A Cognitive Framework for Unifying Human and Artificial Intelligence in Transportation Systems Modeling

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Nov. 7, 2018 Maui, HI

Two general modeling philosophies

Behavior-based (Paramorphic)

- Approximating Revealed Behavior
- Pros: no need to consider "unobservable" explicitly
- Cons: forever in the phase of "catching up" by adding one extension or major modification after another; challenge of explaining paradoxes in reality

Vs.

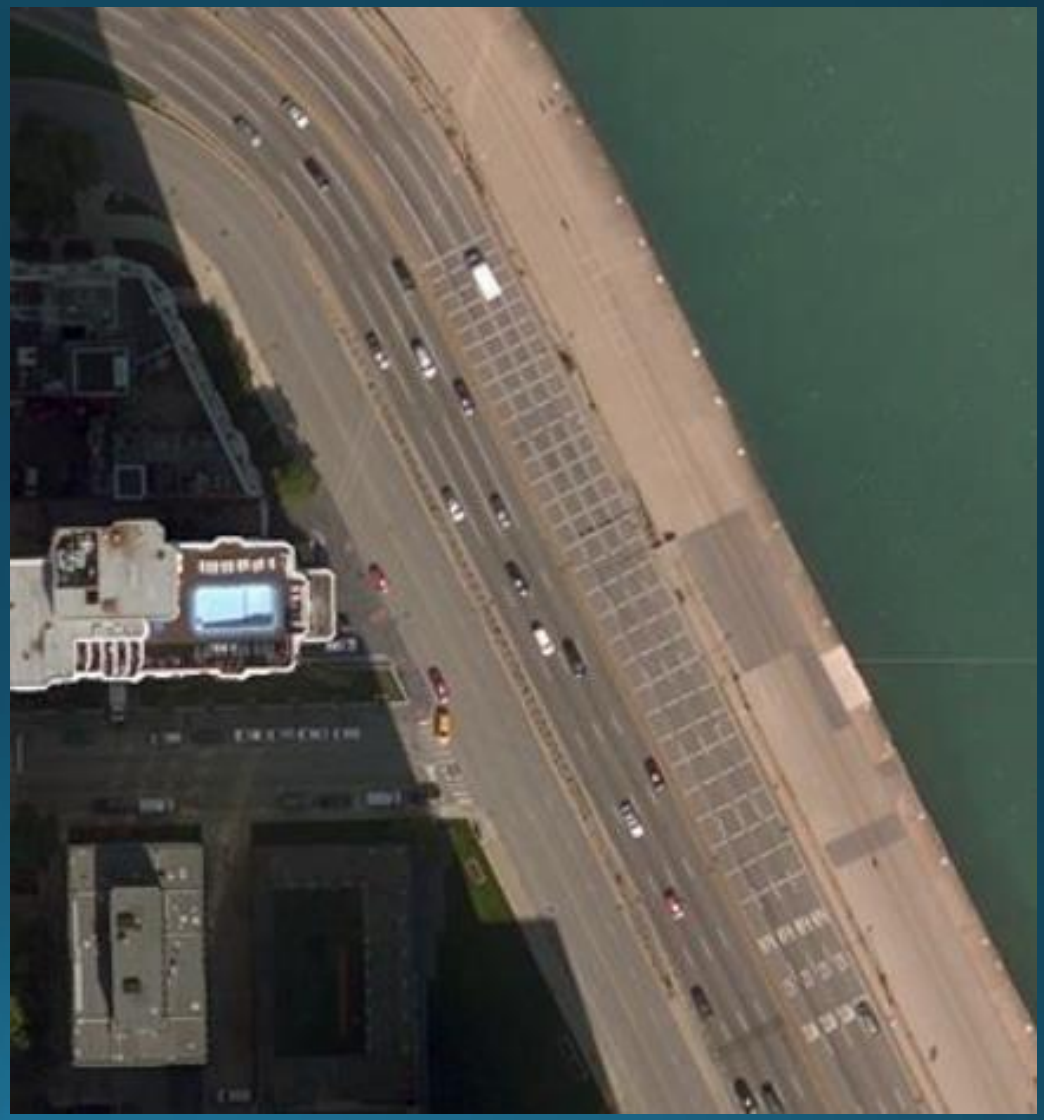
Cognition-based (Homeomorphic)

- Model the underlying mechanism (Cognition)
- Pros: modeling new phenomena becomes just another set of input.
- Cons: more thoughts on assumptions (maybe a good thing)

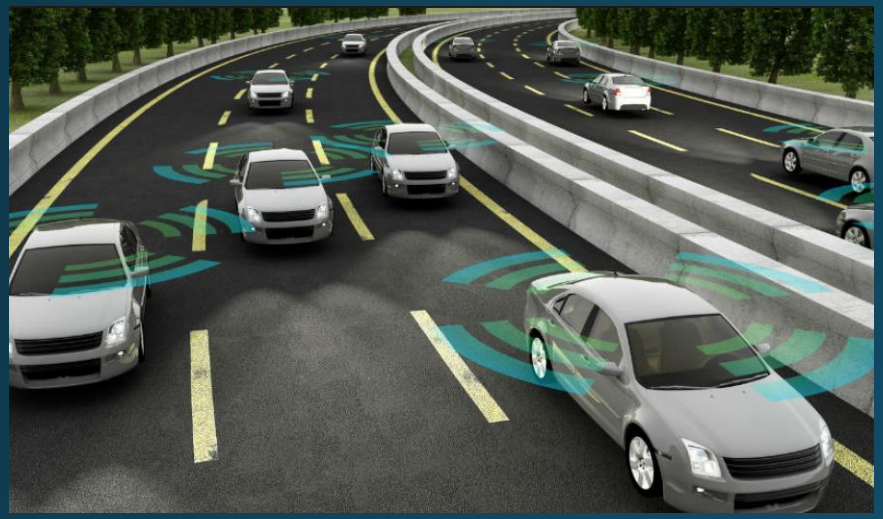
Cognition (Oxford Dictionary Nov. 3, 2018)
"The mental action or process of acquiring knowledge and understanding through thought, experience, and the senses."

