A Collective Adaptive Socio-Technical System for Remote- and Self-Supervised Exercise in the Treatment of Intermittent Claudication

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Abstract

Vascular surgeons have recognised that the condition of many patients presenting with intermittent claudication and peripheral arterial disease is better treated by physical exercise rather than endovascular or surgical intervention. Such exercise causes pain, though, before and until the health improvements are realised. Therefore, patients experiencing pain tend to stop doing that which causes it, unless they are supervised performing the necessary exercise programmes. However, supervised exercise is an extremely costly and time-consuming use of medical resources.

To overcome this series of problems, we propose to develop and deploy a healthcare application which provides patient exercise programmes that are *both* centrally organised and remotely supervised by a health practitioner, *and* self-organized and self-supervised by the patients themselves. This demands that two dimensions of adaptation should be addressed: adaptation prompted by the health practitioner as the patient group improves and meets programme targets; and adaptation prompted from within the patient group enabling them to manage their own community effectively and sustainably.

This position paper explores this application from the perspective of engineering a collective adaptive system for a mobile healthcare application, providing both remote- and self-supervised exercise. This requires, on the one hand, converging recent technological advances in sensors and mobile devices, audio and video connectivity, and social computing; with, on the other hand, innovative value-sensitive and user-centric design methodologies, together with formal methods for interaction and interface design and specification. The ultimate ambition is to create a 'win-win-win' situation in which the benefits of exercise as a treatment, the reduced costs of supervision, and the pro-social incentives to perform the exercise are all derived from computer-supported self-organised collective action.

1 Introduction

Patients with narrowing or blockage of arteries in their legs may suffer from pain in their legs on walking, commonly in the calf. This is caused by an inadequate blood supply and is diagnosed as *intermittent claudication.*

Vascular surgeons have recognised that the condition of many patients presenting with intermittent claudication and peripheral arterial disease is better treated by exercise rather than endovascular or surgical intervention [7, 8]. Moreover, there are long-lasting benefits of supervised exercise over and above revascularisation, which include development of a social network, additional cardiac training and motivational therapy [13]. The initial problem, though, is that this exercise causes pain, before and until the health improvements are realised; but patients experiencing pain tend to stop doing that which causes it – unless they are supervised performing the necessary exercise programmes. Given the scale of the problem, though, supervised exercise can be an extremely costly and time-consuming use of medical resources, assuming that patients even have access to a hospital-based programme.

However, recent years have seen three significant advances in ICT (information and communication technologies): firstly, the development of low-cost sensors integrated with mobile devices which can monitor activity and other health indicators; secondly, increased connectivity which enables virtual (remote) meetings with high quality audio and video; and thirdly, the widespread application of social computing, in which people use social networking and associated tools to develop 'digital communities' to address public action problems. Indeed, it has been argued that the value of communities is that they can resolve certain types of collective and public action situations which are resistant to purely market-based or policy-based solutions [17]. Such situations increasingly arise in the digital society, where the added-value of information, reciprocity or other pro-social behaviour is indeterminate, and/or the qualitative nature of traded services is subjective and cannot simply be measured by kilowatts, tons, etc.

We contend that the provision of supervised exercise programmes can be construed as just such a collective action situation. Consequently, this paper proposes to converge these developments to engineer a system to support exercise programmes for the treatment of intermittent claudication. However, extensive experience of rehabilitation and exercise programmes has revealed that it is fundamental that the engineering of any health-centred computer system should incorporate the direct social relationship between the health practitioner and the patient group at its core; but similarly the 'democratisation' of such socio-technical systems through self-organised collective choice arrangements (i.e. those affected by 'the rules' participate in the selection, modification and application of those rules) can be critical to community formation, its sustainability, and a successful achievement of intended goals.

Therefore, what is required is a *collective adaptive socio-technical system* [10], in which exercise programmes are organized, monitored and supervised through the joint collaboration of both health practitioners and the patients themselves, using a combination of both *remote*- and *self*-supervision. Two dimensions of adaptation need to be addressed: adaptation prompted by the health practitioner as the patient group improves and meets programme targets; and adaptation prompted from within the patient group to manage their own community.

Engineering such a collective adaptive socio-technical system also requires addressing a number of software engineering challenges, not least recognising that the system must meet 'supra-functional' requirements targeting social or qualitative values, like improving collective public health, community well-being or individual 'quality of life' measures. However, recent methodological advances like value-sensitive design [9] also need to be taken into consideration, in conjunction with innovative interface design to support self-governance, to visualise community 'well-being' and to incentivise pro-social behaviour [24].

However, the engineers of collective adaptive of socio-technical systems, especially those underlying the digital transformation, require methodological support for significantly more complex types of design, in particular designs that are sensitive to 'supra-functional' requirements' like (human) values, possess the capacity for continuous re-design and self-organisation, and encapsulate mechanisms for self-governance, knowledge aggregation and coordination that are attuned to context, e.g. the type and scale of problem being addressed, and the type and nature of the social relationships being digitised.

