The Pursuit of Computational Justice in Open Self-Organising Systems

Jeremy Pitt, Dídac Busquets, and Régis Riveret

Department of Electrical & Electronic Engineering
Imperial College London, SW7 2BT, England
{j.pitt,d.busquets,r.riveret}@imperial.ac.uk

Abstract. Computational justice is an interdisciplinary study at an intersection between computer science and social sciences, enabling and promoting an exchange of ideas and results in both directions. From one perspective, computational justice is concerned with the study of formal representations of justice developed in computer science, and transferring them to social settings. From the other perspective, it is also concerned with importing concepts from the social sciences into computing applications. From both perspectives, computational justice has much to offer the design of self-organising systems. The objective of this paper is to contextualise computational justice in self-organising electronic institutions, and from there to expose a broader set of deeper issues to be addressed by future research.

Keywords: Self-Organising Systems, Open Systems, Justice

1 Introduction: What is Computational Justice

There is a requirement for computer systems and networks, to collectivise and distribute computing resources amongst the components of the system. This cuts across different dimensions of scale and geography, and is a feature of distributed systems for cloud and grid computing, and sensor and vehicular networks [6, 4, 7]. The decision-making required to achieve this distribution is too fast, too frequent and too complex for (human) operator intervention, so the system components have to self-organise the distribution by, and between, themselves.

Furthermore, there is another trend towards the automation of critical infrastructure, for example in energy grids, water irrigation and transportation systems, which critically involve active participation of (human) users [9, 5]. In these applications, there is also a requirement to share physical resources amongst the infrastructure users, who can be both producers and consumers of resources (i.e. prosumers, typically found in energy grids). If that infrastructure is instrumented with inter-connected sensors and (personal) devices, producing a so-called 'smart' infrastructure, then the (user-centric) self-determination of the resource distribution can be assisted by computational means.

In both cases, whether a 'technical' system or network composed purely of autonomous computing components, as found in grid computing or sensor networks; or a socio-technical system composed of ICT-enabled people interacting with inter-connected, instrumented (and increasingly intelligent) devices, for example a SmartGrid, we see that the actors have to self-determine the resource allocation; however, they can also self-determine the rules that are used in this self-determination. This is self-organisation: a group of interacting entities who come together for some collective purpose, and agree amongst and by themselves, who is (and is not) a member of the group; what rules should be followed to achieve the collective purpose; what rules should be used to change the rules intended to achieve the collective purpose; and so on.

Given a set of actors needing to share resources, an allocation scheme which maps resources to those actors, and a set of rules for determining that allocation scheme, some natural questions arise – Is this allocation fair? Is the allocation method effective? Is it efficient? Are the decision makers accountable? To what extent did those affected by the rules participate in their selection? Was any punishment for non-compliance with the rules proportional to the severity of the offence? The study of these questions, in the context of automated self-organisation of resource allocation systems, is the field of research we characterise as *computational justice*, an inter-disciplinary investigation at the interface of computer science and philosophy, economics, psychology and jurisprudence, enabling and promoting an exchange of ideas and results in both directions.

From one perspective, computational justice is concerned with the application of formal representations of and reasoning about justice developed in computer science, and with making the outcomes of this representation and reasoning conceptually and perceptually clear to users of socio-technical systems for managing social infrastructure, through visualisation, explanation, active participation, and so on. From the other perspective, it is concerned with importing concepts from the social sciences into computing applications, for example by implementing theories of procedural, distributive or retributive justice in multi-agent systems.

From both perspectives, computational justice has much to offer the study of self-organising systems. The objective of this paper is to contextualise computational justice in self-organising electronic institutions. Accordingly this paper is structured as follows. In Section 2 we identify key features of prototypical applications of self-organising systems for 'technical' or socio-technical applications. This motivates the analysis of multiple different strands of justice discussed in Section 3. These strands of justice are woven together in Section 4, in the context of self-organising electronic institutions, an approach to self-determined resource allocation, role assignment and rule selection/modification grounded on the principles of Ostrom's self-governing institutions [16]. From there, in Section 5 we expose a broader set of deeper issues for computational justice in open self-organising systems to be addressed by future research.

2 Open Self-Organising Systems

In this section, we survey a number of 'technical' and socio-technical systems in which the self-organisation of resource allocation, role assignment and/or rule selection/modification is a crucial aspect of their successful operation; from which we extract a number of key common features.

