

LA-UR- 12-00715

Approved for public release;  
distribution is unlimited.

**Title:** Recommending Routes in the Context of Bicycling:  
Algorithms, Evaluation, and the Value of Personalization

**Author(s):** Reid Priedhorsky  
David Pitchford  
Shilad Sen  
Loren Terveen

**Intended for:** ACM International Conference on  
Computer Supported Cooperative Work  
February 11-15, 2012



Los Alamos National Laboratory, an affirmative action/equal opportunity employer, is operated by the Los Alamos National Security, LLC for the National Nuclear Security Administration of the U.S. Department of Energy under contract DE-AC52-06NA25386. By acceptance of this article, the publisher recognizes that the U.S. Government retains a nonexclusive, royalty-free license to publish or reproduce the published form of this contribution, or to allow others to do so, for U.S. Government purposes. Los Alamos National Laboratory requests that the publisher identify this article as work performed under the auspices of the U.S. Department of Energy. Los Alamos National Laboratory strongly supports academic freedom and a researcher's right to publish; as an institution, however, the Laboratory does not endorse the viewpoint of a publication or guarantee its technical correctness.

**ABSTRACT**

Users have come to rely on automated route finding services for driving, public transit, walking, and bicycling. Current state of the art route finding algorithms typically rely on objective factors like time and distance; they do not consider subjective preferences that also influence route quality. This paper addresses that need. We introduce a new framework for evaluating edge rating prediction techniques in transportation networks and use it to explore ten families of prediction algorithms in Cyclopath, a geographic wiki that provides route finding services for bicyclists. Overall, we find that personalized algorithms predict more accurately than non-personalized ones, and we identify two algorithms with low error and excellent coverage, one of which is simple enough to be implemented in thin clients like web browsers. These results suggest that routing systems can generate better routes by collecting and analyzing users' subjective preferences.

## Recommending Routes in the Context of Bicycling: Algorithms, Evaluation, and the Value of Personalization

Reid Priedhorsky  
David Pitchford  
Shilad Sen  
Loren Terveen

CSCW 2012  
February 13, 2012



Los Alamos  
NATIONAL LABORATORY  
EST. 1944

Cyclopath

LA-UR 12-09090

## Recommending Routes in the Context of Bicycling: Algorithms, Evaluation, and the Value of Personalization

Reid Priedhorsky  
David Pitchford  
Shilad Sen  
Loren Terveen

CSCW 2012  
February 13, 2012



Los Alamos  
NATIONAL LABORATORY  
EST. 1944

Cyclopath

LA-UR 12-09090

map our team privacy help & demos

# Cyclopath

discover your path

Find bike routes that match the way you ride.  
Share your cycling knowledge with the community.

[explore the map](#)

### find a route

begin

end

Cyclopath is available in the 7-county Twin Cities metro area.

[Find Route](#)

#### personalized bikeability

Cyclopath lets you enter personal bikeability ratings for roads and trails. This unique rating system helps find the best routes for you, while also supporting the community with your individual knowledge.

#### geowiki what?

Cyclopath is a newly... an editable map where

#### new features

##### Regions

Share information about and route to neighborhoods and other area-based places.

##### Multiple routes

Cyclopath can now show multiple routes at once, letting you efficiently compare different possibilities.

[more](#)

map our team privacy help & demos

# Cyclopath

discover your path

Find bike routes that match the way you ride.  
Share your cycling knowledge with the community.

[explore the map](#)

### find a route

begin

end

Cyclopath is available in the 7-county Twin Cities metro area.

[Find Route](#)

#### personalized bikeability

Cyclopath lets you enter personal bikeability ratings for roads and trails. This unique rating system helps find the best routes for you, while also supporting the community with your individual knowledge.

#### geowiki what?

Cyclopath is a newly... an editable map where

#### new features

##### Regions

Share information about and route to neighborhoods and other area-based places.

##### Multiple routes

Cyclopath can now show multiple routes at once, letting you efficiently compare different possibilities.

[more](#)

**Cyclopath** Find Route Log In

Not logged in

Discussions Control Panel Routes

**Route Details**

Feedback on this route Show Routes

From: 200 Union St SE, Minneapolis, MN 55455-0...  
 To: Landmark Lagoon Movie Theatre (Lowry H...  
 Length: 4.86 mi  
 Share: [Create Link](#)

Color route by: **Slope** Steep Uphill Steep Downhill

Cue Sheet **Printer Friendly** As GPX

Obs.	Do This	Leg
0.00	Start W on WASHINGTON AVE SE / COUNTY HWY 122	0.10
0.10	SLIGHT_LEFT/SW onto UNNAMED SIDEWALK	0.20
0.29	SLIGHT_LEFT/SW onto WASHINGTON AVE BRIDGE - UPPER DECK	0.27
0.56	LEFT/S onto U OF M WEST BANK SIDEWALK	0.10
0.63	U OF M WEST BANK SIDEWALK changes to U OF M WEST BANK	0.10
0.73	RIGHT/W onto 4TH ST S	0.05
0.80	LEFT/S onto 20TH AVE S	0.46
1.26	20TH AVE S changes to CEDAR AVE S / COUNTY HWY 132	0.33

