Coordinating users of shared facilities via data-driven predictive assistants and game theory

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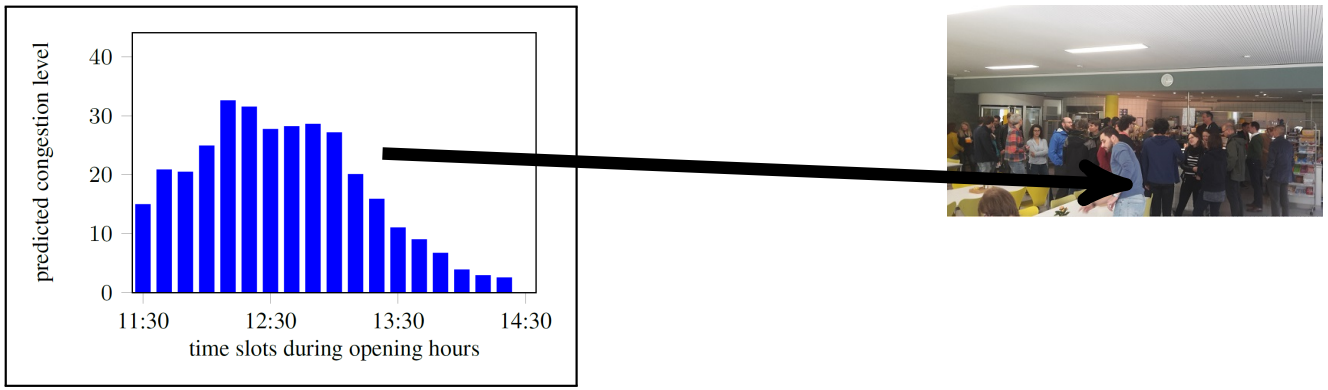
Challenges in collective sys. – ML helps when/how?

Recently, forecasts for more efficient e.g. congested shared facilities

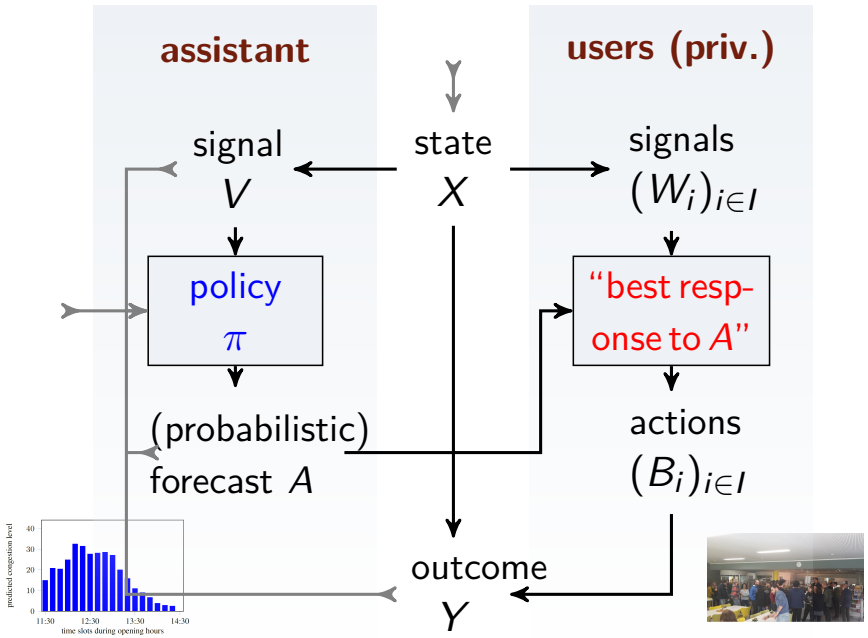


When can ML help? For which 'socio-aware' concept of *objective*?

Which *algorithms* do provably help?

