

# Interactional Justice for Sustainable Management of Common-Pool Resources

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**Abstract.** We argue that IoT-enabled socio-technical systems exhibit two inter-related and inter-dependent commons: one being the commons of resources (both physical and intellectual), and the other being the commons of knowledge. We show that both types of commons can be generically managed by applying Ostrom’s design principles for self-governing institutions. We then propose that one requirement for successful and sustainable management of the dual commons is the effective deployment of open, inclusive and transparent knowledge management processes, inspired by a study of classical Athenian democracy. A process of interactional justice is proposed as an algorithmic approach to formalising these processes in socio-technical systems. We conclude by arguing that the digital transformation needs to be accompanied by a democratisation of platforms and data which empower citizens to support and sustain collective action.

## 1 Introduction

The Internet of Things (IoT) is based on the convergence of (at least) three driving forces: the seamless integration of computer processors and physical artefacts to make programmable devices; the saturation of the physical environment with sensors and actuators; and the development of low-cost, high-speed wireless communication technologies. IoT therefore offers a new approach to embedded systems and ubiquitous computing which can have a profound transformative impact on ‘traditional’ infrastructure, e.g. transportation and transportation logistics, electric power generation and transmission, fresh water supply and waste water management, and so on. With increased algorithmic (machine) intelligence, there follows the use of the prefix “smart” to denote an infrastructure facility that has been instrumented and interconnected in this way, i.e. “smart” city, “smart” grid, “smart” motorway, “smart” building, etc.

However, in the technological rush it sometimes seemed that the human users of this infrastructure were somehow overlooked, and it was forgotten that these “smart” facilities were also places that people wanted to live, work, drive, and

so on; and moreover that these people were not so amenable to being treated as programmable devices as other system components. In socio-technical systems of this kind (i.e. composed of both users and “smart” devices), there is a requirement for a new understanding of human-computer interaction, call it *human-infrastructure interaction* (cf. [10]), which prioritises human values, such as *sustainability* and *fairness*, as a *supra-functional requirement* through, for example, value-sensitive design [6]. IoT therefore offers an opportunity to develop user-facing infrastructure which uses “smart” computing, not to control, but to *empower* users with respect to both their individual consumption, and also their community resource utilisation through collective action. In this paper, we will argue that this empowerment critically depends on satisfying the requirements of self-governance and knowledge management through interactional justice.

To make this argument, this paper is divided into three parts. In the first part, Section 2 discusses a scenario based on a type of “smart” grid called a community energy system (CES) [26] and how it might (and indeed might not be) enabled by a “smart” meter. Section 3 considers a self-governance model for the resource commons in a CES, enacted through the “smart” meter, based on the institutional design principles of Ostrom [14]. In the second part, Section 4 argues that the different levels of interaction between “prosumers” and IoT-enabled infrastructure means that there are actually *two* inter-related and inter-dependent commons in a CES: one being the common-pool of the physical resource (i.e. energy), and the other being the common-pool of knowledge, i.e. the knowledge commons. Generalising our argument from CES to IoT/Big Data applications, Section 5 considers how this knowledge commons can also be self-governed by applying the same institutional design principles as for the knowledge commons.

In the third part, we argue that the successful and sustainable inter-leaving of the dual commons is dependent on a number of open, transparent and inclusive knowledge management processes. For this, we take inspiration from an analysis of the knowledge management processes practised in classical Athenian democracy, which provided a long-lived, and exceptionally successful, governance model for nearly 200 years [12]. This analysis is reviewed in Section 6, following which Section 7 proposes a process of *interactional justice* to support the inter-leaving of a self-governed resource commons (inspired by Ostrom [14]) with a knowledge commons based on robust knowledge management processes (inspired by Ober [12]). We summarise and conclude in Section 8 with comments on how the successful deployment of sustainable, user-centred, self-organising socio-technical systems is predicated on the democratisation of “smart” technology, which would enable the dual commons to function as it could – and indeed should, if the aim is to promote and protect common interests and values.

