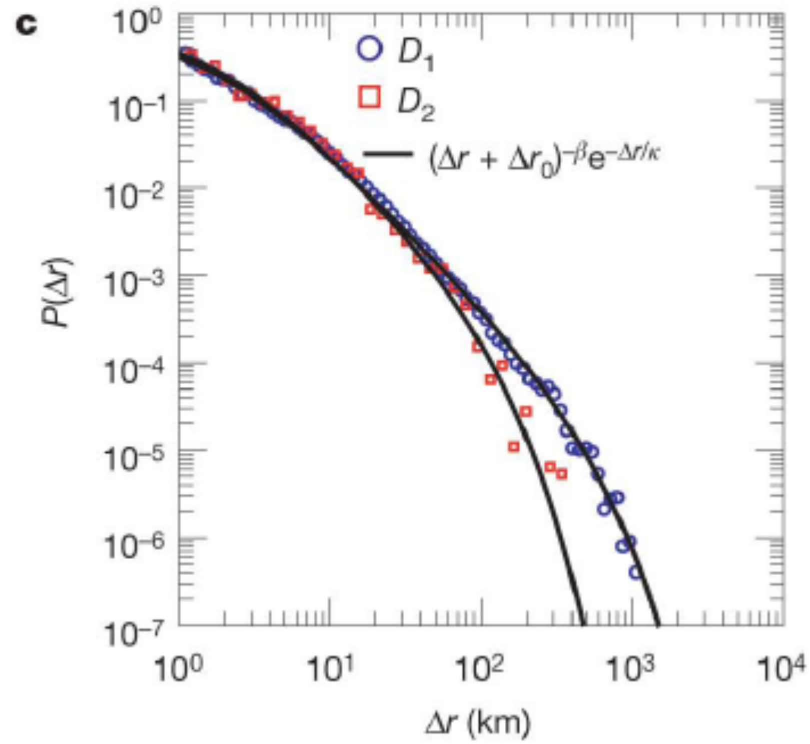
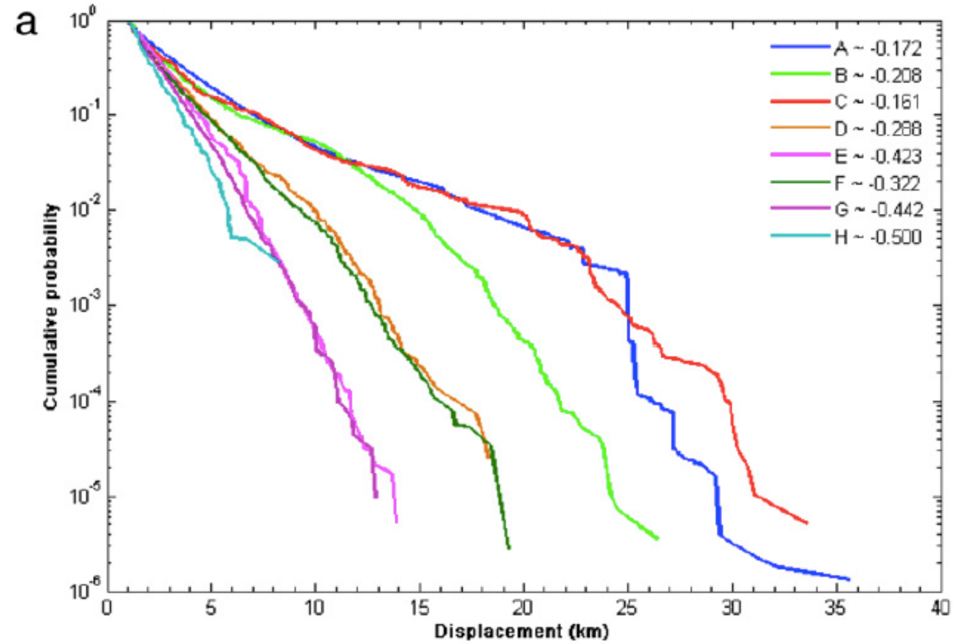
Some main findings from passive data

Displacement

as unit of analysis

Movement patterns

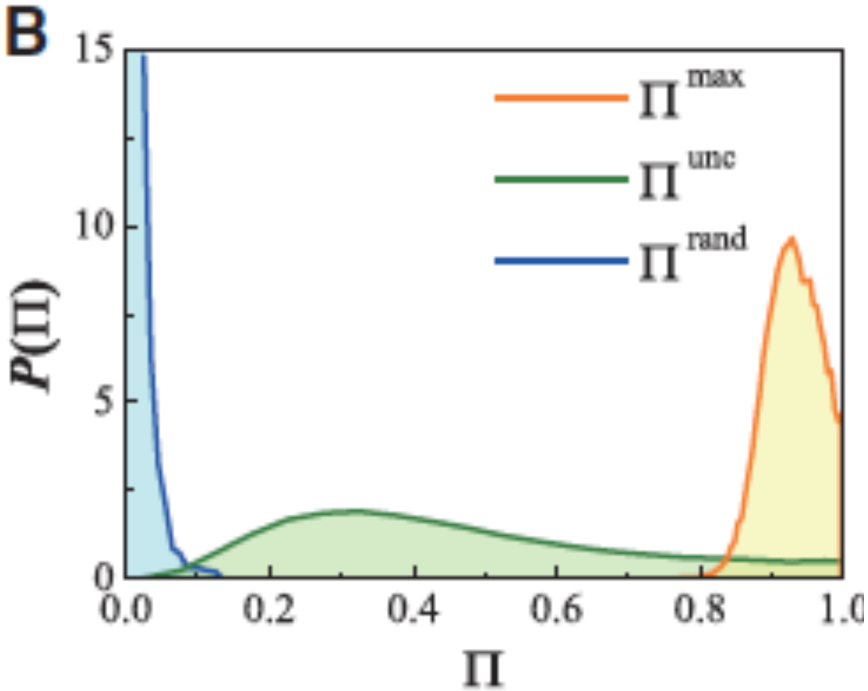


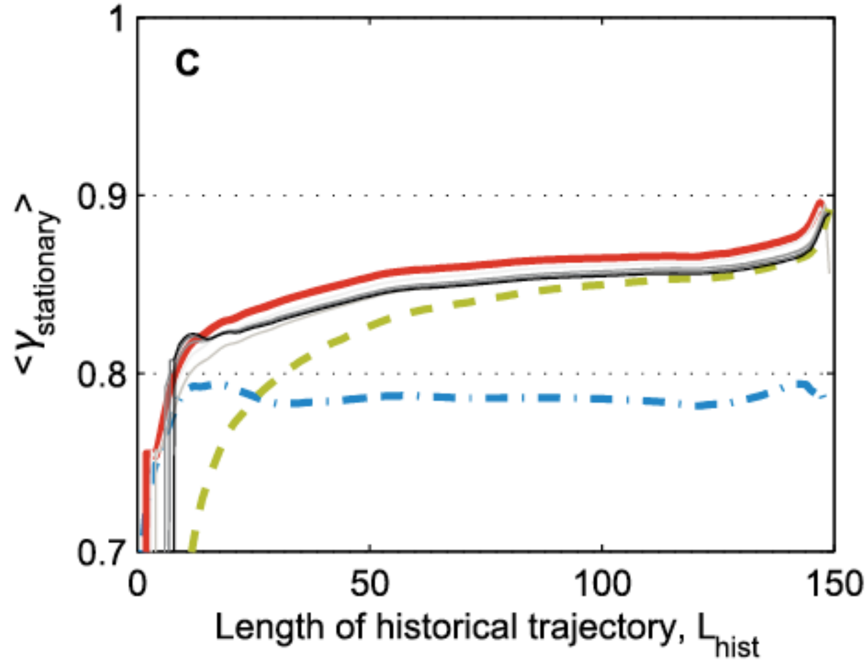


- Both power laws and exponential laws have been found for displacement patterns
- Goal-oriented and random movements result in the same distribution law and it is the underlying street network that matters!

