A simulation of disagreement for control of rational cheating in peer review

Francisco Grimaldo
Departament d'Informàtica
Universitat de València
Av. Universitat, s/n, Burjassot, Spain, 46100
Email: francisco.grimaldo@uv.es

Mario Paolucci
Institute of Cognitive Sciences and Technologies
Italian National Research Council
Via Palestro 32, Roma, Italy, 00185
Email: mario.paolucci@istc.cnr.it

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ABSTRACT

We present an agent-based model of peer review built on three entities - the paper, the scientist and the conference. The systems is implemented on a BDI platform (Jason) that allows us to define a rich model of scoring, evaluating and selecting papers for conferences. Some of the reviewers apply a strategy (called "rational cheating") aimed to prevent papers better than their own to be accepted. We show how a programme committee update based on disagreement control can remove them.

INTRODUCTION

Large scale collaboration endeavors amongst humans are making the headlines of scientific magazines and attracting the attention of the research community. The case of Wikipedia and Amazon's Mechanical Turk are striking examples of what some consider to be the first step in a transition towards collective intelligence (Buecheler et al., 2011), a transition not devoid of risks as averaging effects and isolation (Pariser, 2011). To understand how this transition is happening and what are its consequences, we need to examine carefully the existing social and cultural structures that anticipate this kind of collaboration. The most important of these structures - a social artefact in itself - is the institution known as *peer review*.

Peer review, the process that scrutinizes scientific contributions before they are made available to the community, lies at the core of the social organization of science. Curiously, while the measurement of scientific production, that is, the process that concerns the *citation* of papers - scientometrics - has been an extremely hot research issue in the last years, we can't say the same for what concerns the process of *selection* of papers, although some attention has been focused on its shortcomings. Although being extremely important, the actual effectiveness of peer review in ensuring quality has yet to be fully investigated. In (Neff and Olden, 2006), the review process is found to include a strong "lottery" component, independent of editor and referee integrity. While the heterogeneous review approach to a decision between two options is supported by Condorcet's jury theorem, we move beyond simple accept/reject decisions to a more sophisticated and precise outlook on peer review that considers scoring and ranking. In fact, looking at scoring means looking at the pertinence and reliability of peer evaluation in its current incarnation, which could in turn help to detect kinds of potential failures that are not waived by Condorcet's theorem.

These issues are particularly relevant because peer review should take advantage of the new information publishing approach and technologies created by Web 2.0 and beyond. At the same time, diffuse dissatisfaction of scientists towards the current mechanisms of peer review is perceived - anecdotally, as list of famous papers that were initially rejected and striking fraudulent cases are published, and statistically, as numerical evidence on the failures of peer review (Casati et al., 2009) is starting to appear. To understand and possibly to apply policies to peer review, and in turn, to collective filtering and collective intelligence, we need more evidence coming from both the analysis and review of the process as it is, as well as from the creation of numerical, agent-based models, that could be validated both on the micro and the macro level, and on which we could perform what-if analysis, thus testing "in silico" proposed innovations. In this paper, we propose an agent-based model of peer review and, inspired by the introduction of rational cheaters in (Thurner and Hanel, 2011), we test how a simple mechanism based on disagreement control could help controlling this kind of cheating. The rest of the paper is organized as follows: the next section reviews the (scarce) literature on simulation of peer review. We then outline a general model of peer review endowed with a reviewer disagreement control mechanism, with a few implementation details. In the results section, we show how the mechanism works under two different conditions. In the last section, we present our conclusions and draw the path for future work.

RELATED WORKS

The literature of simulation models about peer review is scarce. We mention (Thurner and Hanel, 2011), where the authors focus on an optimizing view of the reviewer for his or her own advantage. To this purpose, they define a submission/review process that can be exploited by a *rational cheater* (Callahan, 2004) strategy in which the cheaters, acting as reviewers, reject papers whose quality would be better than their own. In that model, the score range for review is very limited (accept or reject) and in case of disagreement (not unlikely because they allow only two reviewers per paper), the result is completely random. They find out that a small number of rational cheaters quickly reduces the process to random selection. The same model is expanded in (Roebber and Schultz, 2011), focusing not on peer review of papers, but of funding requests. Only a limited amount of funding is available, and the main focus is to find conditions in which a flooding strategy is ineffective. The number of cheaters, differently from this study and from (Thurner and Hanel, 2011), is not explored as an independent variable. However, similarly to the present work, the strong dependance of results from the mechanism chosen (number of reviews, unanimity) is evidenced.

