE & ENGINEERING
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Presentation Outline: A few provocative thoughts

- Disruptions challenging the travel demand modelling field.
- The 4 pillars of modelling.
- Towards a next generation of travel demand modelling.
  - Theory.
  - Data.
  - Computing.
- Final words.

Disruptions (1): AVs & MaaS

- The looming potential of autonomous vehicles and the burgeoning of new mobility services are disrupting transportation in ways not seen since the dawn of the automobile age.
- They also are similarly posing unprecedented challenges to travel demand models, which, it is generally conceded, are not adequate for analysing these disruptive new services & technologies.

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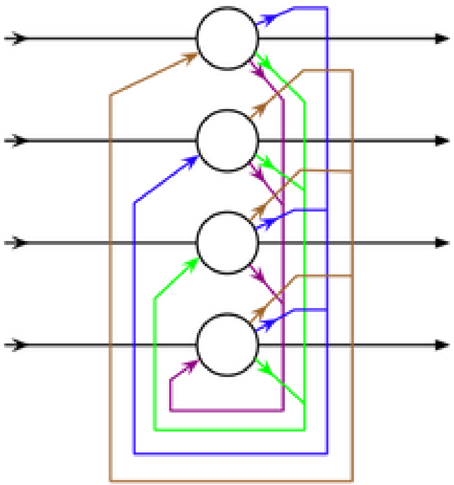
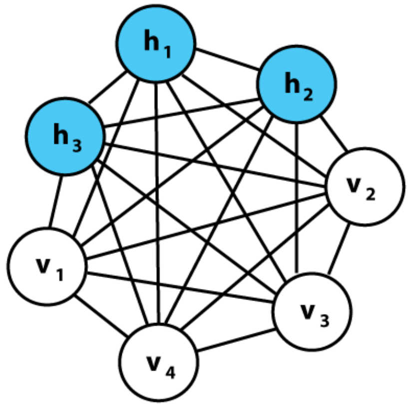
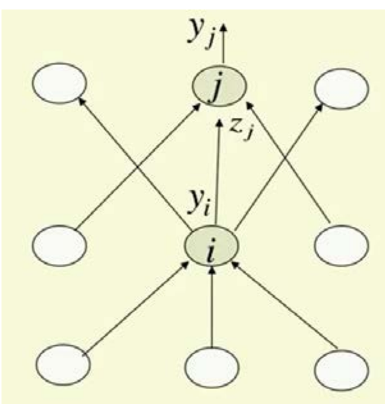
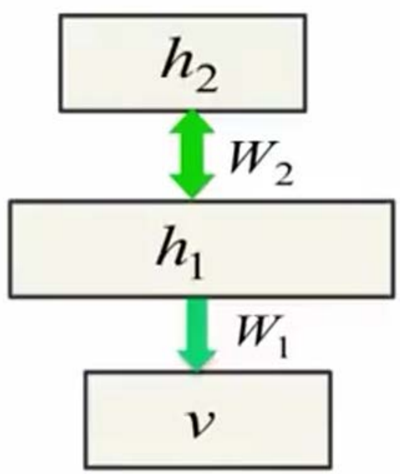
Disruptions (2): ICT, IoT, AI & Big Data

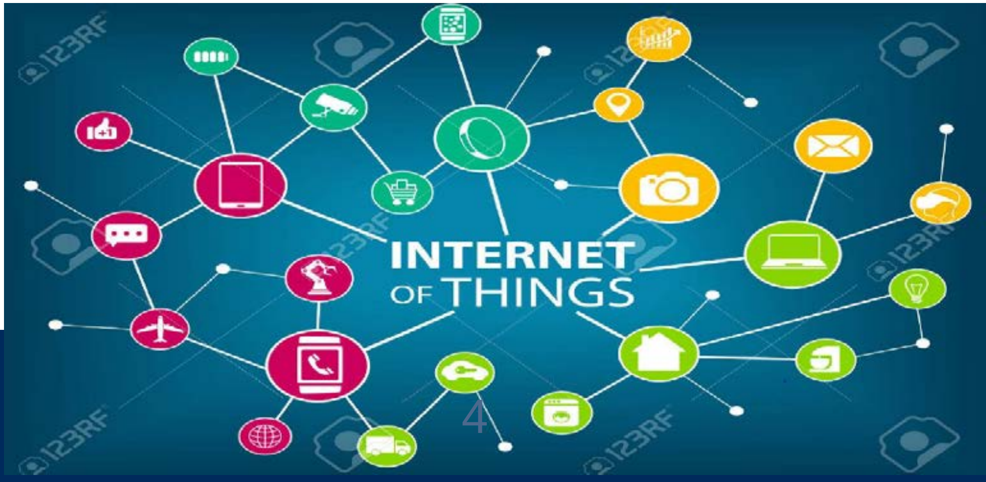




- At the same time, the technology that is so disrupting transportation services is also generating massive amounts of new data about travel behaviour that potentially will allow us to view travel in new ways:
  - Very large samples.
  - Dynamic, time-series.
  - But (usually) lacking socio-economics.
- New analysis and computing methods are enabling the analysis of these huge new datasets (machine learning, etc.).
- They are also challenging our standard conceptions of models and model estimation.