2.1 Prototypical Applications: 'Technical' Systems

Grid Computing. The idea of grid computing is to provide computing services 'on demand', and in particular the Desktop Grid provides a distributed computing infrastructure based on communal pooling of resources [6]. This enables agents (on behalf of their users) to offer or exploit idle computing resources on (respectively) their own or others machines to process large, long-running, computationally-intensive tasks in parallel, thereby increasing throughput, not wasting CPU cycles, and so on. In the Trusted Desktop Grid, the problem of free-riding (i.e. exploiting pooled resources without contributing to the pool) was addressed by the self-organisation of a 'trusted community' [2].

Cloud Computing. One application of multi-tenant cloud computing is to support real-time on-demand provisioning of different types of computing facility, software, platform, infrastructure, etc., undifferentiated as services, hence software-as-a-service, platform-as-a-service, infrastructure-as-a-service, and so on [4]. To reduce the total cost of ownership to the clients and to maximise revenue, the cloud service provider requires as many clients to use the cloud offering, without overloading it such that quality-of-service would be diminished and contractual penalties incurred. In one sense this is a generalisation of well-studied optimisation problems such as job-shop scheduling, except that the 'jobs' and the 'shops' are autonomous decision-makers and availability of both may change over time. Self-organising both tenancy arrangements and the 'schedule' (i.e. the resource allocation) is one proposed approach to resolving this tension [20].

Sensor Networks. A sensor network is a type of open system with resource constraints, in which functionality (i.e. distributed data measurement, aggregation and reporting) may be compromised by a lack of resources, specifically battery power. In particular, a trade off exists between accuracy and longevity for networks implementing in-network data aggregation functions. Given that the major drain on battery power is in communication, one solution is to self-organise the network into clusters to minimise routing and transmission overheads; then self-organise the clusters to distribute power consumption whilst staying within an upper bound for the cluster reporting error. The idea is to achieve a 'synchronised failure' with reliable reporting until the time of network failure with the least power left unused, rather than a prolonged degradation with increasing unreliability and for the network to fail when some nodes still have power.

2.2 Prototypical Applications: Socio-Technical Systems

SmartGrids. The vision for the energy grid of Schönau was a decentralised form of green-energy production, in terms of both increasing the efficiency of energy transmission and empowering citizens to take charge of their energy consumption and production (http://www.ews-schoenau.de). The initial idea was to turn energy consumers into prosumers, a combination of producers and consumers, by motivating individuals to produce and save energy, and to sell the surplus back to the grid. This way of thinking initiated the process of equipping the inhabitants of Schönau with resources to produce energy and manage it through a citizen-owned social business, Power Supplier of Schönau. Most households in this community produced energy by diverse means, and managed the process of its distribution. However, to achieve this, a change in the law was demanded by the community, so that the inhabitants could become the owners of their part of the energy grid and the managers of the distribution process.

Wikipedia and giffgaff. giffgaff is a UK-based mobile phone service which can be differentiated from other operators' services because giffgaff subscribers can also participate in specific aspects of the network operation, in particular sales and marketing, customer services and product testing. For participation in these activities, subscribers earn remuneration in the form of 'Payback', which are points that can be redeemed for cash, credit or charitable donations.

Many other social networking and user-generated content-management platforms demonstrate a similar pattern of user engagement and active participation, sometimes in return for a digital currency, sometimes for social capital. However, the Wikipedia case is unique: user types and associated roles (privileges and responsibilities) are not pre-set by either the platform itself or by the owner of the service. Instead, the rules governing who is responsible for what resource and empowered to perform which actions are determined by the users themselves. Anybody can propose a new rule or a rule change – including the rules how to choose moderators and their privileges and how to change rules. The community decides whether to adopt the proposal or not. Wikipedia is an evolving, self-organising institution adapting to the needs of its users: it is also likely that some mobile network services and social networking platforms will follow suit.

