Proposal - Human Thermodynamics:
Physics of Mobility and Large-Scale Energy Consumption

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Recent, significant, but *largely separate* trends in scientific research:

1. A *statistical physics* approach to Big Data, human behavior, and *human mobility* in particular.

2. Factors contributing to *climate change*. In particular, large-scale energy consumption.

   - Many sustainability problems are phenomena of *scale*… scale of consumption, mobility, behavior.

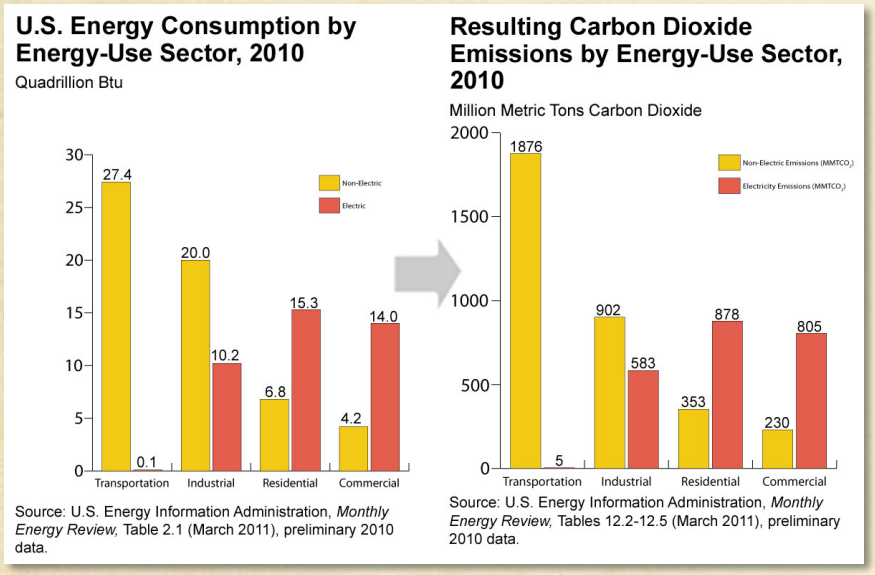
1. Human Mobility Research

Some recent research topics in the Big Data & Complex Systems literature:

- Comparison to Brownian Motion, predictability
- Scaling laws
- Social networks and mobility patterns
- Urban virtual information layer, smart cities, real-time data, control systems
- Mobile applications
- Urban energy efficiency, sustainability, pollution
- Reality mining, route detection, new data sources
- Revision of gravity model

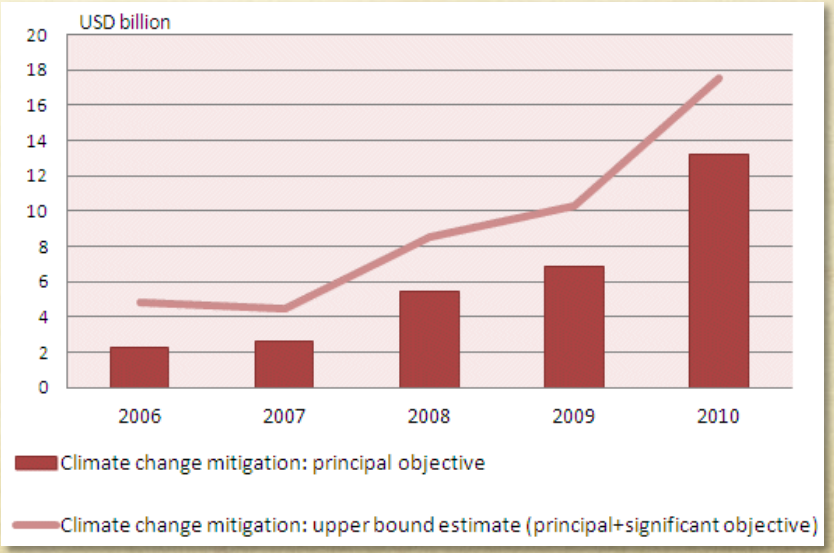
2. Climate Change

Transportation is a significant cause! (EIA, NASA, IPCC, others)



eia.gov

... and research funding is growing ***exponentially***!