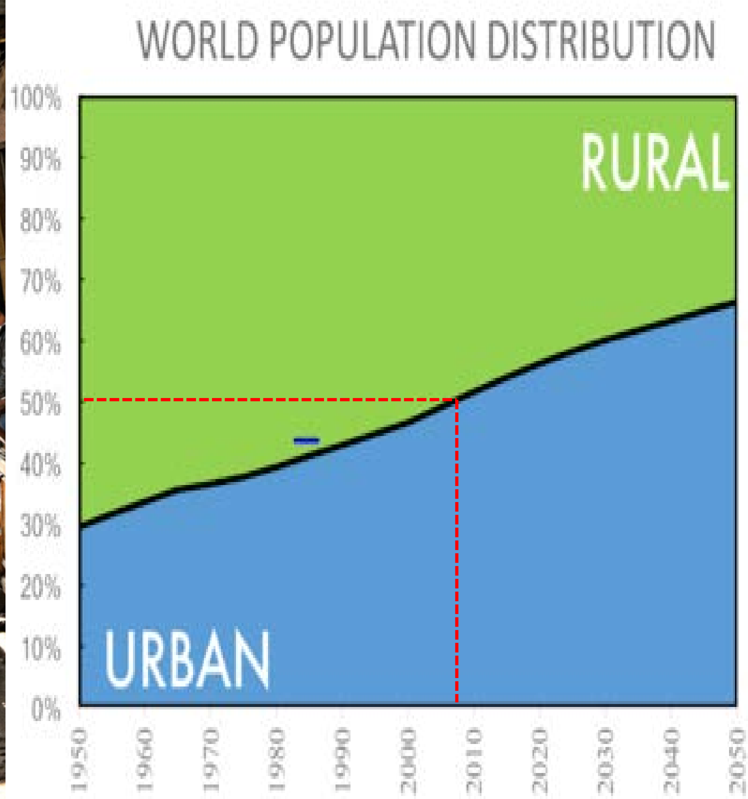




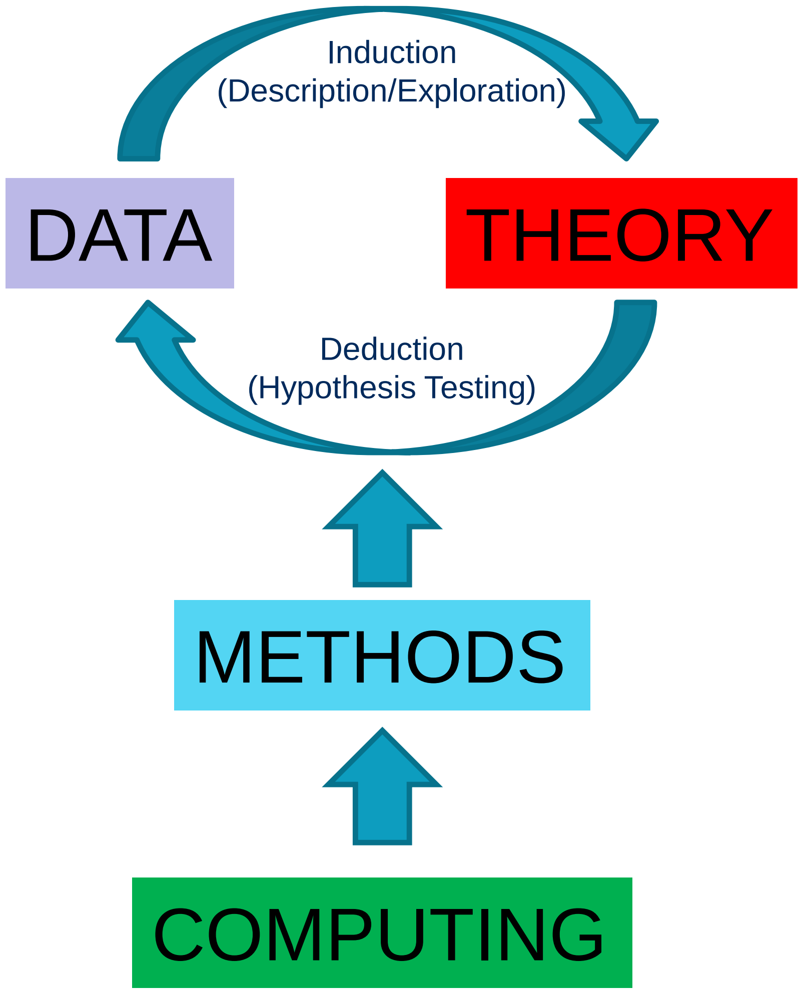


Disruptions (3): Global Urbanization

- The challenge of modelling the world's emerging cities & mega-cities is enormous, but world stability, etc., etc. depends on getting the 21st century urban world "right".
- If we can't plan, we can't get it right, and we can't plan if we can't measure & model.



The 4 Pillars of Modelling



- Models are the operational implementation of theory, built within the limitations of current data, methods & computational capabilities.
- In this talk I would like to focus on theory, as well as how data & computing can support the development of better theory & models.

Towards the next generation of travel behaviour modelling

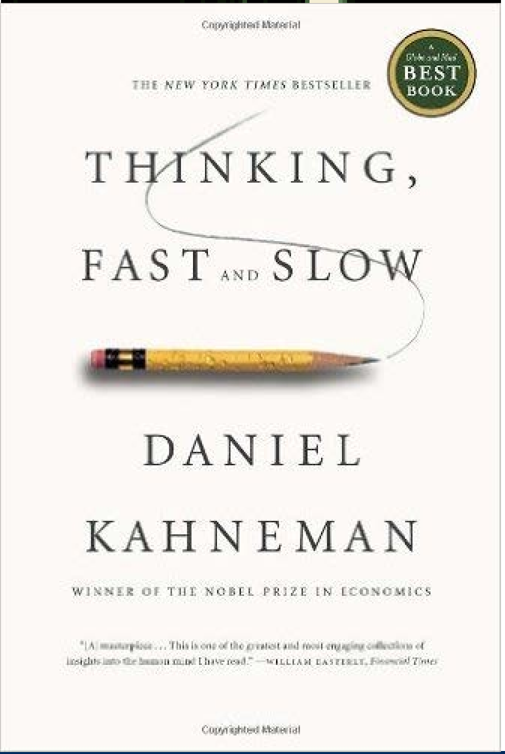
“We know a tremendous amount about how the world works, but not nearly enough. Our knowledge is amazing; our ignorance even more so.”

Donella H. Meadows, Thinking in Systems: A Primer, edited by Diana Wright.

“Find the beginning, the slight silver key to unlock it, to dig it out. Here then is a maze to begin, to be in.”

Michael Ondaatje, “The Collected Works of Billy the Kid: Left-Handed Poems”

Provocation 1: Travel Behavior Theory

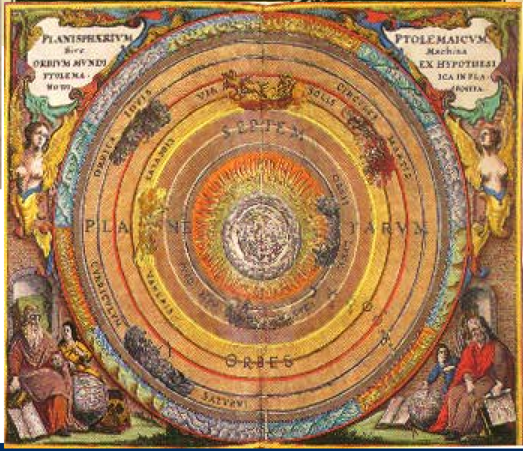


- Random utility theory has been a major success story for our field (where would we be without it?).
- BUT, “arguably” it is largely a framework describing “how” we make decisions (maximize utility) within which we still need to “pour” our understanding of the “what and the “why” and the “when” underlying these decisions (e.g., “What” defines utility? “Why” do we travel?).

Theory (2): Theory & Models

- The complexity (heterogeneity) of travel behaviour makes testable generalized theory difficult to construct.
- As a result, we usually frame our "theory" in terms of a specific model for empirical testing.
- But these models are themselves extremely complicated constructs of many hypotheses & assumptions, many of which are very difficult to independently test.
- How you frame the problem, however, constrains the solutions found.
- We need a much more open process to encourage experimentation, new ideas, the testing of multiple specifications and hypotheses, and the opportunity to fail.