"**36%** fewer crashes in the six month after the lines were painted compared to the same 6-month period of the year"

-- city traffic engineers, Chicago Department of Transportation, 2007



Extension/add-ins vs. varying input?

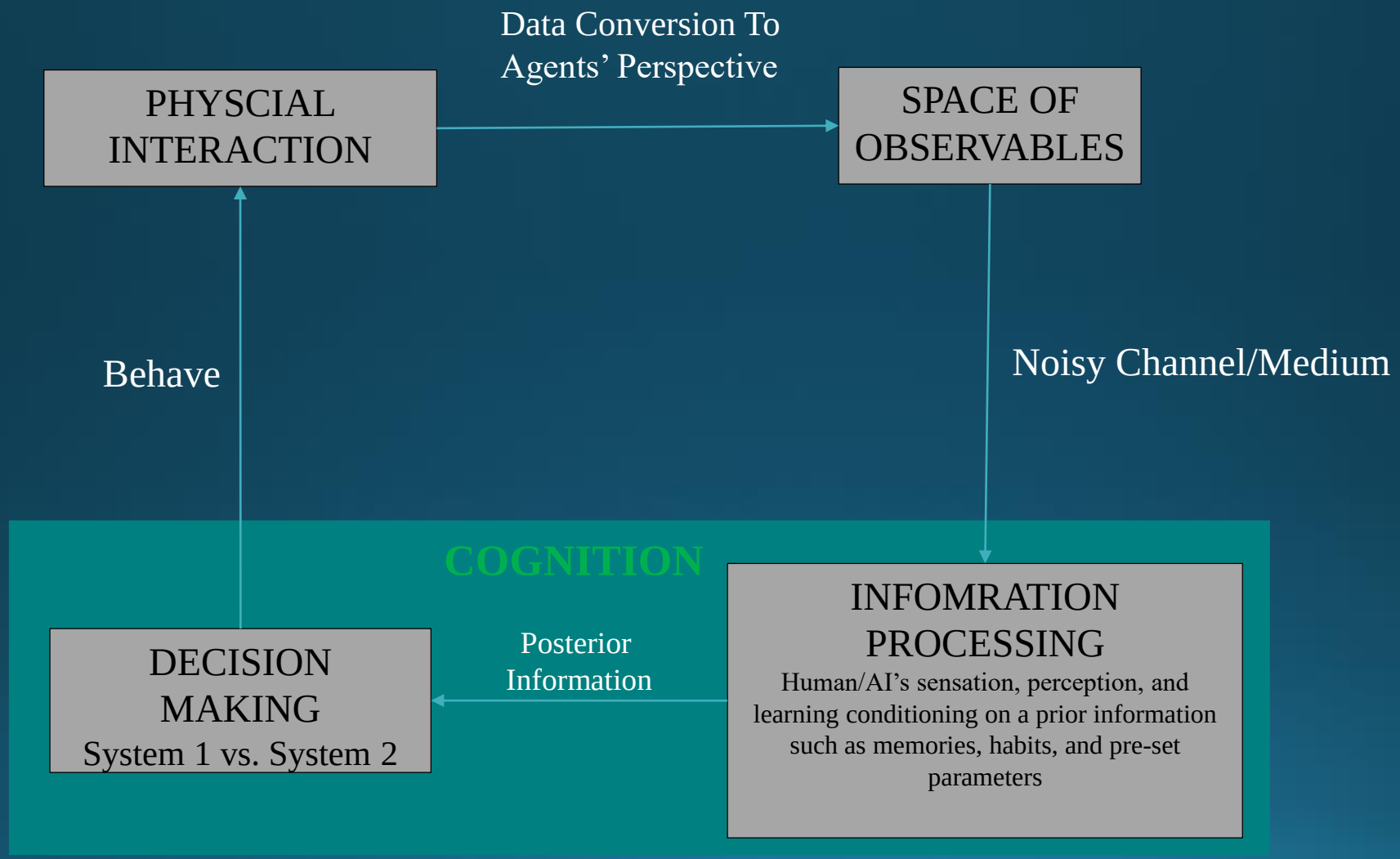


HAIL O
EASY TAXI
lyft
Flywheel
OLA
GRABTAXI
Get Taxi
UBER
BLACKLANE LIMOUSINES
shuddle
Getaround
VIA
99TAXIS
Side·car

