The Intelligent Network: Distributed Learning and Problem Solving

Bernardo A. Huberman
CableLabs

Many minds better than one

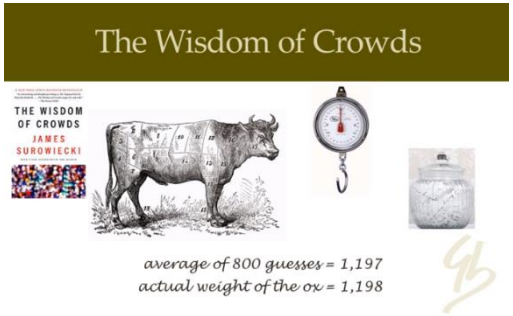
Distributed systems

- Social animals and insects
- Organizations
- Scientific and technical societies
- Jury systems
- Federated learning, many robots
- Crowdsourcing (Blockchain, Wikipedia, Quora,…)

Two types of distributed intelligence

1.- Wisdom of the crowd: many minds better than few; even if they don't interact.

Francis Galton (1907):



Marquis de Condorcet jury theorem (1785): A group reaches a correct decision by majority vote if p>1/2.

Two types of distributed intelligence

2.- Cooperative systems: agents, programs, insects, people, etc. exchange information that *changes the state of those who receive it.*

Examples: large scale collaborations, manufacturing, connected sensors, neural networks, blockchains, etc.

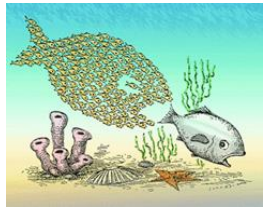
Many of these problems can be seen as searches in large problem spaces.

Questions

- How much better are distributed intelligences than the best individual ones?
- How do we orchestrate large cooperative processes? (IoT, blockchain, network design, enterprises)
- What about partial solutions that are often wrong, ineffective, delayed? => stochasticity of the process.
- How do we secure cooperation from strategic agents (free riding)?

Answers

- Cooperative processes usually outperform the best one.
- The distribution of performance is universal and with a *heavy tail*.
- A sharp transition from exponential to polynomial time as heuristic improves.
- The heavy tail guarantees the existence of some agents with superior performance=> combinatorial implosions.



A Universal Law

Distributed problem solving

Local agents exchange messages reporting partial results towards completion of a goal.

Some of those answers are often incorrect and or delayed.

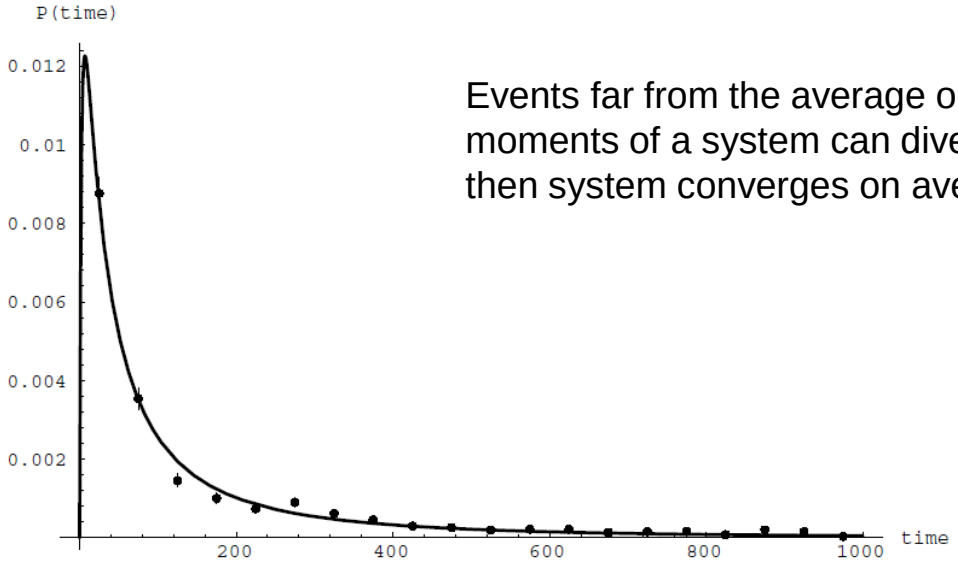
Those making the most progress per unit time set the overall performance of the group.

When searching for an answer the overall search time is set by the agent who arrives at the answer first!

Interactions lead to a non-linear increase in performance.

Universal law

The distribution of performance is log-normally



Events far from the average occur because moments of a system can diverge even when then system converges on average.

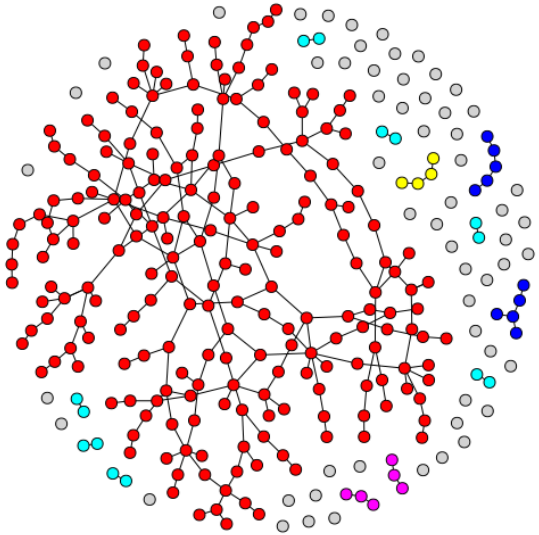
Observed in scientific productivity, income distributions, experiments.