In (Squazzoni and Gandelli, 2012), the authors study the impact of referee reliability on the quality and efficiency of the process. Their results emphasize the importance of homogenity of the scientific community and equal distribution of the reviewing effort.

In this work, we will use the score range and programme commitee update defined in (Grimaldo Moreno et al., 2010), and we will apply it to control the effect of rational cheaters as presented in (Thurner and Hanel, 2011), adding also, partly inspired by (Squazzoni and Gandelli, 2012), two different conditions: homogeneous and heterogeneous conferences.

THE PEER REVIEW MODEL

In this section, we define the entities involved in the peer review process, we propose a new model to reproduce its functioning and we present an agent-based implementation of this model.

Peer review entities

The key entities we identify within the peer review process are: the *paper*, the *scientist* and the *conference*.

The *paper* entity is the basic unit of evaluation and it refers to any item subject to evaluation through a peer review process, including papers and project proposals. We assume that the actual value of a paper is difficult to ascertain and that it can only accessible through a procedure implying the possibility of mistakes.

Scientists write papers, submit them to conferences and review papers written by others. Regarding paper creation, the value of a paper will depend on the writing skills of the authors. The submission decision must consider aspects such as the characteristics of the conference (e.g. acceptance rate), those of the authors (e.g. risk taking), etc. Scientists will also be characterized by their reviewing skills, that represent the chance they actually understand the paper they review, thus being the primary cause of reviewing noise. The evaluation process might involve other strategic behaviors possibly adopted by the scientist, such as the competitor eliminating strategy used by rational cheaters in (Thurner and Hanel, 2011).

The *conference* entity refers to any evaluation process using a peer review approach. Hence, it covers most journal or conference selection processes as well as the project evaluations conducted by funding agencies. Every *paper* submitted to a conference is evaluated by a certain number of *scientists* that are part of the programme committee (PC) of the conference. Thus, the conference is where all the process comes together and a number of questions arise. For example, since the number of evaluations a paper receives are just a few (three being a typical case): can the review-conference system ensure quality in the face of variable reviewing skills or strategic behaviors, thanks to some selection process of PC composition that leans on disagreement control? The peer review model presented below is meant to tackle this kind of questions by concretising the different issues introduced for the general entities presented above.

Proposed model

The proposed model represents the peer review problem by a tuple $\langle S, C\rangle$, where S is the set of *scientists* playing both the role of authors that write papers and the role of reviewers that participate in the PC of a set of *conferences* C. *Papers* produced by scientists have an associated value representing their intrinsic value, and receive a review value from each reviewer. These values are expressed as integers in an N-values ordered scale, from strong reject (value 1) to strong accept scores (value N).

Every scientist $s \in S$ is represented by a tuple $s = \langle ap, aq, as, rd, rs, rt\rangle$. Regarding paper production, each scientist has an associated author productivity ap, meaning the number of papers uniformly written per year. Papers are of the form $p = \langle a, iv\rangle$, being $a \in S$ the author of the paper and $iv \in [1, N]$ the intrinsic value (quality) of the paper. This intrinsic value is calculated considering the author quality $aq \in [1, N]$ and the author skill value $as \in [0, 1]$. Whereas aq represents the canonical author quality, as represents the production reliability of scientists. Hence, scientists write papers of value aq with probability as, and of random value with probability $(1 - as)$ in order to produce, occasionally, some paper with outlying quality with respect to their standard. Similarly, as a reviewer, each scientist has an associated reviewer skill value $rs \in [0, 1]$ as well as a reviewing type $rt \in \{\texttt{normal}, \texttt{rational}\}$. In algorithm 1 we show the pseudocode carried out by scientists to review papers. The **if** statement in line 1 models the noisy evaluation of papers, where the result of reviewing is accurate with probability rs, and completely random with probability $(1 - rs)$. Here, `Random` is a function providing a random float number in the range $[0, 1]$ whereas `RandomInt` returns a random integer in $[1, N]$. Furthermore, in line 7 we have incorporated the rational cheating strategy introduced in (Thurner and Hanel, 2011). Hence, $rational$ cheaters punish those papers whose intrinsic value is greater than his own author quality, thus trying to clear the way for his papers - preventing better papers to appear and, for example, collect more citations than one's own.