Quelle: Deutsche Fotothek



Theory (3): Models as Scientific Hypotheses

Richard Soberman, UofT

- "There is a big difference between 30 years of experience and 1 year's experience repeated 30 times."
- Getting modelling research "off-line" from operational model development and planning study deadlines is absolutely critical.

Ezra Hauer, UofT

- "Do you travel demand modellers ever reject a model?"
- We have to be prepared to fail (science also proceeds through negative results). If we never reject a model, how do we progress?

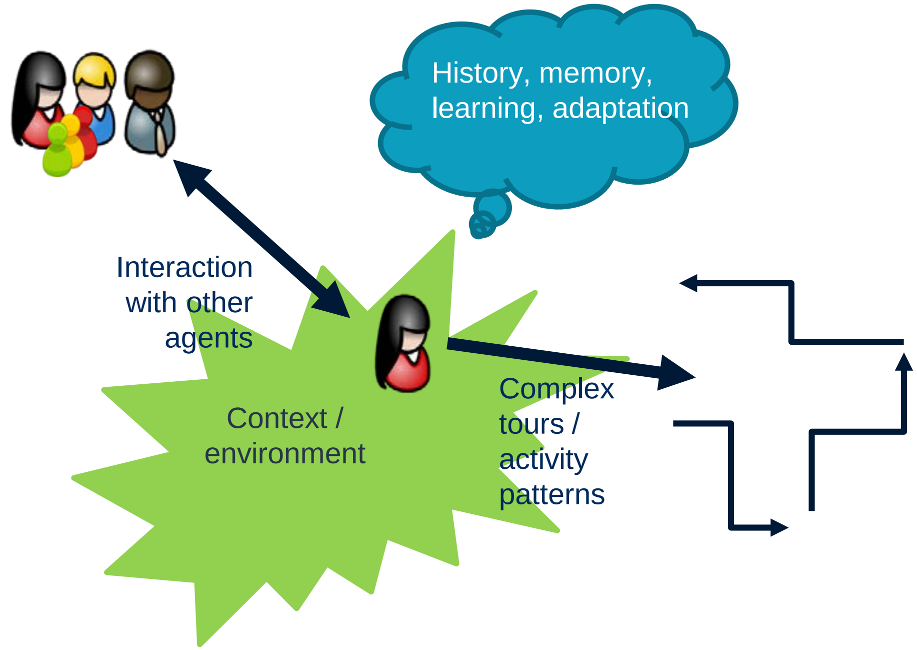
Geoffrey West, Santa Fe Institute

- I was once describing a typical RUM mode choice model to Geoffrey West over lunch at a conference.
- I casually mentioned that such models might have 20, 30, 40 or (usually) more variables & parameters.
- The good Dr. West palpably turned white as a ghost, almost dropped his fork, and exclaimed:
  - **"Good God! Do you call that science?"**

Theory (4): Some Propositions

- Myopic decision-making
  - People are "rational" but <u>not</u> global optimizers.
- Maslow's Hierarchy of Needs
  - Projects.
  - Utility.
- Take the activity-based approach seriously:
  - Activity-scheduling; not tour-based.
- Take human agency seriously.
- Get context & structure right.
  - Decomposition to manage complexity (object-orientation).
  - Model implementations will follow.
  - Model structure should be <u>both</u> behaviourally sound & feasible to implement.
- Build a flexible/extensible framework.
- Computing efficiency is critical (run times matter):
  - Keep it simple, stupid.
  - Detail where needed, not for detail's sake.
- We must respect data (& computing) constraints, but design for what is needed, not what is currently feasible.

Provocation 2: Microsimulation

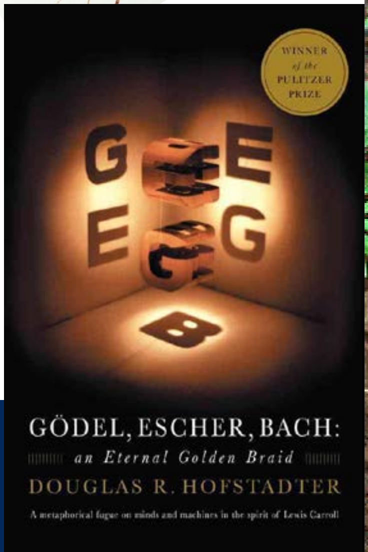


- "We can microsimulate anything."
- BUT:
  - Statistical validity?
  - Proliferation of parameters.
  - Computing times.
  - Complicatedness.
  - Still (predominately) static.
  - …
- The history of travel behaviour analysis & modelling has been one of consistent disaggregation, leading inevitably to microsimulation implementations.
- This approach is well justified and has produced important, practical results.
- But, are more parsimonious, holistic approaches conceivable?

Microsimulation (2)

- Michael Wegener warns of the "Spitfire syndrome" of the possible perils of ever-increasing disaggregation.

- For the past 50+ years we have pursued a *reductionist* approach to modelling travel demand. Does a more *holistic* approach exist?
  - Douglas Hofstadter, *Gödel, Escher, Bach: an Eternal Golden Braid*:
  - Do we model the ants or the anthill?



City Science / Complexity (1)

- It is now clear that cities worldwide exhibit very strong, statistically significant *scaling laws*, similar to those observed in nature:

$$log(Y) = \alpha + \beta log(POP)$$

for a wide range of "output/performance" measures Y.

- All "economic" / "innovation" measures (GDP, patents, etc.) display "super-linear" behaviour (β>1.0):
  - Larger cities exhibit greater agglomeration economies than smaller ones.
  - This behaviour absolutely does not exist in nature: it is a human "invention".
- What are the implications of this macro property of cities for models/theories of travel behaviour?

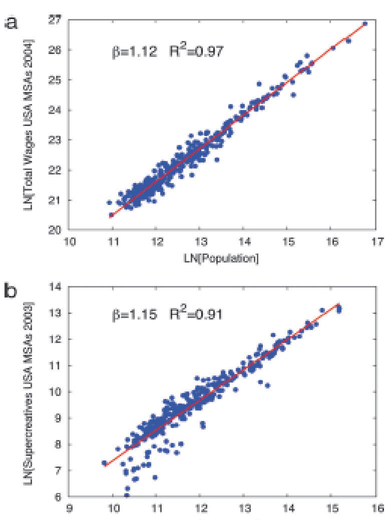


Fig. 1. Examples of scaling relationships. (a) Total wages per MSA in 2004 for the U.S. (blue points) vs. metropolitan population. (b) Supercreative employment per MSA in 2003, for the U.S. (blue points) vs. metropolitan population. Best-fit scaling relations are shown as solid lines.