## 2 Background: Community Energy Systems

### 2.1 Community Energy Systems (CES)

The instrumentation and interconnection of artefacts in a residential building creates a cyber-physical system out of a house, call it a “smart” house. A

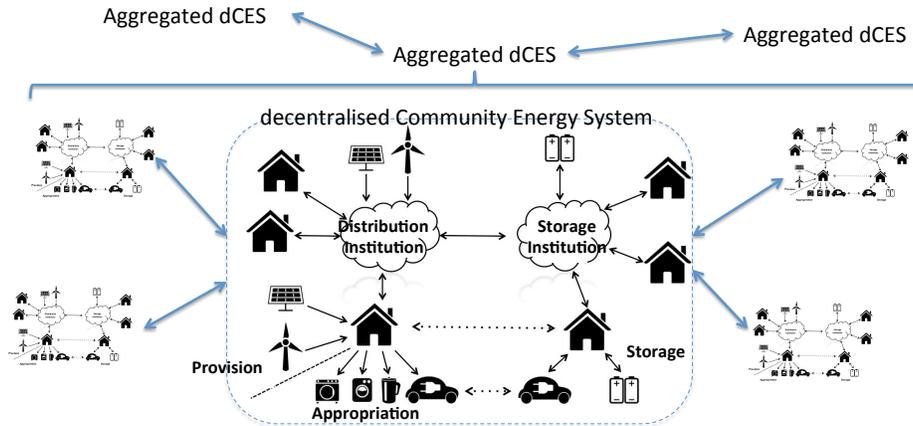


Fig. 1: Decentralised Community Energy System

“smart”house then combines technical systems and programmable appliances that aim to automate *residential services* – e.g. safety and security, home entertainment, control of heating, ventilation and air conditioning – in order to improve owner comfort and experience. Since these systems operate in a social context, a “smart”house itself creates a socio-technical system where several objectives, both technical and social, must be met. The “smart”meter is the crossover point between the cyber-physical system and the socio-technical one.

However, in general, if supply equalled demand, then a “smart”house could operate as an independent unit. However, it is more likely that the “smart”house will either over- or under generate. If it over generates, then it must store the excess (which may be expensive) or burn it off, (which is wasteful). If it under-generates, then the shortfall must be compensated for somehow. Either way, it would be better for the “smart”house not to operate in isolation and must integrate ‘smoothly’ within larger systems – e.g. a Community Energy System (cf. [26]).

A Community Energy System (CES) is an energy generation, distribution and storage system involving local community ownership and participation. A *decentralised* CES (dCES), illustrated in Figure 1, is a network of geographically co-located “smart”houses installed with small-scale renewable sources like photovoltaic (PV) cells or micro wind turbines. At this base level, we assume there is no enterprise-owned Combined Heat and Power (CHP) plant or other large-scale generation: everything is generated in-house (literally), controlled and operated by the residents of Smart Houses. Storage can be provided by in-house batteries or, looking farther ahead, electric vehicles. A group of dCES can be aggregated into a larger institution.

In [26], four types of *community energy system* (CES) are identified: multi-home energy schemes; local energy schemes; district schemes with enterprise collaboration; and, district schemes with large-scale storage and generation (e.g.

through combined heat-power plants (CHP)). As well as having different generation and storage facilities, and different relationships to the (national) grid, the four types are distinguished according to their different ownership models, depending on the variety of agencies in the CES, e.g. private individuals, mutual cooperatives, private enterprise service providers, national regulators, etc. These agencies could have different (and even conflicting) goals, and moreover, could be nested within each other – for example, a group of private individuals could form a multi-home energy scheme, which could be run as a mutual cooperative and itself appear as a single actor in a larger-scale district scheme.

In a CES, the physical infrastructure, including generators, transformers, the grid itself, and its end points (e.g. commercial properties and domestic residences), is saturated with sensors and computing devices. In particular, the point of contact with a domestic consumer is through a “smart” meter, i.e. an ICT-enabled device installed at the edge of the electricity grid, monitoring atomic ‘edge’ behaviour, and enabling communication with a central command and control system. Then the control philosophy of the resulting “smart” grid could follow two contrasting models. Either, it can result in complete centralised control and the diminution of the consumer to a revenue-generating asset – and given the slightly unseemly rush to standardise and roll-out a (quite literally) dumbed down “smart” meter programme across Europe, it is not implausible (if perhaps understandable) that this model was preferred by the larger distribution and transmission operators. Or, it can result in an entirely new model of control, operation and distribution, switching the emphasis from the traditional ‘predict and provide’ model to one that empowers consumers by demand-side management (or rather, demand-side *self-organisation*: given the stochastic nature of renewable energy generators, there is this much energy available – how are you (the community) going to distribute it – *fairly?*). One answer to this question is: interconnect the “smart” meters, and enable them to determine the distribution, with reference to an agreed metric for fairness.