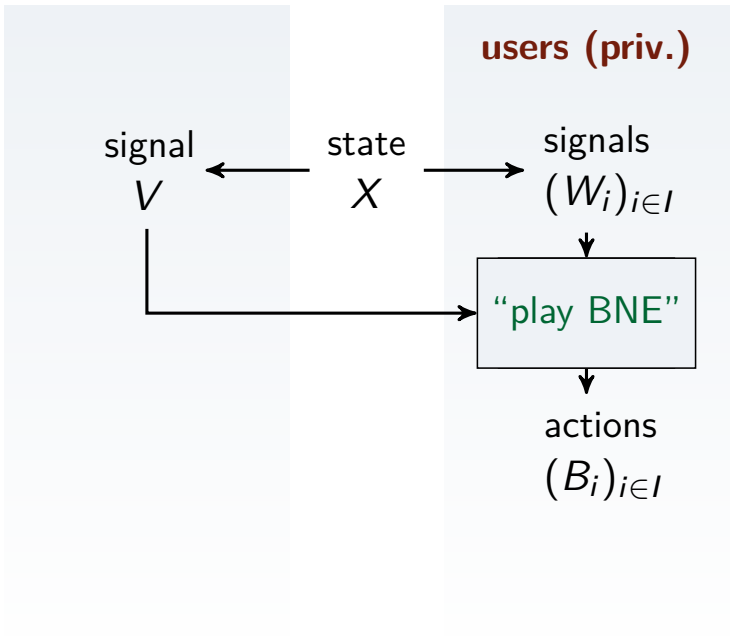
Facility users' decisions – assistant-based and ideal

Assistant-based system:



User $i \in I$ picks (time)slot $B_i \in \{1, \ldots, K\}$,
$\mathbb{E}$-optimal under her utility U_i and forecast A

Benchmark Bayesian game G:



Users have 'true' prior $P(X, V, W)$, know all utility functions, are fully rational [1]

Predictive objective (simple, obs.): minimize "$\|\pi(V) - P_\pi(Y|V)\|$"

Coordination objective (users'-utilities-aware): $(P_\pi(B_i|V,W_i))_{i\in I}$
should be Bayesian Nash eq. of G (BNE; "solution w.r.t. util. U_i")

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Motivation

Setting

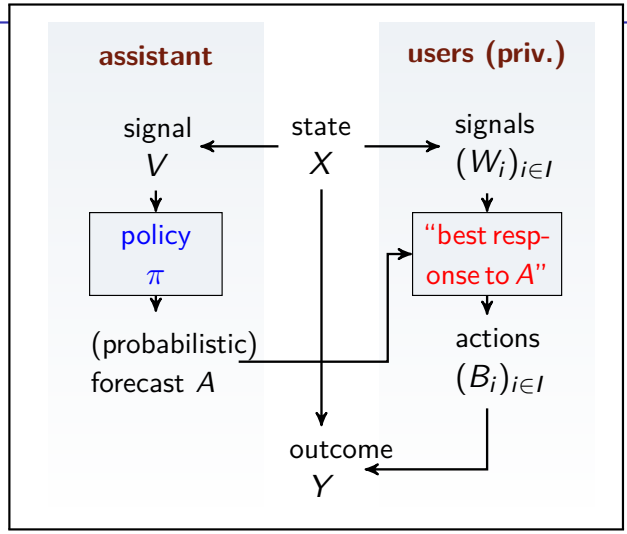
What is the utility of predictions for user coordination?

Which assistant algorithms provably reach optimal predictions?

Further

Conclusions

Self-fulfilling prophecy characterization



Assumptions:

- "$Y \perp\!\!\!\perp W_i | V$" ("assistant-separable")
- "$U_i \perp\!\!\!\perp X | W_i, Y$" ("inference-assistable")
  (plus additional details)

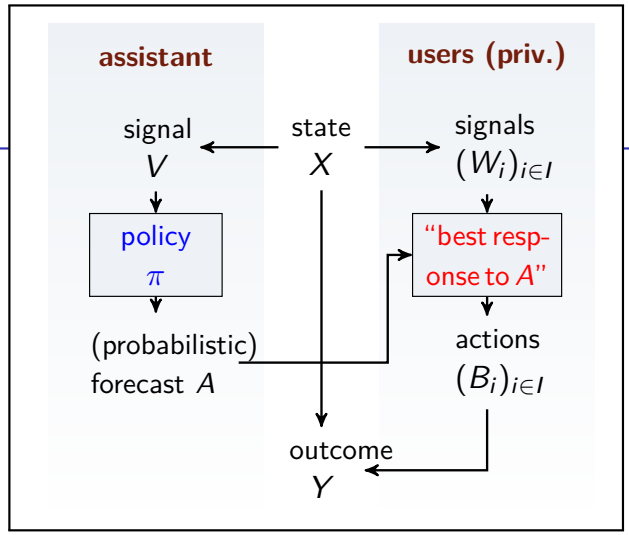
Theorem

If the assistant policy π is a self-fulfilling prophecy ("$\|\pi(V) - P_\pi(Y|V)\| = 0$"),

then the corresponding strategy profile $((P_\pi(B_i|V, W_i))_{i\in I})$ is a Bayesian Nash equilibrium (BNE) of the benchmark game.