2.3 Key Features

All the systems considered so far are *open*, that is to say, that they are composed of autonomous entities of heterogenous provenance; there is no central controller; there is not necessarily a common goal (as distinct from a common purpose), so the entities may be competing, in particular for resources; but both a common 'language' and a mutually agreed and understood rule-set specifying 'socially acceptable' behaviour can be assumed. Entities (agents) can join and leave the system, in particular some entities may leave for good and some trying to join may never have been previously encountered. We can identify these key features:

- *self-determination*: in the absence of a central controller, resource allocation, the rules for determining the resource allocation, etc., must be determined by the entities themselves;
- the *expectation of error*: in the presence of competition and conventional rules, sub-ideal behaviour (contrary to specification) is to be expected, but errors may be a result of accident or necessity as well as malice;
- *enforcement*: these systems might as well use random allocation if agenta can repudiate conventional rules and sanctions for non-compliance by refusing to abide by their outcomes;

- an *economy of scarcity*: there are sufficient resources to keep the appropriators 'satisfied' in the long-term, but insufficient resources to meet everyone's demands at any a particular time-point;
- *endogenous resources*: in a system where all the resources are provided by the appropriators themselves, as in a sensor network or a micro-grid, computing the resource allocation must be 'paid for' from these resources; and
- *no full disclosure*: the appropriators are autonomous and internal states cannot be checked for compliance (with conventional rules), so incoming agents do not have all the information required for necessarily reliable investment decisions (e.g. contributing to a common pool).

However, if we also assume that we are dealing with 'intelligent' entities capable of representing and reasoning with conventional rule-sets, then the features can, we contend, be addressed by different aspects of 'justice'.

3 Justice (Five Different Qualifiers)

In this section, we review five different qualified forms of justice, and then match them to the key features of open self-organising systems of this type.

3.1 Justice

There are many different qualifiers of the term 'justice': the five we consider here are natural, distributive, retributive, procedural and interactional justice.

Natural Justice. The term natural justice in UK law is derived from Roman principles of justice which were assumed to be self-evident or axiomatic and did not need a statutory representation. Such principles were *audi alteram partem* (hear the other side) and *memo iudex in parte sua* (no-one a judge in their own case). More recently, Binmore [3] uses evolutionary game theory to investigate how groups of individuals can come to social arrangements that are fair, equitable and stable. However, for our purposes, we have in mind is a definition of natural justice that comes from the Human Rights principle of Participation and Inclusion, that "All people have the right to participate in and access information relating to the decision-making processes that affect their lives and well-being", which is a founding principle of the international NGO (non-governmental organisation) Natural Justice.

Distributive Justice. Distributive justice is concerned with the 'fairness' of a particular resource allocation to a set of agents, given that there rate many different fairness metrics [14]. Rescher's analysis of distributive justice [23] concluded that the Principle of Utility, taken as a fairness metric expressed as "the greater good of the greater number", is but one of many prevailing considerations which need to be taken into account when determining a 'fair' allocation of resources. Rescher [23] then observed that distributive justice had been held, by various sources, to consist of treating people wholly or primarily according to one of seven *canons* (established principles expressed in English), as the canons of equality, need, ability, effort, productivity, social utility and supply & demand.

Rescher's analysis showed that each canon, taken in isolation, was inadequate as the sole dispensary of distributive justice. Instead, his position was that distributive justice was found in the *canon of claims*, which consists of treating people according to their legitimate claims, both positive and negative. This, Rescher claimed, re-directed the search for distributive justice towards determining what the legitimate claims are, how they are accommodated in case of plurality, and how they are reconciled in case of conflict.

Retributive Justice. There is a cultural tendency according to which, when an agent does something wrong, like non-compliance with a normative system, then the wrongdoer should deserve punishment.

From a utilitarian perspective, a punishment should bring some loss of utility to the wrong-doing agent; and the justification for the punishment is that this loss of utility acts as a deterrent to future wrongdoing, both to prevent recidivism (the same agent repeating the wrongdoing) and to encourage other agents to refrain from offending. This contrasts with retributivist notions of justice: while the utilitarian perspective justifies punishment by its potential benefits (the avoidance of future wrongdoing), the retributivist perspective holds that punishment is a necessary consequence of committing an offence (the punishment of past wrongdoing). Retributivists assert that non-moral agency deserves to be punished in order to maintain a moral order, indeed Kant asserted that no principle but retribution was a legitimate basis for punishment.

Whatever justification for punishment is established, practical questions then arise regarding the design of a punishment system. This includes the forms of punishment, e.g. whether the sanction should be a fine or the suspension of a licence, and the principles of punishment, e.g. a commonly-held principle is that a punishment should be proportionate to the severity of the wrongdoing. Ostrom [16] maintained that a system of *graduated sanctions* was a necessary condition for enduring self-governing commons, but also that there should be a fast and effective dispute-resolution system. There are also different compensation strategies for *restorative* justice, i.e. making good for loss suffered as a consequence of wrong-doing. The notion of forgiveness might also have a role to play [27].