## 2.2 Enabling CES: The “Smart” Meter

In recent times, throughout Europe and elsewhere, there has been a steady deployment of so-called “smart” meters. i.e. an ICT-enabled device installed ‘at the edge’ of the electricity grid, that allows both monitoring and reporting of electricity consumption, as well as two-way communication between the meter and a central system. It purports to offer many benefits to the end user: finer-grained control over energy usage, accuracy in billing, improvements in reliability, and so on.

However, there has been (at least anecdotally) some resistance to the introduction of “smart” meters in domestic residences, which is in stark contrast to the rapid uptake of “smart” phones and their use in telecommunications. We would argue that the reasons for this include<sup>3</sup>: the “smart” phone is (mostly) an

<sup>3</sup> There are some caveats here: the deployment of “smart” phones has not been completely immune to sharp practices, profiteering or customer lock-in.

opt-in technology; it is (usually) owned by the end-user; such ‘intelligence’ that it does exhibit (sometimes) returns a service in exchange for the data collected or submitted; and it facilitates generativity – the innovation of new tools from existing ones, not perhaps imagined or intended by the provider of the original tools [29].

The “smart” meter, by contrast, is a “can’t-opt-out” technology both centrally imposed (by government fiat) and controlled (by an external organisation). It is not owned by the user whose behaviour, it is sensed, is being monitored, raising significant concerns for trust, privacy and security [28]. It is effectively vertically integrated with no APIs, which prohibits generativity [29]; and any ‘intelligence’, such as it is, is definitely not ‘at the edge’, nor is it operating on behalf of the end-user, i.e. the electricity consumer.

As we indicated above, one consequence of the rush to roll-out the “smart” meter in the EU has been to make it less effective in reducing emissions than in preserving an archaic (but profitable) business model. Furthermore, it has precluded any kind of user empowerment and interconnectivity, and in preventing any second-generation (actually) “smart” meter (i.e. one capable of some form of assistive, collective intelligence) reaching the domestic market.

Nevertheless, our argument is that to address the demand-side of electricity supply by active participation and user engagement requires inclusivity and empowerment, which is not necessarily rendered by a relatively small stake or role in some “energy market”. In contrast, inclusivity entails others, and empowerment means meaningful control over decision-making that affects all of those so included. In this case, the consumers form a *collective* or a *community*, and if the emphasis is going to be on demand-side *self-organisation* (rather than demand-side management), then we need to understand how “smart” meters can support the formation of ‘rules of engagement’ for a community, and how this helps to resolve collective action problems. For this, we turn to the theory of Elinor Ostrom and the *supply* of self-governing institutions for sustainable common-pool resource management.

### 3 Resource Commons

Ostrom’s pioneering work [14] showed how self-governing institutions could overcome the ‘tragedy of the commons’ [8] and the zero-contribution thesis [13]. The former purported to show that a group of appropriators with common, unrestricted access to a shared (common pool) resource (CPR) would inevitably act so as to deplete the resource in the short term, even if it was in no-one’s interest in the long term. The latter suggested that unless the number of individuals in a group was “quite small”, or unless there was some mechanism designed to coerce individuals into acting in their common interest, then ‘rational’, self-interested individuals would not coordinate their behaviour to achieve their common or group interests.

Ostrom did not seek to refute either the tragedy of the commons or the zero-contribution thesis; indeed she maintained that if the assumptions and con-

straints that facilitated mathematical analysis or repeatable laboratory experiments were replicated in natural settings, then these are the outcomes that will be observed. However, the real ‘tragedy’ is to suppose that these assumptions and constraints are *necessarily* replicated in such settings, and to advocate policy prescriptions on this basis (e.g., to rely on ‘coercion’ rather than empowerment). Instead, based on extensive fieldwork, the empirical evidence showed how people and communities could avoid these undesirable outcomes, especially through the evolution of *institutions* which enables communities to govern and regulate themselves (i.e. *self-governance*). These institutions (identified as structured rulesets which prescribe who could perform what actions in a specific *decision arena* or *action situation*, what actions were permitted, proscribed or obliged, membership conditions, sanctions for non-compliance with the rules, etc.) could relax assumptions and constraints and promote the sustainability of a common-pool resource, without resorting to privatisation or centralisation.