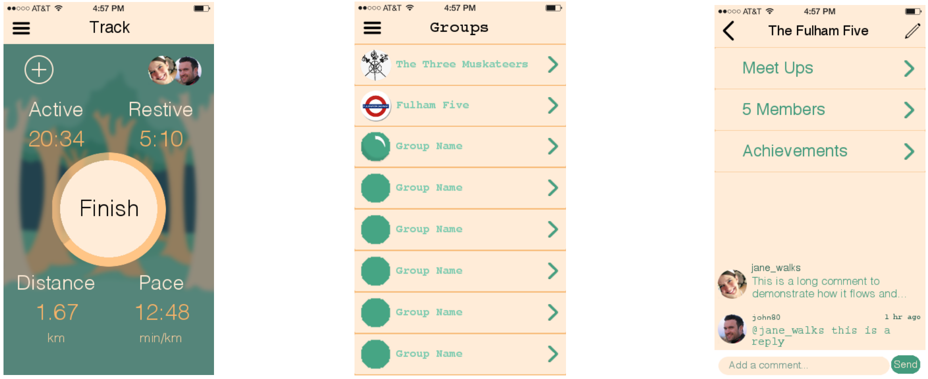
This *position paper* explores this issue from the perspective of designing and implementing a collective adaptive system for a healthcare application, providing remote- and self-supervised exercise for the treatment of diseases such as intermittent claudication, which can respond more effectively to physical exercise rather than surgical intervention. The paper presents an eclectic 'toolset' of possible techniques that might be used to engineer such systems. Following a (partial) envisionment of a proposed system in Section 2, Section 3 reviews two design methodologies and Section 4 considers (formal) specification of three necessary components of such a system: events and the effect of events; interface and interaction design; and the design of social capital, currency, and the system's 'shared reality'.

Our ultimate aim is to create a 'win-win-win' situation in which the benefits of exercise as a treatment, the diminished costs of supervision, and the incentives to follow given exercise programmes are all derived from self-organised collective action based on sound engineering of collective adaptive socio-technical systems. Remote supervision will also improve access to this treatment in areas where no such service is currently available, and improve availability of this treatment in resource-poor healthcare systems, but do have access to smartphones and a communications infrastructure. However, we also conclude that while there appears to be no 'silver bullet' approach to rigorous engineering of collective adaptive systems, this nevertheless presents opportunities for co-design and generativity.

2 (Partial) System Envisionment

Addressing peripheral arterial disease is a significant and unmet clinical and health economic need, but the treatment of intermittent claudication using supervised exercise remains largely under-utilised due to a lack of appropriate resources. In addition, we note that other medical conditions, such as diabetes and hypertension, can also be managed by a similar convergence of self-supervision and ICT, and interactive self-governance. Therefore, we propose an alternative approach based on a digital community for *self-organised, self-supervised exercise*, based on: firstly: information and communication technologies (ICT), including new healthcare sensors and devices; secondly, computing models based on self-organising socio-technical systems to provide communal support and collective action (cf. [25]); and thirdly, structures and procedures that reflect the different relationships in patient-patient self-organisation and the practitioner-patient self-organisation.

In a preliminary investigation, we have experimented with the design and envisionment of a mobile device-based app to support self-organised, self-supervised exercise *within* the patient group. Example interface mock-ups for tracks, groups and communications are illustrated in Figure 1, illustrating the interface design of a putative app which applies some ideas from gamification with the intention to increase self-efficacy. This app is an exploration game in which to progress, the user must exercise in real life. The user has an avatar that has crashed on an unknown world and has been injured. In order to heal themselves and to stay alive they must explore the area and find items such as food or medicinal plants. To do so, the user tracks their walks through the app. Items are awarded at the end of the session depending on how far they've walked. The users can also connect through the app to find people to exercise with and, by tracking exercise in a group, they can pick up bonus items that are too 'heavy' to lift alone, providing both self-supervision, monitoring and mutual verification. If the users stick to the schedule they are rewarded, and incentivised – in appropriate ways (see below).



jane_walks
This is a long comment to demonstrate how it flows and...

john80 1 hr ago
@jane_walks this is a reply

(a) (b) (c)

Fig. 1: App interface mock-ups for self-organised, self-supervised exercise.

Such envisionment is useful for exploratory purposes. For example, when this lab-based envisionment was first demonstrated to healthcare professionals, there were two observations. The first was a recommendation for a ‘first aid’ facility, for example to have some first aid tips or an SOS button on the app that alerts emergency services. Secondly, system designers need to recognise that this approach to ‘gamification’ (based on an avatar landing on alien planet and needing to survive) may not be readily ‘accessible’ to the target demographic of patients who are suffering from intermittent claudication. The concept of an analogy or story on which the patient can put their exercise programme in context is potentially beneficial; but system designers have to ensure that gamification is appropriate to the user demographic.

