When The Wind Is Southerly:
A Bayesian Model of Cue-based Cardinal Direction Estimation

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Introduction

• Previous research suggests people optimally combine perceptual data to estimate perceptual features [2, 3], including spatial directional cues. Do people also combine perceptual data (cues) when learning environments?

• We know that people use perceptual input from the adjacent street when estimating directions on the Tufts campus [1]. To what extent do they combine this information with other available cues?

Research Question

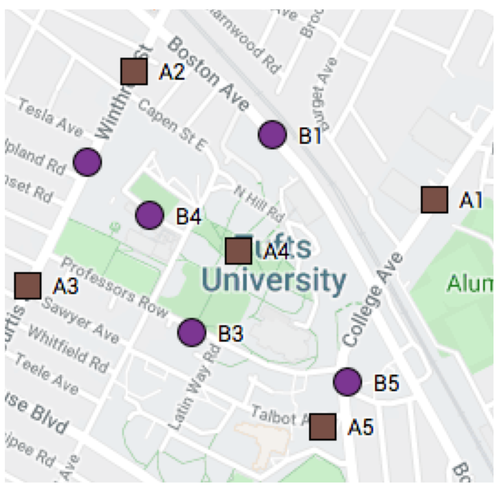
If people use multiple cues, are they limited to local cues or do they use global cues? Further, do they **optimally combine** them?

Previous Experiment

Method

• N = 87 (university students), 50 women, M_{age} = 20 years
• Participants were guided around campus, pointed to cardinal directions.

Tufts Campus Map



Analysis

We investigated participant responses in comparison with 3 different reference frames (RFs): **correct (magnetic north)**, **campus grid north**, and the **local adjacent street** reference frame (see schematized map in right-hand column for RF).

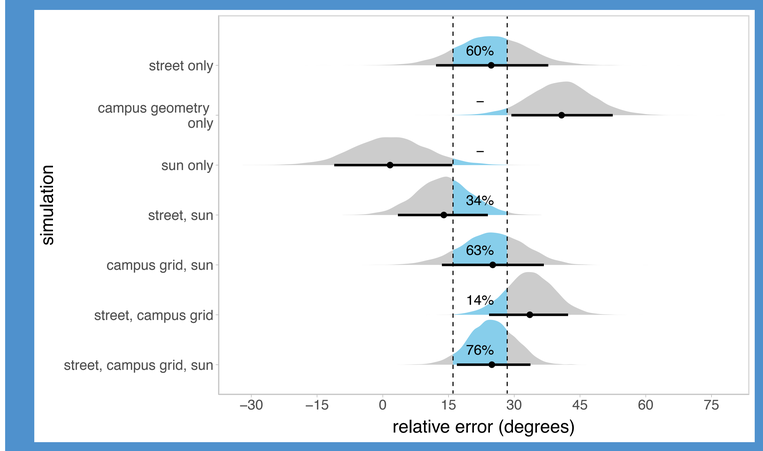
Results

• Responses followed an internally-consistent reference frame
• People did not follow a **correct (magnetic north) RF**
• Preliminary results suggested people may use **campus geometry RF**
• Most findings implied people used the **local street RF**

RESULTS

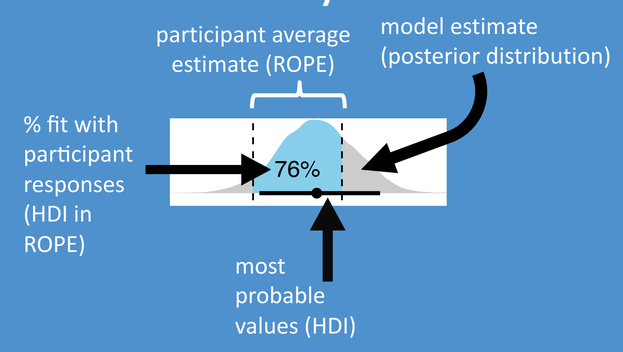
Computational modeling suggests that, when people **estimate cardinal directions**, they **optimally combine directional cues**, and most likely **combine both local and global cues**.

All Locations



• Prediction: two local cues (street+campus simulation) should fit best
• Three-cue simulation provided best fit, two local cues did not provide good fit
• Local street only and campus+sun simulations also provide good fit

Key



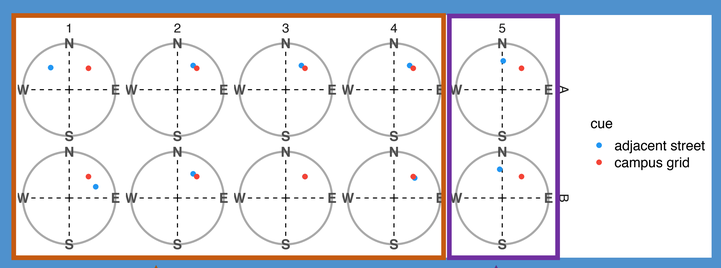
Model Fit

HDI in ROPE: How much (by %) of a model's most probable values (HDI) fall within a region of practical equivalence ("ROPE") based on participant responses.