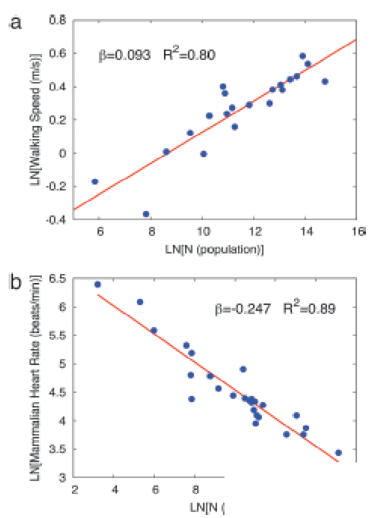
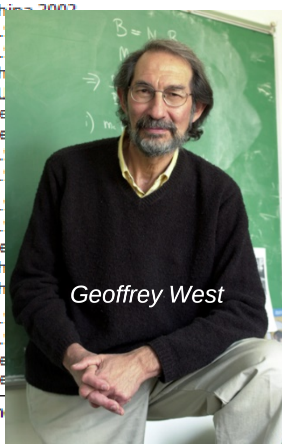


Fig. 2. The pace of urban life increases wit of biological life, which decreases with orga speed vs. population for cities around the w (mass) of organisms.

Table 1. Scaling exponents for urban indicators vs. city size

Y	β	95% CI	Adj-R^2	Observations	Country–year
New patents	1.27	[1.25,1.29]	0.72	331	U.S. 2001
Inventors	1.25	[1.22,1.27]	0.76	331	U.S. 2001
Private R&D employment	1.34	[1.29,1.39]	0.92	266	U.S. 2002
"Supercreative" employment	1.15	[1.11,1.18]	0.89	287	U.S. 2003
R&D establishments	1.19	[1.14,1.22]	0.77	287	U.S. 1997
R&D employment	1.26	[1.18,1.43]	0.93	295	Chi
Total wages	1.12	[1.09,1.13]	0.96	361	U.
Total bank deposits	1.08	[1.03,1.11]	0.91	267	U.
GDP	1.15	[1.06,1.23]	0.96	295	Ch
GDP	1.26	[1.09,1.46]	0.64	196	EU
GDP	1.13	[1.03,1.23]	0.94	37	Ge
Total electrical consumption	1.07	[1.03,1.11]	0.88	392	Ge
New AIDS cases	1.23	[1.18,1.29]	0.76	93	U.
Serious crimes	1.16	[1.11, 1.18]	0.89	287	U.
Total housing	1.00	[0.99,1.01]	0.99	316	U.
Total employment	1.01	[0.99,1.02]	0.98	331	U.
Household electrical consumption	1.00	[0.94,1.06]	0.88	377	Ge
Household electrical consumption	1.05	[0.89,1.22]	0.91	295	Ch
Household water consumption	1.01	[0.89,1.11]	0.96	295	Ch
Gasoline stations	0.77	[0.74,0.81]	0.93	318	U.
Gasoline sales	0.79	[0.73,0.80]	0.94	318	U.
Length of electrical cables	0.87	[0.82,0.92]	0.75	380	Ge
Road surface	0.83	[0.74,0.92]	0.87	29	Ge

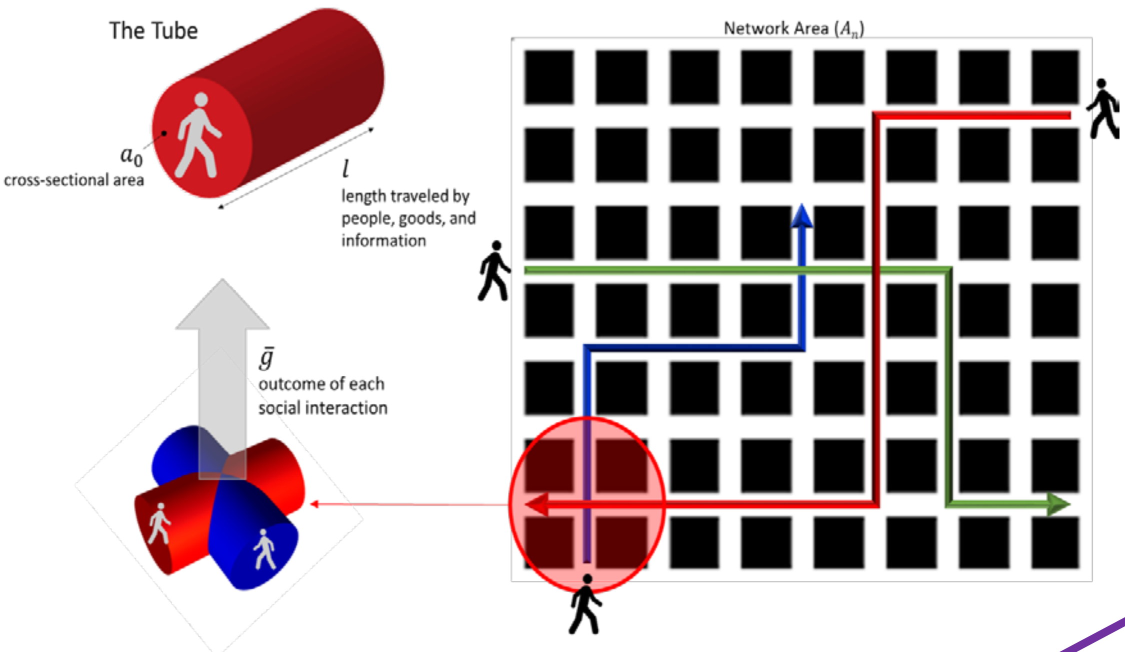
Data sources are shown in *SI Text*. CI, confidence interval; Adj-R^2, adjusted R^2; GDP, gross dom