Therefore the overall approach to envisionment needs system designers to work with healthcare professionals, especially when it comes to formulating an exercise plan that can be self-created, prescribed, monitored and adapted for a particular patient group by a qualified professional health practitioner. Participatory design and user-centred systems design are standard approaches, but for the design of gamification and self-organising socio-technical systems some other design methods need to be considered, as discussed in the next section.

3 Design Methodologies

This section reviews two design methodologies pertinent to the design of self-organising healthcare application: one highlighting the role of user values in design, and the other emphasising the use of digital interventions which can support and encourage behavioural change. Both patient values and changing patient behaviour are, of course, crucial aspects of self-organised and self-supervised exercise.

3.1 Value-Sensitive Design (VSD)

In [9], it is suggested that VSD brings forward a “unique constellation of eight features”, which included proactive influence on technological design from an early stage in the process; enlarging the scope of applications in which values arise as “supra-functional” requirements; the integration and iteration of conceptual, empirical and technical investigations; enlarging the scope of values beyond co-operation and participation to include justice, welfare, virtue, etc.; distinguishing between usability and values with ethical significance; consideration of different classes of stakeholder; being an interactional theory; and building from the psychological proposition that values are universal, if possibly culturally relative.

Healthcare seems to be a particularly promising test application to apply the methodology of VSD for digital communities. For example, we can start with a value of central interest – quality of life and patient care – and move from that value to its implications for app interface design and context of use (remote-and self-supervised exercise). We can next examine the roles of peer-to-peer self-help communities and centralised practitioner-patient group communities in a wider context, with multiple stakeholders and polycentric governance (multiple centres of decision-making). We can identify several direct and indirect stakeholders (e.g. patients, clinicians, health service providers, policy advisors, public health officials, and insurance providers), and from an understanding their co-dependence, we can start to identify and coordinate the values and benefits for each stakeholder group.

Critically, one of the most important values in healthcare applications is *privacy* and the confidential treatment of patient data. However, privacy by design [5] can be seen as an instance of value-sensitive design, and following these principles can help design systems with privacy as primary system requirement (explicitly meeting legal requirements, for example, with respect to GDPR (General Data Protection Regulation)).

3.2 The IDEAS Framework

The rise of mHealth technologies that need to serve both healthcare provider and patient to be efficacious, raises new questions about how best to innovate in the mHealth era. Traditionally, the healthcare sector has relied on linear models of innovation whereby development and commercialisation of a 'product' has followed basic science and applied research; this is commonly known as the 'lab-bench to bedside' model. This traditional approach is slow and potentially produces products that are sub-optimal from the patient perspective.

Modern approaches to bring innovative ideas from conception to market require an alternative approach; one that places patients (users) at the centre of the design process alongside lead clinicians. Ultimately promoting patient responsibility and encouraging them to take control of their own collective health outcomes [2], as well as producing products that the desired user group are likely to use.

The IDEAS Framework (Integrate, Design, Assess and Share), as illustrated in Figure 2 has been proposed as a method for developing digital interventions that lead to effective behavioural change. This approach is grounded in behavioural theory; has an in-depth understanding of the target population, by asking "what matters most" to them; products are rapidly and iteratively designed with multiple episodes of user feedback and are subjected to rigorous evaluation before generalised dissemination [14].

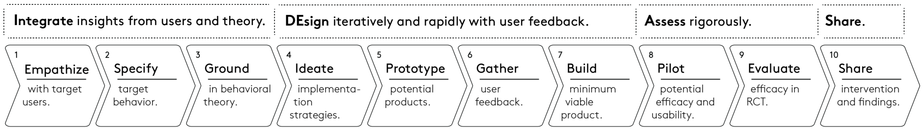


Fig. 2: The IDEAS Design Framework.

4 Formal Specification

Complementing these design methodologies, there are three further aspects that need to be considered in the design and specification of a healthcare application. These are the formal specification of self-adaptation; the visualisation of self-governance; and the construction of shared reality in socio-technical systems. Each of these aspects will be discussed in turn in this section.

Section 4.1 presents a possible formalism for specifying, reasoning about and implementing self-adaptation of the rules, which also includes normative aspects like permission, obligation and institutionalised power [11]. Section 4.2 addresses the issue of interface and affordance design based on the idea of interactive self-governance, and Section 4.3 picks up on the incentivisation of self-supervised exercise through the use of social capital. .