Problems usually come in two flavors

Easy: the time to solution scales as a power of the size of the problem.

Example: choose two nodes in the graph and ask if there is a path between them less than *M*

Answer can be found in polynomial time with respect to the number of nodes.



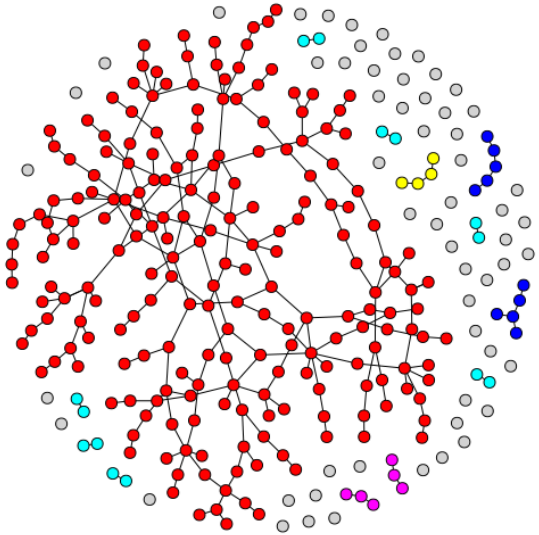
Problems usually come in two flavors

Hard: the time to solution scales exponentially with the size of the problem.

Example: choose two nodes in the graph and ask if there is a path between them larger than M

Answer can be found in exponential time with respect to the number of nodes.

But: if one is given a path whose length is claimed to be >*M*, there is an algorithm that can check if true in polynomial time!



Combinatorial Implosions

Cooperative problem-solving prunes the search space.

And one often observes a *sharp transition* from exponential to polynomial times in their solution.

Analogous to phase transitions in physical systems.
(Huberman and Hogg)

Experimental verification of the law

Cryptarithmetic: the fruit fly of constraint satisfaction problems

- Find letter-> number assignments such that it makes sense as a sum.

```
  S E N D
+ M O R E
---------
M O N E Y
```

```
  9 5 6 7
+ 1 0 8 5
---------
1 0 6 5 2
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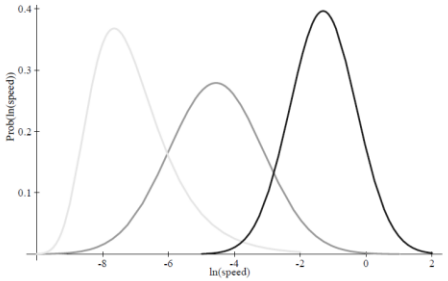


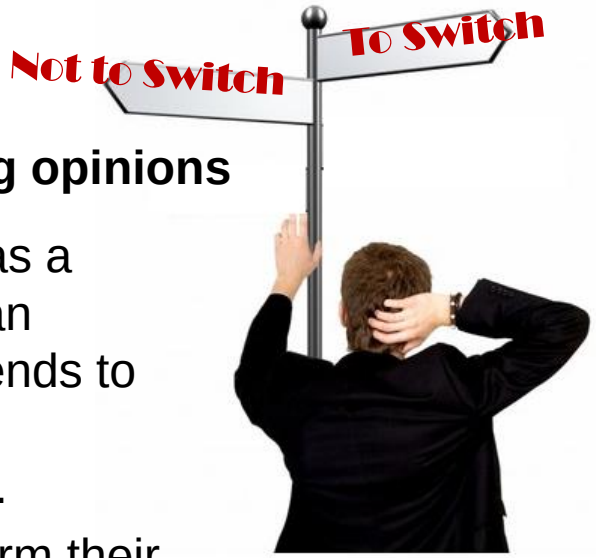
Clearwater, Huberman and Hogg, *Cooperative Solution of Constraint Satisfaction Problems*, Science, Vol. 254, pp. 1181-1183

Social Influence

Question

Will the preferences from others make people reverse their own opinions?

To switch or not to switch



Confirming existing opinions

- Once one has a position on an issue, one tends to look for confirmation.
- People confirm their existing opinions to avoid dissonance.

Social conformity

When facing others' disapproval, people choose to conform to others.

People conform in order to form an accurate interpretation of the reality and obtain social approval.

Basic Idea

Participants were asked to provide their preferences between pairs of items, with or without knowing others' preferences.

Results

- People are most likely to reverse their choices when facing a moderate, as opposed to large, number of opposing opinions.
- Influence is stronger when people are required to make their second decision after a while.
- The longer the time people spend making the first decision the more likely they will reverse their own choices. *Conformity*.

GRACIAS!