oecd.org

Energy Model

Infer *mean field* values for:

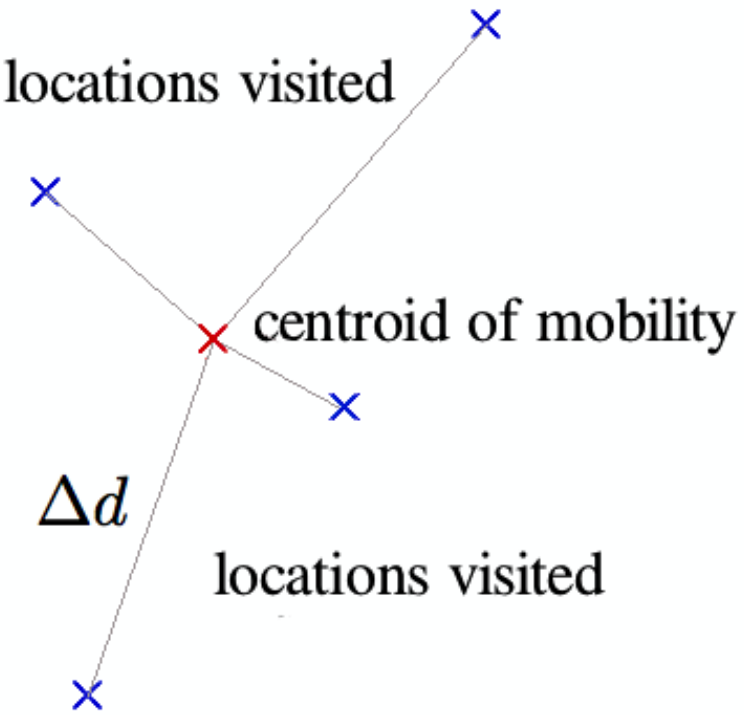
- How individuals move
- How much energy that motion requires (from vehicle fleet, mean mpg, and census/survey data)
- Collective energy consumption for large geographic areas.

Kinetic Energy

Summing over individuals:

