A research framework for sustainable software

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Abstract

This paper proposes a conceptual Sustainable Lens as an underlying metaphor for a research agenda in development of a sustainable approach to software development.

Keywords

Sustainability, software, research agenda

Introduction

This paper proposes a conceptual Sustainable Lens as an underlying metaphor for a research agenda in development of a sustainable approach to software development. A set of questions are posed using the *Sustainable Lens* to form a research agenda.

Several authors have noted the piecemeal and limited understandings of sustainability inherent in much of the sustainable computing literature (Hirsch & Anderson, 2010, Aoki *et al.*, 2009, Dourish, 2010, Silberman & Tomlinson 2010). While sustainability is considered in genres including persuasive, technology and ambient awareness, what constitutes sustainable behaviour is fairly general, often with predetermined desired behaviours. In 14 citations of a seminal paper Holmes (2007), almost all are limited in scope to single resource reduction (primarily energy consumption in the home). Frame concludes that this "does not reflect

the reality of sustainability in our highly complex, uncertain, value-laden issues facing a resource constrained world". (Frame & Cavanagh, 2009)

The sustainability journey is described as a "wicked problem" (Morris & Martin, 2009). This means it involves complexity, uncertainty, multiple stakeholders and perspectives, competing values, lack of end points and ambiguous terminology. It means dealing with a mess that is different from the problems for which our current tools and disciplines were designed (indeed it could be argued that they caused it). Wicked problems mean unique decision situations that cannot be easily reversed, for which there are contradictory certitudes, without a clear set of alternative solutions (Rayner, 2006). These persistent and insoluble problems have redistributive implications for entrenched interests.

Mann (2011) uses the following statement as a guide for identifying the role of disciplines in sustainability:

> *As a society we have to learn to live in a complex world of interdependent systems with high uncertainties and multiple legitimate interests. These complex and evolving systems require a new way of thinking about risk, uncertainty, ambiguity and ignorance. These systems require that we can think simultaneously of drivers and impacts of our actions across scales and barriers of space, time, culture, species and disciplinary boundaries (Mann 2011).*

Using this statement as a guide, sustainable computing should not be seen as an extra subject area and should not be confused with 'green', or merely as information systems that happen to be about the about the environment. Instead it provides a context for everything we do. While every software development should be seen as contributing to sustainability, we can also explore the potential for a *Sustainable Lens as a* framing example for development of a research agenda.

Framing the world through a Sustainable Lens

Imagine you had a pair of glasses that had a sustainability mode. This mode meant that you looked at the world through a "sustainable lens". What would you see?

These lenses wouldn't merely be green tinted glasses like the ones from the Emerald City in the Wizard of Oz. Instead, think about the analytical eyes of the Predators (robots) in the Terminator movies. These eyes scan the landscape, identifying threats, analysing options and proposing actions. In late 2010 'Terminator Vision' took a major step towards becoming a reality when DARPA released a request for the development of Soldier Centric Imaging via Computational Cameras (Defense Sciences Office, 2010). SCENICC proposes an augmented reality system for soldiers in war situations. Among other goals, DARPA describes "Automated Threat Detection and Mitigation" and "Multi-Platform Collaborative Imaging" systems that include "imagery (that) may be analyzed automatically in real-time to determine the existence/location of interesting objects (e.g., a person carrying a weapon) within a soldier- centered 1 km sphere of influence and a suitable alarm could then accompany an image of the potential threat".

We do not discuss here the ethics of spending on military hardware, rather the intention is to borrow

from the compelling image of the SCENICC/Terminator Vision and use it to begin to consider a potential *Sustainable Lens*.

A *Sustainable Lens* can be seen at multiple levels: a goal for an actual object (similar to the solder centric SCENICC); a description for wider efforts in sustainable computing; a plea to recognise that all computing needs to be considered as part of a sustainability ethic; or merely as a conception for our personal (biological) heads-up display we see through as we are designing and developing software solutions.

Seeing through the Sustainable Lens – or as Mann and Smith 2008 describe: acting as a sustainable practitioner (Mann & Smith, 2008b) – is not an optional extra or something for a few 'experts' or heroes, it has to be integrated into discipline. The goal is to ensure it becomes a normal part of everyday business, even if 'normal business' is very different for each profession.