Algorithm 1 Pseudocode to review papers

Input: Paper Intrinsic Value (iv), Reviewer Skill (rs), Reviewer's Author Quality (aq), Reviewing Type (rt)
Output: Review Value for the paper ($reviewValue$)

```
if rs > Random() then
    estimatedValue ← iv
else
    estimatedValue ← RandomInt(1, N)
end if
if rt = rational then
    if estimatedValue < aq then
        reviewValue ← estimatedValue
    else
        reviewValue ← 1
    end if
else
    reviewValue ← estimatedValue
end if
```

Conferences $c \in C$ are represented by the following tuple: $c = \langle m, PC, rp, pr, av, I, dt, pu \rangle$. Each conference is celebrated every year in a certain month m, in which it sends its call for papers. In algorithm 2 we show the pseudocode executed by scientists when deciding whether to submit a paper to a conference after having received its call for papers. Note how the noisy evaluation of papers also occurs when evaluating the own papers in lines 2 - 6. Scientists decide whether to submit papers or not in accordance with their submission risk degree, expressed through the integer value rd. Hence, the submission happens when the distance between the estimated paper value and the conference acceptance value av is less than or equal to rd (see line 7).

Algorithm 2 Pseudocode to submit papers

Input: Available Papers (AP), Reviewer Skill (rs), Risk Degree (rd), Conference (c), Conference Acceptance Value (av)

```
1:  for all p such that p ∈ AP do
2:      if rs > Random() then
3:          estimatedValue ← iv
4:      else
5:          estimatedValue ← RandomInt(1, N)
6:      end if
7:      if |estimatedValue − av| ≤ rd then
8:          Submit(p, c)
9:      end if
10: end for
```

Conferences employ a subset of scientists $PC \subseteq S$ as their programme committee, whose size depends on the number of reviews received per paper rp and the number of reviews done per PC member pr. Then, they accept those papers whose average review value is greater than the acceptance value av.

Conferences also keep track of disagreements between reviewers, as they might be a signal of low reviewer skill or cheating. One disagreement event is not enough to find out which of the disagreeing parts is to blame. Thus, conferences maintain an image $i \in I$ of each scientist that has ever been a PC member, accounting for the number of disagreements with the other reviewers. Images are of the form $i = \langle s, nd, nr \rangle$, where s is the scientist, nd is the accumulated number of disagreements and nr is the total number of reviews carried out. Disagreements are calculated on a paper basis as the difference between the review value given by the reviewer and the average review value for that paper. When this difference gets higher than a disagreement threshold dt, the reviewer disagreement count grows by one. The dt parameter could also be fine-tuned for the detection of more sophisticated cheating approaches.

Reviewer images are used to update the PC by discarding the $pu\%$ of reviewers with a higher ratio nd/nr and selecting new ones from S. This way, conferences perform a selection process which selects reviewers who provide similar evaluations. Given our choice for reviewers' mistakes (i.e. if they don't understand the paper, the evaluation is random), this mechanism should also select good reviewers.

In algorithm 3 we show the pseudocode executed when celebrating a new edition of a conference. Firstly, function `CallForPapers` in line 3 broadcasts the conference call for papers and receives papers submitted during a fixed period of time (currently, two months). Secondly, function `UpdatePC` in line 4 adjusts the PC to the number of papers received as well as discarding the $pu\%$ of reviewers with the worst image. New members for the PC are selected randomly from the set of scientist S. Thirdly, the **for** statement starting in line 5 is in charge of the evaluation process: function `AskForReviews` returns the reviews from rp reviewers, different to the author and randomly chosen from the PC, in the form of pairs $[s, rValue]$, where s is the reviewer and $rValue$ is the grade given to the paper; function `ComputeAvgReview` computes the average review value for the paper; lines 12 - 16 accept those papers over the acceptance value; and functions `GetImage` and `UpdateImage` in lines 17 - 24 retrieve and update the image of the reviewers after checking for disagreements. Finally, accept and reject notifications are sent to the authors by functions `NotifyAccepts` and `NotifyRejects`.