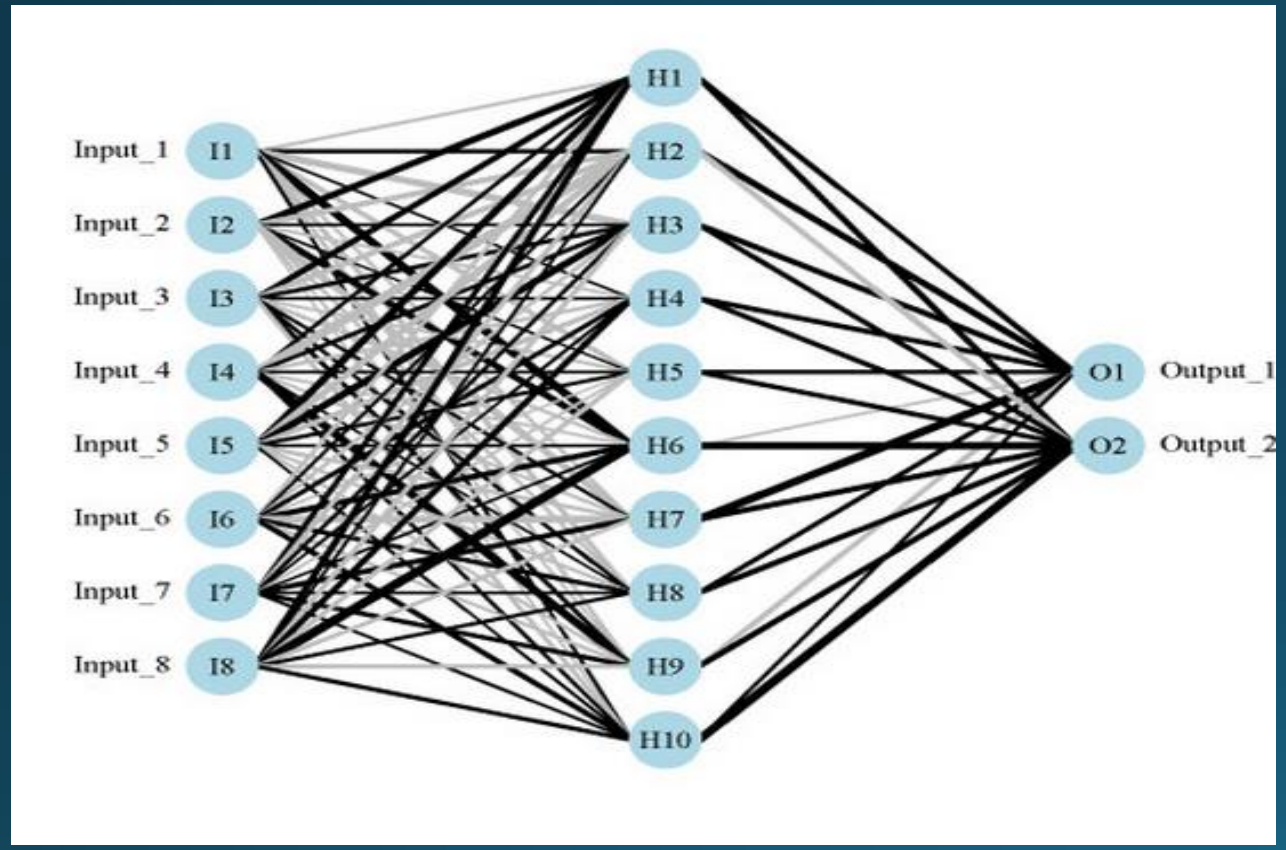
Outline

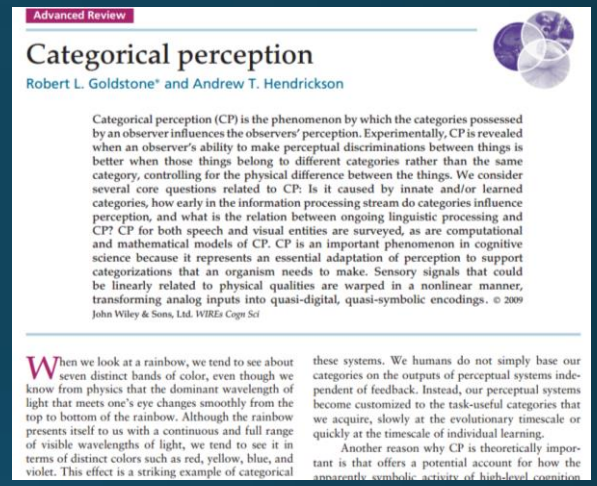
- Cognition-based Framework (homeomorphic)
- Example

Cognition-based Framework



Cognition-based Framework: Categorical Perception





Advanced Review

Categorical perception

Robert L. Goldstone* and Andrew T. Hendrickson

Categorical perception (CP) is the phenomenon by which the categories possessed by an observer influences the observers' perception. Experimentally, CP is revealed when an observer's ability to make perceptual discriminations between things is better when those things belong to different categories rather than the same category, controlling for the physical difference between the things. We consider several core questions related to CP: Is it caused by innate and/or learned categories, how early in the information processing stream do categories influence perception, and what is the relation between ongoing linguistic processing and CP? CP for both speech and visual entities are surveyed, as are computational and mathematical models of CP. CP is an important phenomenon in cognitive science because it represents an essential adaptation of perception to support categorizations that an organism needs to make. Sensory signals that could be linearly related to physical qualities are warped in a nonlinear manner, transforming analog inputs into quasi-digital, quasi-symbolic encodings. © 2009 John Wiley & Sons, Ltd. *WIREs Cogn Sci*

When we look at a rainbow, we tend to see about seven distinct bands of color, even though we know from physics that the dominant wavelength of light that meets one's eye changes smoothly from the top to bottom of the rainbow. Although the rainbow presents itself to us with a continuous and full range of visible wavelengths of light, we tend to see it in terms of distinct colors such as red, yellow, blue, and violet. This effect is a striking example of categorical

these systems. We humans do not simply base our categories on the outputs of perceptual systems independent of feedback. Instead, our perceptual systems become customized to the task-useful categories that we acquire, slowly at the evolutionary timescale or quickly at the timescale of individual learning.