Recent Changes My Watched Regions

Map Key

**Cyclopath** Find Route Log In

Not logged in

Discussions Control Panel Routes

**Route Details**

Feedback on this route Show Routes

From: 200 Union St SE, Minneapolis, MN 55455-0...  
 To: Landmark Lagoon Movie Theatre (Lowry H...  
 Length: 4.86 mi  
 Share: [Create Link](#)

Color route by: **Slope** Steep Uphill Steep Downhill

Cue Sheet **Printer Friendly** As GPX

Obs.	Do This	Leg
0.00	Start W on WASHINGTON AVE SE / COUNTY HWY 122	0.10
0.10	SLIGHT_LEFT/SW onto UNNAMED SIDEWALK	0.20
0.29	SLIGHT_LEFT/SW onto WASHINGTON AVE BRIDGE - UPPER DECK	0.27
0.56	LEFT/S onto U OF M WEST BANK SIDEWALK	0.10
0.63	U OF M WEST BANK SIDEWALK changes to U OF M WEST BANK	0.10
0.73	RIGHT/W onto 4TH ST S	0.05
0.80	LEFT/S onto 20TH AVE S	0.46
1.26	20TH AVE S changes to CEDAR AVE S / COUNTY HWY 132	0.33

Recent Changes My Watched Regions

Map Key

**Cyclopath** Find Route Log In

Not logged in

Discussions Control Panel Routes

**Route Details**

Feedback on this route Show Routes

From: 200 Union St SE, Minneapolis, MN 55455-0...  
 To: Landmark Lagoon Movie Theatre (Lowry H...  
 Length: 4.86 mi  
 Share: [Create Link](#)

Color route by: **Slope** Steep Uphill Steep Downhill

Cue Sheet **Printer Friendly** As GPX

Obs.	Do This	Leg
0.00	Start W on WASHINGTON AVE SE / COUNTY HWY 122	0.10
0.10	SLIGHT_LEFT/SW onto UNNAMED SIDEWALK	0.20
0.29	SLIGHT_LEFT/SW onto WASHINGTON AVE BRIDGE - UPPER DECK	0.27
0.56	LEFT/S onto U OF M WEST BANK SIDEWALK	0.10
0.63	U OF M WEST BANK SIDEWALK changes to U OF M WEST BANK	0.10
0.73	RIGHT/W onto 4TH ST S	0.05
0.80	LEFT/S onto 20TH AVE S	0.46
1.26	20TH AVE S changes to CEDAR AVE S / COUNTY HWY 132	0.33

Recent Changes My Watched Regions

Map Key

**Cyclopath** Find Route Log In

Not logged in

Discussions Control Panel Routes

**Route Details**

Feedback on this route Show Routes

From: 200 Union St SE, Minneapolis, MN 55455-0...  
 To: Landmark Lagoon Movie Theatre (Lowry H...  
 Length: 4.86 mi  
 Share: [Create Link](#)

Color route by: **Slope** Steep Uphill Steep Downhill

Cue Sheet **Printer Friendly** As GPX

Obs.	Do This	Leg
0.00	Start W on WASHINGTON AVE SE / COUNTY HWY 122	0.10
0.10	SLIGHT_LEFT/SW onto UNNAMED SIDEWALK	0.20
0.29	SLIGHT_LEFT/SW onto WASHINGTON AVE BRIDGE - UPPER DECK	0.27
0.56	LEFT/S onto U OF M WEST BANK SIDEWALK	0.10
0.63	U OF M WEST BANK SIDEWALK changes to U OF M WEST BANK	0.10
0.73	RIGHT/W onto 4TH ST S	0.05
0.80	LEFT/S onto 20TH AVE S	0.46
1.26	20TH AVE S changes to CEDAR AVE S / COUNTY HWY 132	0.33

Recent Changes My Watched Regions

Map Key

Goal: Best route for me

**Challenge:**

- Quality factors are complex
- People don't agree

(see papers for details...)

**Goal: Best route for me**

**Challenge:**

- Quality factors are complex
- People don't agree

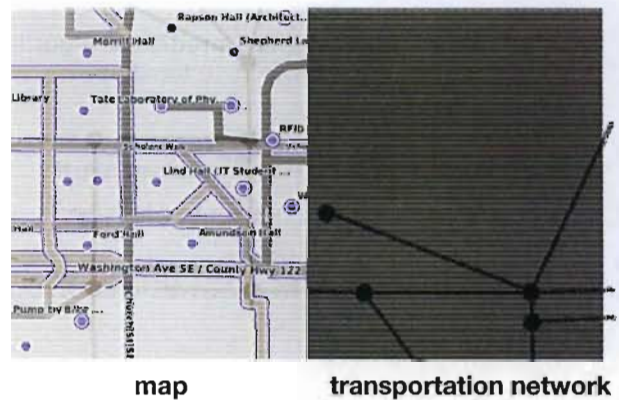
(see papers for details...)