SCENARIOS

The proposed peer review model has been implemented as a MAS over Jason (Bordini et al., 2007), which allows the definition of both scientists and conferences as BDI agents using an extended version of AgentSpeak(L) (Rao, 1996). In this section, we present the results of a set of simulations involving 1000 scientists and 10 conferences across 50 years. Each scientist writes 2 papers per year ($ap = 2$), so that the overall production amounts to 2000 papers uniformly distributed over the year.

Paper intrinsic values (quality) and review values are expressed in a 10-values ordered scale from 1 to 10 ($N = 10$). Author qualities ($aq \in [1, 10]$) follow a discretized Beta distribution with $\alpha = \beta = 5$. The beta distribution is the obvious choice for a statistic in a fixed interval as the one we are using - the alternative being a normal distribution with cut tails, which is just a less flexible approximation, for example, in terms of central value. We choose this shape, a bell shaped curve with mean 5.5

Algorithm 3 Pseudocode to celebrate a conference

Input: Celebration Year ($year$), Conference Acceptance Value (av), Current Programme Committee (PC), Current Scientists' Images (I), Percentage of PC update (pu), Scientists (S), Reviews Per Paper (rp), Papers Per Reviewer (pr), Disagreement Threshold (dt)

Output: New Programme Committee (PC), New Scientists' Images (I)

```
AccPapers ← φ
RejPapers ← φ
RcvPapers ← CallForPapers(year, av)
PC ← UpdatePC(PC, S, I, pu, ⌈|RcvPapers| ∗ rp/pr⌉)
for all p such that p ∈ RcvPapers do
    Reviews ← AskForReviews(p, rp, PC)
    sumOfReviews ← 0
    for all r = [s, rValue] such that r ∈ Reviews do
        sumOfReviews ← sumOfReviews + rValue
    end for
    avgReviewValue ← sumOfReviews/|Reviews|
    if avgReviewValue ≥ av then
        AccPapers ← AccPapers ∪ {[p, avgReviewValue]}
    else
        RejPapers ← RejPapers ∪ {[p, avgReviewValue]}
    end if
    for all r = [s, rValue] such that r ∈ Reviews do
        [nd, nr] ← GetImage(I, s)
        if |avgReviewValue − rValue| > dt then
            I ← UpdateImage(I, s, nd + 1, nr + 1)
        else
            I ← UpdateImage(I, s, nd, nr + 1)
        end if
    end for
end for
NotifyAccepts(AccPapers)
NotifyRejects(RejPapers)
```

and symmetrically distributed between 1 and 10, in the hypothesis that average papers are more common than either excellent or bogus papers. Authors' skills (as) and reviewers' skills (rs) follow instead a Uniform distribution in [0.5,1], that we consider a moderate level of noise in the production and evaluation of papers. With respect to the reviewing type (rt), we show results with rational cheaters up to 30%. We have performed simulations up to 90% of rational cheaters but, when rational cheaters become majority, the probability of having two over three cheating reviews grows enough to turn the system upside down - PCs get filled with rational cheaters and no papers are accepted at all.

Conference parameters have been set to reproduce two different experimental scenarios that we call *homogeneous condition* and *heterogenous condition*. These scenarios are a first step to understand the emergence of quality specialization in the structure of workshops, conferences and papers. To this purpose, we compare a system without specialization with one in which conference differ in the quality they request from a paper.