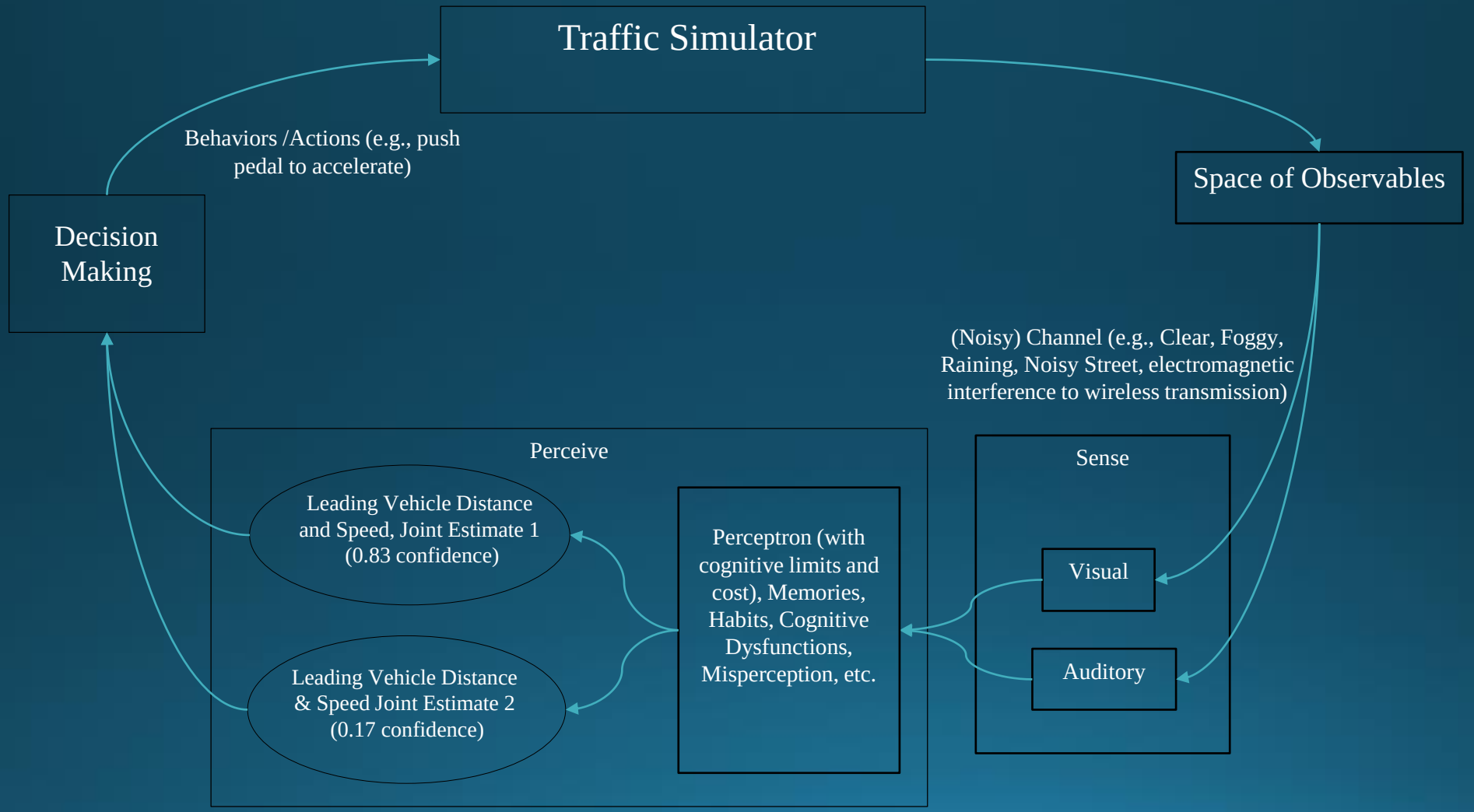
Another reason why CP is theoretically important is that offers a potential account for how the apparently symbolic activity of high-level cognition

Sensed Information
(Pixel-based)

Perceived Information
(Category-based)

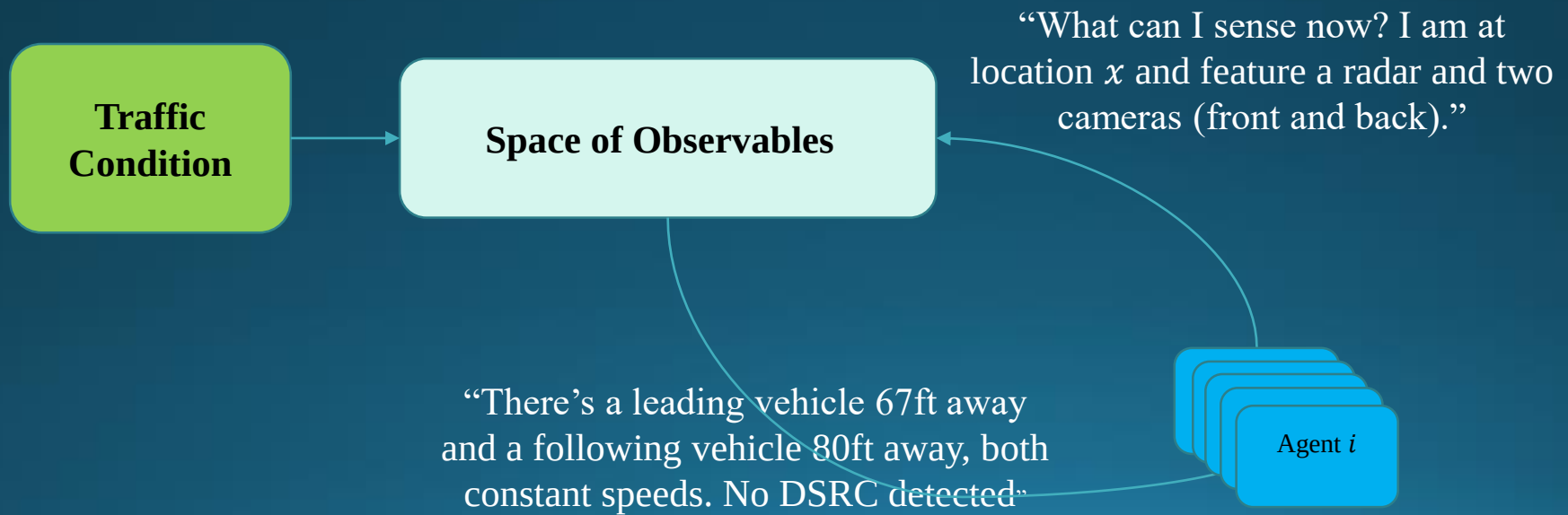
"Sensations are the first stages in the functioning of senses to represent stimuli from the environment, and perception is a higher brain function about interpreting events and objects in the world." (David G. Myers (2004). *Exploring Psychology* (6th ed.). Macmillan. pp. 140–141.)

Example: Mixed-Flow Traffic



One (Surprising) Computational Benefit

- Agents have no need to scan the entire model thanks to the Space of Observables
- Especially helpful when non-local information is prevalent



Driving Rules

- Human Agents: Newell's 2002 model
- ACVs: target on staying in the middle of the leading and following vehicle by accelerating/decelerating, while in sparse traffic, accelerate in a designed rate until reach the safety distance to the front vehicle or reach maximum allowable speed.