Procedural Justice. Robert's Rules of Order [25] is a comprehensive manual of procedures for conducting business in a deliberative assembly, i.e. a group of individuals making a decision about some policy or course of action, and mutually agreeing some conventional rules and procedures which regulate how that decision is to be made. Procedural justice is concerned with ensuring that those rules and procedures are fit-for-purpose (which includes 'fairness').

Concepts of procedural justice, i.e. what makes a procedure fit-for-purpose, are of concern to many other fields of human endeavour as well as political deliberation, including dispute resolution in law, public health, organisational psychology, and philosophy. This has led to a number of different definitions, but essentially they concur on measuring fitness according to three criteria: engagement, openness and efficiency.

Interactional Justice. Interactional justice comprises two specific types of interpersonal treatment [10]. The first is interpersonal justice, which is a measure of how 'well' those who are responsible for executing procedures or determining outcomes treat those who are subject to the procedures and outcomes. The second is informational justice, which is a measure of the justifications provided to the subjects about which procedures were used or why resources were allocated as they were.

3.2 Justice and the Key Features

We are now in a position to state how different qualifiers of justice can be used to address the key features of open self-organising systems previously identified:

- self-determination requires a concept of natural justice, namely the right of participation and inclusion, usually by voting;
- recognising the occurrence of errors and the enforcement of sanctions (and agreements reached by conventional rules) requires a concept of retributive justice: distinguishing between different types of error and offering the chance of redemption and allowing for appeals are also essential;
- in an economy of scarcity, familiar fairness and efficiency criteria, like Pareto efficiency and envy-freeness, may be ineffective in the short-term, and a concept of distributive justice (or outcome justice) and a subjective agreement on fairness norms is required [8];
- dealing with endogenous resources requires a concept of procedural justice: if the administration of the rules has to be 'paid for' from the same resources that are otherwise allocated for 'useful' jobs, then it is necessary to ensure that they are efficient; and
- dealing with lack of full disclosure requires an element of interactional justice, namely informational justice, to force disclosure of relevant information.

The next step is to weave the five different strands of justice together and represent them in computational form: our proposal for achieving this is the *self-organising electronic institution*.

4 Justice in Self-Organising Electronic Institutions

4.1 Self-Governing Institutions

Self-Organising Electronic Institutions are grounded in Ostrom's work on self-governing institutions for common-pool resource management [16]. Ostrom defined such an institution as a set of working rules that specified procedures for operational-, collective- and constitutional-choice, which were, respectively, concerned with provision, appropriation and monitoring; determining the operational-choice rules, rule enforcement and dispute resolution; and eligibility for determining the collective-choice rules.

These rules were role-based, mutually agreed, mutable and nested within each other in *action situations*. Distinguishing between nested action situations requires a formal characterisation of institutionalised power [11], whereby an agent appointed to a role in an action situation is empowered to bring about a fact of conventional (or institutional) significance by performing a designated action in that specific context.

Ostrom also observed that on some occasions the resource was not depleted, and on others it was. Eight principles were identified as necessary and sufficient conditions for a common-pool resource managed by a self-governing institution to *endure*, [16, p. 90], including: (1) clearly defined boundaries, (2) congruence between appropriation and provision rules and the state of the prevailing environment; (3) collective-choice arrangements: those affected by the operational-choice rules participate in selection and modification of those rules; (4) monitoring by accountable agencies; (5) graduated sanctions; (6) accessible conflict-resolution mechanisms; (7) no external interference; and (8) system of systems.

4.2 Self-Organising Electronic Institutions

A Self-Organising Electronic Institution is essentially a collection of agents plus a specification of a dynamic norm-governed system [1] which should encapsulate Ostrom's principles. Formally it can be denoted by $\mathcal{IC}_t$ which is a multi-agent system at time t defined by:

$$\mathcal{IC}_t = \langle \mathcal{A}, \mathcal{C}, R, \mathcal{L} \rangle_t$$

where (omitting the subscript t if clear from context):

- $\mathcal{A}$ is the set of all agents;
- $\mathcal{C}$ is the set of action situations;
- R is a binary *nesting* relation on $\mathcal{C}$;
- $\mathcal{L}$ is a dynamic norm-governed system specification.