$$E_k \propto \sum \bar{v}_i^2$$

$$\bar{v} \propto \Delta d$$



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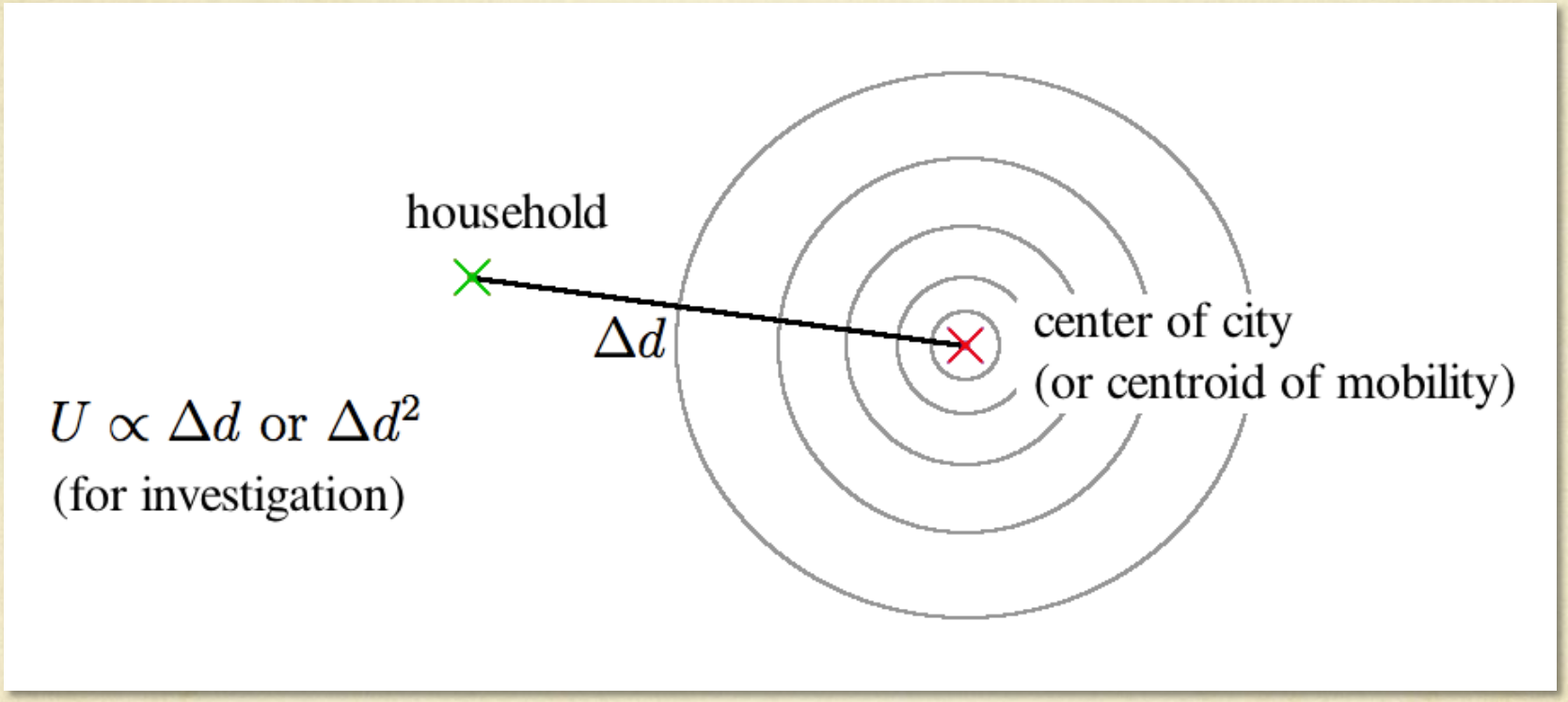
An individual's energy usage may scale with the square of total of distance traveled.

Kinetic Energy

- Using tweets, mobile phone calls, or other geo-tagged *check-ins*, model how much an individual moves.

- Using transportation mode and vehicle fleet information, together with mobility estimation, model energy consumed.