4.1 Reasoning about Events

In many applications, especially those with it is often necessary to reason about actions, constraints on actions, and the effects of actions, which in turn are dependent on who performed the action – or rather, which person occupying a designated *role* performed the action, i.e. some actions have different adaptive effects depending on whether it was a patient or a practitioner who performed it. This section outlines a formalism for specifying and reasoning about actions which can be used at both design-time (e.g. for proving system properties) and at run-time as an executable specification (e.g. for determining the validity and computing the effects of actions).

The Event Calculus (EC) The Event Calculus (EC) [12] is a logic formalism for representing and reasoning about actions or events and their effects. The EC is based on a many-sorted first-order predicate calculus. For the version used here, the underlying model of time is linear, so we use non-negative integer time-points (although this is not an EC restriction). It is not assumed that time is discrete (the numbers need not correspond to a uniform duration) but we do impose a relative/partial ordering for events: for non-negative integers, $<$ is sufficient.

An *action description* in EC includes axioms that define: the action occurrences, with the use of happensAt predicates; the effects of actions, with the use of initiates and terminates predicates; and the values of the fluents, with the use of initially and holdsAt predicates. Table 1 summarises the main EC predicates. EC variables, that start with an upper-case letter, are assumed to be universally quantified unless otherwise indicated. Predicates, function symbols and constants start with a lower-case letter.

Where F is a *fluent*, which is a property that is allowed to have different values at different points in time, the term $F = V$ denotes that fluent F has value V. Boolean fluents are a special case in which the possible values are *true* and *false*. Informally, $F = V$ holds at a particular time-point if $F = V$ has been

Table 1: Main Predicates of the Event Calculus.

Predicate	Meaning
Act happensAt T	Action Act occurs at time T
initially $F = V$	The value of fluent F is V at time 0
$F = V$ holdsAt T	The value of fluent F is V at time T
Act initiates $F = V$ at T	The occurrence of action Act at time T initiates a period of time for which the value of fluent F is V
Act terminates $F = V$ at T	The occurrence of action Act at time T terminates a period of time for which the value of fluent F is V

initiated by an action at some earlier time-point, and not *terminated* by another action in the meantime.

Events initiate and terminate a period of time during which a fluent holds a value continuously. Events occur at specific times (when they *happen*). A set of events, each with a given time, is called a *narrative*.

The utility of the EC comes from being able to reason with narratives. Therefore, the final part of an EC specification is the domain-independent 'engine' which computes what fluents hold, i.e. have the value *true* in the case of boolean fluents, or what value a fluent takes, for each multi-valued fluent. This can be used to compute a 'state' of the specification in terms of the fluents representing institutional facts. This state changes over time as events happen, and includes the roles, (institutionalised) powers, permissions and obligations of agents, and the protocols selected to implement a community's operational-, collective- and constitutional-choice rules [16].

A particularly relevant concept to formalise is of *institutionalised power* [11], by which a designated agent occupying a distinguished role is empowered to perform specific actions of conventional significance, which result in "seeing to it that" *institutional facts* are true (facts which are true by agreement, or convention, in the context of the institution). Examples include an agent in the role of auctioneer in an auction house 'decision arena' banging a gavel and saying "sold", which sees to it that the auctioned lot is contracted to the highest bidder in return for payment of the bid price; or an agent in the role of priest in the context of a marriage ceremony 'decision arena' pronouncing two people "man and wife" sees to it that they are married (according to the religious institution; according to the state, the fact that they are married may only be true after another act of conventional significance, for example signing a register).

Institutionalised power is particularly important to specify because of the different roles and relations that obtain in remote- and self-supervised exercise: the institutionalised powers that exist between peers within the self-supervised patient group are rather different from the institutionalised powers that exist between the practitioner and her patients. Powers, permissions and obligations of agents can be uniformly represented in EC using the following boolean fluents:

$$\begin{aligned}&\mathbf{pow}(\mathit{Agent}, \mathit{Action}) = \ldots\\&\mathbf{per}(\mathit{Agent}, \mathit{Action}) = \ldots\\&\mathbf{obl}(\mathit{Agent}, \mathit{Action}) = \ldots\end{aligned}$$

We illustrate the formal specification of powers, permissions and obligations in the EC in the next subsection.

Self-Supervised Exercise This section presents an example specification for reasoning about events in the context of self-supervised exercise. We assume (for simplicity) that there are only two roles, *health_practitioner* and *patient*. A person occupying the health-practitioner role can assign a person who is a patient to a group, and appoint a member of that group to the role of being a supervisor for that group. Both actions are subject to certain conditions: the assignment to a group depends on the readiness of the patient for the exercise regime of the group; while the appointment to the supervisor role depends on the number of times the patient him/herself has been supervised exercising (recorded by an exercise count *ex_ct*). These institutionalised powers can be specified as follows:

