

## MINI-COURSE “COLLECTIVE INTELLIGENCE THEORY WITH APPLICATIONS IN MEDICINE”

NIKOLAY N. OSIPOV

Collective intelligence systems are intended for aggregation of agents’ opinions on something (mostly on the probability of some event) in such a way that the aggregated opinion approximates the opinion of a hypothetical omniscient agent who owns all the information. We outline a CI theory that incorporates empirical and theoretical considerations: we rethink and combine topics from various fields such as probability interpretations, probabilistic logic, decision theory, statistics, and algorithmic game theory. We also describe how CI for medical studies should be designed.

### REFERENCES

#### General manuals.

- [1] G. Parmigiani and L. Y. T. Inoue. *Decision Theory: Principles and Approaches*. John Wiley and Sons, 2009.

#### Bayesian probabilities.

- [2] B. de Finetti. “Foresight: Its Logical Laws, Its Subjective Sources”. In: *Breakthroughs in Statistics. Foundations and Basic Theory*. Ed. by S. Kotz and N. L. Johnson. New York: Springer, 1992, pp. 134–174. DOI: 10.1007/978-1-4612-0919-5\_10. Trans. of “La prévision : ses lois logiques, ses sources subjectives”. In: *Ann. de l’inst. Henri Poincaré* 7.1 (1937), pp. 1–68.
- [3] J. B. Kadane and R. L. Winkler. “Separating Probability Elicitation From Utilities”. In: *J. Am. Stat. Assoc.* 83.402 (1988), pp. 357–363. DOI: 10.2307/2288850.
- [4] J. Williamson. “Philosophies of Probability”. In: *Handbook of the Philosophy of Mathematics*. Ed. by A. Irvine. North Holland: Elsevier, 2009, pp. 493–533. Draft: <https://blogs.kent.ac.uk/jonw/files/2015/04/philprob2009.pdf>.
- [5] J. Williamson. *In Defence of Objective Bayesianism*. Oxford University Press, 2010. DOI: 10.1093/acprof:oso/9780199228003.001.0001.
- [6] J. Williamson. “Objective Bayesianism, Bayesian conditionalisation and voluntarism”. In: *Synthese* 178.1 (2011), pp. 67–85. DOI: 10.1007/s11229-009-9515-y. Draft: <https://blogs.kent.ac.uk/jonw/files/2015/04/0BBCstances2011.pdf>.
- [7] I. Arieli, Y. Babichenko, and R. Smorodinsky. “Robust Forecast Aggregation”. In: *Proc. Natl. Acad. Sci. U.S.A.* 115.52 (2018), E12135–E12143. DOI: 10.1073/pnas.1813934115. arXiv: 1710.02838 [q-fin.EC].

#### Utility theories.

- [8] J. P. Quirk and R. Saposnik. “Admissibility and Measurable Utility Functions”. In: *Rev. Econ. Stud.* 29.2 (1962), pp. 140–146. DOI: 10.2307/2295819.
- [9] J. L. Becker and R. K. Sarin. “Lottery Dependent Utility”. In: *Manag. Sci.* 33.11 (1987), pp. 1337–1382. DOI: 10.1287/mnsc.33.11.1367.
- [10] M. Cohen. “Security level, potential level, expected utility: A three-criteria decision model under risk”. In: *Theory Decis.* 33.2 (1992), pp. 101–134. DOI: 10.1007/BF00134092.

- [11] U. Schmidt. “Lottery Dependent Utility: a Reexamination”. In: *Theory Decis.* 50.1 (2001), pp. 35–58. DOI: 10.1023/A:1005219005058.

### Special likelihood functions.

- [12] D. R. Cox. “Partial Likelihood”. In: *Biometrika* 62.2 (1975), pp. 269–276. DOI: 10.1093/biomet/62.2.269. URL: <https://www.jstor.org/stable/2335362>.
- [13] K. M. Leung, R. M. Elashoff, and A. A. Afifi. “Censoring Issues In Survival Analysis”. In: *Annu. Rev. Public Health* 18 (1997), pp. 83–104. DOI: 10.1146/annurev.publhealth.18.1.83.