Gonzalez et al, 2008; Jiang et al., 2009; Kang et al., 2012

Predictability





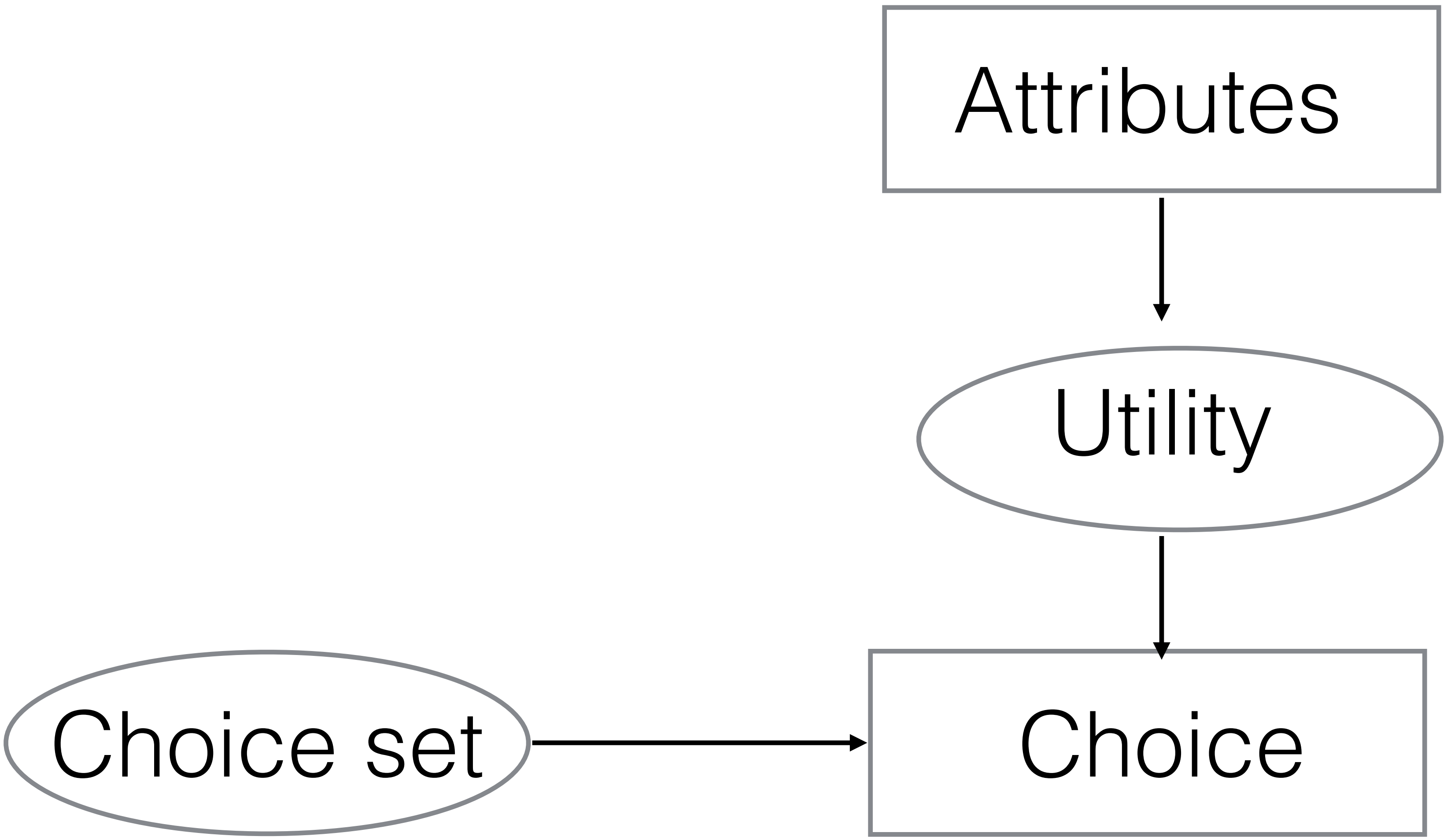
- Theoretical predictability limit: 0.93
- Practical predictability: above 0.8

Song et al., 2010; Lu et al., 2013

model development
- behavior choices

Discrete choice models

- Properties of a discrete choice
  - answering the question of which one
  - a finite and feasible choice set


Attributes
Utility
Choice set
Choice

Random utility theory

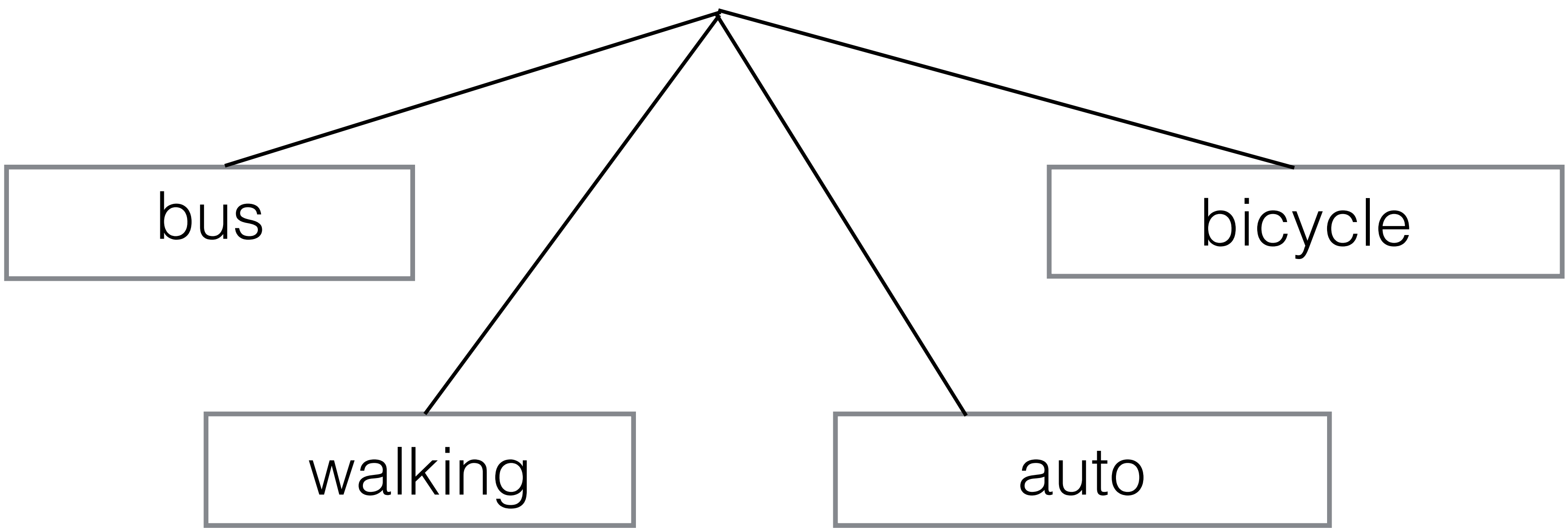
$$
\begin{aligned}
Pr[U_i] &= Pr[U_i \geq U_j, \forall i, j \in C] \\
&= Pr[V_i + \epsilon_i \geq V_j + \epsilon_j] \\
&= Pr[\epsilon_j - \epsilon_i \leq V_i - V_j]
\end{aligned}
$$