In the framework of [1], a number of degrees of freedom (DoF) are identified, so $\mathcal{L}$ defines a specification space, where each specification instance is defined by a different set of values assigned to the DoF. For example, one degree of freedom is the method by which the resources are allocated (e.g., at random, by ration, or using legitimate claims), and another might be which role-assignment protocol to use. Some of the degrees of freedom may be changed by rules contained within the action situation, and some may be changed by decisions made in the action situation with which it is nested, as determined by the nesting relation R.

Each action situation $C_{i,t} \in \mathcal{C}_t$ is defined by:

$$C_{i,t} = \langle \mathcal{M}, l, \epsilon \rangle_t$$

where (again omitting the subscripts as clear from context):

- $\mathcal{M}$ is the set of members, such that $\mathcal{M} \subseteq \mathcal{A}$
- l is a specification instance of $\mathcal{L}$; and
- ϵ is the cluster's local environment, a pair $\langle Bf, If \rangle$

Regarding the environment ϵ, Bf represents the set of 'brute' facts whose values are determined by the *physical* state, including the sum of common-pool resources P as a result of provision by the agents. If represents the set of 'institutional' facts, whose values are determined by the *conventional* state, i.e. are asserted by the exercise of institutionalised power.

4.3 Computational Representation of Institutional Rules

One way to represent the rules of $\mathcal{L}$ is to use the Event Calculus (EC) [12] to define an executable specification. The EC is a logical formalism for representing and reasoning about actions or events and their effects based on a many-sorted first-order predicate calculus. An *action description* in EC includes axioms that define a narrative (the occurrence of actions), using the happensAt predicate; the effects of actions, using initiates and terminates predicates; and the values of the fluents, using initially and holdsAt predicates. A fluent is then a proposition whose values can change over time.

$\mathcal{L}$ is then an EC action description containing axioms of the form:

$$Action \quad \mathsf{initiates} \quad F = V \quad \mathsf{at} \quad T \quad \leftarrow \quad Conditions$$

which are read as stating: the occurrence of action *Action* at time T initiates a period of time for which the value of fluent F is V, if the *Conditions* are satisfied. The physical and institutional facts in an action situation's environment ϵ are represented as EC fluents.

As an executable specification, given a narrative of events (*Action*s) and a starting state at time t of an action situation $C_{i,t}$, the EC specification can be queried to determine what was the state of the action situation at some later time point t', $C_{i,t'}$, and indeed at every time point in-between.

4.4 Ostrom's Principles and Computational Justice

Our final move in this section is to relate Ostrom's principles to specific qualifiers of justice and then encode them as EC specifications in, or about, $\mathcal{L}$.

For example, Ostrom's principles (1) clearly defined boundaries and (3) collective choice arrangements indicate a need for a system of natural justice. This can be encoded in role-assignment protocols and voting protocols [19]. Similarly, Ostrom's principle (2) refers to appropriation and provision rules and the need for a system of distributive justice which if 'fair' and stable is *sine qua non.* An encoding of Rescher's theory of legitimate claims in the context of self-organised resource allocation in an economy of scarcity can be found in [21]. Finally, Ostrom's principles (5) graduated sanctions and (6) access to conflict-resolution procedures indicate a need for a system of retributive justice. A preliminary investigation of self-organisation of a system of graduated sanctions against the frequency of offences in a linear public good games is undertaken in [18].

However, fully ensuring the *congruence* of the appropriation and provision rules to the state of the prevailing environment indicates a requirement for a system of procedural justice. Furthermore, the notion of 'satisfaction' needs to be related to individual preferences and social capital, especially in self-organising socio-technical systems. This goes beyond quantitative measures of utility used in previous experiments, and requires a computational theory of emotion together with a system of interactional justice, and in fact the first part – the need for interpersonal justice measured by 'quality of treatment'.

These are issues for further work, and in the next section we consider some more issues for further research.

5 Issues for Further Research

Some of the issues for further research concern applying Ostrom's principles and computational justice to knowledge commons, visualisation in socio-technical systems, evidence-based policy-making and self-governing learning agents. We briefly consider each in turn.