### Wagering mechanisms.

- [14] J. Wolfers and E. Zitzewitz. “Prediction Markets”. In: *J. Econ. Perspect.* 18.2 (2004), pp. 107–126. DOI: 10.1257/0895330041371321.
- [15] C. F. Manski. “Interpreting the Predictions of Prediction Markets”. In: *Econ. Lett.* 91.3 (2006), pp. 425–429. DOI: 10.1016/j.econlet.2006.01.004. Draft: <https://www.nber.org/papers/w10359.pdf>.
- [16] J. Wolfers and E. Zitzewitz. *Interpreting Prediction Market Prices as Probabilities*. Working Paper 12200. National Bureau of Economic Research, 2006. DOI: 10.3386/w12200.
- [17] R. Hanson. “Logarithmic market scoring rules for modular combinatorial information aggregation”. In: *J. Predict. Markets* 1.1 (2007), pp. 3–15. URL: <http://www.ubplj.org/index.php/jpm/article/view/417>.
- [18] J. Feigenbaum et al. “Computation in a distributed information market”. In: *Theor. Comput. Sci.* 343.1–2 (2005), pp. 114–132. DOI: 10.1016/j.tcs.2005.05.010.
- [19] D. M. Pennock and R. Sami. “Computational Aspects of Prediction Markets”. In: *Algorithmic Game Theory*. Ed. by N. Nisan et al. Cambridge: Cambridge University Press, 2007, pp. 651–676. DOI: 10.1017/CB09780511800481.028.
- [20] M. Ottaviani and P. N. Sørensen. *Aggregation of Information and Beliefs: Asset Pricing Lessons from Prediction Markets*. Discussion Paper 09-14. University of Copenhagen (Department of Economics), 2009. DOI: 10.2139/ssrn.1447369.
- [21] L. Page and R. T. Clemen. “Do prediction markets produce well-calibrated probability forecasts?” In: *Econ. J.* 123.568 (2013), pp. 491–513. DOI: 10.1111/j.1468-0297.2012.02561.x.
- [22] N. S. Lambert et al. “An axiomatic characterization of wagering mechanisms”. In: *J. Econ. Theory* 156 (2015), pp. 389–416. DOI: 10.1016/j.jet.2014.03.012. Draft: <http://nrs.harvard.edu/urn-3:HUL.InstRepos:22556440>.
- [23] R. Freeman, D. M. Pennock, and J. Wortman Vaughan. “The Double Clinching Auction for Wagering”. In: *Proceedings of the 2017 ACM Conference on Economics and Computation*. 2017, pp. 43–60. DOI: 10.1145/3033274.3085118. eprint: <https://users.cs.duke.edu/~rupert/double-clinching-auction-ec17.pdf>.

### Play-money mechanisms.

- [24] D. M. Pennock et al. “The Real Power of Artificial Markets”. In: *Science* 291.5506 (2001), pp. 987–988. DOI: 10.1126/science.291.5506.987.
- [25] E. Servan-Schreiber et al. “Prediction Markets: Does Money Matter?” In: *Electron. Mark.* 14.3 (2004), pp. 243–251. DOI: 10.1080/1019678042000245254.
- [26] E. S. Rosenbloom and W. Notz. “Statistical Tests of Real-Money versus Play-Money Prediction Markets”. In: *Electron. Mark.* 16.1 (2006), pp. 63–69. DOI: 10.1080/10196780500491303.

### Self-resolving mechanisms.

- [27] K. Ahlstrom-Vij and N. Williams. “Self-resolving Information Markets: An Experimental Case Study”. In: *J. Predict. Markets* 12.2 (2018).

**Collective intelligence in medicine.**

- [28] P. M. Polgreen et al. “Use of Prediction Markets to Forecast Infectious Disease Activity”. In: *Clin. Infect. Dis.* 44.2 (2007), pp. 272–279. DOI: 10.1086/510427.
- [29] T. Pfeiffer and J. Almenberg. “Prediction markets and their potential role in biomedical research — A review”. In: *Biosystems* 102.2 (2010), pp. 71–76. DOI: 10.1016/j.biosystems.2010.09.005.
- [30] A. Graefe. “Prediction Markets for Forecasting Drug Development”. In: *Foresight (Colch.)* 17 (2010), pp. 8–12.
- [31] *CrowdWorx interview with Carol Gebert: Prediction Markets in the Pharmaceuticals Industry*. 2011. URL: <https://www.crowdworx.com/news/crowdworx-interview-carol-gebert-prediction-markets-pharmaceuticals-industry>.
- [32] A. Dreber et al. “Using prediction markets to estimate the reproducibility of scientific research”. In: *Proc. Natl. Acad. Sci. U.S.A.* 112.50 (2015), pp. 15343–15347. DOI: 10.1073/pnas.1516179112.
- [33] A. N. D. Meyer, C. A. Longhurst, and H. Singh. “Crowdsourcing Diagnosis for Patients With Undiagnosed Illnesses: An Evaluation of CrowdMed”. In: *J. Med. Internet Res.* 18.1 (2016), e12. DOI: 10.2196/jmir.4887.
- [34] R. H. J. M. Kurvers et al. “Boosting medical diagnostics by pooling independent judgments”. In: *Proc. Natl. Acad. Sci. U.S.A.* 113.31 (2016), pp. 8777–8782. DOI: 10.1073/pnas.1601827113.
- [35] E. Y. Li, C.-Y. Tung, and S.-H. Chang. “The wisdom of crowds in action: Forecasting epidemic diseases with a web-based prediction market system”. In: *Int. J. Med. Inform.* 92 (2016), pp. 35–43. DOI: 10.1016/j.ijmedinf.2016.04.014.