- *V* is the systematic utility,
- ϵ is the random error term

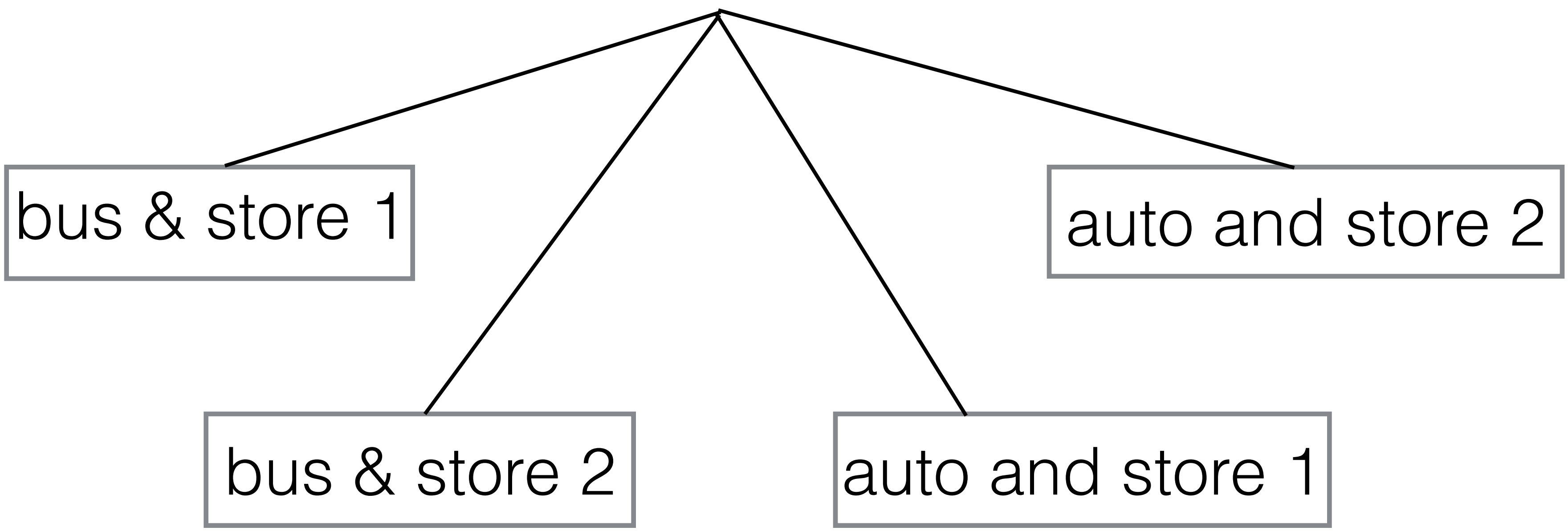
Logit model

$$Pr[i] = \frac{e^{V_i}}{\sum_j e^{V_j}}$$

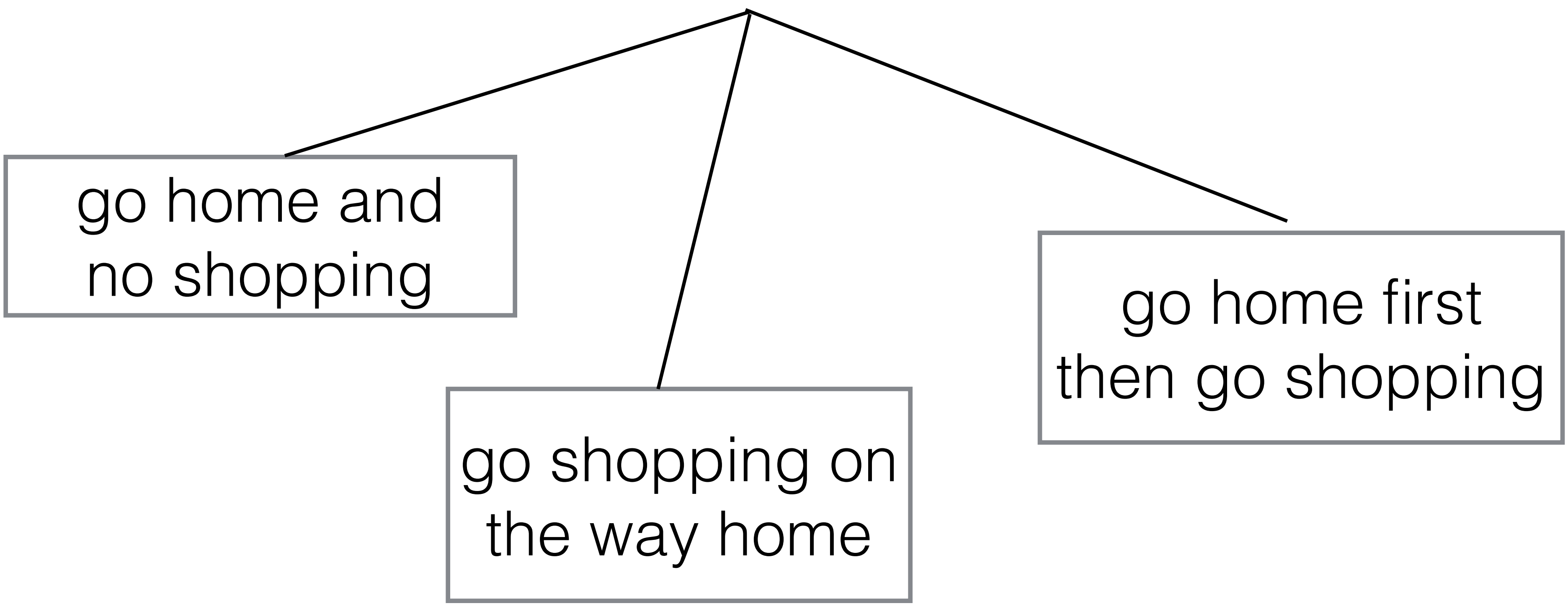
Example choices



from single to multiple choices



From single to multiple trips



Limitations

$$U_i = V_i + \epsilon_i$$

- random utility is independent and identically distributed (IID) with a type 1 extreme value distribution
  - no random taste variation
  - proportional substitution $$\frac{P^1_{ni}}{P^1_{nk}} = \frac{P^0_{ni}}{P^0_{nk}}$$

Bhat, 1997, 2000; Train 2009

Proportional substitution

	Before	After
large gas cars	0.66	0.6
small gas cars	0.33	0.3
EV cars	0.01	0.10

Heteroscedastic models

$$U_i = V_i + \epsilon_i, \text{where } \epsilon_i \sim G(0, \theta_i)$$
$$Pr(i) = Pr(U_i > U_j), \forall j \neq i, j \in C$$
$$= Pr(\epsilon_j \leq V_i - V_j + \epsilon_i), \forall j \neq i, j \in C$$
$$= \int_{\epsilon_i = -\inf}^{\epsilon_i = +\inf} \sum_{j \in C, j \neq i} \Lambda[\frac{V_i - V_j + \epsilon_i}{\theta_i}] \frac{1}{\theta_i} \lambda(\frac{\epsilon_i}{\theta_i}) d\epsilon_i$$
$$\text{where } \lambda(t) = e^{-t} e^{-e^{-t}} \text{ and } \Lambda(t) = e^{-e^{-t}}$$

Bhat, 2000

GEV models

Let $Y_i = exp(V_i); \quad G = G(Y_1, Y_2, ...Y_J); G_i = \partial G / \partial Y_i$

if G satisfies certain conditions, then $P_i = \frac{Y_i G_i}{G}$

is the choice probability for a discrete choice model that is consistent with utility maximization

1. $G \geq 0$ for all possible values of $Y_j \forall j$.
2. G is homogeneous of degree one.
3. $G \to \infty$ as $Y_j \to \infty$ for any j
4. The cross partial derivative of G change signs in a certain way. That is, $G_i \geq 0$ for all i, $G_{ij} = \partial G_i / \partial Y_j \leq 0$ for all $j \neq i$, $G_{ijk} = \partial G_{ij} / \partial Y_k \geq 0$ for any distinct i,j,k, so on for higher cross-partials

Train, 2009

An example GEV model for dest. choices

$$G(y_1, y_2, \ldots y_c) = \sum_{i=1}^{c-1} \sum_{j=i+1}^{c} [(k_{i,ij} y_i)^{1/(1-\rho_{ij})} + (k_{j,ij} y_j)^{1/(1-\rho_{ij})}]^{1-\rho_{ij}}$$