In the *homogeneous condition* (SR) all the conferences act in the same way and they aim at accepting papers whose quality is just above the average score ($av = 5.5$). Scientists are then configured to submit papers to the first conference available after the moment of production (their risk degree rd is set to 10). In the *heterogeneous condition* (MR) we have one conference for each acceptance value from 1 to 10. In this way, we distinguish high-quality from low-quality conferences. Scientists submit papers to a conference whose av differs at most of 1 score from the estimated paper value ($rd = 1$). For instance, a conference with $av = 7$ would only receive papers of estimated quality from 6 to 8. Conferences are scheduled along the year so as to avoid conferences of similar acceptance value to appear next to each other and reduce contention for the papers.

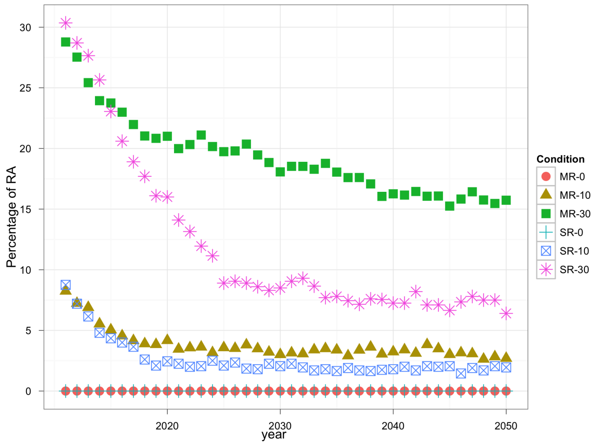

Figure 1: Percentage of rational cheaters (RA) under homogeneous (SR) and heterogeneous (MR) conditions with initial percentages from none to 30%, averaged over 10 runs. The presence of rational cheaters decreases in the first ten years, with the MR being more effective.

Conferences in both the *homogeneous condition* and the *heterogenous condition* ask for 3 reviews per paper (rp) and each PC member carries out a maximum number of 3 reviews (pr). The disagreement threshold (dt) is set to 4 and the percentage of PC members that are updated each year is 10% (pu).

Results

Our research hypothesis is that the PC update mechanism proposed will effectively find out and expel the rational cheater scientists. The argument that rational cheaters will find themselves in disagreement with others every time they act strategically makes sense and, in fact, in figure 1 we can observe how rationals decrease substantially in the conditions where they are more abundant. For the homogeneous condition, averaging removes little information, while in the heterogeneous one, where conferences differ in their acceptance value, this averaging could hide information. We address heterogeneous conferences individually in . The PC update mechanism results significantly more effective in the homogeneous condition than in the heterogeneous one (two-sided t test with p-value of 0.036, comparing MR-30 and SR-30).

Let's now focus on indicators showing the effectiveness of the rational cheating strategy. The purpose of adopting a rational cheating strategy is to remove potential competition from better authors and papers. Thus, the effect of rational cheaters should be seen as an increase in the number of papers that should be accepted, but end up being rejected. We call these "good papers rejected" (GPR). The opposite, that is, the papers that

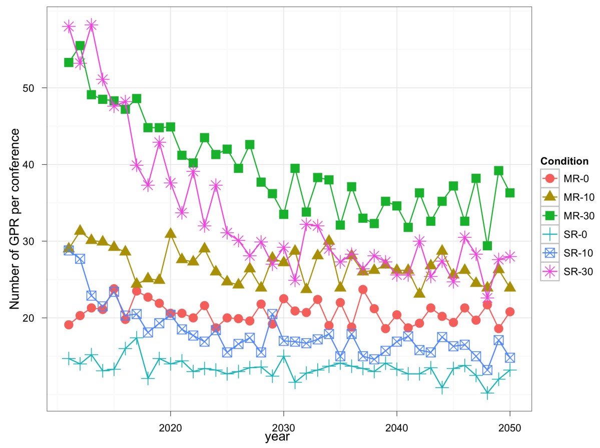

Figure 2: Number of Good Papers Rejected (GPR) under homogeneous (SR) and heterogeneous (MR) conditions with initial percentages of rational cheaters from none to 30%, averaged on ten runs. GPRs decrease significantly for both conditions with 30% of rational cheaters.