$$\begin{aligned}&\mathbf{pow}(HP, \mathit{assign}(HP, P, G, H)) = \mathit{true} \quad \mathsf{holdsAt} \quad T \quad \leftarrow\\&\qquad \mathit{role\_of}(HP, \mathit{health\_practitioner}, H) = \mathit{true} \quad \mathsf{holdsAt} \quad T \quad \wedge\\&\qquad \mathit{role\_of}(P, \mathit{patient}, H) = \mathit{true} \quad \mathsf{holdsAt} \quad T \quad \wedge\\&\qquad \mathit{regime}(G, H) = L1 \quad \mathsf{holdsAt} \quad T \quad \wedge\\&\qquad \mathit{readiness}(P, H) = L2 \quad \mathsf{holdsAt} \quad T \quad \wedge\\&\qquad L1 \leq L2\\&\mathbf{pow}(HP, \mathit{appoint}(HP, P, G, H)) = \mathit{true} \quad \mathsf{holdsAt} \quad T \quad \leftarrow\\&\qquad \mathit{role\_of}(HP, \mathit{health\_practitioner}, H) = \mathit{true} \quad \mathsf{holdsAt} \quad T \quad \wedge\\&\qquad \mathit{members}(G, H) = M \quad \mathsf{holdsAt} \quad T \quad \wedge\\&\qquad P \in M \quad \wedge\\&\qquad \mathit{threshold}(G, H) = T \quad \mathsf{holdsAt} \quad T \quad \wedge\\&\qquad \mathit{ex\_ct}(P, G, H) = S \quad \mathsf{holdsAt} \quad T \quad \wedge\\&\qquad S \geq T\end{aligned}$$

When the health practitioner *HP* performs either an empowered assignment or appointment action, then the results are as follows:

$$\begin{aligned}&\mathit{assign}(HP, P, G, H) \quad \mathsf{initiates} \quad \mathit{members}(G, H) = [P \mid M] \quad \mathsf{at} \quad T \quad \leftarrow\\&\qquad \mathit{members}(G, H) = M \quad \mathsf{holdsAt} \quad T \quad \wedge\\&\qquad \mathbf{pow}(HP, \mathit{assign}(HP, P, G, H)) = \mathit{true} \quad \mathsf{holdsAt} \quad T\\&\mathit{appoint}(HP, P, G, H) \ \mathsf{initiates} \ \mathit{role\_of}(P, G, H) = \mathit{supervisor} \ \mathsf{at} \ T \ \leftarrow\\&\qquad \mathbf{pow}(HP, \mathit{appoint}(HP, P, G, H)) = \mathit{true} \quad \mathsf{holdsAt} \quad T\end{aligned}$$

The power to supervise, and the effect of a *self-supervision* can then be specified as follows:

$$
\begin{array}{l}
\mathbf{pow}(\mathit{P1}, \mathit{supervise}(P1, P2, G, H)) = \mathit{true} \quad \textsf{holdsAt} \quad T \quad \leftarrow \\
\qquad \mathit{members}(G, H) = M \quad \textsf{holdsAt} \quad T \quad \wedge \\
\qquad P1 \in M \quad \wedge \\
\qquad P2 \in M \quad \wedge \\
\qquad \mathit{role\_of}(P1, G, H) = \mathit{supervisor} \quad \textsf{holdsAt} \quad T \quad \wedge \\
\mathit{supervise}(P1, P2, G, H) \ \textsf{initiates} \ \mathit{ex}_c t(P2, G, H) = S \ \textsf{at} \ T \ \leftarrow \\
\qquad \mathit{supervisions}(P2, G, H) = S \quad \textsf{holdsAt} \quad T \quad \wedge \\
\qquad S1 = S + 1 \quad \wedge \\
\qquad \mathbf{pow}(\mathit{P1}, \mathit{supervise}(P1, P2, G, H)) = \mathit{true} \quad \textsf{holdsAt} \quad T
\end{array}
$$

In other words, a patient $P1$ is empowered to supervise a patient $P2$ if s/he is appointed to the role within the group by an empowered health practitioner; and the effect of a supervision of $P2$ (reported by $P1$) is to increase $P2$'s exercise count (so that when it reaches or passes the group threshold, $P2$ can also be appointed to a supervisor role).

4.2 Interface and Interaction Design

In [3], we described a Serious Game called *Social mPower*, which investigated how smart meters could be used to encourage pro-social behaviour and collective action (as opposed to simply monitoring or managing electricity consumption). Based on this work and other exemplars [23], we have derived the following interface guidelines for implementing interactive self-governance in collective adaptive socio-technical systems:

- Interface cues and affordances for collective action, indicating that participants are engaged in a collective action situation – for example the use of avatars, and especially those which express emotions [26];
- Visualisation: appropriate presentation and representation of data, making what is conceptually significant perceptually prominent, in particular significant events, the status of rules, the progress of protocols and the structure of multiple organisations – for example, the status of norms and powers;
- Social networking: fast, convenient and cheap communication channels to support the propagation of messages in a seamless, unobtrusive way – emphasising contextually meaningful private communication between members of a local community known to each other, rather than global platforms that encourage the pursuit of 'followers', 'friends' or 'likes' from strangers;
- Feedback: inform individuals that their ('small', individual) pro-social action X contributed to some ('large', collective) action Y which achieved beneficial outcome Z – for example the representation of the collective ambience or 'mood' according to monitored physical contributions of collective members;

- Incentives: typically in the form of social capital [19], awarded for absolute/collective rather than relative/individual endeavour and achievement.