Invisible made visible

As we go about our daily lives we are good at avoiding threats - we can see the pothole and drive around it. We are good at recognising impacts and taking action - we can see when our child has cut her knee and offer care and sympathy. We can also see the relationship between our actions and the consequences - when I push on a pile of blocks I can see them tumble to the floor. We're not so good when the threats are hidden (such as poison in a stream). We're not good when the action and consequences are separated by time or space, or when the effects are cumulative or bedevilled by a myriad of complicating factors. Such factors are inherent in sustainability - we cannot easily see the impact of our actions on generations to come, or how our situation is affected by decisions made on the other side of the world, or how seemingly innocuous behaviours multiplied across society result in possibly irreparable damage to our connected socio-ecosystems.

Our way of seeing the world frames our behaviour, as does the context of our skills, knowledge and occupation. No matter what our discipline, we need everyone to act in a sustainable manner. So what could a *Sustainable Lens* contribute to anyones' discipline? to their understandings? to the behaviours expected of being a sustainable practitioner in any specific discipline? The answers lie beyond the almost trivial, the things that every worker should do (recycling office paper, walking up stairs etc), but with harder questions about the nature of the trade or profession. Mann and Ellwood (2009) describe the role of the sustainable practitioner and describes the daily decisions faced by a hypothetical forestry worker to explore sustainable practice (Mann (2011) expands the metaphor to even more complex decisions (by expansion to the commons) and argues that equivalent scenarios can be found in every discipline – giving examples of application in other discipline areas: computing and construction.

Mann and Smith (2011) describe some initial requirements for a *Sustainable Lens*:

- See opportunities for sustainable practice skills
- Recognition of unseen elements
- Identify un/sustainabilityness of actions – that is recognise if something is unsustainable, or distinguish degrees of sustainability
- Present options and ways of framing alternatives

In applying the forestry worker example to construction, Mann and Smith (2011) explore the relationship between sustainability and safety – whereby workers are required to intervene if someone is potentially a threat to themselves or others. The wobbly ladder poses an immediate peril, sustainability may have an equal threat – but only if seen through a lens of different spatial and temporal scales.

Resource visualisation is a useful start

A necessary component of the *Sustainable Lens* is resource visualisation (eg Holmes, 2007, Pierce, Odom, & Blevis, 2008 etc). These though are just the beginning. It is our contention that much of this work falls short of adequately recognising the complexity of sustainability – in oversimplifying the issues and the responses. Acting sustainably is not a (relatively) simple matter of changing ones driving habits or reducing home electricity consumption.

Purpura *et al.* (2011) propose a provocative 'Fit4Life' as persuasive technology in promoting healthy behaviour. The novel twist in their paper is that Fit4life is a fictitious strawman designed to explore ethical and sociocultural aspects of persuasive computing. In a similar vein, we propose a smoking laptop (Figure 1).

A laptop computer takes power to run and its manufacture resulted in considerable carbon emissions. These embodied emissions can be elucidated with a life cycle assessment giving between 5247 to 7826 MJ (a desktop machine is 25% higher), over an average laptop life span average 3-5 years gives 3500MJ per year day (Deng, Williams, & Babbitt, 2009). Despite being concerned about carbon footprints, however, this information means little to us. Converted to coal equivalent, this gives about 400grams of coal per day. If we could see this smoke, if our computers were dirty and emitted smoke, would we perceive them differently? Would we be more vigilant about turning it off when not in use? Would we use it less? Would we value it more? Hopefully we might reconsider decisions about upgrade cycles and try to extend its functional life. We might seek a laptop designed for upgradeability rather than planned obsolesce. We might even investigate a different model of computing ownership. Unfortunately, the simple visualisation does little to promote these activities. We really need our *Sustainable Lens* to have a context of action (Petzel, Archer & Fei 2009, Dourish, 2010) and ongoing transformation (Woodruff, Hasbrouck, & Augustin, 2008).

Figure 1: smoking laptop as a hypothetical resource visualisation.