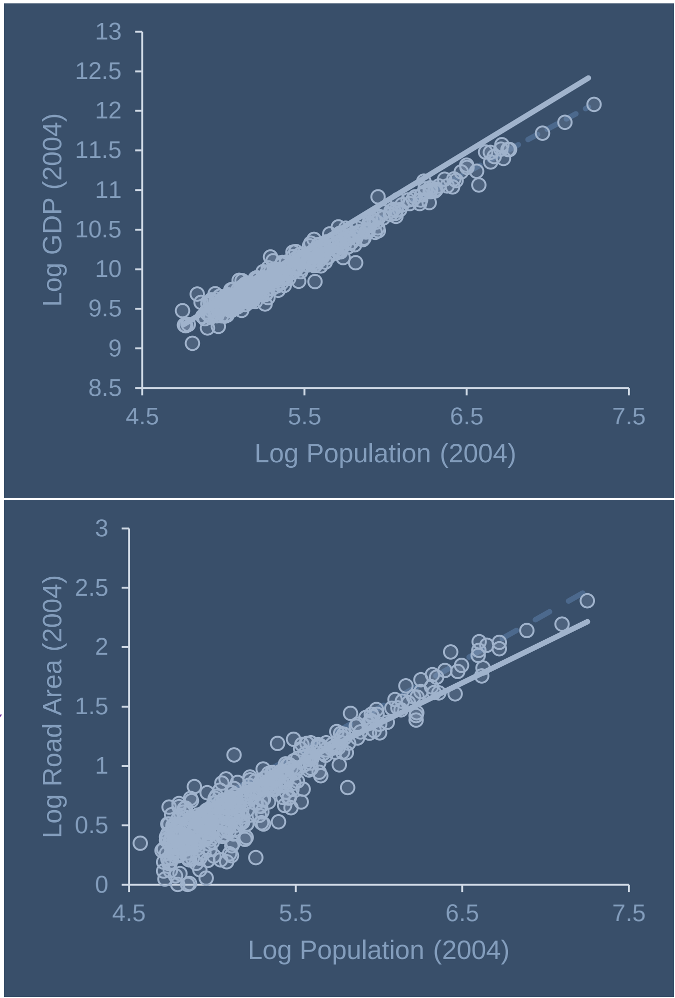


City Science/Complexity (2)

- Bettencourt argues that this super-linear behaviour is the result of non-linear increases in social networks/interactions as cities grow larger.

Conceptualization of individual 'tubes' as they travel around the city on a network. When tubes cross, a social interaction occurs producing an average social interaction outcome

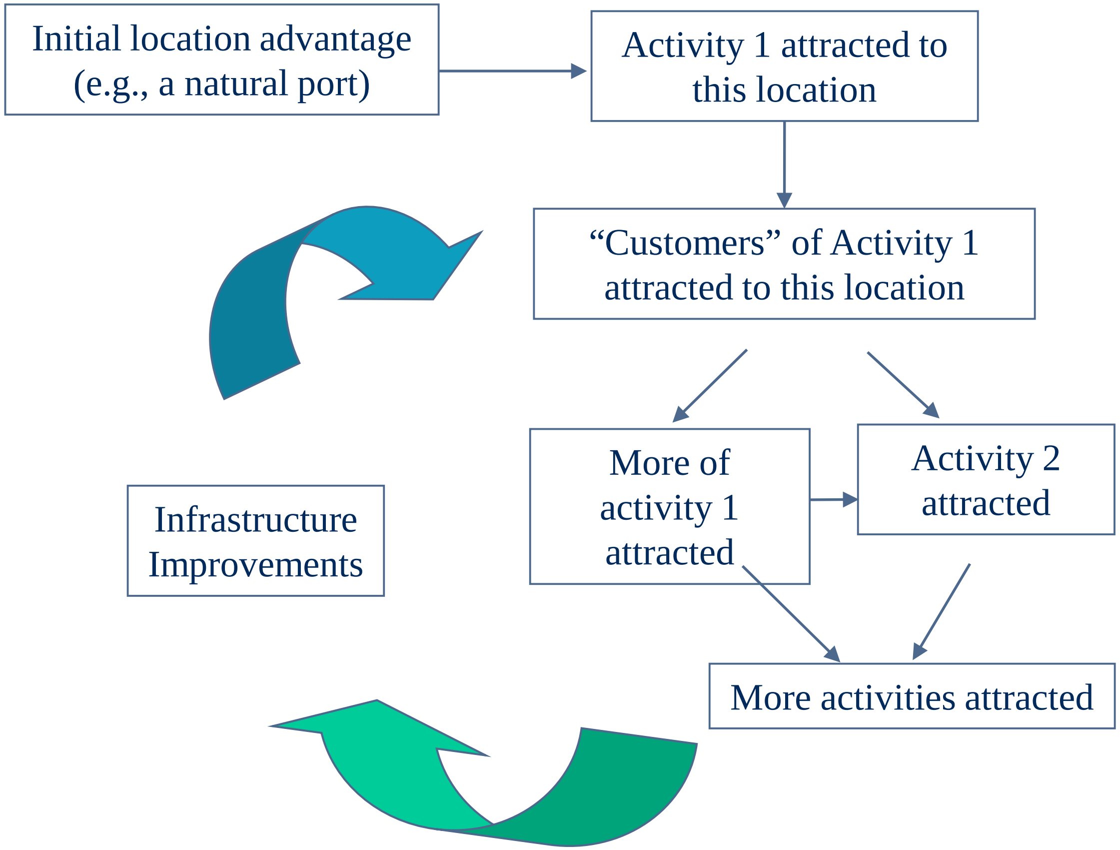




Scaling of GDP (Y) and Road Area (A_n) vs. population for U.S. cities from 2000 to 2015.

Source: Sugar, L. & C.A. Kennedy, "Dynamics of Urban Scaling", submitted to *Environment & Planning B: Urban Analytics and City Science, 2018.*

City Science/Complexity (3)



- The accessibility <-> agglomeration "nexus" is not as well understood as it should be.
- This surely ties into the transportation – land use interaction as well, which also is still not as well understood as it should be.
- Agglomeration is clearly an example of feedback-driven, self-adaptive emergence of a hierarchical system – a classic complex system process.
- It also clearly ties into the "super-linear" scaling behaviour asserted to exist in cities worldwide.

Bridging the Gap: From micro to macro (1)

- In traffic flow theory, it can be shown that micro car-following models can be integrated to yield steady-state, average macro speed-density relationships.

$$\ddot{x}_{n+1}(t+\Delta t) = \frac{\lambda_0\, \dot{x}_{n+1}(t)^M\, [\dot{x}_n(t) - \dot{x}_{n+1}(t)]}{[x_n(t) - x_{n+1}(t)]^L} \quad \xrightarrow{\int} \quad v = f(k)$$

v = avg. speed; k = avg. density

- This provides strong theoretical support for both the micro and macro models and deeper insights into traffic flow behaviour at both levels.
- Might something similar exist in travel behaviour?