Where,

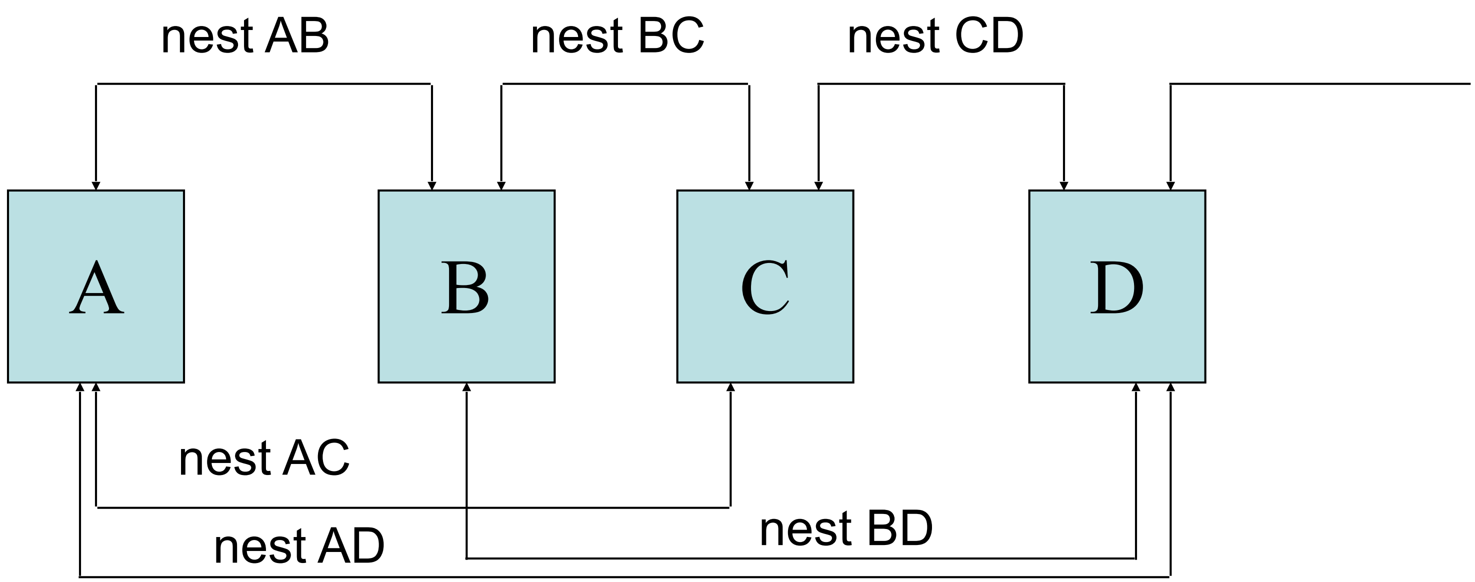
$y_k \geq 0$ for all i,

$k_{i,ij}$ is weighting parameter for alternative i in nest ij.

ρ_{ij} and $k_{i,ij}$

- ρ_{ij} is the similarity index, measuring the degree of correlation between alternatives *i* and *j* in nest *ij*
- $k_{i,ij}$ is the weighting parameter, measuring the extent alternative *i* belongs to nest *ij*

Assumed correlation structure



The probability function for household n is:

$$P_n(j) = \frac{\sum_{i=1, i\neq a}^{c} (k_{j,ij} e^{V_{n,j}})^{1/1-\rho_{ij}} [(k_{j,ij} e^{V_{n,j}})^{1/1-\rho_{ij}} + (k_{i,ij} e^{V_{n,i}})^{1/1-\rho_{ij}}]^{\rho_{ij}-1}}{\sum_{i=1}^{c-1} \sum_{j=i+1}^{c} [(k_{j,ij} e^{V_{n,j}})^{1/\rho_{ij}} + (k_{i,ij} e^{V_{n,i}})^{1/\rho_{ij}}]^{\rho_{ij}}}$$

Where,

$$\begin{cases} \rho_{ij} = \exp(-\lambda \times dist_{ij}^{0.2}), \text{if } \mathrm{dist}_{ij} \leq 3.5 \text{ miles} \\ \rho_{ij} = 0, \text{if } \mathrm{dist}_{ij} > 3.5 \text{ miles} \end{cases}$$

$$k_{i,ij} = \frac{I(\rho_{ij})}{\sum_{m=1, m\neq i}^{c} I(\rho_{im})}$$

mixed logit model

$$P_{ni} = \int (\frac{e^{\beta^{'} x_{ni}}}{\sum_j e^{\beta^{'} x_{nj}}}) f(\beta) d\beta$$

$$\frac{\Delta P_{ni}/P_{ni}}{\Delta x_{nj}^m / x_{nj}^m} = -x_{nj}^m \int \beta^m L_{nj}(\beta)[\frac{L_{ni}(\beta)}{P_{ni}}] f(\beta) d\beta$$

$$L_{ni}(\beta) = \frac{e^{V_{ni}}(\beta)}{\sum_{j=1}^J e^{V_{nj}}(\beta)}$$

Train, 2009

mixed logit model

error component model

$$U_{ni} = \gamma' y_{ni} + \zeta_{ni} = \gamma' y_{ni} + \mu' z_{ni} + \epsilon_{ni}$$

random coefficient model

$$U_{ni} = \beta_n' x_{ni} + \epsilon_{ni}$$

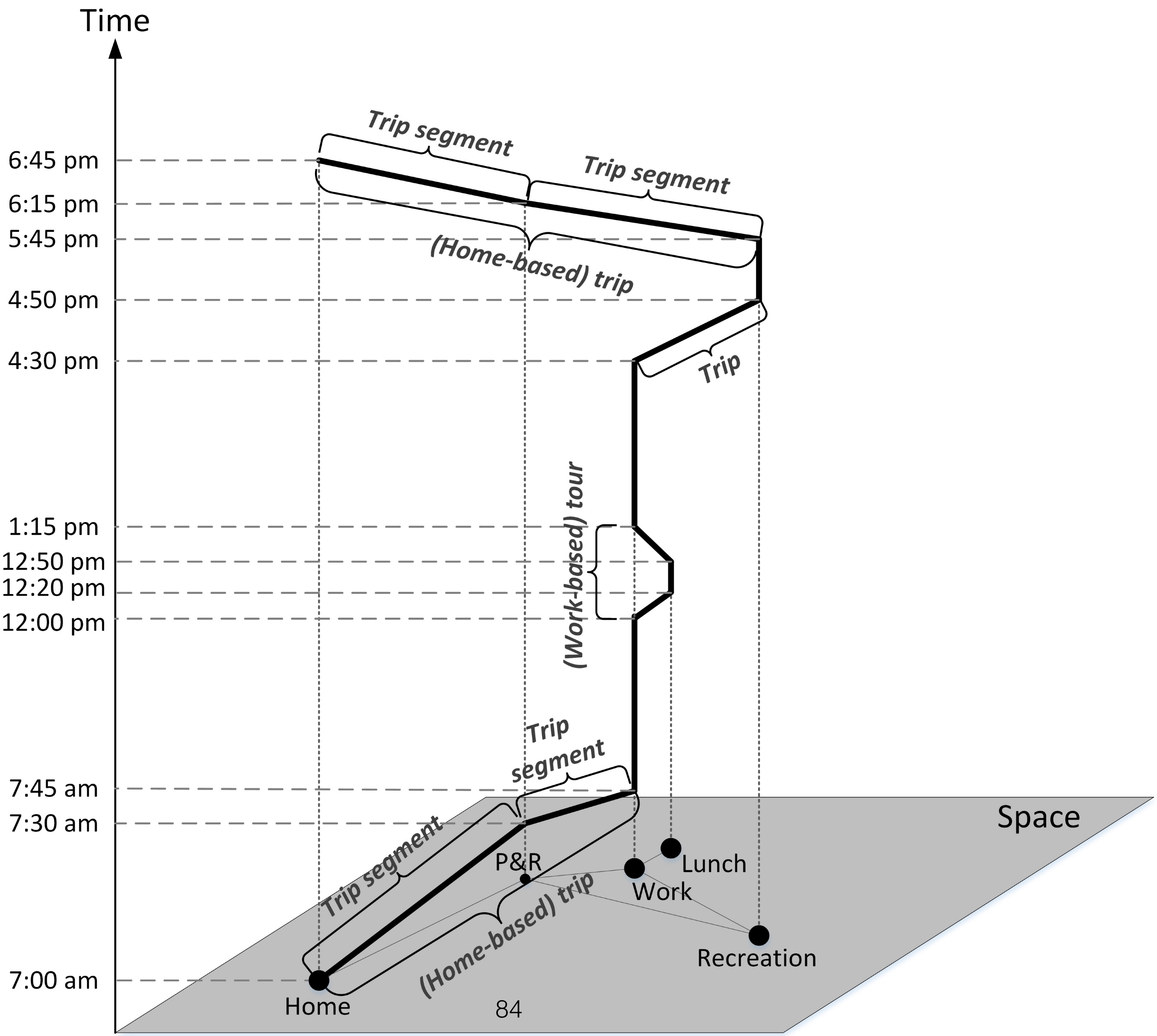
Hazard model

$$F(t) = Pr[T < t]$$

$$f(t) = \frac{dF(t)}{d(t)} = \lim_{dt \to 0} \frac{Pr(t \leq T < t + dt}{dt}$$

$$S(t) = Pr[T \geq t] = 1 - F(t)$$

$$h(t) = \frac{f(t)}{S(t)} = \lim_{dt \to 0} \frac{Pr(t \leq T < t + dt | T \geq t)}{dt}$$