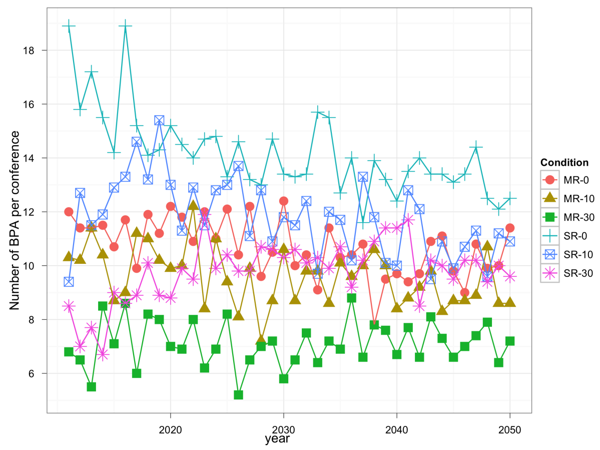

Figure 3: Number of Bad Papers Accepted (BPA) under different conditions: homogeneous (SR) and heterogeneous (MR) conditions with initial percentages of rational cheaters from none to 30%.

should end up rejected but do not, are named as "bad papers accepted" (BPA). They are shown respectively in Figure 2) and Figure 3).

For the simulations starting with more rational cheaters (SR-30 and MR-30 in figure 2), the decrease in the number of GPR , following the removal of rational cheaters from the PC, is already significant after a few years (p-value of 0.02 between 2011 and 2015). However, notwithstanding the very low quantity of rational cheaters at the end of the simulation (consider for example the case of SR-30), the complexive number of GPR remains rather high.

Referring to the number of bad papers accepted, they remain rather stable (Figure 3), and lower than the num-

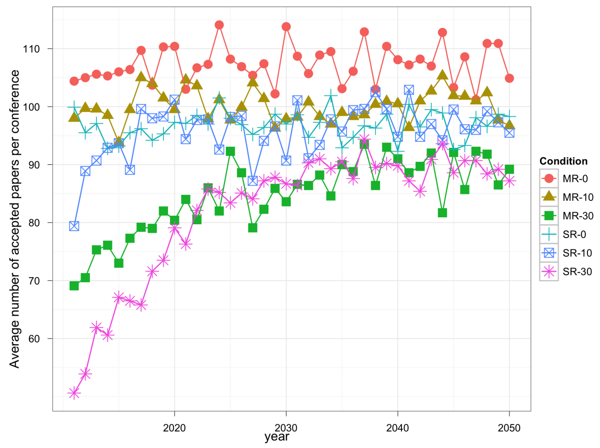

Figure 4: Number of Accepted Papers under homogeneous (SR) and heterogeneous (MR) conditions with initial percentages of Rational Agents (rational cheaters) from none to 30%, averaged over ten runs. Conferences in the heterogeneous condition systematically accept more papers than in the homogeneous condition.

ber of GPRs. Only in the SR-0 condition they seem to decrease in time. But what is more interesting is that the number of BPA at the onset of the simulation and during the first years is inversely proportional to the quantity of rational cheaters at the start. Thus, no rational cheaters bring more BPA than a 30% of rational cheaters, and this is true for both conditions. In figure 4 we show the number of accepted papers, that grows in time for the conditions with rational cheaters. As they are expelled from the PCs, the number of accepted papers grows to approach that of conditions without rational cheaters. This is likely to be happening also because of the reduction in the GPR (i.e. less good papers rejected means more papers accepted).

What about quality? Is the removal of rational cheaters from the programme committees going to make a difference in the quality of accepted papers? Surprisingly, in figure 5, we can see that the removal of rational cheaters does not contribute to higher average quality of papers. Only the MR-30 condition shows an initial increase in quality (two-sided t-test between 2011 and 2025 gives a p-value of 0.003).