Knowledge commons. [17] was concerned with treating knowledge as a shared resource, motivated by the increase in open access science journals, digital libraries, and mass-participation user-generated content management platforms. It then addressed the question of whether it was possible to manage and sustain a knowledge commons, using the same principles used to manage ecological systems with natural resources. A significant challenge in the democratisation of Big Data is the extent to which formal representations of intellectual property rights, access rights, copy-rights, etc. of different stakeholders can be represented in a system of computational justice and encoded in Ostrom's principles for knowledge commons. As observed in [26], the power of Big Data and associated tools for analytical modelling: "... should not remain the preserve of restricted government, scientific or corporate élites, but be opened up for societal engagement and critique. To democratise such assets as a public good, requires a sustainable ecosystem enabling different kinds of stakeholder in society".

Visualisation. People occupying a physical space have to access its physical resources and services water, energy, mobility, etc. To this end, an infrastructure is developed and deployed; the automation of that infrastructure results in calling it 'Smart' (SmartGrids, SmartCities, etc.), and demand-side active participation and user engagement is presumed. However, the user-infrastructure interface and interaction dynamics are often neglected with critical consequences for sustainability [13]. To get both a better understanding of the behaviour of energy consumers and getting energy consumers to understand better the effects of their behaviour on the grid, virtual environments can be used as an innovative energy infrastructure interface, with a particular emphasis on visualisation of the principles for self-organisation of the resource allocation [5]. Effectively, we are looking towards the visualisation, animation and explanation of the justice system(s) underlying all decision-making in the 'Smart' infrastructure.

Evidence-based policy making. This is another issue concerning socio-technical self-organising systems. Whatever policies are developed in order to achieve macro-level goals, like sustainability, or low-carbon emission, etc., people do not simply comply or not comply with the policy, they react to incentives implied by the policy [15]. Those incentives often stimulate behaviour different from what was intended, because people have other incentives to find loopholes in the policy or because the policy has unintended secondary and even tertiary consequences. The logical representation of policy as a system of computational justice, in conjunction with agent-based population simulation, offers an intriguing route to building an evidence-base for informing systematic decision-making.

Self-governing learning agents. A major challenge to build durable open systems holds in the cybernetic loops between norm-governed agents and institutions. To adapt to and learn to shape their normative environment, a solution consists in endowing autonomous agents with reinforcement learning. Considering rewards and punishements, they may comply and internalise the cost of non-compliance. As the social system may turn to be unfair, these agents shall also learn to influence existing insitutions and even self-organise to constitute their owns. In this view, and in conjunction with an extractable algebraic representation akin to utilitarian quantitative calculus of implementation theory, the executable logical representation of norm-governed learning agents as proposed in [24] paves the way for the study of durable self-governed systems of learning agents.

6 Summary and Conclusions

In summary, this is a part survey paper, part position statement on the multidisciplinary nature of computational justice in open self-organising systems. It has also attempted to give an indication of our approach to grounding computational justice in self-organising electronic institutions founded on Ostrom's principles for enduring self-governing institutions. However, while we feel we have made some progress on the formal representation of natural, distributive and retributive justice, there are still many unanswered questions, other aspects of justice yet to be fully investigated (i.e. procedural and interactional justice), and further substantial research challenges to be addressed. We believe that answering these questions and addressing these challenges is important and necessary, as we have shown that (computational) justice is an essential requirement for self-organising socio-technical systems, without which adaptive institutions for addressing sustainability and climate change [22] may not even be possible.

References

1. Artikis, A.: Dynamic specification of open agent systems. Journal of Logic and Computation p. doi: 10.1093/logcom/exr018 (2011)
2. Bernard, Y., Klejnowski, L., Cakar, E., Hähner, J., Müller-Schloer, C.: Efficiency and robustness using trusted communities in a trusted desktop grid. In: Self-Adaptive and Self-Organizing Systems Workshops (SASOW), 2011 Fifth IEEE Conference on (2011)
3. Binmore, K.: Natural Justice. Oxford, UK: Oxford University Press (2005)
4. Birman, K., Chockler, G., van Renesse, R.: Toward a cloud computing research agenda. SIGACT News 40(2), 68–80 (2009)
5. Bourazeri, A., Pitt, J., Almajano, P., Rodriguez, I., López-Sánchez, M.: Meet the meter: Visualising smartgrids using self-organising electronic institutions and serious games. In: Proceedings SASOW12 (2012)
6. Choi, S., Buyya, R., Kim, H., Byun, E.: A Taxonomy of Desktop Grids and its Mapping to State of the Art Systems. Tech. rep., Grid Computing and Distributed Systems Laboratory, The University of Melbourne (2008)
7. Ding, M., Cheng, X., Xue, G.: Aggregation tree construction in sensor networks. In: IEEE Vehicular Technology Conference. vol. 4, pp. 2168–2172 (2003)
8. Elster, J.: Local Justice: How Institutions Allocate Scarce Goods and Necessary Burdens. Russell Sage Foundation (1992)