**68,274 bikeability ratings**

**Goal: Best route for me**

The Cyclopath map is a graph

approach



Finding a personalized route

1. Predict edge ratings
2. Convert ratings to edge weights
3. Find least-cost path with graph search

7

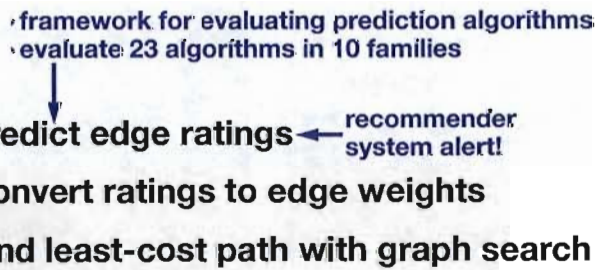
Finding a personalized route

1. Predict edge ratings ← recommender system alert!
2. Convert ratings to edge weights
3. Find least-cost path with graph search

7

Finding a personalized route

· framework for evaluating prediction algorithms  
· evaluate 23 algorithms in 10 families

- 
1. Predict edge ratings ← recommender system alert!
  2. Convert ratings to edge weights
  3. Find least-cost path with graph search

7

Why is this hard?

8

Why is this hard?

1. Need 100% coverage

Why is this hard?

1. Need 100% coverage
2. Structure of ratings data

**MovieLens:**

7.6 users per item

1 rating per 100 (user, item) pairs

**Cyclopath:**

321 items per user

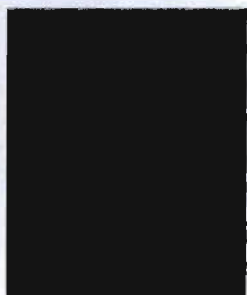
1 ratings per 1,000 (user, item) pairs

8

8

Why is this hard?

1. Need 100% coverage
2. Structure of ratings data
3. Inter-item and output structure



Evaluation framework (3 stages)

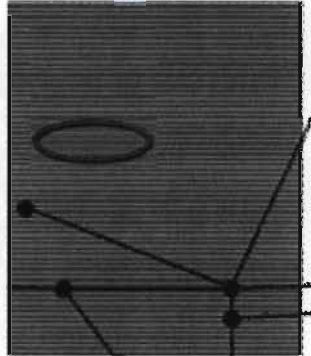


8

9

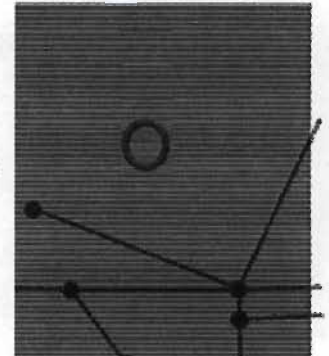
Evaluation framework (3 stages)

1. Test rating predictions  
(edge = item)



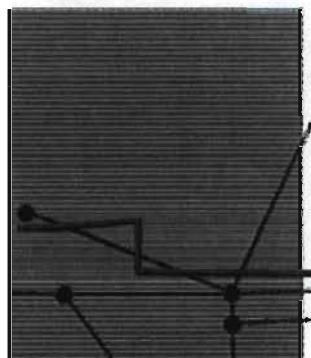
Evaluation framework (3 stages)

1. Test rating predictions  
(edge = item)
2. Test node-level algorithm differences



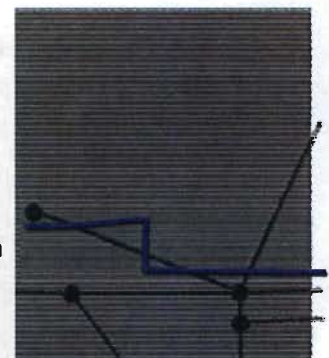
Evaluation framework (3 stages)

1. Test rating predictions  
(edge = item)
2. Test node-level algorithm differences
3. Test route-level algorithm differences  
now: numerically  
later: user study



Evaluation framework (3 stages)

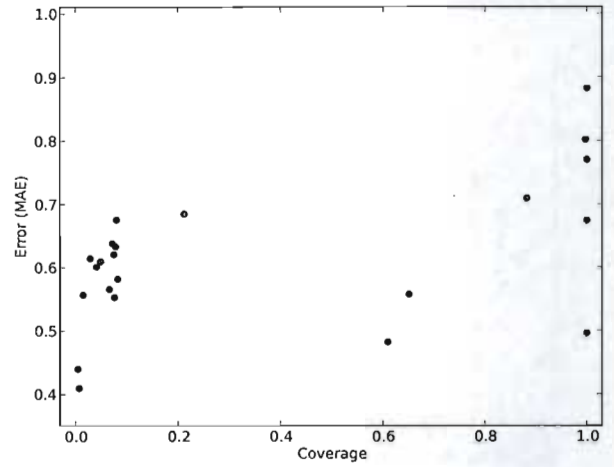
1. Test rating predictions  
(edge = item)
2. Test node-level algorithm differences
3. Test route-level algorithm differences  
now: numerically  
later: user study