Time
6:45 pm
6:15 pm
5:45 pm
4:50 pm
4:30 pm
1:15 pm
12:50 pm
12:20 pm
12:00 pm
7:45 am
7:30 am
7:00 am
Trip segment
Trip segment
(Home-based) trip
Trip
(Work-based) tour
Trip segment
Trip segment
(Home-based) trip
Space
P&R
Lunch
Work
Recreation
Home

Activity-based models

- Types of underlying models
  - Feasibility based
  - Feasibility and behavior based
  - behavior based
- Building an activity/travel pattern
  - simultaneous
  - sequential

BEHAVIORAL FACTORS

Motivation

- Understanding spatial behaviors
  - factors
  - underlying behavioral mechanisms
- Policy evaluation
- *Finding behavioral triggers*

The usual factors

Most often

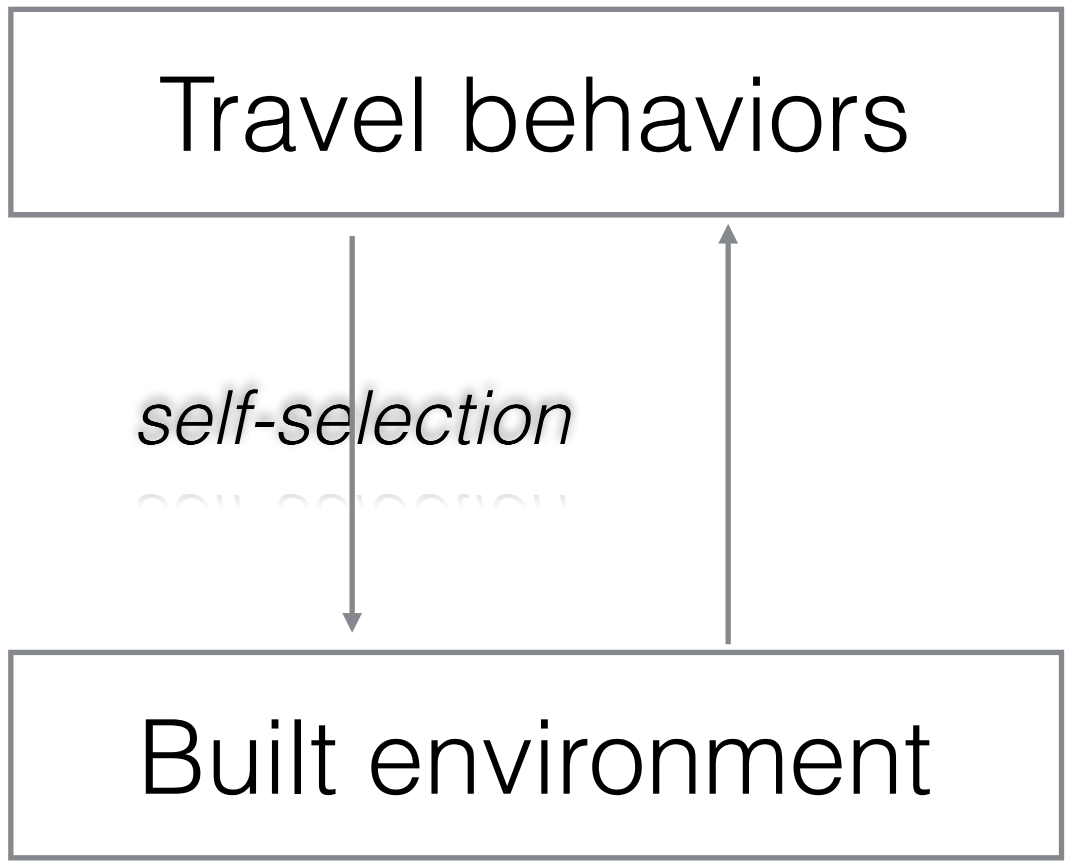
- socio-demographics
- the built environment
- trip/alternative related factors