From micro to macro (2)

Martinez, for example, shows that under certain assumptions his disaggregate bid-choice models of urban housing models generates a super-linear scale law relationship between rents and population:

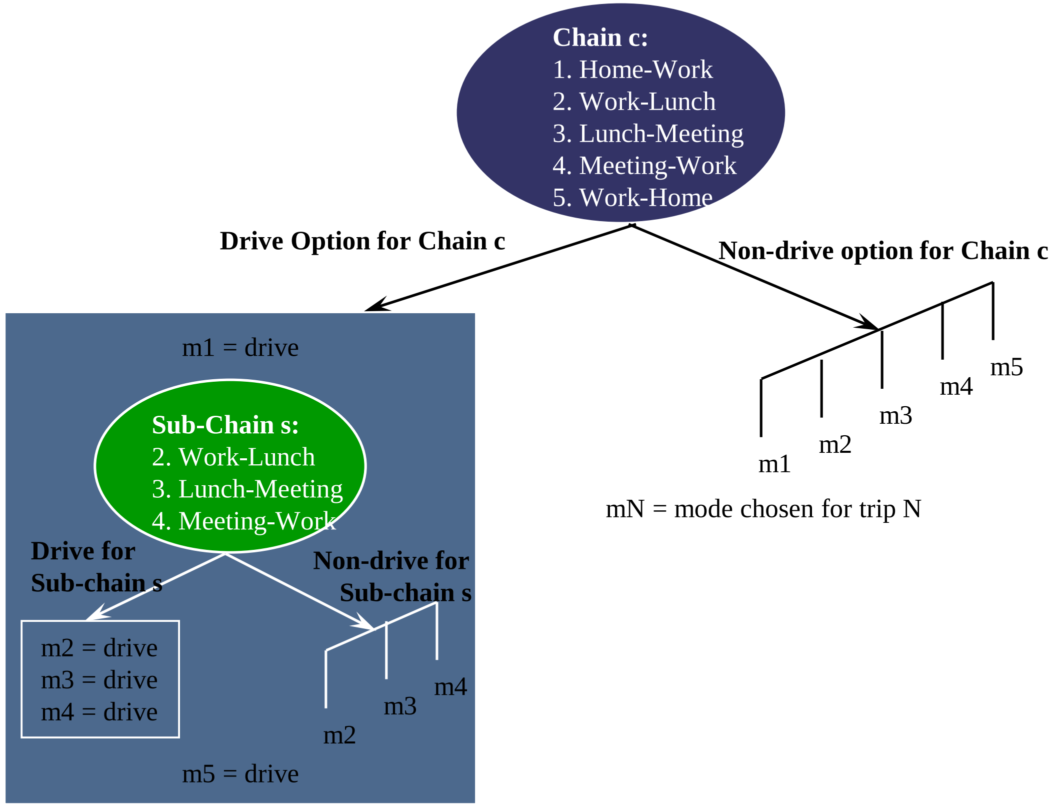
$$\log(\text{Average Rent}) = R_0 + \beta * \log(\text{POP}) \qquad \beta > 1.0$$

Martinez, F.J. (2016) "Cities' Power Laws: The Stochastic Scaling Factor, *Environment & Planning B, 43(2)* 257-275.

From micro to macro (3)

$$\tilde{U}_{ik} = \sum_{t=1}^{T} U_{im(t|k)t} = \sum_{t=1}^{T} V_{im(t|k)t} + \sum_{t=1}^{T} \varepsilon_{im(t|k)t}$$

- Unlike logit models, probit models can be mathematically aggregated.
- With current computing power, is it time to revisit probit formulations as a way of building more parsimonious models?
- In Toronto, for example, we have been successfully using a probit formulation to aggregate trip utilities into tour utilities to build operational tour-based mode choice models.



Miller, E.J. and M.J. Roorda, "A Prototype Model of Household Activity/Travel Scheduling", *Transportation Research Record, Journal of the Transportation Research Board*, No. 1831, 2003, pp. 114-121.

Provocation 3:
"Social Heisenberg Uncertainty Principle":
What we can/cannot observe

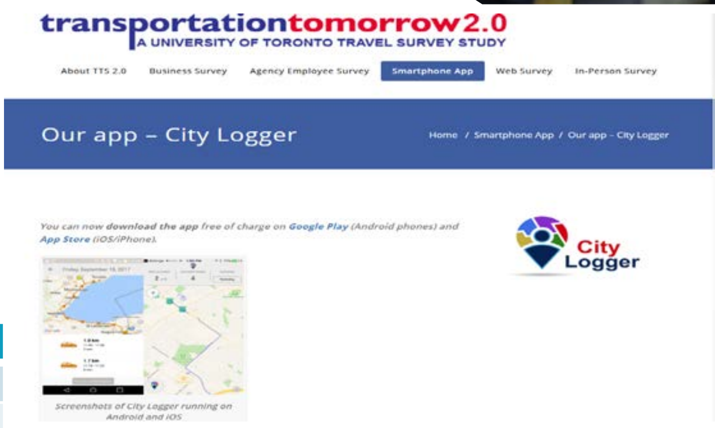
No, not him!

Him

- We are a very empirically driven field.
- But we have always faced significant limitations on what we can & cannot observe:
  - Expensive, small-sample, one-day surveys.
  - Static, cross-sectional data.
  - ....
- This, however, is changing.

“Social Heisenberg Uncertainty Principle” (2)

- New, “big” datasets are providing the opportunity to observe massive amounts of passive, revealed preference data concerning urban trip-making.
- These data are:
  - Potentially consistent across urban regions, since they are often collected using common methods (e.g., a cellphone trace is – by and large – a cellphone trace whether it is collected in Toronto or Montevideo).
  - Continuously collected, day after day, week after week.
  - Potentially VERY large sample.
- BUT:
  - Spatial precision is often problematic.
  - Data are usually anonymized and so lacking in trip-maker attributes.
  - Household information often/usually lacking.



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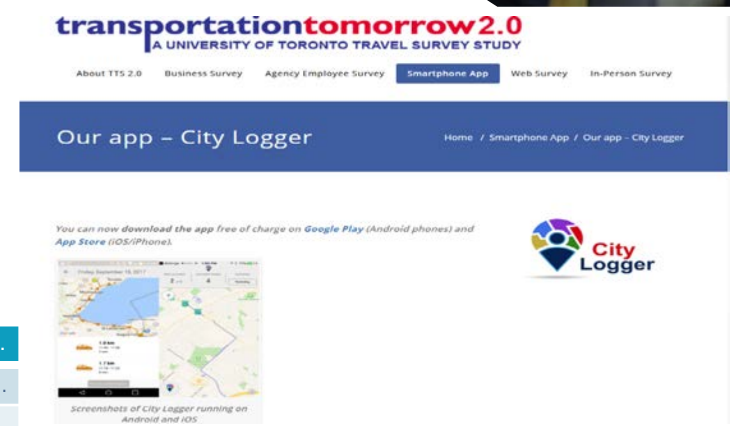
Zone	...	221	230	229	218	...		212	...	212	218	...	218	236	230	221	...
	Home		Travel		Activity 1			Activity 2			Activity 3			Travel		Home	

"Social Heisenberg Uncertainty Principle" (3)

- HOWEVER:
  - Is cellphone data (for example), fused with Census & POI data, collected across very large segments of the population over extended periods of time "any worse" than what we have been working with all these years? Might it not be much better?
  - Might a "quantum" / "statistical" approached <u>informed/guided</u> by behavioural theory not be a better framework for model-building?