These guidelines are offered in the same 'spirit' as Nielsen's ten usability heuristics for user interface design [15], i.e. these guidelines are currently closer to 'rules of thumb' than specific methodological steps. This iteration of the guidelines for the purposes of this position paper is at a much earlier stage of development than Nielsen's heuristics, and much more work is required to make them fully operational for the increased benefit of system developers. However, in relation to the (partial) envisionment of Section 2, it would be possible to apply the guidelines for future interface development.

For example, for the first guideline, various indicators of successful collective action could be used, for example, multiple ants carrying a leaf that each on their own could not. However, as suggested above, the use of avatars for personalisation, demonstrating status (e.g. through some indication of emotive state) and cor conveying a sense of belonging could be helpful.

For the second guideline, three of the most important aspects to visualise would be the 'health' status of the collective (i.e. group 'well being' rather than personal health of the group members), the extent of individual contributions, and progress towards the next 'readiness' level. One possible visualisation that captures all three could be inspired by the Forest app[4] Each member of the group is represented by a tree, and the tree grows (or withers) according to active contribution.

For the third guideline, many social media applications become unusable as the group becomes larger. It is therefore important for the health practitioner to maintain 'workable' group sizes. Furthermore, the app should support standard conversation types (or allow the user to customise such conversations). For example, if there is a regular meeting time and place, then there should be a screen for that week (or month's) meeting, offering a button for indicating intention to participate (or not), and showing who is/is not currently committed to participating. There should not be a need for sending notifications, if a member of the group is concerned with attendance then they can consult this screen.

For the fourth and fifth guidelines, these could possibly also be achieved through the appropriate visualisation, for example showing an animation of the forest growing as an historical record, but also an option to see what the forest *would have* looked like without the individual's contribution. The aim would be to provide a better incentive to increased participation than 'naming and shaming'. However, the final guideline on incentives is related to a more general concern about *values*, in the form of social capital, as discussed in the next subsection.

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[4] https://www.forestapp.cc/en/. This app encourages people to stay concentrated on their jobs and away from their Smartphones by growing a forest through not interacting with their phone during designated times.

4.3 Construction of Shared Reality

In remotely-supervised exercise, the health practitioner is in effect a centralised controller, and orchestration of collective action can follow a 'leader'. For the self-supervised exercise, the patient community must instead rely on *self-organisation* to achieve the necessary agreement on, or synchronisation of, collective action. However, self-organising approaches often require other incentives to participate, contribute, or select an action which maximises the collective, rather than individual, utility.

One possible type of incentive is social capital. Social capital has been defined as attributes of individuals that assist them with resolving collective action situations [18]. These attributes come in many forms, such as trustworthiness, social networks, and institutions. However, we find that while social capital is fine as a concept, as a term it is potentially misleading, as it suggests something that can be owned, traded or (even worse) 'spent'.

For example, in an experiment to examine self-organisation based on negotiation and social capital, we examined a consumer exchange arena in which social capital was represented in terms of 'favours' [19]. Whenever one consumer traded a good with another which resulted in a more favourable arrangement, it counted as a 'favour'; moreover, if the exchange benefitted both then it counted as *two* favours. Over time, the favour-based situation achieved a more optimal distribution of goods; however, the risk is that, in a less abstract formulation, the favours could become commodified as currency. Therefore, in *digital communities*, there is fundamental tension is between retaining the complexity-reducing short-cuts offered by transactional information, which could be realised through a community cryptocurrency, without losing the benefits of relational information that social capital brings with it.

In self-supervised exercise, the digital representation social capital in terms of concrete attributes or as the consequence of specific actions or event which can be recorded with the use of the Event Calculus. However, this runs the risks of commodifying the concept, with the concomitant loss of the actual 'value' or leverage that social capital has or can achieve (cf. [21]). In other words, it is more important not to focus so much on what social capital *is*, but on what social capital *does*; and what it does is to coordinate expectations [20] and provide a basis for community governance [4]. Therefore, any framework for *electronic* social capital which can be used to support successful collective action in self-organising systems will need not just to define, in computational form, the attributes that agents need to represent and reason with, but also the *processes* by which those same agents can coordinate their expectations and govern their communities.