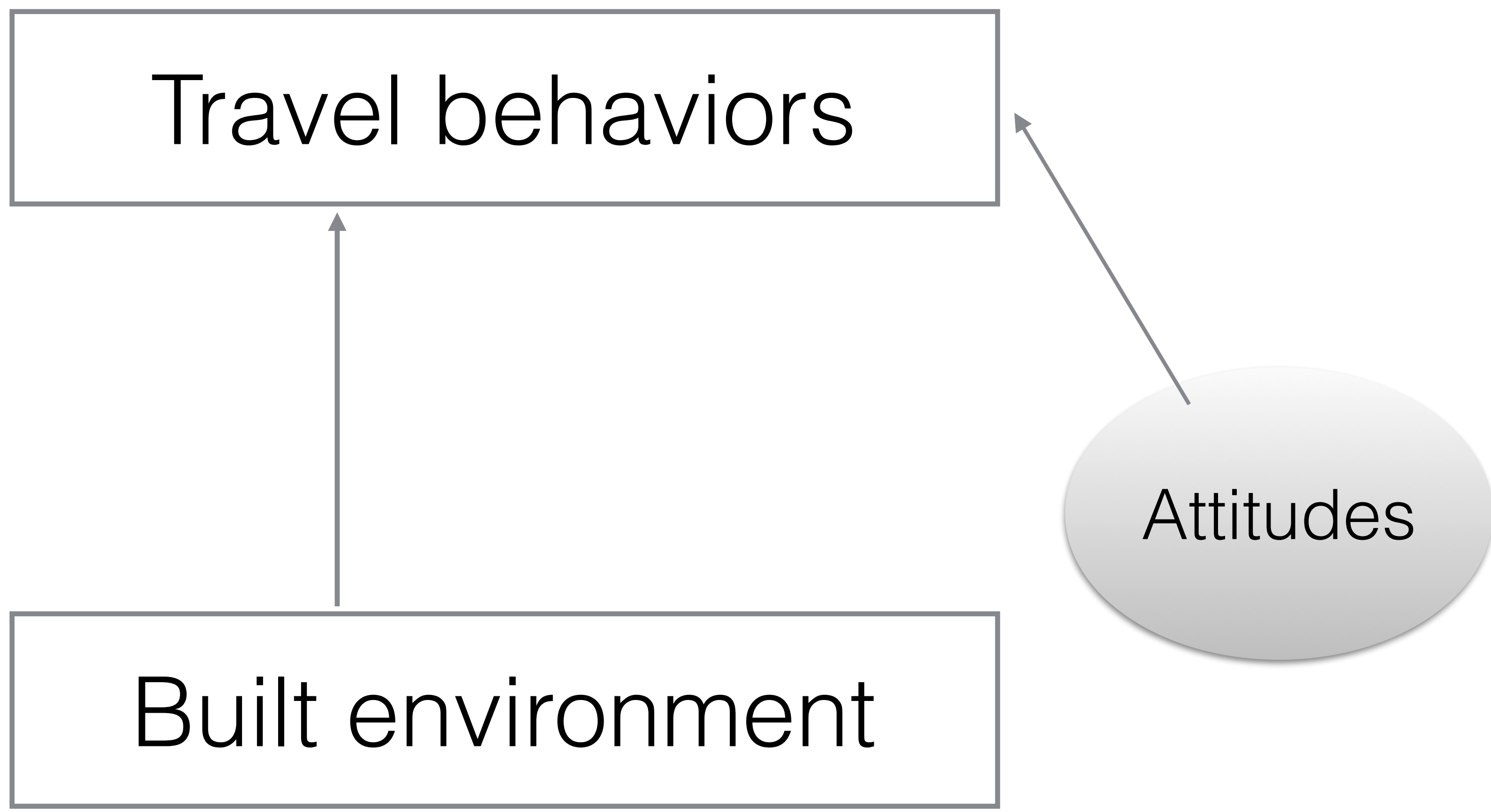
Less often

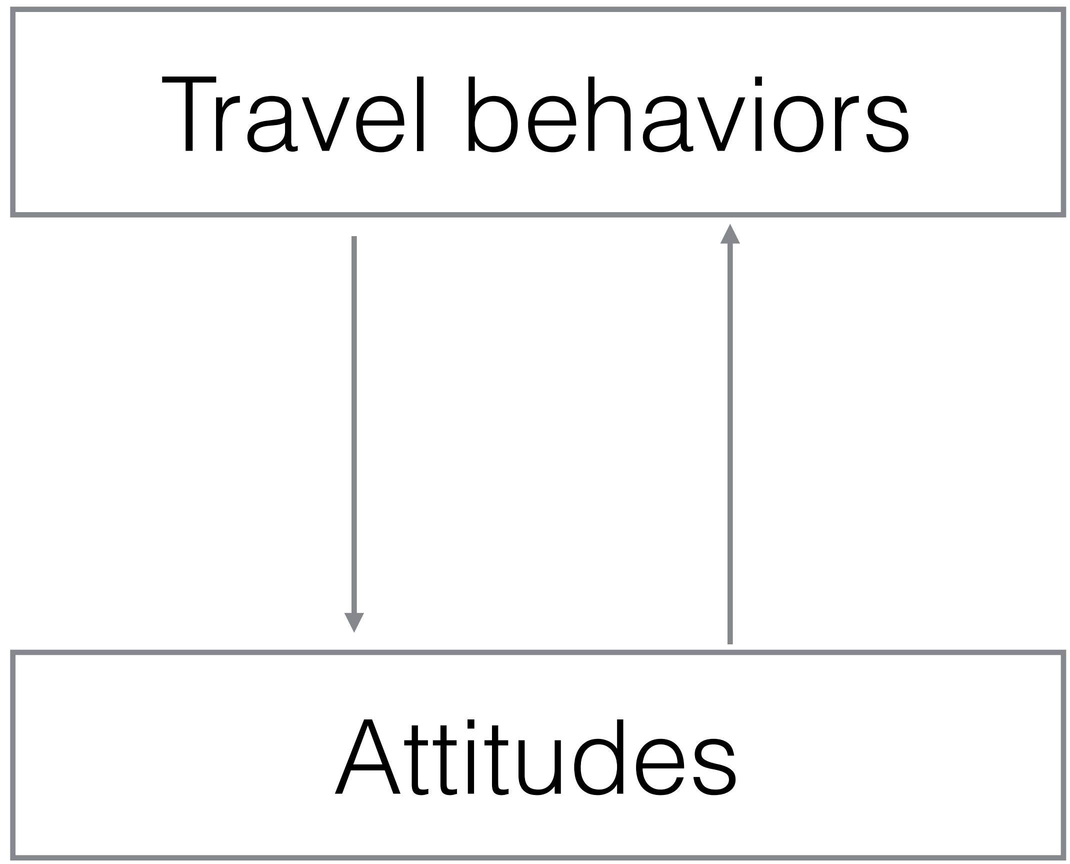
- attitudes
- feelings

Accessibility

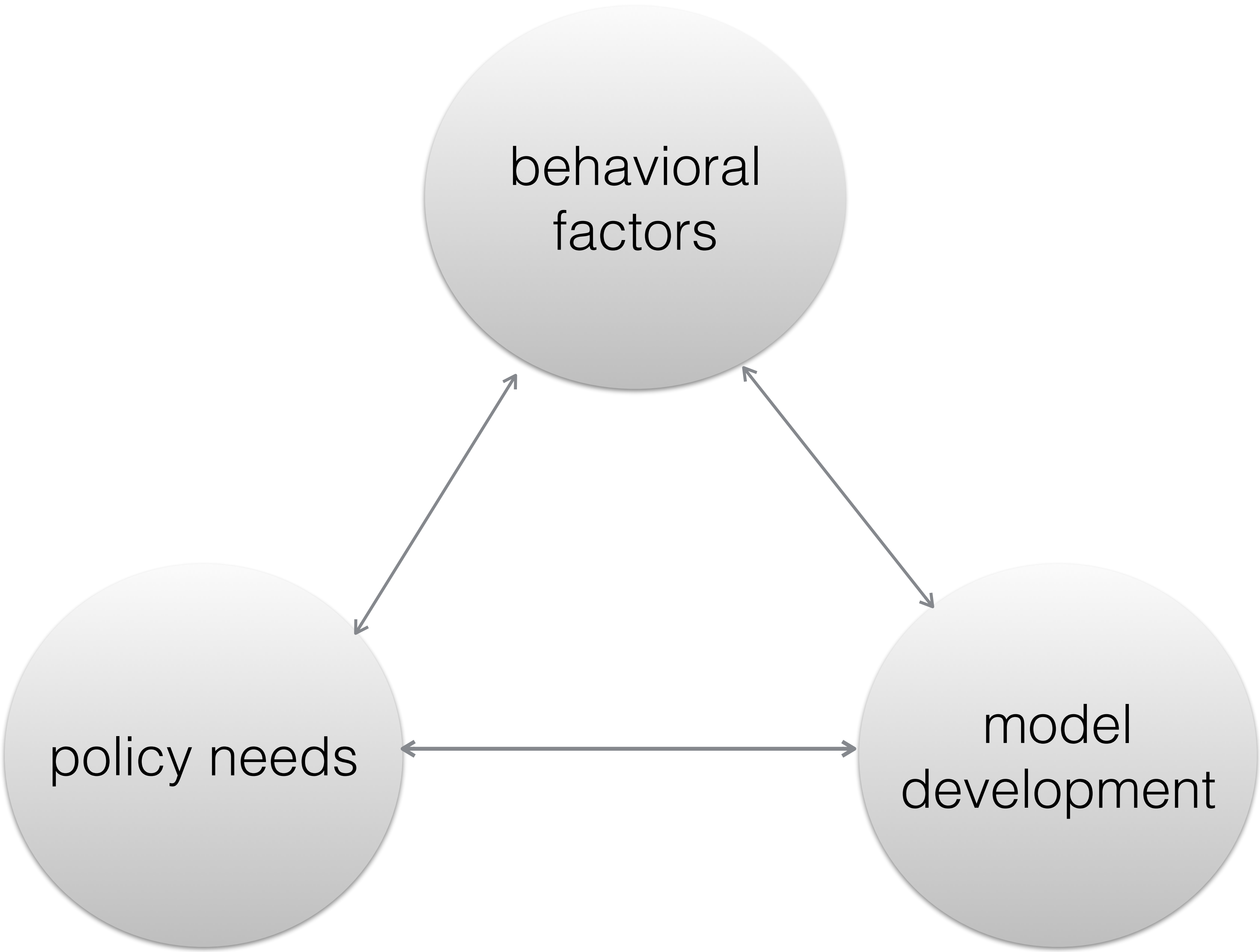
- Conventional measures (relative or integral)
  - uses a single reference location
  - enumerates all possible destinations
  - uses an impedance function to capture the effect of distance decay
- Space-time accessibility measures


