Why Swarms of Agents Are Better than Clouds?

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1. Formulation of the Problem

- Expert estimates are often very crude.

- It is known, however, that:
  - if we ask several independent experts to estimate a quantity, and
  - then average the resulting estimates,
  - we often get a reasonably accurate estimate.

- This is the main idea behind *crowd intelligence.*

- It was recently discovered that:
  - if we first divide the experts into small groups,
  - let each group ("swarm") combine their estimates into a single value,
  - and only average the group results,
  - we get a much more accurate estimate.

Our Explanation

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2. Formulation of the Problem (cont-d)

- Why is swarm intelligence better than the crowd intelligence?

3. Our Explanation

- Let $x_1, \ldots, x_n$ be estimates of different experts.

- Let $\rho(x)$ be the probability density function of the expert's approximation error.

- Then, ideally, we should select an estimate a with the largest possible likelihood

$$L \stackrel{\text{def}}{=} \prod_{i=1}^{n} \rho(x_i - a).$$

- It is known that:

  - when $\rho(x)$ is a normal distribution,

  - maximum likelihood estimate is indeed the arithmetic average

$$a = \frac{1}{n} \cdot \sum_{i=1}^{n} x_i.$$

4.   Our Explanation (cont-d)

- For normal distributions, the maximum likelihood estimate is the arithmetic average.

- However, for other distributions, the maximum likelihood estimate is different from the arithmetic average.

- This explains why the crowd intelligence results are not perfect.

- We allow agents from each swarm s to come to an agreement between themselves.

5.   Our Explanation (cont-d)

- It is reasonable to assume that:

  - within each swarm,

  - the agents will come up with a maximum likelihood (ML) estimate $a(s)$

  - i.e., an estimate for which the following value is the largest:
  $$\prod_{i \in s} \rho(x_i - a(s)).$$

- It is known that:

  - when the number of combined estimates is reasonably large,

  - the ML estimates $a(s)$ are approximately normally distributed.

6. Our Explanation (cont-d)

- When the number of combined estimates is large, the ML estimates $a(s)$ are almost normally distributed.

- Thus:

  - to combine values corresponding to different swarms,

  - we can use the method which is optimal for normal distributions,

  - i.e., taking the arithmetic average.

- Thus, the estimate provided by swarm intelligence is asymptotically equal to the maximum likelihood one.

- It is thus (asymptotically) optimal.

7.   Main Reference

- L. Rosenberg, D. Baltaxe, and N. Pescetelli, "Crowds vs. smarms, a comparison of intelligence", *Proceedings of the IEEE Swarm/Human Blended Intelligence Workshop SHBI'2016*, Cleveland, Ohio, October 21–23, 2016.