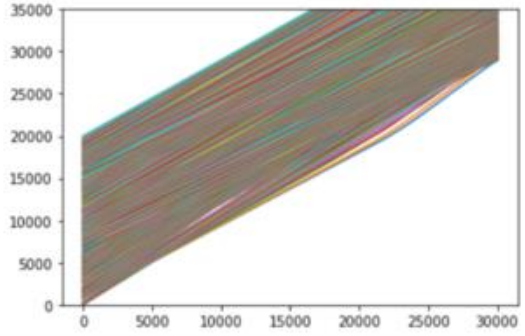
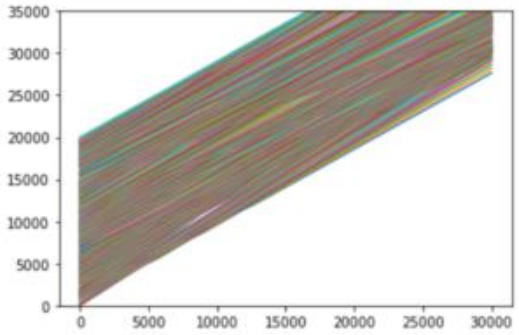
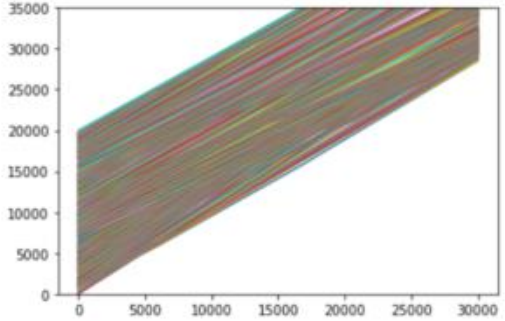
TABLE. Information available for an agent to sense.

Information Type	Human	ACV
Leading vehicle distance and speed	Vision	Radar/Lidar/Camera
Following vehicle distance and speed	--	Radar/Lidar/Camera
*Location and speed of immediate vehicles on the left & right lane(s)	--	Radar/Lidar
*Location and speed of immediate vehicles on the left & right lane(s) within view range	Vision	Radar/Lidar/Camera
DSRC within 1000ft (FHWA recommended range, 2016)	--	Radar

Sensitivity Test on Different Sensors in Foggy Weather

- Type A: Heavily-relying on camera info
- Type C: Heavily-Relying on radar/Lidar info
- Type B: Equal Weights

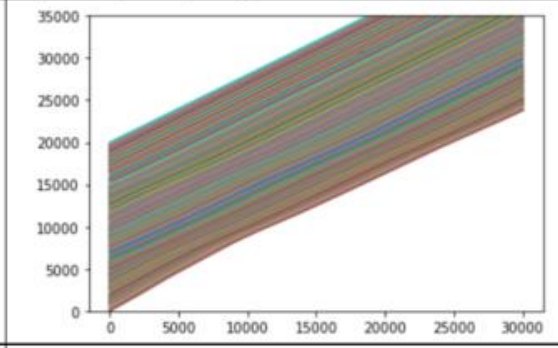
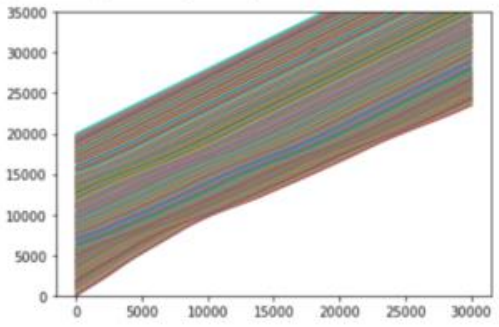
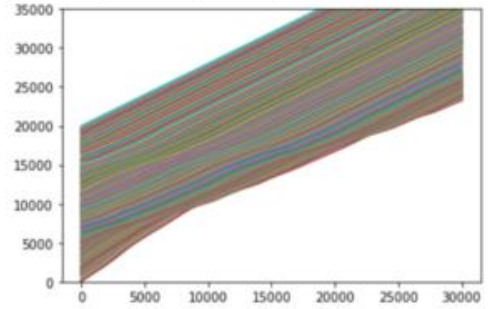
TABLE 2. Trajectory Comparison over Type A, B, and C Autonomous Vehicles (fixed random seed) during the simulation 0 to 30,000 steps (0.01sec/step). x-axis being the distance (ft) and y-axis being simulation step.

	(80%, 10%, 10%)	(10%, 80%, 10%)	(10%, 10%, 80%)
Trajectory Visualization			
VMT (ft.)	2.04e+4	2.07e+4	2.05e+4
VHT (sec.)	2.34e+2	2.43e+2	2.41e+2
VMT/VHT (ft./sec.)	84.7	85.1	84.9

Sensitivity Test on Different Perceptive Capabilities

- Group 1: No dyslexia or missed info on the dynamic message board on speed limit change
- Group 2: 0.5% mild dyslexia (slow response) & 7% severe
- Group 3: 1.5% mild dyslexia (slow response) & 10% severe

TABLE 3. The trajectory comparison of the simulated vehicles with and without sever dyslexia when he/she sense the message board's speed recommendation (81 ft/sec) at the beginning of the simulation. x-axis being the distance (ft) and y-axis being simulation step.

	(100%, 0%, 0%)	(92.5%, 0.5%, 7%)	(88.5%, 1.5%, 10%)
Trajectory Visualization			
VMT (ft.)	2.01e+4	1.99e+4	1.97e+4
VHT (sec.)	2.45e+2	2.46e+2	2.49e+2
VMT/VHT (ft./sec.)	82.0	80.9	79.1