👉 used to evaluate 23 algorithms in 10 families

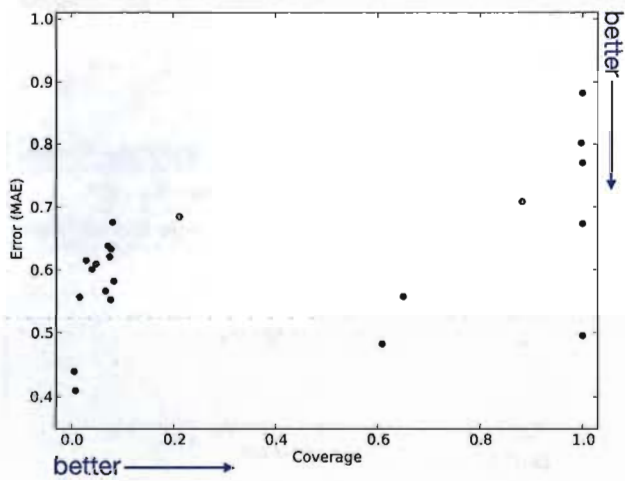
# results

Test edge rating predictions (Stage 1)



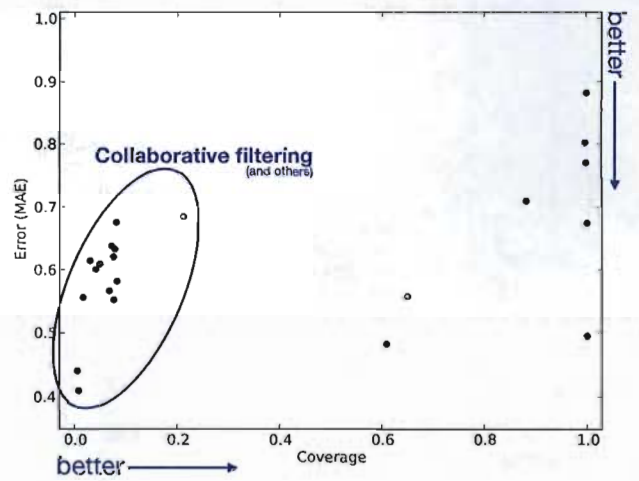
11

Test edge rating predictions (Stage 1)



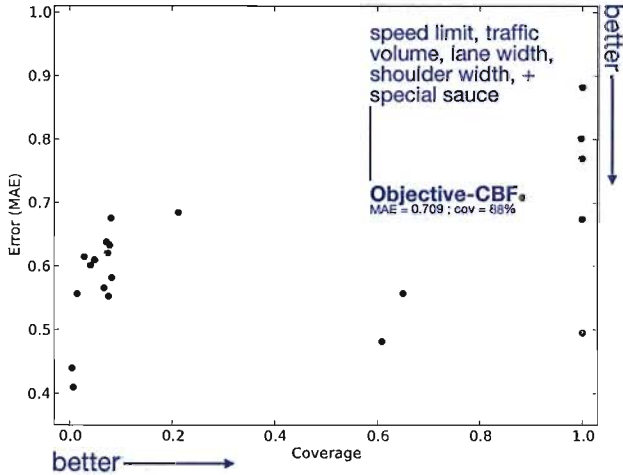
11

Test edge rating predictions (Stage 1)

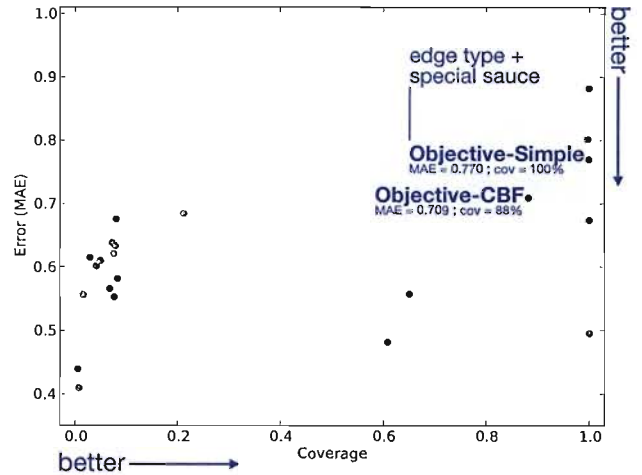


11

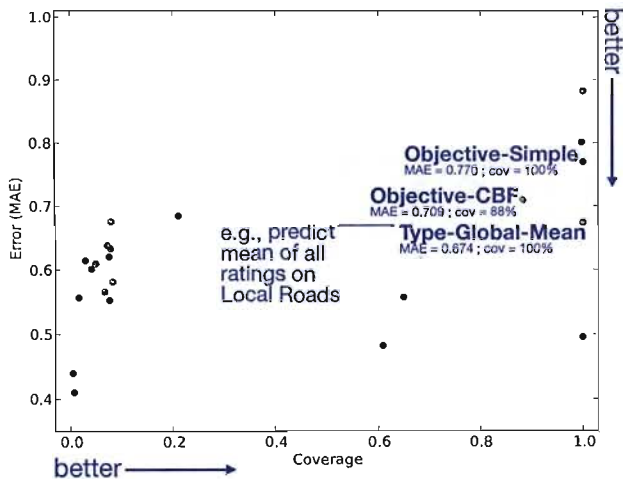
Test edge rating predictions (Stage 1)