However, the evolution or presence of an institution alone did not guarantee enduring resource management: sometimes there were such institutions but the common-pool resource (CPR) management was fragile or failed. Accordingly, Ostrom identified common features of these institutions which differentiated success stories from failures, i.e. those features which were all present in the the successful cases, but one or more of which were missing in the failure cases (for example, [14, p. 180], no clear membership boundaries, no support for self-determination, inadequate monitoring, or no support for ‘efficient’ conflict resolution).

Given this, she then considered the issue of ‘supply’. Faced with a common-pool resource management problem, she recommended not to rely on ‘evolution’ to produce an institution with the requisite features. Instead, supported by an appropriate framework and accompanying tools and methods, institutions should be *designed* with these features specified as requirements (much as, for example, Robert’s Rules of Order [24] provides a handbook that specifies the methods and procedures of a deliberative assembly). Therefore, the features were re-cast as a set of eight institutional design principles.

The challenge, therefore, is to use Ostrom’s institutional design principles to design self-governing institutions for Community Energy Systems. Ostrom’s commitment to specifying institutions in concrete form, e.g. through principles, design methods and grammars, was rooted in political and economic science, but less so in computational, psychological and complexity sciences. As a result, her definition and analysis of ‘action situations’ did not explicitly distinguish between physical capability, institutionalised power and permission (a distinction commonly made in the study of social, legal and organisational systems, cf. [1]). *institutionalised power* [9] denotes when a designated agent, acting in a specific role in an institutional context, is empowered to create facts of conventional significance by the performance of certain actions; often, but not necessarily, speech acts.

By invoking this concept, the design principles can be formalised in computational logic and used as an executable specification of *protocols* for managing resource allocation in open computer systems and networks [21], just as they

Table 1: CES Oriented Towards Social Relationships

Ostrom Principle	Protocol Implementation
P1. Membership	Access control & role assignment
P2. Congruence of provision and appropriation rules	Self-organised legitimate claims [17]
P3. Participation in rule selection	Voting
P4. Monitoring	SmartMeter with event recognition
P5. Graduated sanctions	Argumentation
P6. Conflicts	Alternative dispute resolution

were used for distributing physical resources in social systems. This paves the way for using the design principles as the basis for implementing *algorithmic self-governance* in socio-technical systems. For example, one way of implementing six of the eight design principles in a CES oriented towards social relationships, is shown in Table 1. There are other ways of doing this, for example, in a CES that was based on a transactional (market-based) economy rather than a relational economy. (Note also that the eighth principle concerns structure and the seventh concerns a specific constraint on that structure: see the discussions in [5, 18].)

## 4 Dual Commons

In an IoT-enabled CES, including programmable appliances, “smart” devices and local storage/generation facilities, there are (at least) three levels of interaction for energy distribution as a provision and appropriation system:

- *delegated*: operation is controlled by “smart” automation, which works without (or with limited) user awareness; e.g. coordination of refrigerator compressor cycles for load-balancing;
- *interactive*: operational requirements are specified by users, and automation resolves the constraints; e.g. programmable appliances: the user specifies a time to complete, and the appliance negotiates a schedule according to availability, or to minimise e.g. cost;
- *attentive*: automation indicates active intervention is required by humans; e.g. collective action for overload prevention.

Furthermore, we note that a prosumer in a CES may occupy multiple different stakeholder roles besides producer and consumer: for example, a market participant, green citizen, charitable donor (e.g. to address energy poverty), etc. In addition, there are multiple different agencies involved, i.e. not just the prosumers, but also administrators, service and infrastructure providers, ombudsman (for resolving disputes), regulators, pressure groups and indeed (if the “smart” meter API were open and unbundled) app entrepreneurs. It has been