Potential Energy



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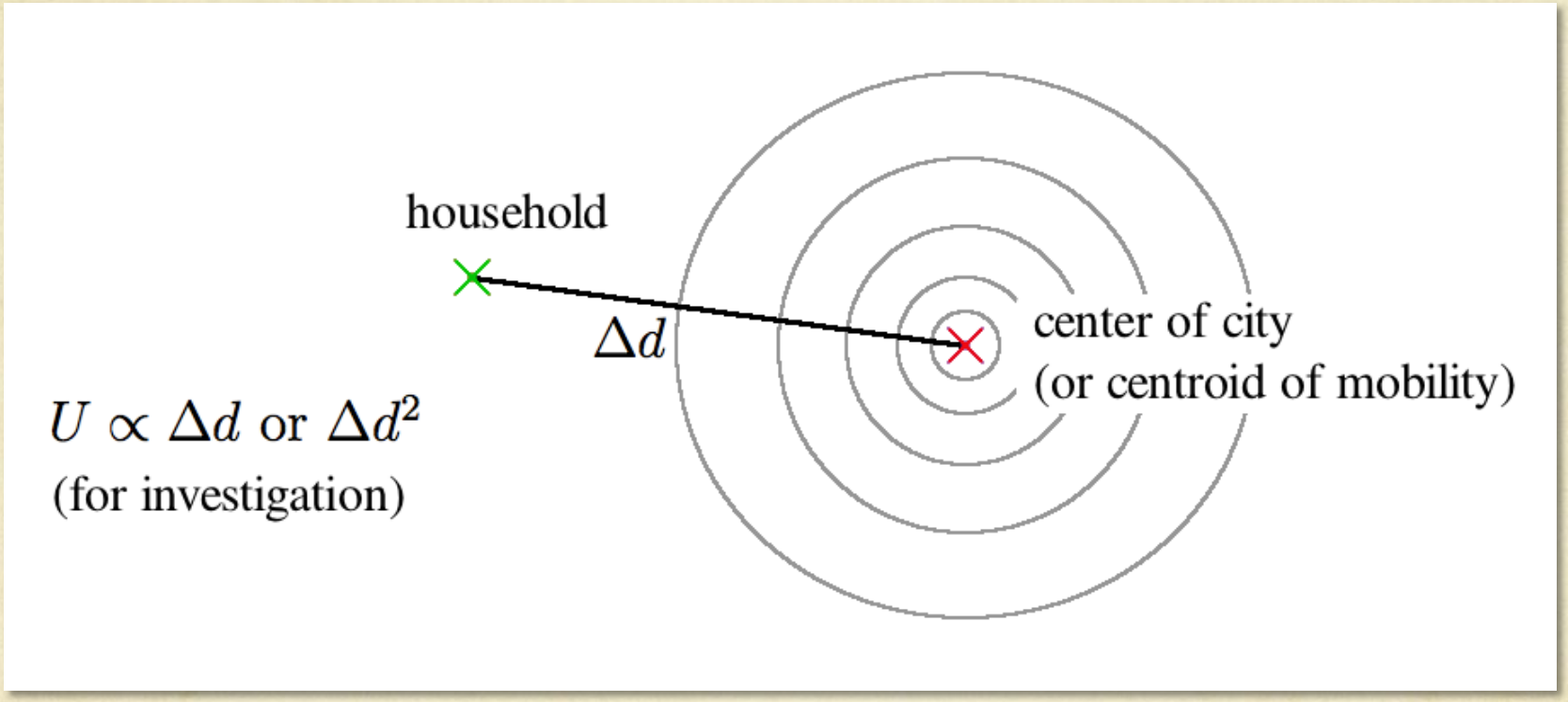
An idealized city with a single urban center, *potential energy* as a function of distance from household to city center or center of mobility.

Potential Energy



We can estimate household locations:

- *check-ins* between e.g. 11 pm and 5 am
- most frequent check-in locations

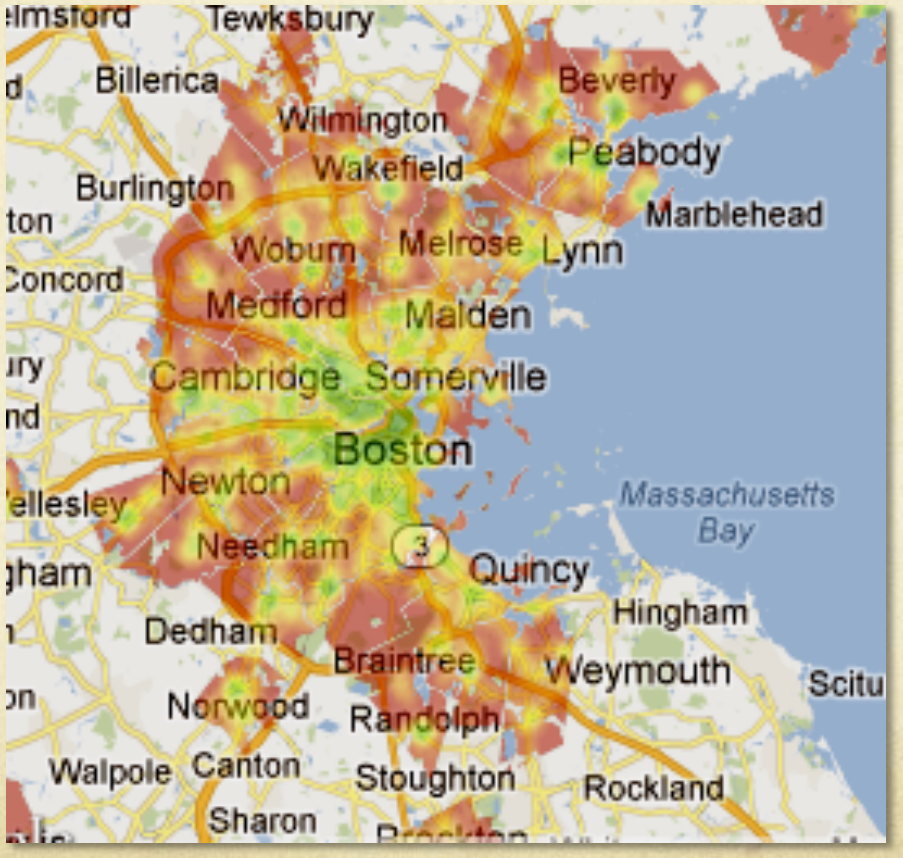
Potential Energy

- Since *every household comes with mobility required to maintain it*, it has an embedded *potential energy*, perhaps correlated with the distance from the household to:
  - the center of mobility,
  - to the urban center,
  - or to the center of job markets.

- This is very relevant to suburbanization.

Urban Efficiency

Heat maps can reveal distributions of potential or kinetic energy over a geographic area:



Example heat map – walkability of Boston: walkscore.com

Urban Efficiency

- Mean values for potential energy or kinetic energy can be calculated for an entire region, revealing *large-scale measures of efficiency*.

- Kinetic- and potential- energy models possibly capture different aspects of mobility efficiency.
  - The *kinetic* model might be parameterized in terms of a mean mobility *temperature*, and perhaps social network influences.
  - The *potential* model is possibly a function of elasticity of demand for housing location and job market access.

Hamiltonian Models?

- Interestingly, we started by applying statistical physics thinking to a large-scale human mobility phenomenon - a frequent occurrence in *Complex Systems*
- Since our application involves *actual* energy measures, it has brought us full circle, back to statistical physics and thermodynamics.

  I.e. Each individual has a *potential* and *kinetic* energy, yielding a *Hamiltonian*, often used in many-body systems:

$$H = E + U$$

Hamiltonian Models?

Using large datasets and a variety of cities, we might find:

- Scaling properties of potential and kinetic energy.
- Independent/dependent components of potential and kinetic energy (elasticity of demand/relative scaling – e.g. job location versus grocery store)
- How cities and countries compare.
- Influence of real fuel price on mobility (phase transitions)

Temperature, Entropy

With large-scale mobility, we might also consider:

- *temperature* (the average kinetic energy)
- *entropy* (the distribution of kinetic energy)
- related measures (e.g. Does *free energy* – the energy available for work - have meaning here?)

Fields

... Of course, potential energy implies one might infer *fields* that affect potential as a function of location.

I.e. predict average potential energy based on location relative to urban centers, perhaps the result of markets, social network influences, and other preferences.

Outcomes

- Reverse climate change?
  - Stop futile, proscriptive dialogue, instead address system-level problem.
- Interaction between Big Data, analysis, and planning:
  - Dynamic road pricing, incentives, or adjustments in transportation schedules, routes, or locations.
  - Finding underserved areas or other mismatches in supply and demand.
  - Effects of real fuel price, large economic fluctuations
  - Understanding congestion, traffic flow, energy, pollution.
- Intelligent interaction with individuals to improve macro-scale efficiency. (i.e. How to use the information layer to influence mobility?)
- "Laws of urban metabolism"
- Paradigm-shift towards *mobility* rather than *transportation mode*. (It's about getting from A to B, not about cars, buses, etc.)

Summary

- New mobility data and new ways to analyze it may be meaningfully applied to *urban metabolism*, in particular energy consumption, relevant to climate change and related critical phenomena.
- Effective individual and large-scale *kinetic* and *potential energy* may feasibly be estimated from mobility patterns.
- It may be possible to model behavior analytically using the *Hamiltonian* or similar formalism from statistical physics.
- *Potential energy* might be modeled in terms of a *field*.
- *Temperature* and *entropy* might also be dealt with in the framework of many-particle systems.

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Thanks!

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