A further limitation of such visualisations is an inability to represent the complexity of sustainability. Bonanni's *et al.*'s (2010) work on open source supply chain mapping gives an example of the sources of the components of a typical laptop. Their approach takes life-cycle analysis in a different direction - instead of focussing on energy independent of geography, they examine transparency of the supply chain with disclosure of materials and processes and where they occur. Imagery of a smoking laptop provided a direct visualisation of one component of sustainability. While energy/smoke is admittedly useful as an integrator, it does not provide a visualisation the complexity of sustainability.

While the *Sustainable Lens* must include ecovisualisation, this must be only the start of our efforts.

Questions for a new agenda

In the remainder of this paper we present a discussion on the scope and nature of the Sustainable Lens. To begin to form a research agenda we pose questions that we believe will be fruitful in generating answers and structures useful for positioning sustainability as a basis for software development. To aid the reader in exploring these questions, appropriate references are given. The questions come after the each discussion.

Sustainability requires a systems approach. People need to have awareness that their actions will have impacts. These impacts may be intended and unintended, across scales: temporal, spatial, social, and have positive and negative effects. They need to understand forms of relationships (hierarchies, partnerships, feedback) and that humans form part of a complex web. Systemic thinking emphasizes patterns, trends and feedback loops.

Scale is a recurring theme in sustainability – multiple scales of time and space nest around local contexts. A goal is to make the future seem more real, recouple costs of mitigation borne by current generation and benefit of avoided harm accruing to future generations (Sheppard *et al.* 2011).

Scale is more complex than ability to zoom on a map. Antunes *et al.* (2010), for example, uses time and place differences to define collaborative awareness as perception of temporal and spatial structures in group of peers. They define types of space – geographic (Cartesian and topological), physical (focus on mobility), virtual (conceptual topology), social space, and workspace – activities organized according to logical sets. Fisher and Dourish (2004) described the social patterns of contact that emerge – between people. Changes over time are considered the rhythms and trajectories of collaboration.

We argue that these ideas could be expanded to include collaboration with future generations (and then extended future for collaboration across scales for space and species).

- *How can our Sustainable Lens be able to operate on multiple scales of space and time simultaneously?*
- *How can we develop systems explicitly account for both our ancestors and future generations?*

There is a considerable literature in the sustainability arena on behaviour change. Most of this has progressed beyond persuasion through argumentation

(Nguyen & Masthoff, 2008). It is our argument that a *Sustainable Lens* that relies primarily on providing confrontational information would falter, instead motivational interviewing seems more promising (Miller & Rollnick, 2002).

- *How can a collaborative approach based on motivational interviewing be used to overcome barriers in behaviour change?*

Different people have different perceptions and understandings of sustainability. Such differences have to date been poorly accommodated in sustainable computing (DiSalvo, Sengers, & Brynjarsdóttir, 2010, (Dourish, 2010).

- *To what extent will solutions need to be tailored to individual situations?*
- *How can we to communicate across these divides of understanding form an opportunity for collaboration?*

Willard (2005) describes stages of organisational sustainability maturity. Woodruff describes ongoing trajectories of sustainability trajectories rather than a simple discrete and bounded action (Woodruff, *et al.*, 2008). Piirinen *et al.* (2009) describe this as managing the coevolution of problem – it applies here in both interpretation and artefact.

- *How can support for the sustainable practitioner adapt to changing understandings?*

The Collaboration Engineering field (Kolfschoten & de Vreede, 2007) looks for patterns in collaborations (e.g. Thinklets (Kolfschoten, Briggs, & Appelman, 2004)). It would be worthwhile to attempt to describe sustainability in terms of patterns. Care would have to be taken not to oversimplify and to always allow for different paths (see Mann and Smith's 2008a discussion on biomimicry).

- *How might we begin to describe sustainability in terms of patterns?*

The ecological and sustainability literature makes little distinction between human and bio-physical systems. Human and ecological systems are being viewed as being tightly and inextricably linked (Alessa, Kliskey, & Brown, 2008) in fields such as Human ecology (Steiner, 2008) and concepts such as The Human Ecosystem (Naveh & Lieberman, 1994). In a short, simple statement: humans are a part of nature.