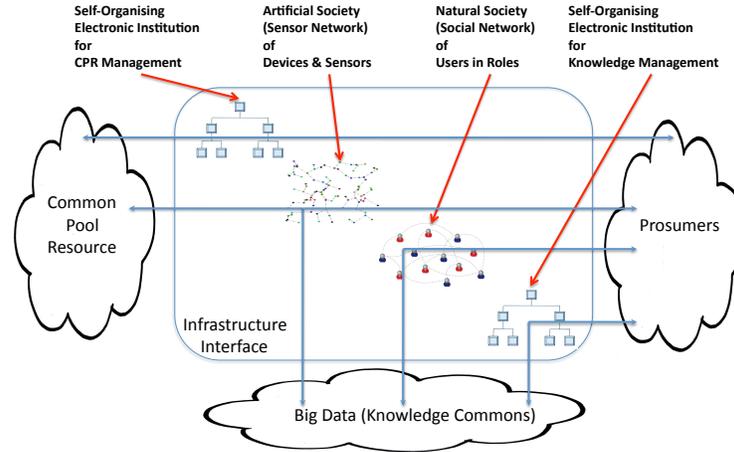


Fig. 2: Dual Resource and Knowledge Commons

argued that sustainability of a complex system such as this requires a particular emphasis on polycentric governance [5].

However, the key feature of the different levels of interaction, the different stakeholder roles, and the multiplicity of decision-making entities is that *“smart” meters generate content*. This content is effectively being provisioned to a pool of data, while information and knowledge is being appropriated from it. Therefore, following on from a previous analysis of sensor networks, big data and collective awareness [16], we contend that in a CES there are two inter-related and inter-dependent commons: one being the common-pool of the physical resource (i.e. energy), and the other being the common-pool of knowledge, i.e. the knowledge commons, as illustrated in Figure 2. This shows a network of “smart” meters with a self-governing institution to manage the resource commons; and there is a network of prosumers (and other agencies) with a self-governing institution to manage the knowledge commons.

Although we would argue that all resource commons have implicitly had this dual structure, especially with regard to knowledge codification, the *digital transformation* has made the knowledge commons more visible and more valuable, and has exposed both different perspectives and a number of risks.

For example, rather than passively viewing end-product content that has been produced by a studio for mass-consumption, people actively participate in mass content creation, where prosumers (acting as both content creators and consumers) collectively create “works of mind” using collaborative tools for sharing, and building on, user-generated content. Examples include social networking sites, sites for image and video sharing, wikis, mashups, and cloud services and web applications for computer-supported cooperative work. Increasingly, pervasive computing tools and technologies can be used to collect what is, in effect, also user-generated content (also referred to as environment-generated content),

for example using A/V equipment such as cameras and microphones, wireless sensor networks, mobile phones, radio-frequency identification (RFID) tags in cards and implants, and so on.

This content can be used to develop hitherto unexpected applications, such as supplementing earthquake early warning systems through detecting the movement of mobile phone accelerometers en masse in a localised geographical space. This is an example of implicit user-generated content being aggregated in an application which can provide benefits in both coarse monetary and value-sensitive terms. However, the downside of the appropriation of user-generated content, the ownership of the means of coordination by corporate or political elites are such that it is necessary to democratise Big Data [27].

Therefore, with regard to user-generated content, a different approach to intellectual property is required, for reasons relating to notions of copyright, ownership and credit, privacy concerns. As the *value* of many social networking platforms has demonstrated, there are substantial social and economic benefits that can be derived from data-mining both implicitly- and explicitly-generated content. This is especially so when user-generated content is such a significant component of Big Data, including the seismic tremors mentioned above, but also, for example, the spread of disease, as well as business, social and cultural trends.

One possible approach is to consider the intellectual property rights of user-generated content and Big Data from the perspective of a knowledge commons. Management of knowledge as a commons can then also be considered from the perspective of design principles for self-governing institutions. Furthermore, when the provision and appropriation mechanisms are automated and instrumented (for example, provision of user-generated content by “smart” meters, social networks or sensor networks; appropriation of that content by search engines, data mining or analytics) we advocate management of the knowledge commons using the same framework as for resource commons. We need to investigate how these principles can be transformed and transferred to the management of user-generated content, environment-generated content, and Big Data, as addressed in the next section.

## 5 Knowledge Commons

In this section we propose an architecture for provision and appropriation of information and knowledge for participatory sensing and analyse it, using the Institutional Analysis and Development (IAD) framework [15], as an information and knowledge commons.