Q: But when does a self-fulfilling prophecy *exist*?

Self-fulfilling prophecy existence



"Large-scale/aggregated setting"

- set of user *types* $I = [0, 1]$
  ($\rightarrow$ *nonatomic* benchmark game [3])
- V, W constant
- $Y_k := \int [B_i = k] r(i|X) di$ (fraction of user types choosing slot k)
- $U_i(k, y) - U_i(l, y) = \sum_m i^m q_m(y)$, with one q_m constant, $\neq 0$

Theorem

There exists a self-fulfilling prophecy assistant policy π in this large-scale setting.

Proof idea Weak-* topology on distributions A, Leray-Schauder-Tychonoff fixed point theorem

Corollary Nonatomic game Bayesian Nash eq. existence result

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Assistant algorithm with guarantees, experiment

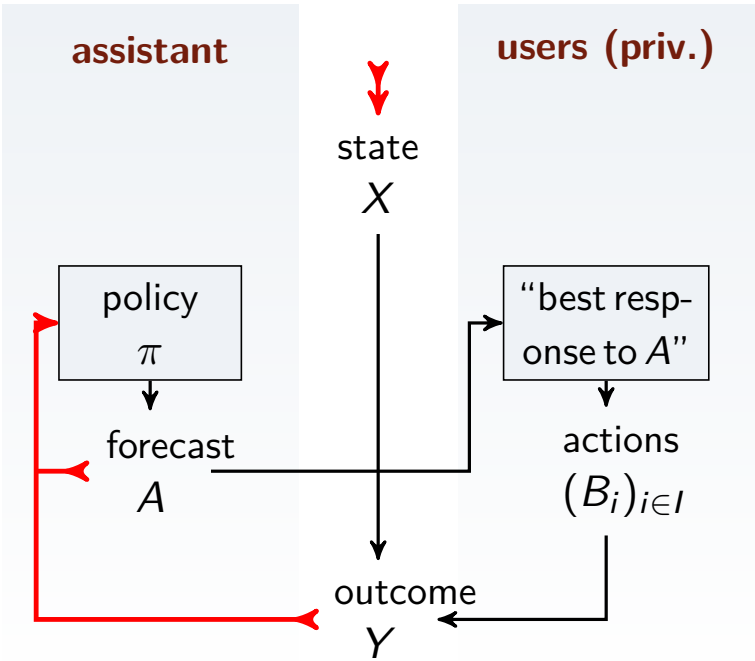
Assume dynamic large-scale, linear utilities ($\rightarrow$ *point* forecast A of Y)

Algorithm "Expodamp": For all stages $t \geq 1$, output

$$A^t := \pi(A^{t-1}, Y^{t-1})$$
$$:= A^{t-1} + \alpha(Y^{t-1} - A^{t-1})$$

Proposition: Expodamp's A_t *converges* to self-fulfilling prophecy (Y_t to Nash).

Assistant-based dynamic sys.:



Recall: forecast influences outcome

Large real-world experiment in our campus cafeteria: confirms Expodamp against baseline

Related work and further results and

Closest related work:

- *Learning in (congestion) games* [1] studies interacting agents, but without "assistant"
- *Control-theoretic* approaches for congestion in *smart cities* via "assistants" [2], but unaware of individual users' utilities
- Complementary: *fairness in ML*, *social welfare optimization*
- (Google's "Popular times" algorithms etc. – unknown to us)
- (*Exponential smoothing* – no non-influential predictions)

Omitted parts of the paper: small-scale setting with algorithm, stochastic optimality guarantees for Expodamp

- [1]: Y. Shoham and K. Leyton-Brown. Multiagent systems: Algorithmic, game-theoretic, and logical foundations. Cambridge University Press, 2008
- [2]: J. Marecek, R. Shorten, and J. Y. Yu: Signalling and obfuscation for congestion control. International Journal of Control, 88(10):2086–2096, 2015.
- [3]: D. Schmeidler. Equilibrium points of nonatomic games. Journal of statistical Physics, 7(4):295–300, 1973

Take home message

ML for collective challenges – need analysis aware of social context

Here: predictive assistants – game theory, algorithms w. guarantees

Potentially many more such mechanisms with interesting analysis!

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