Travel behaviors
self-selection
Built environment


Travel behaviors
Attitudes
Built environment



Wang and Chen, 2012

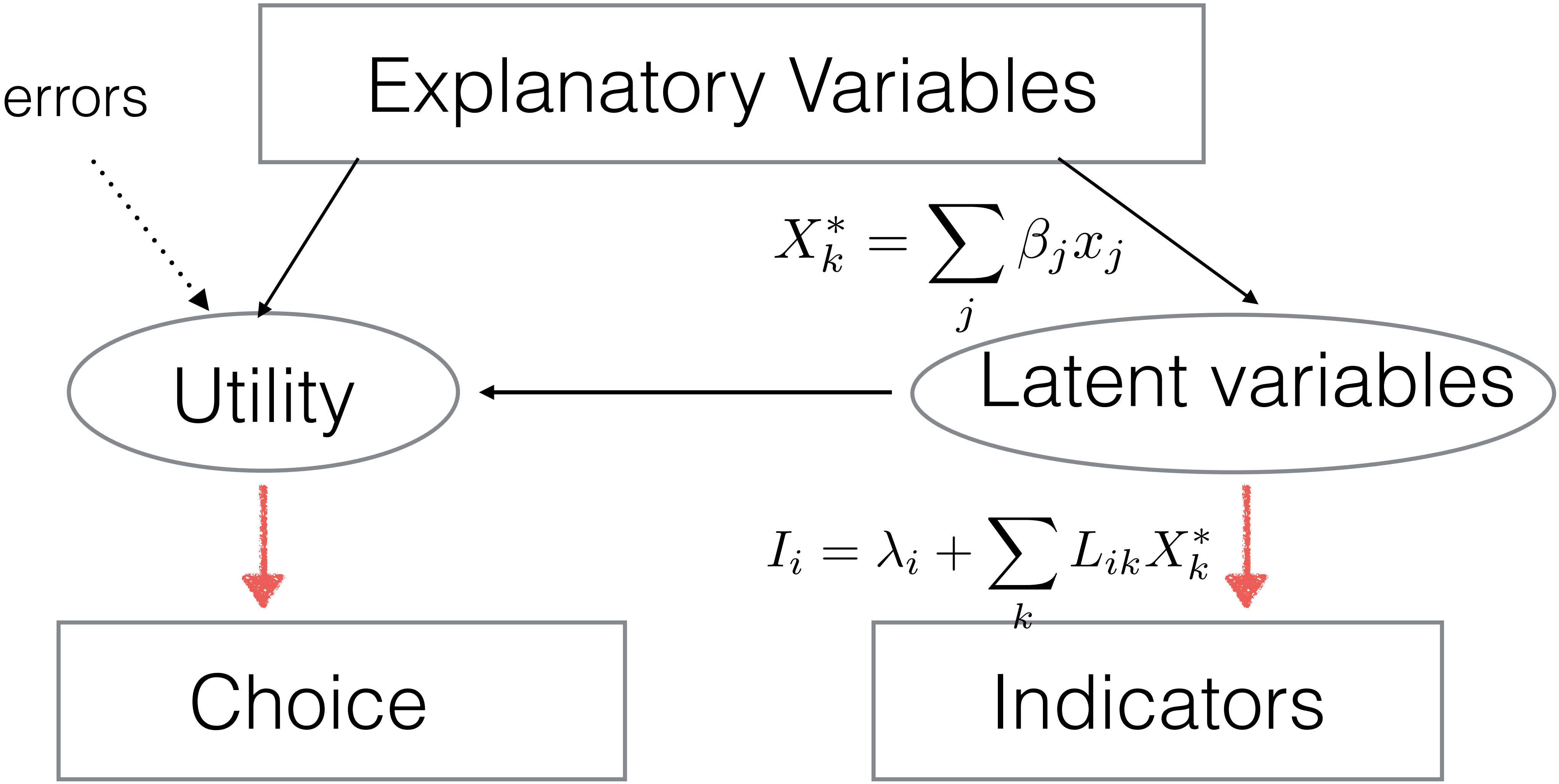

behavioral factors
policy needs
model development

Attitudinal statements

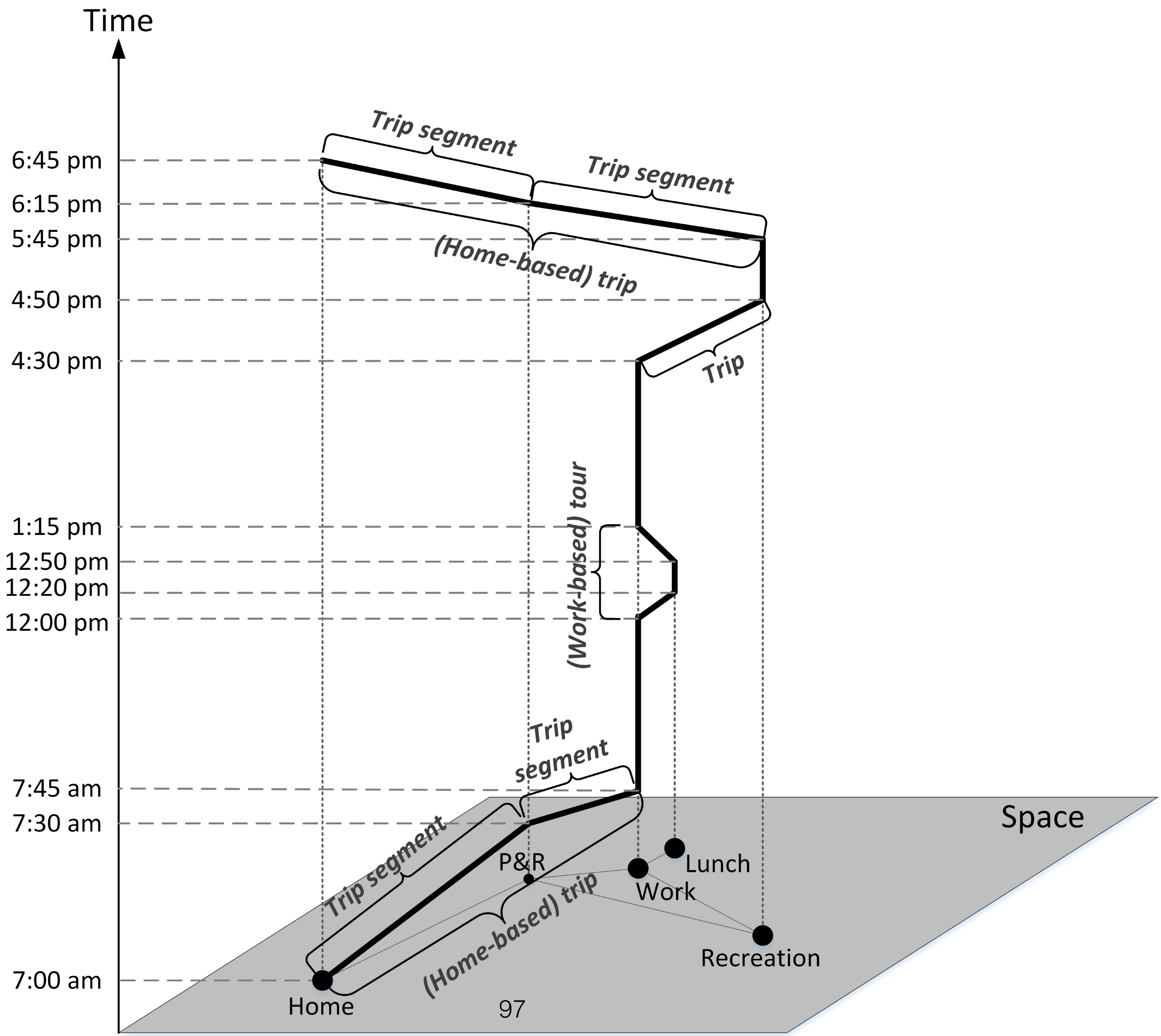
For each question, response on a scale: strongly agree, agree, neutral, disagree, strongly disagree, no idea.

- The price of oil should be increased to reduce congestion and pollution
- More public transportation is necessary, even if it means additional taxes
- Ecology is a threat to minorities and small companies.
- People and employment are more important than the environment.
- I feel concerned by the global warming.
- Decisions must be taken to reduce the greenhouse gas emission.

Bierlaire, 2010


errors
Explanatory Variables
$X_k^* = \sum_j \beta_j x_j$
Utility
Latent variables
$I_i = \lambda_i + \sum_k L_{ik} X_k^*$
Choice
Indicators

Mathematicians and travel behavior researchers in partnership to answer ***policy-relevant questions***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Validation, validation, validation

Movement patterns

We need models that describe our activity/travel patterns evolve over time and a framework that tie the models together!

A few other suggestions

- Plot probability distributions under different circumstances (e.g., context, population…)
- Scramble with random movements too
- Get temporal: look at changes over time
- Downscale: look at metrics at the individual level