In order to define a participatory-sensing application, we take a set of four general user roles, as defined by [4], and add a fifth role. These roles are:

- *initiators*, who initiate the application and form an organisation around it;
- *gatherers*, who participate in the information gathering and provision it;
- *evaluators*, who verify and classify received information;

- *analysts*, who process the information to create conclusions on the data, often in form of new information and/or knowledge; and
- *consumers* who demand the derived, or second-order, information and knowledge.

We consider a ‘role’ in this context to be an institutionally assigned label to denote what is expected and/or permitted for a user to do. Note that user roles are not mutually exclusive and a user may occupy many roles simultaneously within one institution. For example, in a large proportion of cases *gatherers* are also *consumers*, and in fact their compensation for their gathering efforts is the right to consume. Equally, *initiators* often are *evaluators* and *analysts* too. Therefore the model allows appropriation of knowledge by a user occupying the role of consumer, if that user also occupies the role of *analyst*. The formulation of role in this section specifically allows agents to occupy multiple roles in the same institution, and indeed different roles in different institutions.

We consider this participatory-sensing application in the form of a provision and appropriation system, where the resources being provisioned and appropriated are information and knowledge. Expanding on the bottom-right corner of Figure 2, Figure 3 illustrates a knowledge commons with multiple types of information and knowledge. Solid arrows denote provision or appropriation actions by role, and dotted arrows represent optional actions for that role.

Using the IAD framework, we can then define the characteristics of the information and knowledge gathered through sensing as a resource (bio-physical characteristics), the community of individual actors involved in the sensing process (attributes of the community), and how institutional rules are, or could be, created (rules-in-use). In this way, a knowledge commons can be analysed from the same perspective as resource commons. Furthermore, an institution can be *supplied*, according to the eight design principles. This design can then be given the same formal (algorithmic, rule-based) characterisation in computational logic, which can be animated as an executable specification. For full details, see [11].

## 6 Knowledge Management Processes

Having observed that both a resource commons and a knowledge commons can be characterised as a provision and appropriation system, and supplied with self-governing institutions. In the final part of this paper, comprising the next two sections, we argue that the successful and sustainable inter-leaving of the dual commons is dependent on the implementation of a number of open, transparent and inclusive knowledge management processes. This argument is based, in this section, on the study of classical Athenian democracy of Ober [12], and in the next section we will discuss the realisation of these knowledge management processes in *interactional justice*.

Ober argues that Athenian democracy, on a number of independent metrics, massively outperformed its rival city states, economically, architecturally,



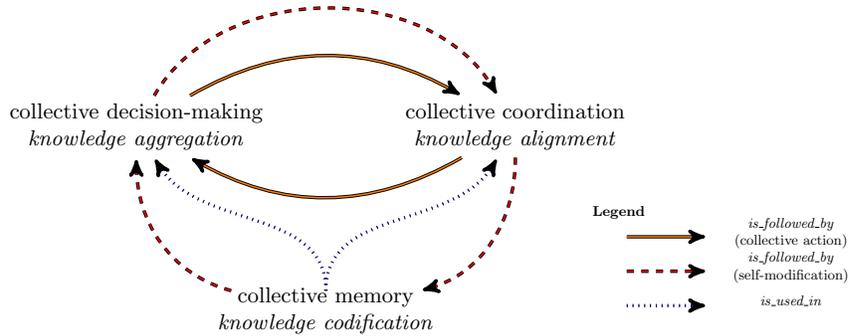


Fig. 4: Athenian knowledge management processes (adapted from [12])

Ober’s analysis is that the Athenians developed highly effective, transparent and interdependent epistemic processes for dealing with each of these problems, respectively, i.e. *knowledge aggregation*, by which dynamic knowledge, created by and between citizens, was used to select the ‘right’ course of action that ‘best’ represented or served their shared values; *knowledge alignment*, which used mutual knowledge to coordinate people’s actions in successfully satisfying the chosen course of action; and *knowledge codification*, which standardised institutional structures and procedures, increasing openness and effectiveness and supporting inclusiveness, verification and accountability (see Figure 4: note the arrows represent sequencing rather than dataflows. There are two sequences: in the inner sequence (solid arrows), knowledge aggregation precedes knowledge alignment and both processes are supported by codified knowledge (dotted arrows) to solve collective action problems (e.g. the distribution of common-pool resources). However, codified knowledge itself can be modified by a “knowledge aggregation—knowledge alignment” sequence, as represented by the outer sequence (dashed arrows), used for selecting and modifying the rules for the distribution of common-pool resources).