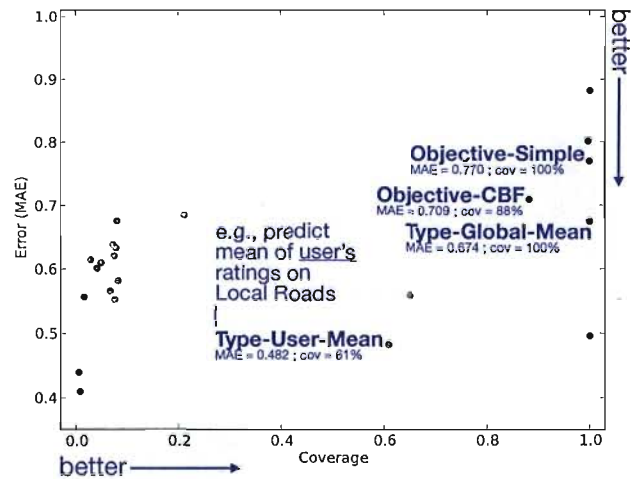
Test edge rating predictions (Stage 1)



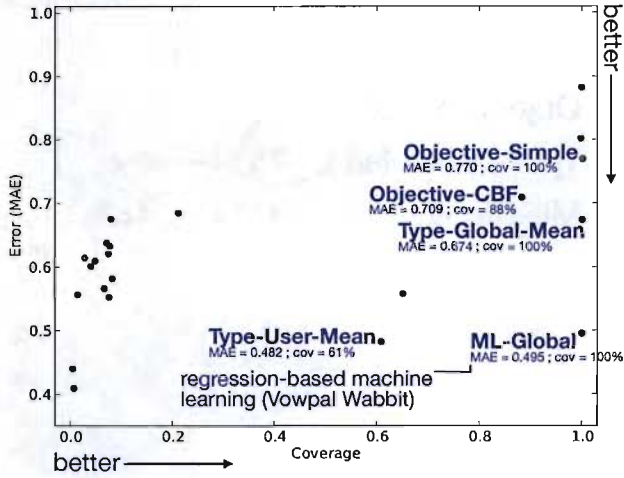
Test edge rating predictions (Stage 1)



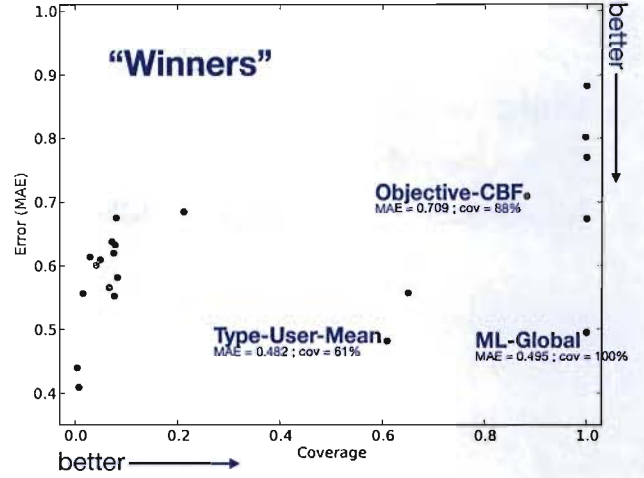
Test edge rating predictions (Stage 1)



Test edge rating predictions (Stage 1)



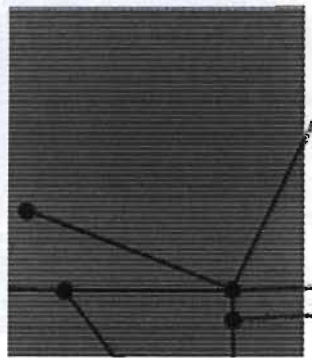
Test edge rating predictions (Stage 1)



11

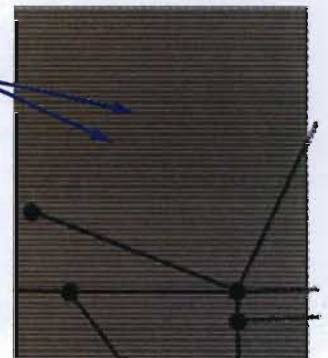
11

Node-level difference metric (Stage 2)



Node-level difference metric (Stage 2)

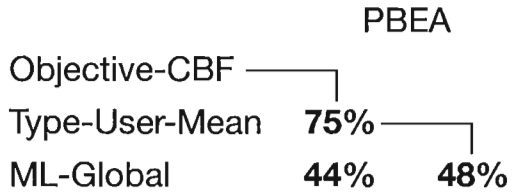
Pairwise best edge agreement (PBEA)