Looking at heterogeneous conferences

We now open up the box of heterogeneous conferences to see how they contribute to the averages shown previously. From figure 6, where we show the percentage of rational cheaters for each individual conference (characterised by an acceptance value), we see immediately how the PC update mechanism fails in moving rational cheaters away from the PC when the quality of the conference is low. If the acceptance value reaches 4 or lower, there is no decrease at all. This happens due to the paper quality being too near to the lowest possible value used

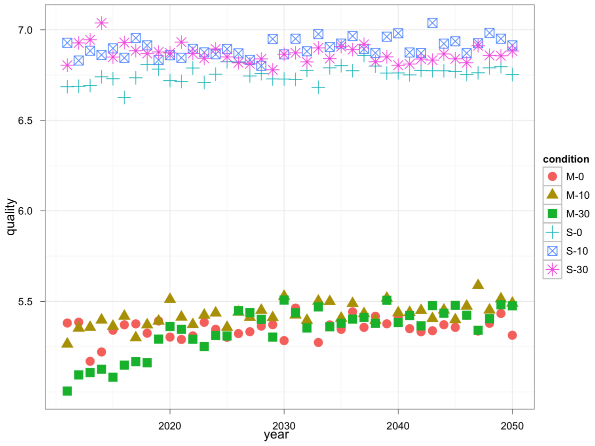

Figure 5: Average paper quality under different conditions: homogeneous (SR) and heterogeneous (MR) conditions with initial percentages or rational cheaters from none to 30%. The quality remains constant notwithstanding the removal of rational cheaters. Only the MR-30 condition shows an initial increase in quality.

by rational cheaters to prevent publication of competitive papers. Consider, for example, a rational cheater with author quality 6. Within a conference of quality 8, it will act as a rational in all cases. But if that same agent ends in a PC for a conference with acceptance value 4, it will never act as a rational because rationals give fair reviews to papers under their author quality. Thus, that conference feels no need to drive it away from the PC.

Finally, we examine the number of accepted papers per conference. As it was foreseeable, more papers are accepted by mid-quality conferences, simply because our distribution of quality is chosen so that more papers of this kind are available. The interesting part of figure 7 is the increasing trend that is distinguishable for conferences with acceptance value greater or equal to 5. The cause here, in accordance with the ratio of rational cheaters seen in figure 6, is the improvement of PC quality thanks to the removal of rational scientist, that increases the number of papers accepted, mainly through the decrease of unfair good papers rejected.

CONCLUSIONS AND FUTURE WORK

This work highlights the importance of adopting more transparent and adaptive policies for conference programme committees. Whereas PC formation is currently more influenced by issues such as path dependency, inertia or self-selection, the application of objective and independent criteria may be beneficial to the quality of science.

Our results show how the mechanism introduced to control disagreement in the PCs is also effective in removing most of the rational cheaters from the process. The benefits can be measured in terms of the growing number of accepted papers and of the decrease in the number of mistakes (good papers rejected).

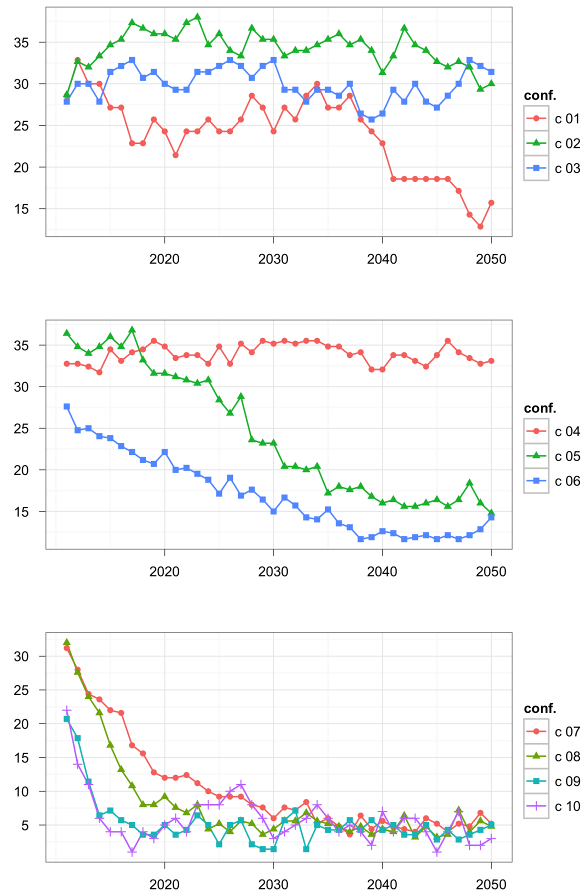

Figure 6: Percentage of rational cheaters in time, condition (MR-30), ten conferences with acceptance threshold from 1 (c01) to 10 (c10). Conferences with higher acceptance threshold push rational cheaters away faster.