Processes of knowledge aggregation proved to be highly effective in enabling a group of otherwise disparate and heterogenous individuals, when acting as (or in the context of)  $\mathcal{I}$ , to get the ‘right’ answer to a given question, in three ways: firstly, by providing incentives for knowledgeable individuals to pool their knowledge for the benefit of the group (these incentives did not have to be financial, but could be in the form of social capital (reputation) in an economy of esteem [3]); secondly, by ensuring that the cost of communication was sufficiently low to overcome the imposition of getting information from “where it was” to “where it needed to be”; and thirdly, sorting processes sifted not only false information from the true but also sifted information useful in a given context from the irrelevant.

Having reached the ‘right’ decision by aggregating knowledge, processes of knowledge alignment ensured that this same group of individuals with a common

interest in coordinating their actions could do so effectively. Ober argues that Athens achieved high levels of coordination between individuals and institutions by intermixing four epistemic mechanisms for accurate collective coordination. These are first choice, where one agent acts and the others follow in an alignment cascade; informed leader, where one agent deemed ‘more informed’ is designated the leader and the others follow his/her direction; rule-following, where each agent believes there is a rule, expects others’ actions to conform to that rule, and so follows the rule itself; and commitment-following, where credible pre-commitments from each are required to ensure that all will act in unison (e.g. turning up for a battle with a weapon and armour is a credible pre-commitment to join in the coming fight as opposed to turning up empty-handed).

Having achieved a successful coordination by aligning common knowledge, the outcomes of both collective decision-making and collective coordination yield even greater benefit through processes of knowledge codification. This effectively creates an institutional ‘memory’ which can inform future behaviour of institutional members. In Athens, dynamic forms of knowledge used in the aggregation and alignment processes were codified in written laws or decrees. However, the Athenians managed to ensure that such codified knowledge was sufficiently stable to allow for confident planning, political engagement and civic education, but also sufficiently fluid to avoid ossification and allow introspective improvement by amendment.

## 7 Interactional Justice

In sociology, *interactional justice* has been defined as the extent to which people affected by the decisions of an institution are treated with dignity or respect [25]. It has been further refined in organizational theory to include two different forms of interpersonal treatment: firstly, the extent to which stakeholders in an institution are dealt with by the decision-making executive implementing procedures (*interpersonal justice*), and secondly, the explanations offered to stakeholders about how procedures were followed or why certain outcomes were reached (*informational justice*) [7].

In this paper, interactional justice reflects two dimensions of interaction; the first being an evaluation of the interpersonal treatment of the individual vis-a-vis the institution, and the second being the communication between individuals about their treatment by the institution. Specifically, interactional justice is aimed at realising shared *values* amongst a set of disparate agents who are members of the same institution. It has three essential aspects:

- How does an ‘agent’ individually ‘feel’ that it is being ‘treated’ by the institution and the outcomes of its deliberations?
- How does a group of ‘agents’ collectively ‘feel’ that they are being ‘treated’ by the institution and the outcomes of its deliberations?
- What does this group of agents ‘do’ with this knowledge, if they think that their treatment is ‘unfair’?

Correspondingly, there are three steps to a *process* of interactional justice:

- Firstly, each agent makes an individual evaluation of its interpersonal treatment as a subjective self-assessment.
- Secondly, the agents have to aggregate disparate knowledge, in the form of these subjective self-assessments, into a collective assessment.
- Thirdly, if this collective assessment is an indicator of the ‘quality’ of an institution with respect to a particular value, then the agents should use a negative indication to motivate self-organisation;

The first step can be achieved by using frameworks developed for distributive, retributive and procedural justice (cf. [20]), whereby each agent applies to its *own* metrics to its *own* experiences to determine the extent which a value is being satisfied personally. The second step can be achieved by using its social network and an opinion formation framework [22] to determine the extent which a value is being satisfied collectively. The third step can be achieved by using ideas from dynamic systems [1] and self-organising electronic institutions [21].

This is a subject for ongoing research, but we propose that (some of) the steps needed include:

- use social networking to aggregate subjective self-assessments of fairness (e.g. using some notions of procedural justice [19]) into a collective assessment;
- use the collective assessment as an indicator of the ‘quality’ of an institution to motivate its adaptation/self-organisation
- use ideas from John Rawls [23] on justice in ‘well-ordered societies; and cybernetics pioneer Ross Ashby [2] on quasi-stability to reform the institution accordingly.