Sensitivity Test on Human-ACV Market Share

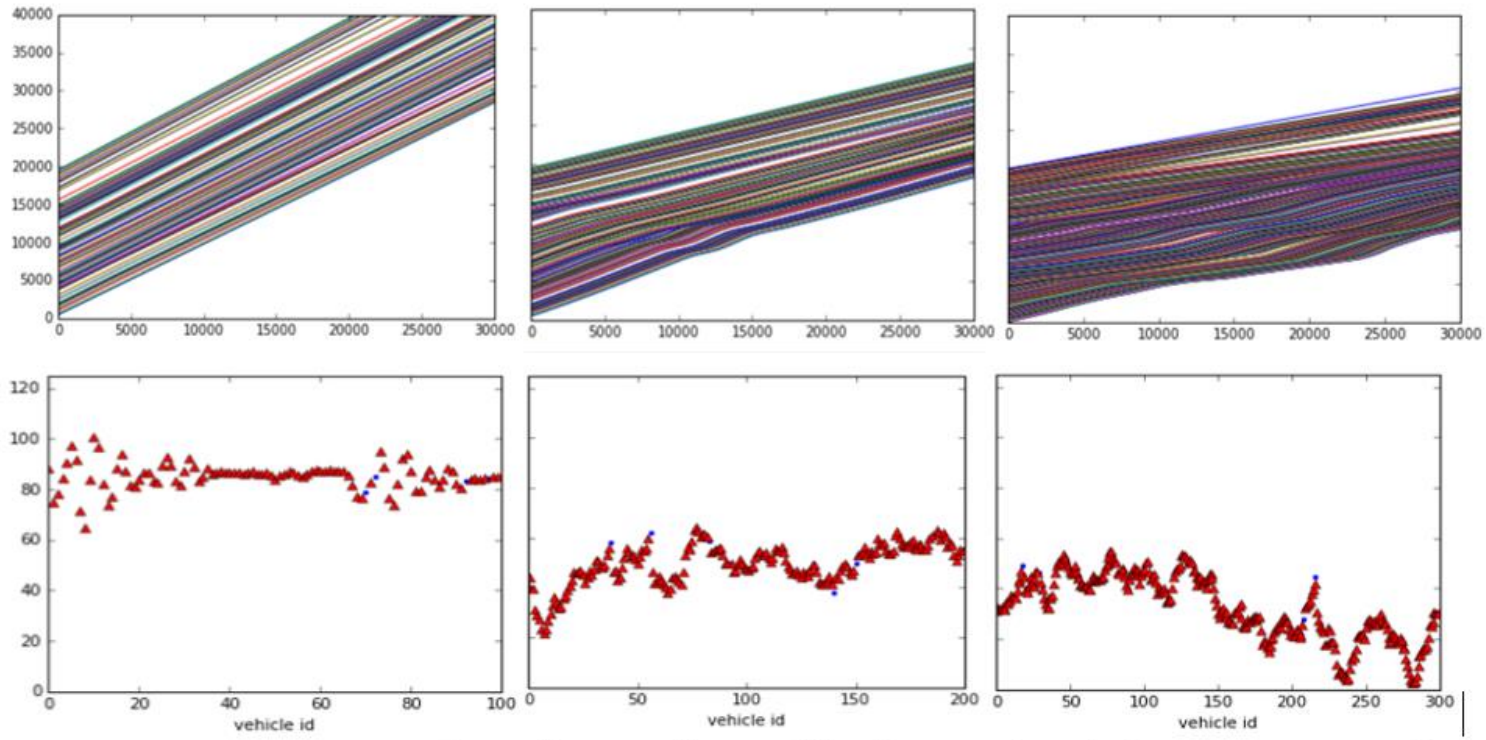


Figure 2.11 The trajectories (upper) and speed profile (lower) while 5% MP and 5-min simulation horizon; number of vehicle is set as 100, 200, and 300, respectively.

Sensitivity Test on Human-ACV Market Penetration (MP)

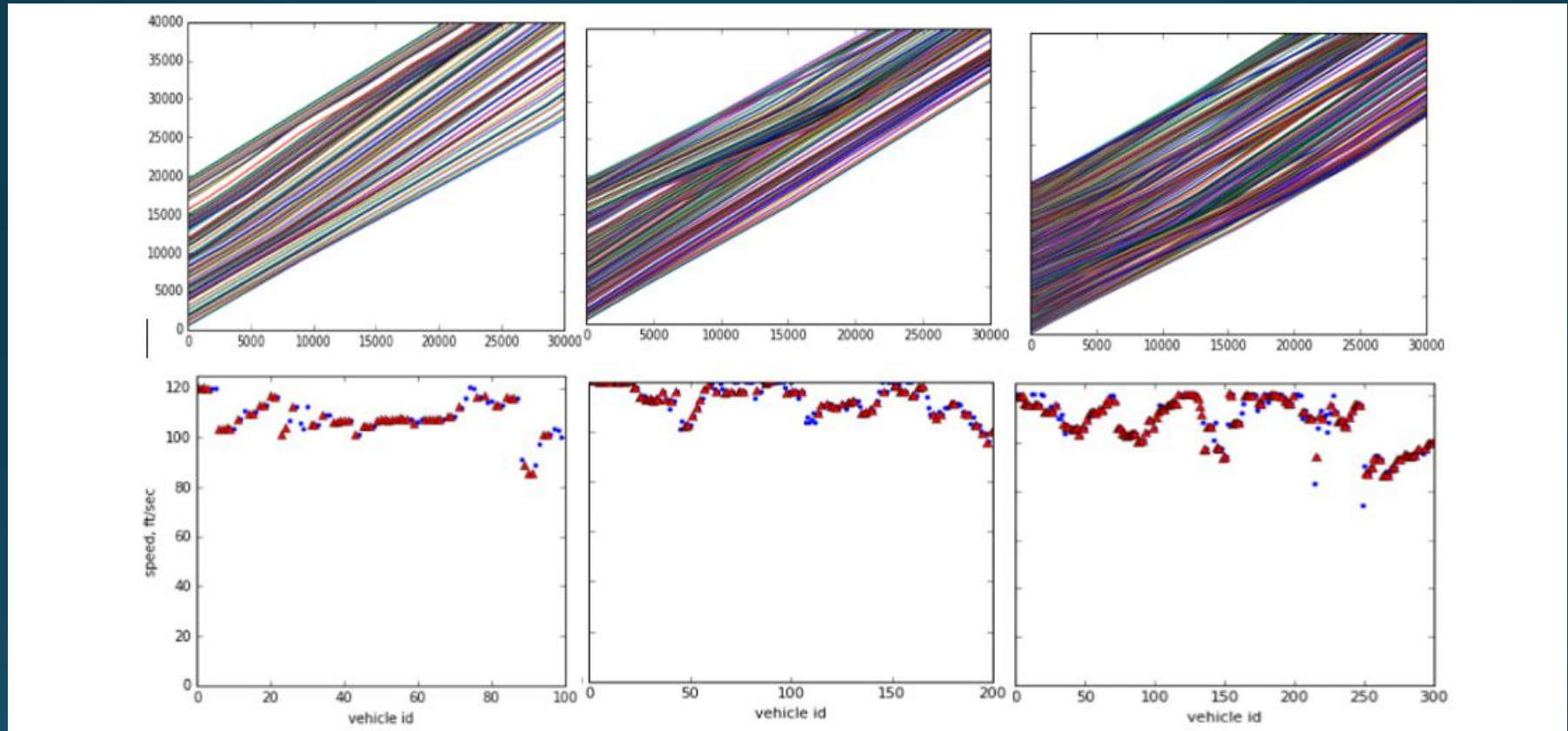


Figure 2.12 50% MP and 5-min simulation horizon; veh = 100, 200, 300

Sensitivity Test on Human-ACV Market Penetration (MP)