HDI in ROPE	Model fit with participant results
< 2.5%	significantly different
< 50%	bad fit
> 50%	good fit
> 97.5%	equivalent

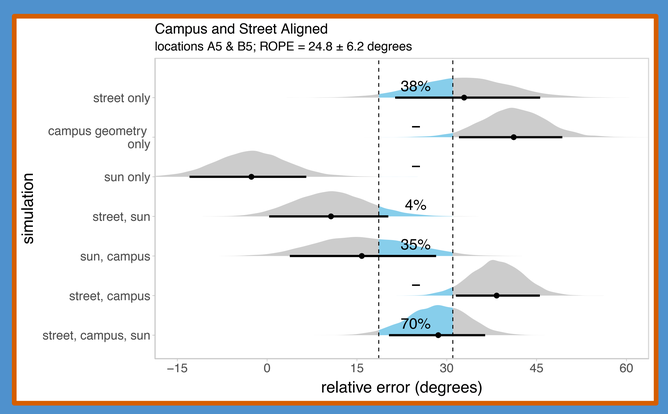
Cue Conflict Locations

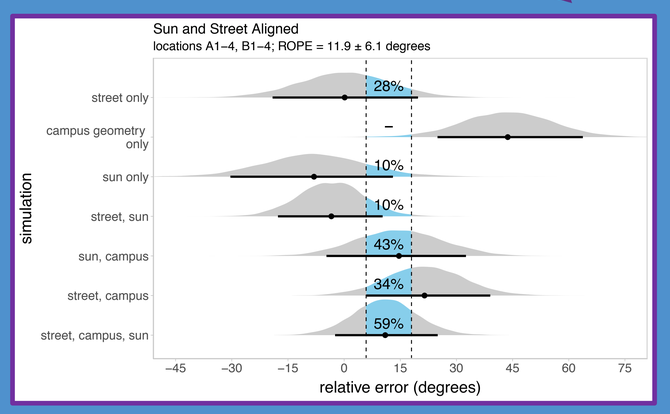
• Traditional approaches develop environments so cues parametrically contrast
• Ours was a real-world environment, so we divided locations by cue conflict
• Here, the campus and sun cues always conflict, and the street varyingly concords with either of those two cues



Campus and street align, conflict with sun

Sun and street align, conflict with campus





• At both sets of locations, three-cue simulation fit best
• No other simulations provide good fit (among other things, this means people likely do not only rely on the adjacent street)

Modeling Method

• Cue combination studies test whether people **combine** cues **optimally** (i.e., according to Bayesian statistics). Specifically, cues are weighted by reliability, and combined according to those weights.

• We developed a Bayesian hierarchical model, comparing single- and multi-cue simulations against previous experimental results.

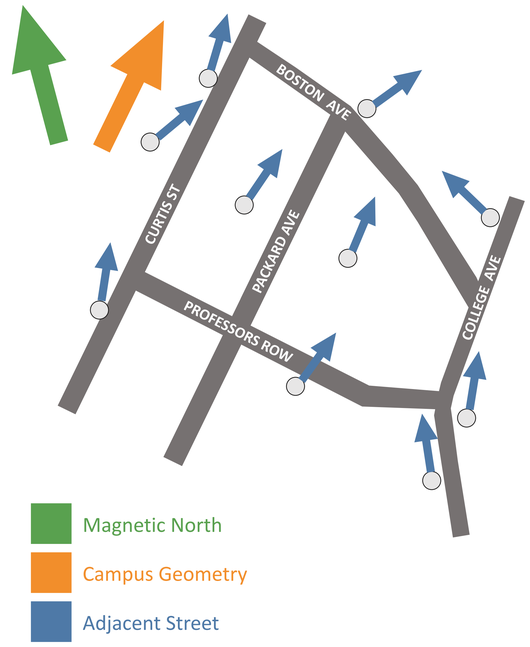
• Our model uses perceptual information to estimate each cue, then uses cue estimates to indicate cardinal directions.

Candidate Cues

We compared all combinations of three possible cues, weighted approximately equally:

- **Sun (global)**: a reliable indicator of cardinal directions
- **Campus geometry**: the campus street grid (42 degrees)
- **Local street**: the north-most heading of each locations' adjacent street

Tufts Campus Map



Discussion

• People likely optimally combine cues, rather than using a single cue
• While previous research suggests people use the adjacent street [1], our results imply people combine that information with other local (campus geometry) and global (sun direction) information
• Changing cue weighting (results not discussed here) did not alter the findings: simulations that balance weighting between cues show best fit

Future Directions

• Replicate other aspects of previous experiment (cardinal direction training)
• Apply to other experiments

REFERENCES:
[1] Brunyé, T. T., Burte, H., Houck, L. A., & Taylor, H. A. (2015). The Map in Our Head Is Not Oriented North: Evidence from a Real-World Environment. *PLoS ONE*, *10*(9).
[2] Ernst, M. O., & Banks, M. S. (2002). Humans integrate visual and haptic information in a statistically optimal fashion. *Nature*, *415*(6870), 429.
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