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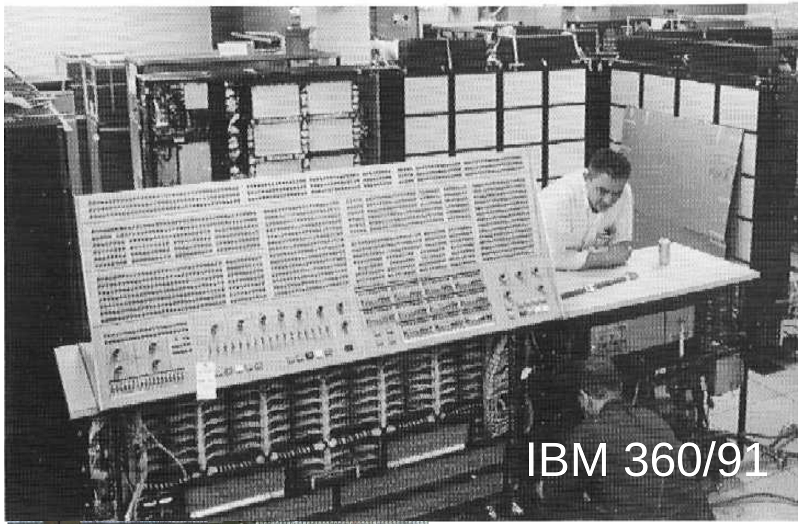
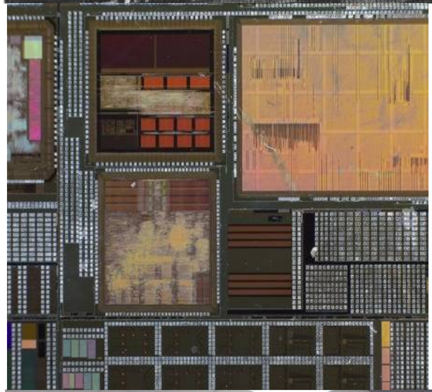
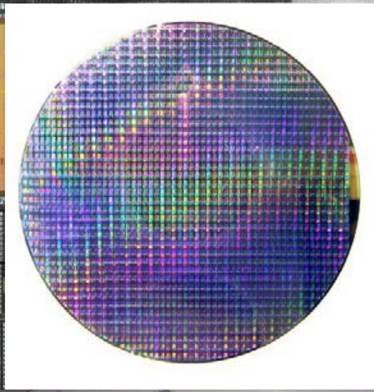
Zone	…	221	230	229	218	…		212	…	212	218	…	218	236	230	221	…
	Home		Travel		Activity 1			Activity 2			Activity 3			Travel		Home	

Provocation 4: Computing

- The history of travel demand modeling is tied directly to the history of digital computing.
- We are in the software business as much as the travel behavior & econometrics business.
- Even in today's computing world, big urban models are computationally big.
- Computational efficiency remains critical.
- Many/most models still run much too slowly: a week per run simply isn't good enough.

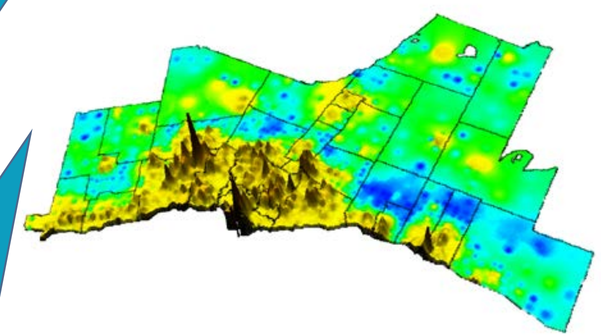


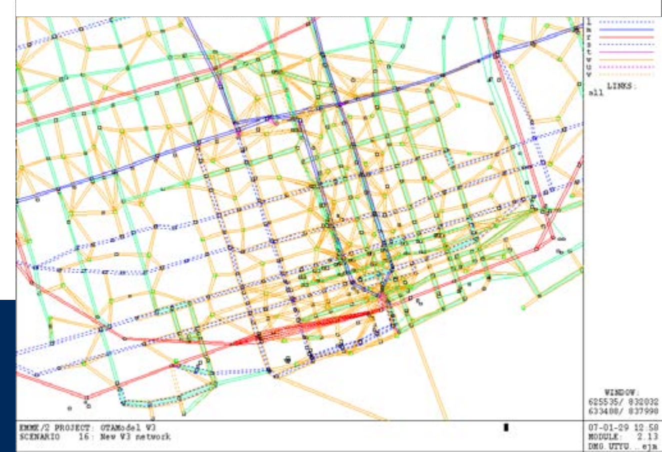




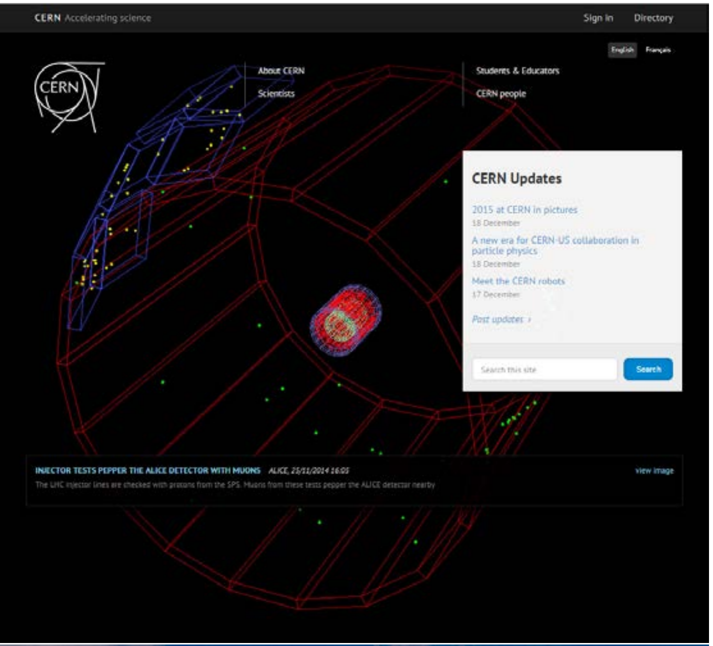
Computing (2)

- The computer is our "lab" just as much as, and in some ways more so, than the city itself.
- As a field we arguably have not exploited advances in High Performance Computing (HPC) capabilities that would greatly assist us in dealing with the large, messy, complex, computationally-intensive problems we are studying.
- We also have a proliferation of software that often represents expensive & inefficient reinvention of wheels.