9. Ferscha, A., Davies, N., Schmidt, A., Streitz, N.: Pervasive socio-technical fabric. Procedia Computer Science 7, 88–91 (2011)
10. Greenberg, J.: The social side of fairness: interpersonal and informational classes of organizational justice. In: Cropanzano, R. (ed.) Justice in the work place: approaching fairness in human resource management, pp. 79–103. Hillsdale, NJ: Erlbaum (1993)
11. Jones, A., Sergot, M.: A formal characterisation of institutionalised power. Journal of the IGPL 4(3), 427–443 (1996)
12. Kowalski, R., Sergot, M.: A logic-based calculus of events. New Generation Computing 4, 67–95 (1986)
13. Lam, W.F.: Governing Irrigation Systems in Nepal: Institutions, Infrastructure and Collective Action. Oakland, CA: ICS Press (1998)
14. Lan, T., Kao, D., Chiang, M., Sabharwal, A.: An axiomatic theory of fairness in network resource allocation. In: INFOCOM. pp. 1343–1351. IEEE Press, Piscataway, NJ, USA (2010)
15. López, E.: The Pursuit of Justice: Law and Economics of Legal Institutions. New York, NY: Palgrave MacMillan (2010)
16. Ostrom, E.: Governing the Commons. CUP, Cambridge (1990)
17. Ostrom, E., Hess, C.: A framework for analyzing the knowledge commons. In: Hess, C., Ostrom, E. (eds.) Understanding Knowledge as a Commons: From Theory to Practice, pp. 41–82. MIT Press, Cambridge, MA (2006)
18. Pitt, J., Schaumeier, J.: Provision and appropriation of common-pool resources without full disclosure. In: PRIMA. pp. 199–213 (2012)
19. Pitt, J., Schaumeier, J., Artikis, A.: The axiomatisation of socio-economic principles for self-organising systems. In: Fifth IEEE International Conference on Self-Adaptive and Self-Organizing Systems (SASO). pp. 138–147 (2011)
20. Pitt, J., Schaumeier, J., Artikis, A.: Coordination, conventions and the self-organisation of sustainable institutions. In: Agents in Principle, Agents in Practice. LNCS, vol. 7047, pp. 202–217. Springer-Verlag, Berlin, Heidelberg (2011)
21. Pitt, J., Schaumeier, J., Busquets, D., Macbeth, S.: Self-organising common-pool resource allocation and canons of distributive justice. In: Sixth IEEE International Conference on Self-Adaptive and Self-Organizing Systems (SASO) (2012)
22. RCEP: 28th report: Adapting institutions to climate change. Royal Commission on Environmental Protection (Chairman: John Lawton), The Stationery Office Limited, UK (2010)
23. Rescher, N.: Distributive Justice. Indianapolis: Bobbs-Merrill (1966)
24. Riveret, R., Rotolo, A., Sartor, G.: Probabilistic rule-based argumentation for norm-governed learning agents. Artif. Intell. Law 20(4), 383–420 (2012)
25. Robert, S.C., Robert, H., Evans, W.J., Honemann, D.H., J., B.T.: Robert's Rules of Order, Newly Revised, 10th edition. Perseus Publishing, Cambridge, MA (2000)
26. Shum, S.B., Aberer, K., Schmidt, A., Bishop, S., Lukowicz, P., Anderson, S., Charalabidis, Y., Domingue, J., de Freitas, S., Dunwell, I., Edmonds, B., Grey, F., Haklay, M., Jelasity, M., Karpistenko, A., Kohlhammer, J., Lewis, J., Pitt, J., Sumner, R., Helbing, D.: Towards a global participatory platform: Democratising open data, complexity science and collective intelligence. European Physical Journal: Special Topics 214 (2012)
27. Vasalou, A., Hopfensitz, A., Pitt, J.: In praise of forgiveness: Ways for repairing trust breakdowns in one-off online interactions. Int. J. Hum.-Comput. Stud. 66(6), 466–480 (2008)