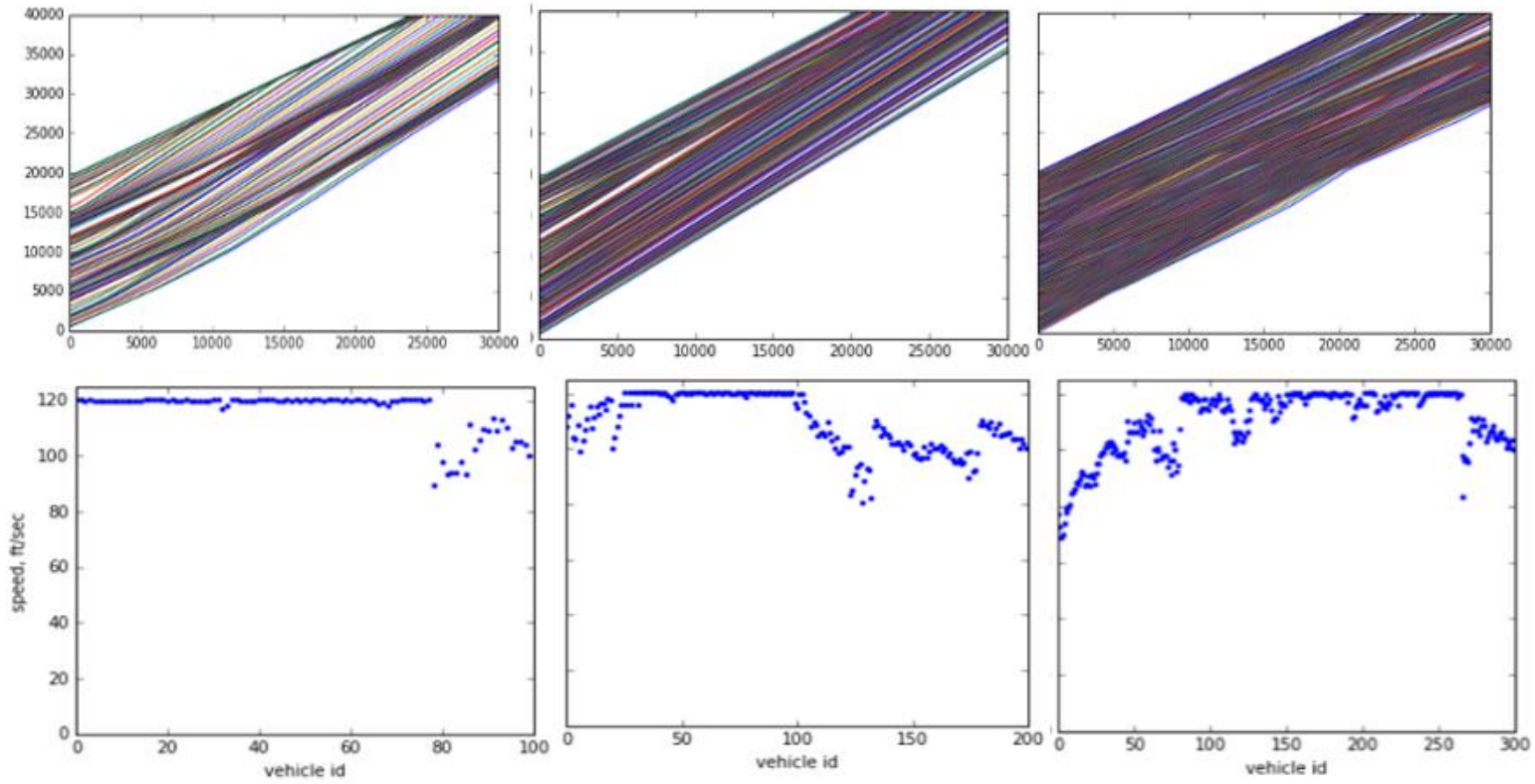


Figure 2.13 100% MP and 5-min simulation horizon; veh = 100, 200, 300

Inferred "3D" Fundamental Diagram

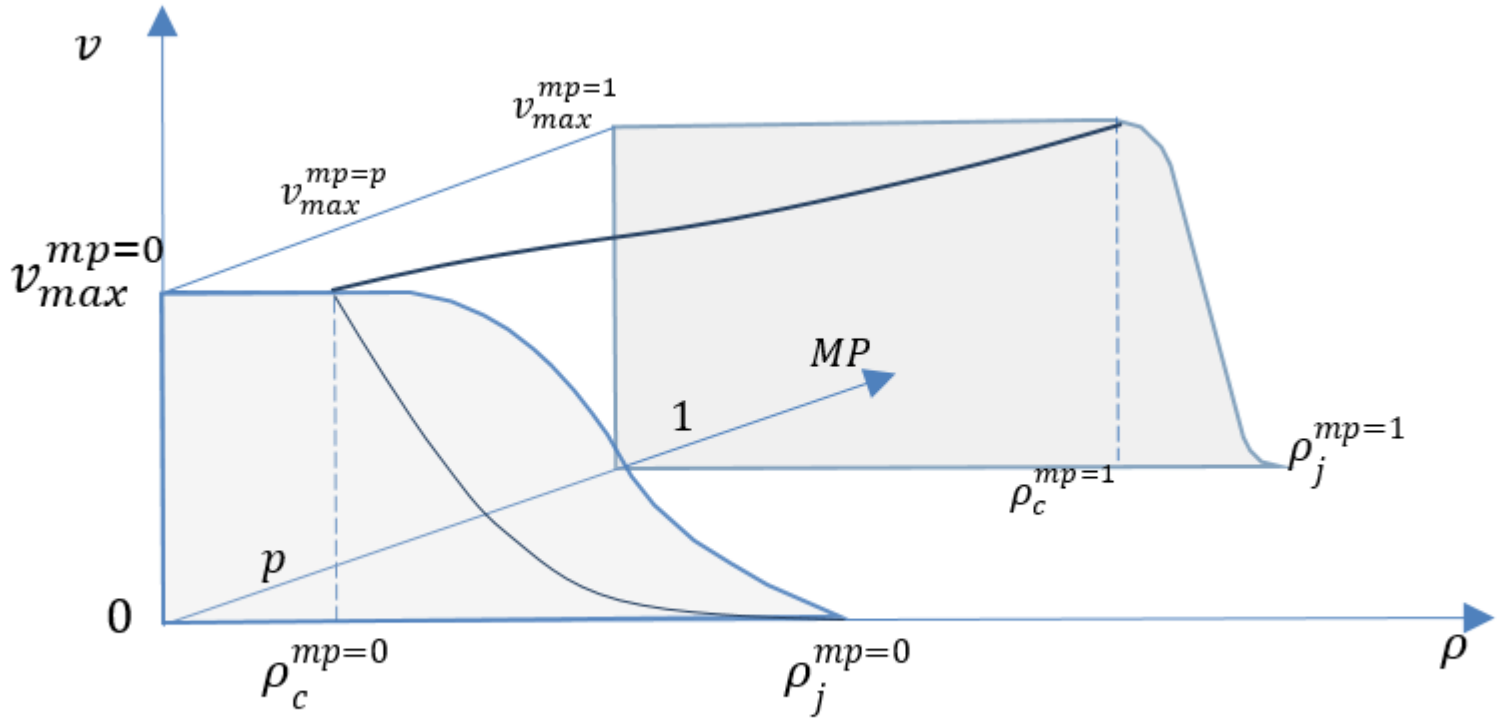


Figure 2.15 Hypothetical MP-v-ρ relationship based on the experimental results.

Inferred "3D" Fundamental Diagram

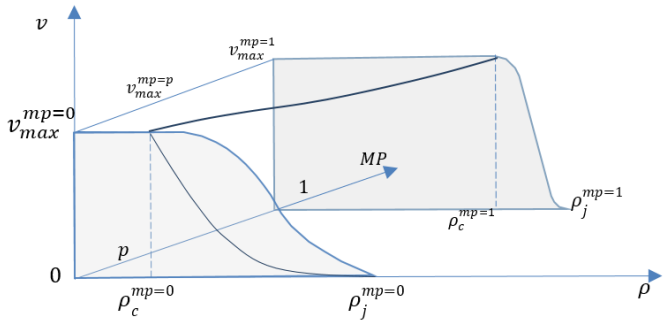


Figure 2.15 Hypothetical MP-v-ρ relationship based on the experimental results.

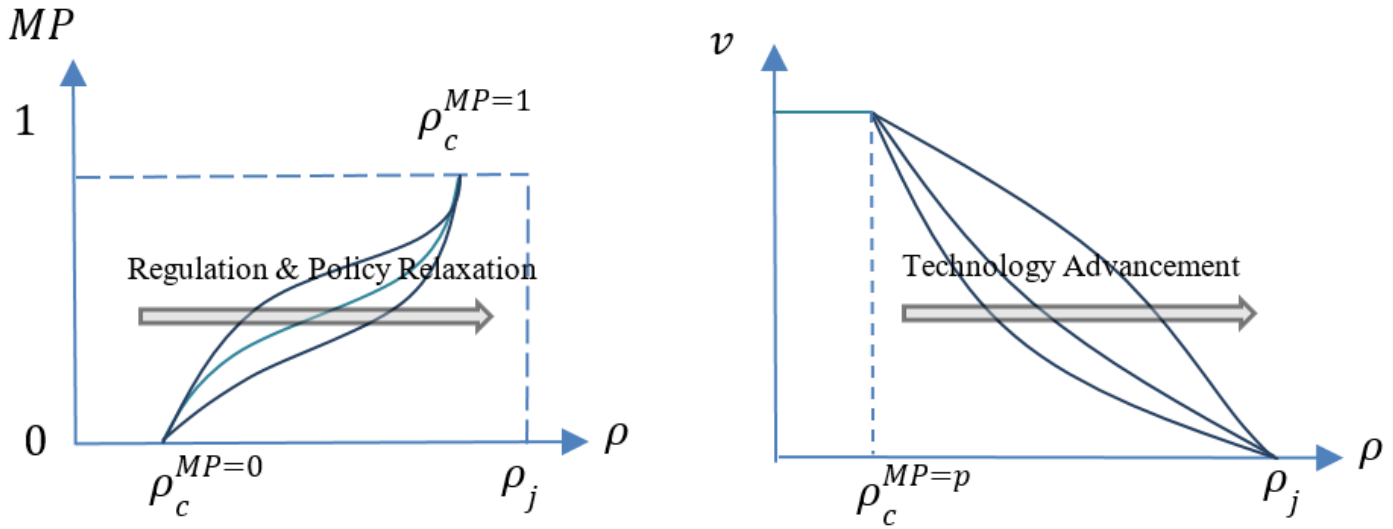


Figure 2.14 Hypothetical v_c region in MP-ρ_c space and hypothetical v-ρ_c relationship based on the experimental results.

Conclusions

- The proposed cognition-based framework advocates homeomorphic modeling and analysis approach. Humans and machines (AI) can be considered as under the same entity when consider sensation and perception explicitly.
- The framework provides a guideline of modeling and analyzing emerging technologies and behavioral policies extendably.
- Uncertainty and Information are considered consistently with Information Theory.
- Agents have no need to scan the entire model thanks to the Space of Observables
  - Especially helpful when non-local information is prevalent
- Other Applications
  - Quantifying Traveler Information (under review)
  - Risk-preference in modeling driving and routing behaviors (under review)
  - Multi-criteria multi-class dynamic traffic assignment algorithm with heterogeneous risk preference (Published)

Thank You

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Future Study

- Three General Directions:
  - Further develop the paradigms (with more case studies)
  - Consider traffic operators, planners, and decision makers as part of the systems
  - More studies on modeling "behavioral" strategies
    - Incorporate CognAgent into activity-based model
    - Consider dual-system cognition (Kahneman, 2008)
      - Sys. 1: Irrational, Pattern Matching, Judging
      - Sys. 2: Rational, Error-correcting, easily-exhausted