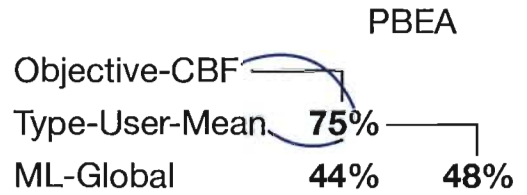
12

12

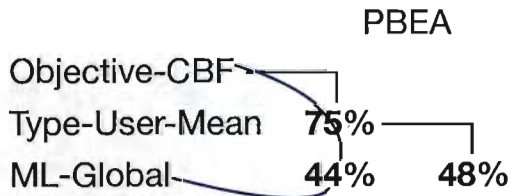
Test node-level differences (Stage 2)



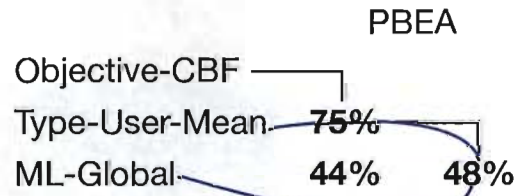
Test node-level differences (Stage 2)



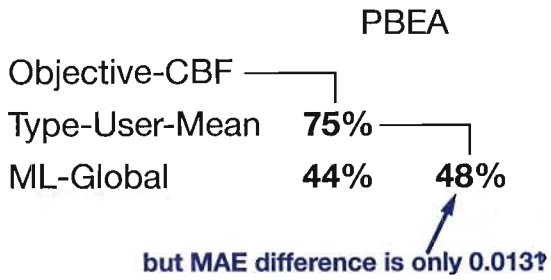
Test node-level differences (Stage 2)



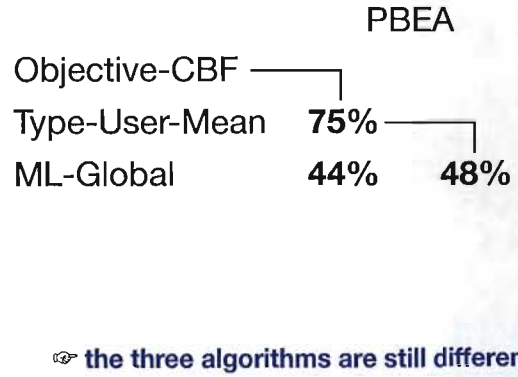
Test node-level differences (Stage 2)



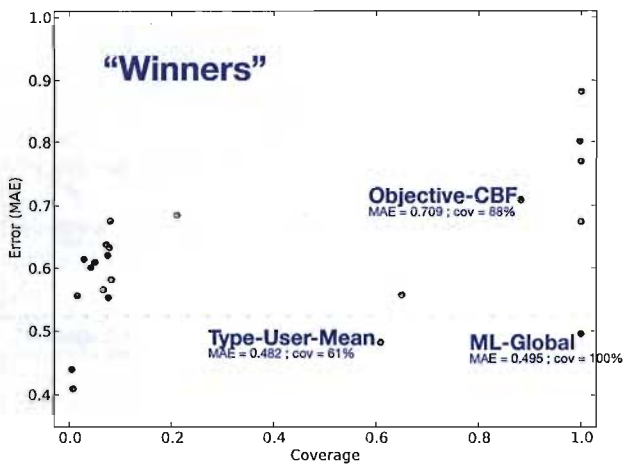
Test node-level differences (Stage 2)



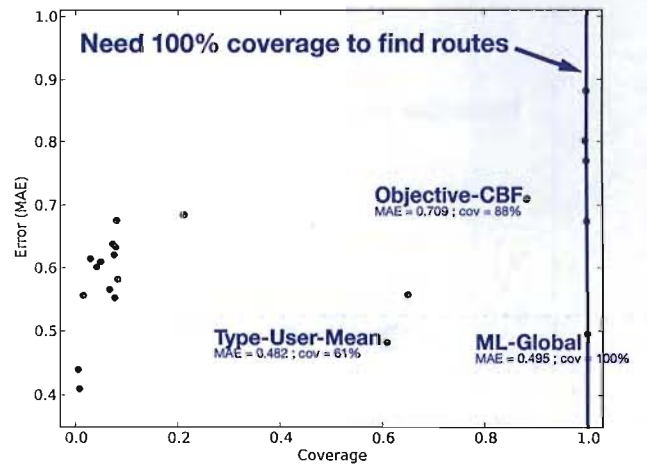
Test node-level differences (Stage 2)