This is the principal requirement of a framework for electronic social capital in a mobile healthcare application: it should define data structures for representing attributes of agents (i.e. in objective terms such as reputation and institutions, and subjective terms such as their social networks), and also define processes for updating, evaluating and visualising social capital. In fact, as an *axial currency*, careful consideration needs to be give to its design and deployment [22], beyond the engineering of the collective adaptive systems itself.

Therefore, social capital, which encompasses all concepts created by institutions (such as the norms and values mentioned previously), fits within the framework of Artificial Social Constructivism (ASC). This theory, based on the original premise from [1], expands on the idea that language shapes society. This idea has been highlighted previously in the medical field, specifically in online weight loss communities, where community language is used to indicate appropriate behaviour when members are interacting with one another [6]. ASC proposes that by allowing human users and digital agents to educate each other about norms of behaviour, a shared reality can be created where both the users and the agents uphold values they find important. This is particularly important in scenarios such as this, where the user needs to feel invested in the technology and in its assistance to reach a common goal, here being exercise despite pain, in order keep using it.

5 Summary and Conclusions

The accumulation of atherosclerotic disease in the lower limbs can result in narrowing or occlusion of arteries. The resultant reduction in blood supply to the musculature of the affected limb(s) can result in pain in the leg, distal to diseased site, that occurs on exertion. Pain is predictably relieved by rest. This predictable onset and offset of symptoms caused by a restricted blood supply is known as intermittent claudication. These symptoms are often the first clinical manifestation of peripheral arterial disease (PAD).

PAD prevalence increases with age and may be as high as 20% in populations aged over 75. The treatment of intermittent claudication includes the management of atherosclerotic risk factors, such as smoking, hypertension, diabetes and hypercholesterolaemia. In addition, the National Institute for Health and Care Excellence (NICE) recommends that patients diagnosed with intermittent claudication should be offered access to a supervised exercise programme. This consists of monitored exercise 2 hours per week for at least 3 months.

Nationally, the provision of supervised exercise programmes is poor. In 2009 only 24% of vascular surgery departments had access to a supervised exercise programme; by 2016 only a modest improvement was observed, with 39% of departments having access. Such a lack of provision is disappointing given recent evidence that successfully run supervised exercise programmes can be as effective as invasive management for lower limb atherosclerosis6.

The chronic underfunding and lack of access to supervised exercise programmes makes adherence to NICE guidelines impossible for most NHS Trusts. Novel methods aimed at improving access to supervised exercise programmes are required. The design and development of a remotely supervised exercise programme delivered by a disease-specific mobile phone application would be a novel and cost-effective method for delivering exercise therapy. The app will allow accurate measurement of walking distances and regular remote supervision by clinical teams who will have the ability to interact with patients by sending messages via the app.

In this paper, we have proposed that the development of a disease-specific application to enable remotely supervised and self-regulated exercise and the creation of a resultant digital community will best serve the needs of healthcare professionals and patients alike. However, the proposed system has the characteristics a collective adaptive socio-technical system, and this requires:

- collectivity: we need to be polycentric, i.e. we have people and software involved in the decision-making, and the people are "empowered" in those decision-making processes in different ways, in particular the health practitioner to patient group is a centralised one, while within the patient group it is a decentralised (or peer-to-peer) one. Software in this case needs to be largely data collecting but privacy preserving, and providing analytics to support the decision-making processes and for the health economics, evaluation, etc.
- adaptivity: one of the important innovations being proposed here is the synthesis of remote and self-supervision with the extra insight of adaptation in *two* dimensions: adaptation initiated by the health practitioner as the capabilities/health of the patient group improves with exercise, and adaptation initiated within the patient group to incentive and visualise that progress

However, as evidenced by the eclectic mix of design methodologies, formal specification languages and interaction design techniques presented in this position paper, there is no 'silver bullet' approach to rigorous engineering of a collective adaptive system in conjunction with the requirements of a mobile healthcare application. There is no need to despair, though, since the corollary is increased opportunities for co-design and most importantly, generativity (the ability for people to fashion new tools out of existing ones that were neither expected nor intended by the original tool's designers [27]).

References

1. Berger, P., Luckmann, T.: The Social Construction of Reality. Penguin Books (1966)
2. Bhatti, Y., del Castillo, J., Olson, K., Darzi, A.: Putting humans at the center of health care innovation. Harvard Business Review (2018)
3. Bourazeri, A., Pitt, J.V.: An agent-based serious game for decentralised community energy systems. In: PRIMA 2014: Principles and Practice of Multi-Agent Systems - 17th International Conference, Gold Coast, QLD, Australia, December 1-5, 2014. Proceedings. Lecture Notes in Computer Science, vol. 8861, pp. 246–253. Springer (2014)
4. Bowles, S., Gintis, H.: Social capital and community governance. The Economic Journal 112(483), F419–F436 (2002)
5. Cavoukian, A.: Privacy by design [leading edge]. IEEE Technol. Soc. Mag. 31(4), 18–19 (2012)