In essence, Ashby [2] defined a *quasi-stable system* as one which has a number of control variables, and is stable in one configuration of those variables. It then goes through a period of disruption but eventually settles in another stable configuration, but unlike a return to a homeostatic equilibrium, the new configuration is *different* from the prior one.

Rawls suggested that: “A well-ordered society is quasi-stable with respect to the justice of its institutions and the sense of justice needed to maintain this condition. While a shift in social circumstance may render its institutions no longer just, in due course they are reformed as the situation requires, and justice is restored.” [23, 456]. Therefore we hypothesise that a dCES can firstly form a “well-ordered (agent) society” which is “quasi-stable” with respect to the “justice of its institutions” and a (collective) “sense of justice”; and secondly, that a dCES can determine whether or not its institutions are no longer just, that it can adapt (“reform”) its institutions as required, and that justice can therefore be “restored”.

## 8 Summary and Conclusions

In summary, the classical Athenian model of democracy was robust, successful and sustainable due to the way that the city-state managed and organized

the processes of knowledge aggregation, alignment and codification by, and between, its citizens (for example, by social networking, transparent institutions, and voting, respectively).

In stark contrast, digital communities (rather than city states) based on IoT-enabled infrastructure — such as those found in community energy systems, but also sharing economy applications, peer production systems, and participatory sensing applications relying on user-generated data and content — exhibit an asymmetry in the power, control and ownership of knowledge production and distribution. The outcome is disadvantageous to the majority: “big” data (and the knowledge, and hence the power that follows) remains the preserve of political or corporate elites; shared values that are congruent among a group or community are diminished by processes of commodification and metrication; and opportunities for successful collective action are inhibited.

To address these problems, in this paper we have converged three lines of research: the first is Ostrom’s institutional design principles for sustainable common-pool resource management applied to resource and knowledge commons; the second is the insights provided by Ober into the knowledge management processes observed in classical Athenian democracy applied to a dual resource-knowledge commons; and the third is interactional justice, as a component of computational justice, which aims to increase the ‘correctness’ or ‘appropriateness’ in outcomes of algorithmic decision-making and deliberative processes in socio-technical systems.

Interactional justice can support the inter-leaving of a resource commons with a knowledge commons (inspired by Ostrom) underpinned by these knowledge management processes (inspired by Ober), and can inform the successful deployment of platforms for sustainable, user-centred, self-organising socio-technical systems. This includes sharing economy applications, peer production cooperatives and infrastructure management systems, wherein a congruent set of qualitative (pro-social) values, like fairness in the distribution of resources, minimal rights to self-organise, and so on, are a product of this inter-leaving.

This is important, for if the platform is ‘closed’ it can lead to an asymmetry in the distribution of power and information, and a tight control over the means of coordination, that can inhibit successful collective action. Instead, an ‘open’ platform is required: in “smart” grid for community energy systems this entails the ‘democratisation’ of the “smart” meter and the (big) data generated by implementing an operational layer (based on unbundling the “smart” meter), which in turn supports a prosumer-centric self-governance layer. This ‘upper’ layer manages the dual commons for example, collective action through the self-management and distribution of both data and energy, various forms of self-organisation and governance (e.g. based on Ostrom’s principles), and the promotion and preservation of values, like justice. This is the route to fully engaged active participation of consumers in, for example, decentralised community energy systems.

Finally, we contend that this argument generalises to other socio-technical and cyber-physical systems, for example for architecture, urban mobility and

other infrastructure management. In particular, polycentric governance offers an alternative, institution-centric paradigm for developing “smart” cities, which realise values shared by the inhabitants and aligned through interactional justice. We conclude that if we want to encourage active participation of citizens in different roles, for example in sustaining natural resources, helping communities to address collective action problems, or to self-organise local arrangements, then we need open, participatory platforms which represent values congruently, distribute power fairly, and manage knowledge transparently. In other words, we need to democratise “smart” technology, and the infrastructure, platforms and data that are developed from it.

### Acknowledgements

The first author has been partially supported by the Leverhulme Trust, Research Fellowship RF-2016-451.

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