Model development

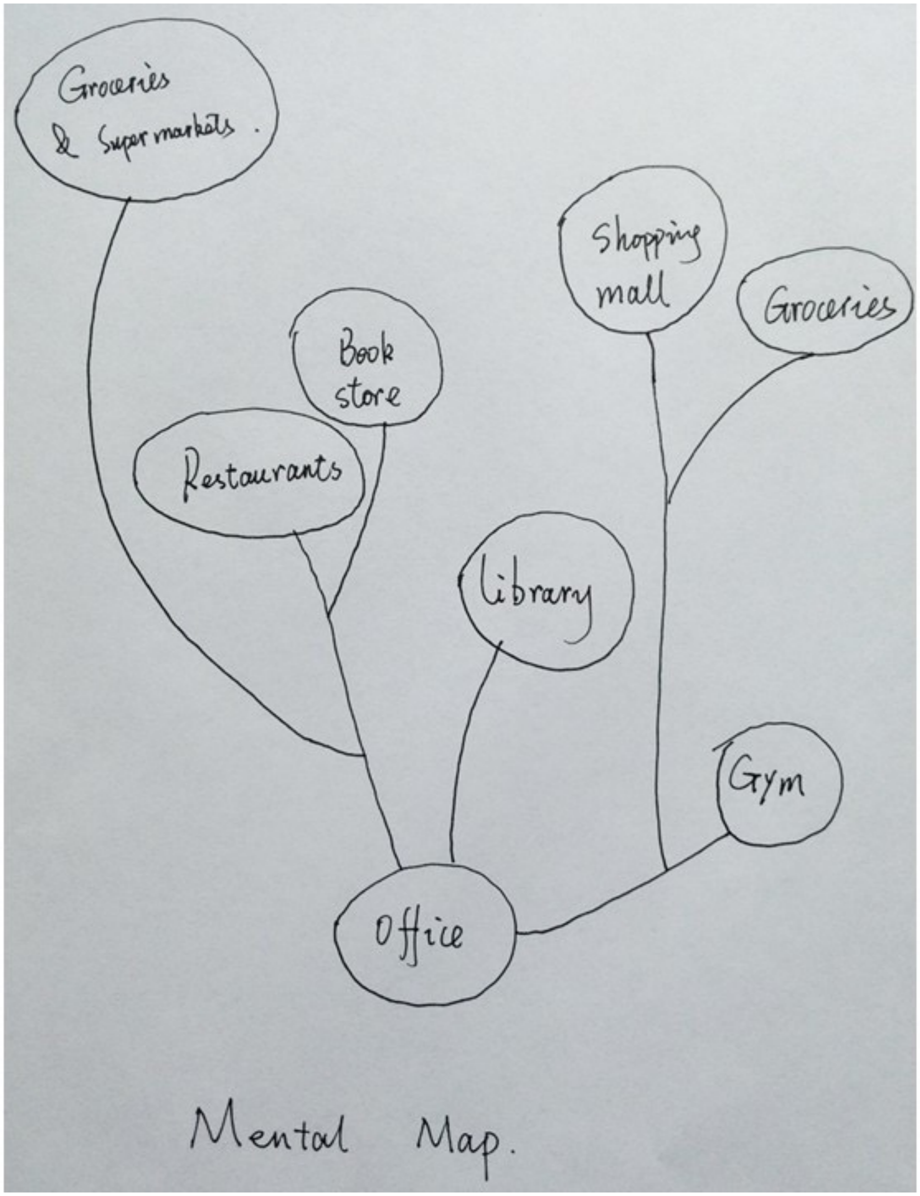
Choice set

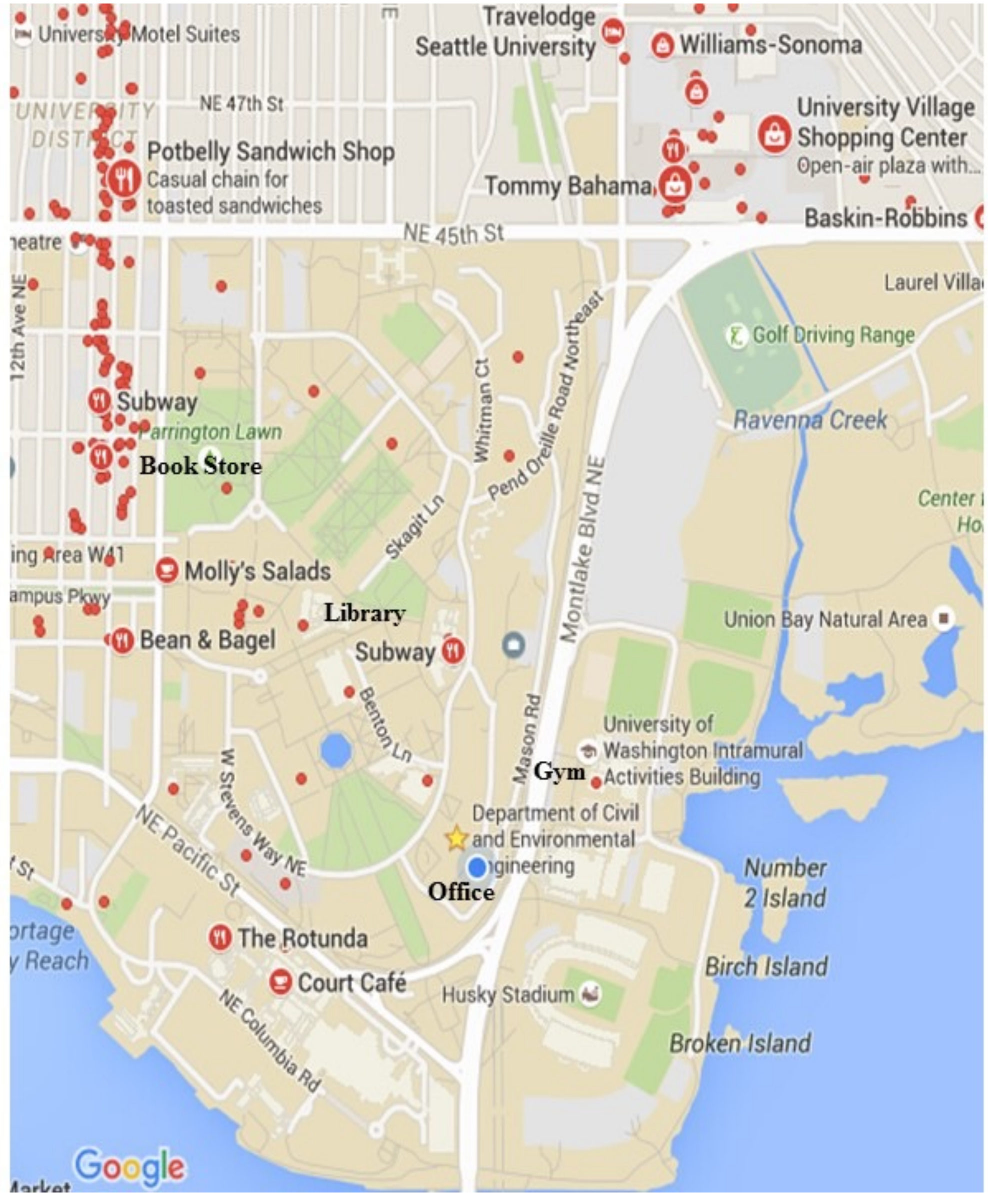
Can we leverage the mobile phone dataset and knowledge on space-time prisms to generate more realistic choice sets for individuals?

Destination choices

- a choice problem that does not correspond to the use of standard discrete choice models
    - *complex substitution patterns*
    - *choice set formation*

Spatial set and mental map





Comparing models

- To uncover source of disagreement
- To identify critical data that are needed to resolving these differences and solidify our understanding of a phenomenon

The need for simple, analytical models

- Need to think more about the fundamental mechanisms that govern the observed travel patterns

- Connect to data-driven computational approaches to investigate the impact of the various complex features of real systems on the basic properties

Behavior factors

Understanding behaviors

- Identifying additional factors (e.g., social network factors, though it is not a new discovery)
- Uncovering decision rules applied
- Understanding experience accumulated, feelings generated and attitudes formed

Policy evaluation

Some policy-relevant questions

- If density is increased, will people use bus or walk more often?
- What incentives shall be provided for people to reduce driving?
- How are emerging transportation services (e.g., Uber) changing people's travel patterns?
- If we build a light rail, will people use it?
- How to move toward reducing auto ownership and moving to more compact locations?
- ….

Cannot be answered with cross-sectional data!

What about those passive mobile phone data?

- If we can correctly guess:
  - essential elements about one's travel pattern
  - other attributes such as socio-demographics
  - behavioral triggers (what, when and where)
- data length is sufficiently long

We still need:

- Conceptual frameworks that describe behaviors
- Carefully designed experiments
- Hypotheses
- …
- …

Prediction, Policy and Behavior Triggers

- Let us talk about meaningful locations!
- Move beyond just location prediction or even trip-related prediction
- Learn individual preferences over time
- Be innovative on the alternatives offered — Think Marketing
- Find the low-hanging fruit
- Together, contribute to both individual and societal welfare!

Why not cross-sectional data?

- no notion of (ir)regularity of individual behaviors
- infrequent trips (e.g., long-distance trips) are not captured
- not possible to distinguish between intra- and inter-personal variability
- if behavior changes are inferred, we assume that they are:
    - instantaneous, symmetric, and stationary

What can be learned from a panel survey?

- many subjects, multiple time points (explicit time dimension)
- best suited for policy analysis (e.g., how a change in the system will affect travel behaviors?)
- causal analysis (since causes and effects are observed)
- potential to improve model forecasts (due to temporal and interpersonal aspects)
- can explicitly measure and model asymmetric effects, response lags/leads, and state dependence etc.
- explicitly recognize the "multiple equilibria" phenomenon (Mahmassani, 1990)