6. Chancellor, S., Hu, A., De Choudhury, M.: Norms Matter: Contrasting Social Support Around Behavior Change in Online Weight Loss Communities. Proc. 36th ACM Conf. Human Factors in Computing Systems (CHI'18) (Paper no. 666), 1–14 (2018)
7. Cheetham, D., Burgess, L., Ellis, M., Williams, A., Greenhalgh, R., Davies, A.: Does supervised exercise offer adjuvant benefit over exercise advice alone for the treatment of intermittent claudication? a randomised trial. European Journal of Vascular and Endovascular Surgery 27, 17–23 (2004)
8. Conte, M., Pomposelli, F., Clair, D., Geraghty, P., McKinsey, J., Mills, J., Moneta, G., Murad, H., Powell, R., Reed, A., Schanzer, A., Sidawy, A.: Society for vascular surgery practice guidelines for atherosclerotic occlusive disease of the lower extremities: Management of asymptomatic disease and claudication. Journal of Vascular Surgery 61(3), 2S–41S (2015)
9. Friedman, B., Kahn, P., Borning, A.: Value sensitive design and information systems. In: Himma, K., Tavani, H. (eds.) The Handbook of Information and Computer Ethics, pp. 69–101. Wiley (2008)
10. Hillston, J., Pitt, J., Wirsing, M., Zambonelli, F.: Collective adaptive systems: Qualitative and quantitative modelling and analysis (dagstuhl seminar 14512). Dagstuhl Reports 4(12), 68–113 (2014), https://doi.org/10.4230/DagRep.4.12.68
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. Mazari, F., Khan, J., Samuel, N., Smith, G., Carradice, D., McCollum, P., Chetter, I.: Long-term outcomes of a randomized clinical trial of supervised exercise, percutaneous transluminal angioplasty or combined treatment for patients with intermittent claudication due to femoropopliteal disease. Journal of Vascular Surgery 65(4), 1239–1240 (2017)
14. Mummah, S., Robinson, T., King, A., Gardner, C., Sutton, S.: Ideas (integrate, design, assess, and share): A framework and toolkit of strategies for the development of more effective digital interventions to change health behavior. J Med Internet Res 18(e317) (2016)
15. Nielsen, J.: Usability Engineering. Academic Press (1994)
16. Ostrom, E.: Governing the Commons: The Evolution of Institutions for Collective Action. Cambridge University Press (1990)
17. Ostrom, E.: Beyond markets and states: Polycentric governance of complex economic systems. In: Grandin, K. (ed.) Les Prix Nobel. The Nobel Prizes 2009, pp. 408–444. Nobel Foundation (2010)
18. Ostrom, E., Ahn, T.: Foundations of Social Capital. An Elgar Reference Collection, Edward Elgar Pub. (2003)
19. Petruzzi, P.E., Busquets, D., Pitt, J.V.: Experiments with social capital in multiagent systems. In: PRIMA 2014: Principles and Practice of Multi-Agent Systems. pp. 18–33 (2014)
20. Peyton Young, H.: Social norms. In: Durlauf, S., Blume., L. (eds.) The New Palgrave Dictionary of Economics (2nd Edition). Palgrave Macmillan (2008)
21. Pitt, J., Nowak, A.: The reinvention of social capital for socio-technical systems. IEEE Technology & Society Magazine 33(1), 27–33 (2014)
22. Pitt, J., Clippinger, H., Sorensen, C.: Values, axial currencies and computational axiology. IEEE Technol. Soc. Mag. p. to appear (2018)
23. Pitt, J., Diaconescu, A.: Structure and governance of communities for the digital society. In: Workshop on Self-Improving System Integration (2015)

24. Pitt, J., Diaconescu, A.: Interactive self-governance and value-sensitive design for self-organising socio-technical systems. In: FAS* Workshop Proceedings: SASOST (2016)
25. Valetto, G., Bucchiarone, A., Geihs, K., Büscher, M., Petersen, K., Nowak, A., Rychwalska, A., Pitt, J.V., Shalhoub, J., Rossi, F., Silingardi, P., Bernardeschi, P.: All together now: Collective intelligence for computer-supported collective action. In: 2015 IEEE International Conference on Self-Adaptive and Self-Organizing Systems Workshops, SASO Workshops 2015, Cambridge, MA, USA, September 21-25, 2015. pp. 13–18 (2015)
26. Vasalou, A., Joinson, A., Bänziger, T., Goldie, P., Pitt, J.: Avatars in social media: balancing accuracy, playfulness and embodied messages. International Journal of Human-Computer Studies 66, 801–811 (2008)
27. Zittrain, J.: The Future of the Internet – And How to Stop It. New Haven, CT: Yale University Press (2008)