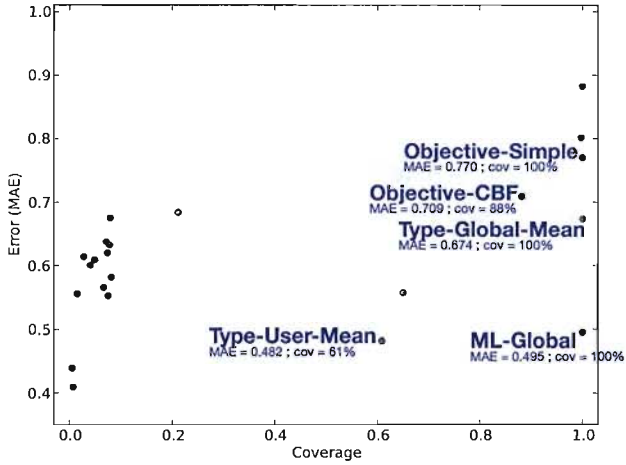
New predictors needed for Stage 3



New predictors needed for Stage 3

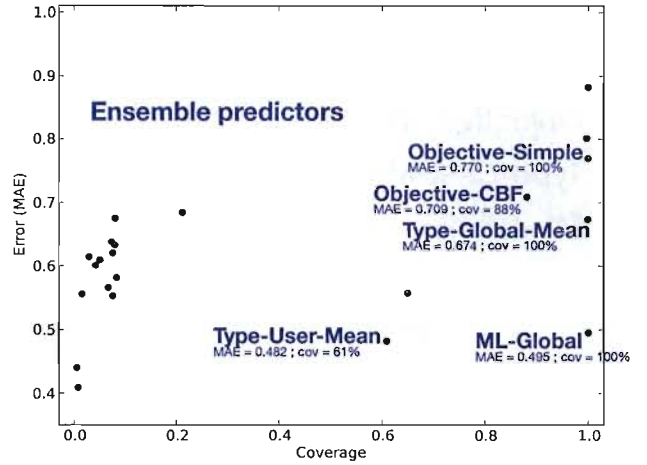


New predictors needed for Stage 3



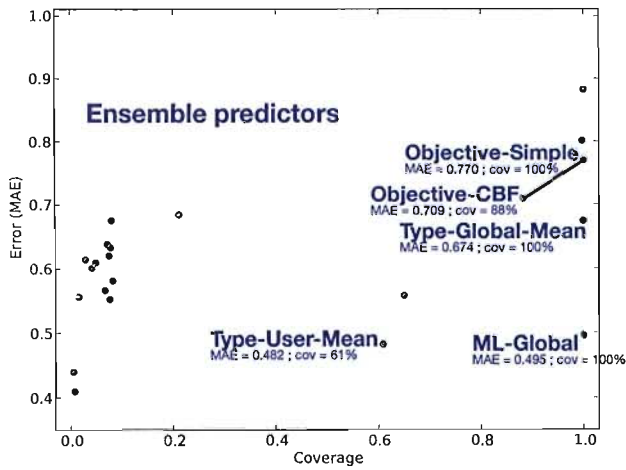
14

New predictors needed for Stage 3



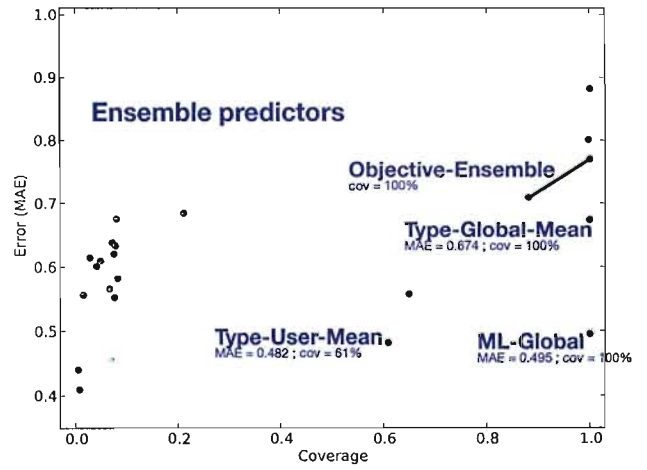
14

New predictors needed for Stage 3



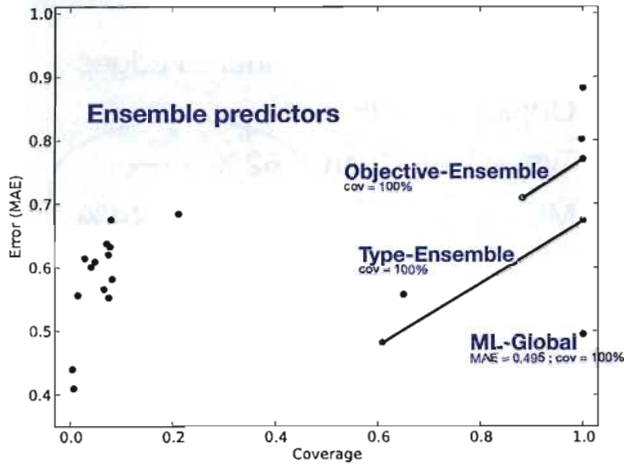
14

New predictors needed for Stage 3



14

New predictors needed for Stage 3



14

Procedure for testing route-level differences (Stage 3)