When the quality of the conferences is homogeneous, rational cheaters are reduced but at the expenses of the number of accepted papers. It is important to note that neither the homogeneity nor the heterogeneity of conferences determined the sharp transition to random selection shown in (Thurner and Hanel, 2011). We hypothesise that this is due to the fact that our model is based on a larger score range and three, instead than two, reviewers.

A next step in this research would be to ground our model against data extracted from one of the several automated conference review systems. However, this data has proven surprisingly difficult to obtain. Not only our queries to the owners of those systems went unanswered, but we knew that other researchers had the same situation (neither of (Squazzoni and Gandelli, 2012; Thurner and Hanel, 2011) managed to ground their assumption either). The difference between the immediate availability of publication and citation data is especially striking.

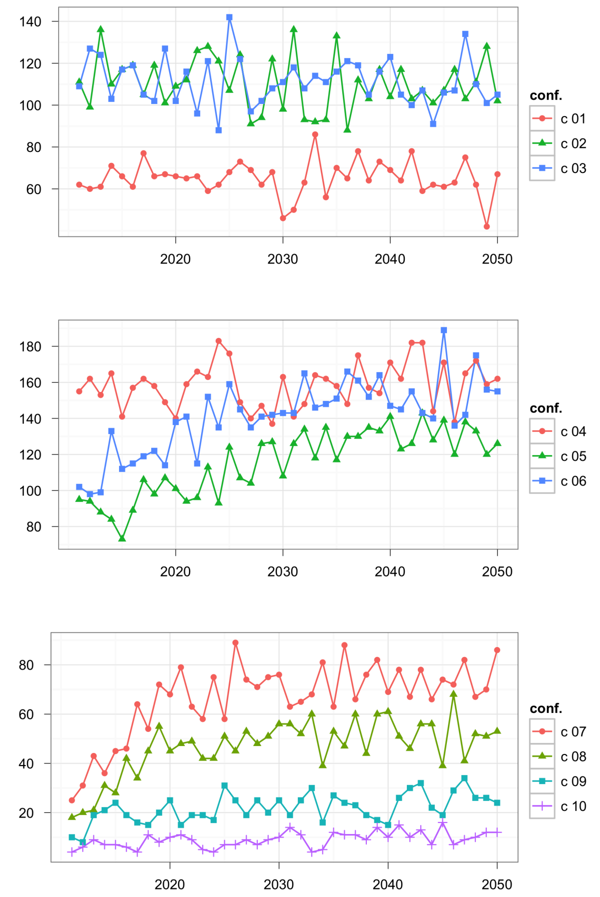

Figure 7: Number of accepted papers in time, , condition (MR-30) with ten conferences with acceptance threshold from 1 (c01) to 10 (c10). Conferences with acceptance threshold over 5 increase the number of papers accepted as a result of the expulsion of rational cheaters.

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AUTHOR BIOGRAPHIES

FRANCISCO GRIMALDO is a lecturer at the Universitat de València, Spain. His research is focused on applied artificial intelligence, agent-based modelling/simulation and social decision making. He is a member of the HiPEAC network of excellence and of the IEEE Systems, Man & Cybernetics Society. His email is `francisco.grimaldo@uv.es` and his personal webpage `http://www.uv.es/grimo`.

MARIO PAOLUCCI is a researcher of the ISTC/CNR (Institute for Cognitive Science and Technology), Rome. He is studying and applying multiagent-based social simulation and agent theory to understand social artefacts, in particular Reputation, Norms, Responsibility, and the cultural evolutionary mechanisms that support them. Mario's publications include a book on reputation with Rosaria Conte and articles on JASSS, ACS and Adaptive Behavior. His email is `mario.paolucci@istc.cnr.it` and his webpage `http://labss.istc.cnr.it/mario-paolucci`.