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Achieving Reliability in Master-Worker Computing via Evolutionary Dynamics

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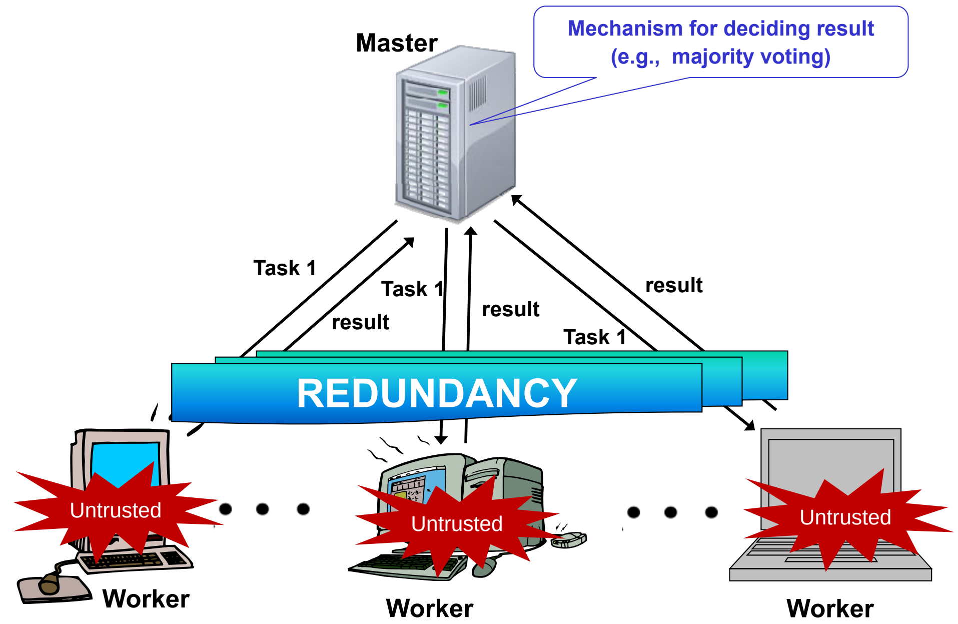
SETI-like Internet-based Computing



Prior Work

- Rational workers: act upon their best interest, i.e., choose the strategy that maximizes their own benefit [Shneidman Parkers 03]
  - Honest: compute and report correct result
  - Cheat: fabricate and return a bogus result
- Mechanisms with reward/punish schemes that provide incentives to workers to be honest
  - One shot: in each round a task is performed and no knowledge is forwarded to the next round [Yurkewych et al 2005, Fernandez et al 2008]

Can the repeated interaction between the master and the workers be exploited effectively?

Our Approach

- We introduce the concept of *evolutionary dynamics* under the biological and social perspective and relate them to Internet-based master-worker task computing
- Employ *reinforcement learning* both on Master and Workers
  - Positive payoffs increase probability of strategy just chosen
  - Negative payoffs reduce the probability
  - Knowledge only of the payoffs received, not of the strategies involved [Camerer 03,Szepesvari 10]
- Objective: Develop a reliable computation platform where the master obtains the correct task results (whp).

Model: Master

- The Master can audit the responses (with some cost)
  - Auditing means performing the task
  - $p_{\mathcal{A}}$:probability of auditing
    - It may change from round to round
- *Eventual correctness*: After some finite number of rounds, the master obtains the correct task in every round, with minimal auditing, while keeping the workers satisfied

Model: Workers

- Each worker i has
  - a probability of cheating p_{C_i}
    - It may change from round to round
  - an aspiration a_i
    - the minimum benefit it expects to obtain in a round
- Payofffs

WP_C	Worker's punishment for being caught cheating
WC_T	Worker's cost for computing a task
WB_y	Worker's benefit from master's acceptance

Master's Protocol

Set initial $p_{\mathcal{A}}$ (e.g., 0.5)
Repeat
  Send a task to all *n* workers
  Upon receiving all answers **do**
    Audit the answers with probability $p_{\mathcal{A}}$
    If the answers were *not* audited **then**
      Accept the value returned by the majority
    Else

$$p_{\mathcal{A}} \leftarrow p_{\mathcal{A}} + \alpha_m \cdot \left(\frac{cheaters}{n} - \tau \right)$$

    Give appropriate payoff Π_i to each worker i

α_m : learning rate (tunes the extent of change)
τ : tolerance (tolerable ration of cheaters, e.g., 0.5)

Protocol for Worker i

Set initial p_{C_i} (e.g., 0.5)
Repeat
  Receive a task from the master
  Set S_i = -1*with* probability p_{C_i} , S_i = 1 otherwise
  If S_i = 1 then **compute** the task and **send** the result
  Else send an arbitrary result
  Get payoff Π_i

$$p_{C_i} \leftarrow p_{C_i} - \alpha_w \cdot (\Pi_i - a_i) \cdot S_i$$

α_w: learning rate (tunes the extent of change)

Results

- We analyze the evolution of the master-worker system as a *Markov chain* and we show:

  For the system to achieve eventual correctness, it is necessary and sufficient to set

  $$WB_y \geq a_i + WC_T, \;\; \forall i \in Z, \; |Z| > n/2$$

- Convergence time: The number of rounds to achieve eventual correctness
  - We show, both in expectation and with high probability, that our mechanism reaches convergence time quickly
  - We complement the analysis with simulations.

Examples of Convergence

- *Under certain conditions, the expected convergence time is*

  $$\left(\alpha_w \cdot (WB_y - WC_T - \max_i\{a_i\}) \cdot \varepsilon\right)^{-1}$$

  where

  $$\varepsilon \in (0, 1 - (WC_T + \max_i\{a_i\})/WB_y).$$

- *Under certain conditions, the converge time is at most*

  $$\ln(1/\varepsilon)/p + 1/dec$$

  with probability at least

  $$(1-\varepsilon)(1-e^{-n/96})(1-e^{-n/36})^{1/dec}$$

where

$$dec = \min_i\{\alpha_w \cdot \min\{a_i, \, WB_y - WC_T - a_i\}\}, \text{and } \varepsilon \in (0,1)$$

Thank you!

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