1. Random sample of route searches
2. Recompute with each ensemble
3. Count the fraction of shared edges

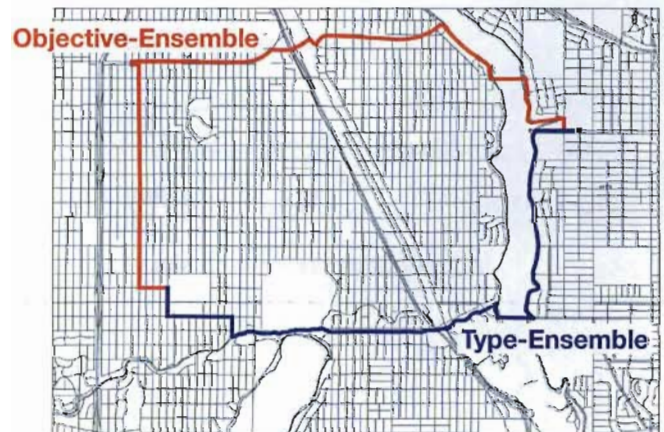
15

Sample route difference



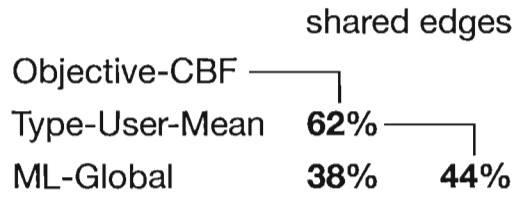
16

Sample route difference

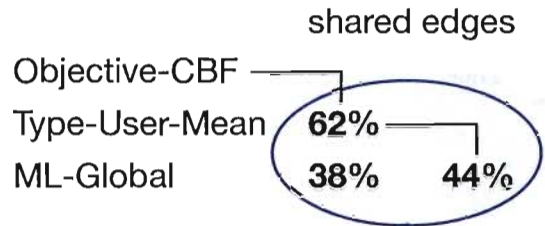


16

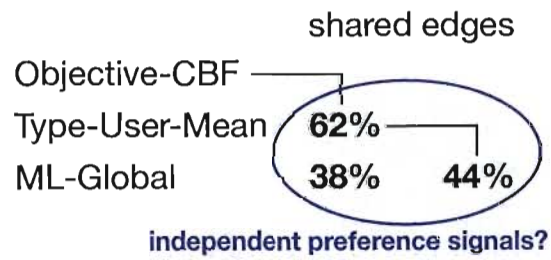
Test route-level differences (Stage 3)



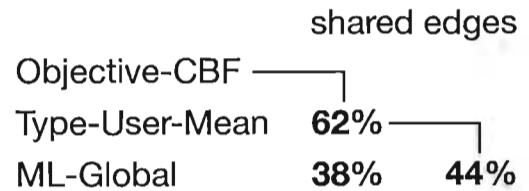
Test route-level differences (Stage 3)



Test route-level differences (Stage 3)

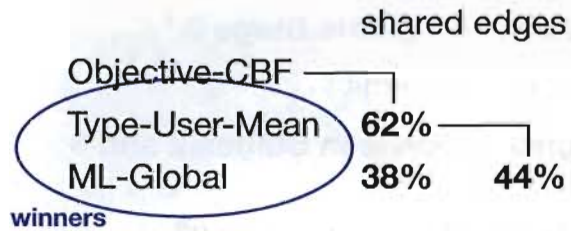


Test route-level differences (Stage 3)



**better: at Stage 1 + different at Stage 3 ⇒ better overall!**

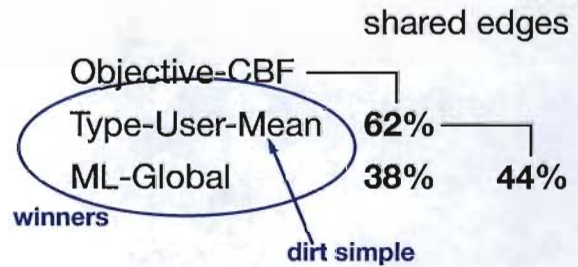
Test route-level differences (Stage 3)



better at Stage 1 + different at Stage 3 ⇒ better overall

17

Test route-level differences (Stage 3)



better at Stage 1 + different at Stage 3 ⇒ better overall

17

**wrapping up**

The point

**Personalized routing FTW**

... subjective data often easier to collect

**New framework for evaluation**

**Algorithms for edge rating prediction**

... one of which is extremely simple

18

19

$$\int_{\Omega} \mathbf{B} \cdot d\mathbf{A} = \frac{Q(V)}{\epsilon_0}$$

$$\int_{\Omega} \mathbf{B} \cdot d\mathbf{A} = 0$$

$$\int_{\text{loop}} \mathbf{E} \cdot d\mathbf{l} = -\frac{\partial \Phi_E(\mathbf{B})}{\partial t}$$

$$\int_{\text{loop}} \mathbf{D} \cdot d\mathbf{l} = \rho_{\text{ext}} + \rho_{\text{ext}} \frac{\partial \Phi_E(\mathbf{B})}{\partial t}$$

**Reid Priedhorsky**  
reid@reidster.net



Los Alamos  
NATIONAL LABORATORY  
EST. 1947

**Cyclopath**

LA-UR 12-00909

Future work

**User study to validate Stage 3 \***

**Try other algorithms \***

**Relationship between Stages 2 and 3**

... can we skip Stage 3?

**Predictions based on sensing?**

**Path cost is a nonlinear function**

**Loop routes**