Computing (3): Building the Virtual Lab



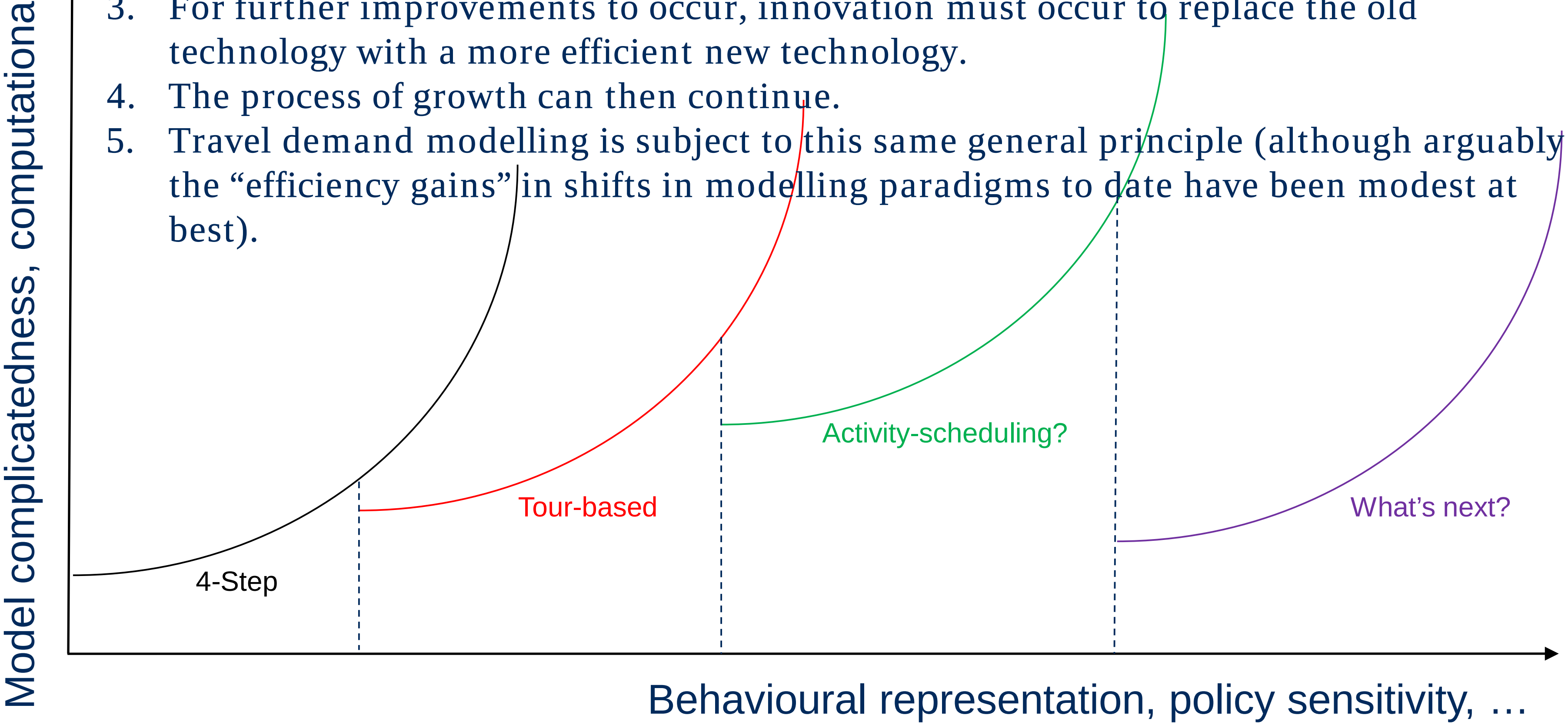
Karl G. Jansky Very Large Array

- Can/should we be standardizing within a common, open source software "environment" which everyone can use and to which everyone can contribute?
- This is not a new idea, but it has not yet come to pass.
- We see this in other fields, why not ours?

Technological Growth Curves

Most technologies follow growth curves in which:

1. Performance increases within a given technology come at exponentially increasing costs.
2. At some point additional growth in performance is restricted by the highly non-linear growth in cost (energy, etc.).
3. For further improvements to occur, innovation must occur to replace the old technology with a more efficient new technology.
4. The process of growth can then continue.
5. Travel demand modelling is subject to this same general principle (although arguably the "efficiency gains" in shifts in modelling paradigms to date have been modest at best).



Towards the next generation (1)

- Massive, time-series databases represent a “brave new world” of possibilities – we need to aggressively & imaginatively exploit this opportunity.

Towards the next generation (2)

- HPC can provide the computational environment needed to both exploit big datasets and to "properly" deal with the inherently probabilistic nature of our problem.

Towards the next generation (3)

- Standardization of software "modelling environments" (<u>not</u> models *per se*) would be extremely helpful to create a common "virtual laboratory" for experimentation, sharing of data and convergence in theories & models.

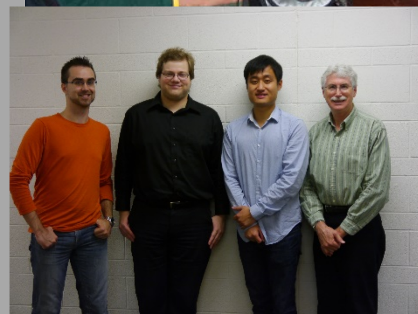
Towards the next generation (4)

- But we need to step back from “just building better models” and be much more explicitly trying to build generalized theories of travel behaviour that can be robustly validated empirically.

Towards the next generation (5)

- If travel behaviour science is to grow and be practically useful, activities must include:
  - Replication of studies.
  - Meta-analyses of results.
  - Rejection of “weak models”.
  - Seeking convergence/consensus in specifications (getting away from the “my model syndrome”).
  - Seeking transferability of parameters.
  - Developing more robust, parsimonious, theory-based models.

Acknowledgements to the ILUTE project team (past & present):



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- Loy Cheah
- Leo Chen
- Wilson Chen
- Franco Chingcuanco
- Louis-Etiene Couture
- Len Eberhard
- Ilan Elgar
- Bilal Farooq
- Yiling Deng
- Leila Dianat
- Williams Diogu
- Sean Doherty
- Jared Duivestein
- Ahmadreza Faghih-Imani
- Wenli Gao
- Martin Giroux-Cook
- Kathryn Grond
- Ahsan Habib
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- Murtaza Haider
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- Torsten Hahmann
- Murtaza Haider
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- Luna Xi
- Yunfei Zhang