The "new business as usual" needs commitment across the board. This means we expect sustainable behaviour from everyone because everyone has both a vested interest in a sustainable future, and is entirely complicit in the need for sustainability. Bonanni's *et al.*'s (2010) work on supply chains highlights the nature of the connectedness of the collaboration. Our collaborative lives affect and are affected by what happens on the other side of the world.

- *How can Sustainable Lens provide engaging, accessible and understandable interactions? (Sheppard, et al. 2011)*

How can *Sustainable Lens* provide inspirational and motivational communication of things that are salient-things people can identify with and care about?

- *What would be the consequence of considering an basis of interaction that is a collaboration with the environment (rather than on, or about the environment)?*

- *How can Sustainable Lens position human as actors rather than stressors? (Dearing, 2007)*
- *How can Sustainable Lens combine human and biophysical information into a single coherent narrative? (Alessa, et al., 2008 describes coupled social-ecological space with social-ecological hotspots where multiple and diverse values are co-located with a biophysical resource).*
- *How can Sustainable Lens allow people to ''drill down'' past the charisma (of the surface) and access the back stories – the researchers, management? (Alexander et al., 2008)*
- *How can Sustainable Lens represent uncertainty? (Rounsevell et al., 2006)*

Dix *et al.* (2010) describe appropriate intelligence as "doing good things when it works and not do bad things when it does not". It should not, Dix argues, interrupt. This is a challenge for the Sustainable Lens - many of the activities we carry out need this very interruption.

- *How can Sustainable Lens support situational awareness – directing attention, integrating elements to understand meaning of critical elements, and considering understanding of possible future scenarios? (Endsley, Bolté, & Jones, 2003)*

The amount of support and depth of engagement to support sustainable practice is an interesting question for future research. There is a clear trade off with complexity of models and engagement with degree of participation. These will vary for different sustainability scenarios (Robinson *et al.* 2011, Mann & Brown, 2000)).

- *What is the nature of the complexity of models and engagement with degree of participation?*

Participation is fundamental in sustainability (Arnstein's ladder of participation, 1969). This can be seen in participatory modelling (Mann, 1996) participatory multi-scale scenario approaches (Shaw *et al.*, 2009), public participation GIS (Elwood, 2009, Sheppard, *et al.* 2011) community engagement with climate change. Such collaboration lifts sustainability above a "thou shall not…" perspective but to one of equal partners examining options for the future (described by Frame and O'Connor (2011) as "post normative articulating situations of social choice.

The Sustainable Lens will need to combine and visualise data from multiple sources across multiple scales of space and time. This is not new but the tools required are not simple and rarely applied in participatory or real-time situations (Prince, Becker-Reshef, & Rishmawi, 2009, Mann & Benwell, 1996, Wieland, Voss, Holtmann, Mirschel, & Ajibefun, 2006).

Robinson *et al.* (2011) describe participatory backcasting that

- Allows stakeholders to express views (assumptions are made transparent)
- Has intensively participatory nature of scenario building
- Scenarios – day in life of future citizen
- With transition to a desirable sustainable future

The success of this work can be seen to be a result of the integration of participation and visualisation through collaboration for sustainability (see also collaborative planning process for British Columbia's Bowen Island (Salter *et al.* 2009); GIS modelling of ecosystem services using qualitative storylines to model Tanzania landscape change (Swetnam *et al.*); urban impacts (Xing *et al.* 2009); participatory assessments (Siebenhüner & Barth, 2005).

Perhaps the important work in developing a Sustainable Lens will be an integration of underlying frameworks. A useful framework is that used to describe challenges in collaborative design (Piirainen *et al*, 2009). This is based on the concept of "actors who design". Coming from the sustainability angle Petzel *et al.* (2009) describes the integration of the Framework for Strategic Sustainable Development (FSSD) that leads participants through a process of understanding, defining success, guidelines to relate success to actions, evaluating actions against strategic guidelines, and considering tools to support these actions. Other potentially useful approaches are the transtheorectical model of behaviour change (He, Greenberg, & Huang, 2010) and the action competence cycle (Jensen & Schnack, 1997; Wals & Jickling, 2002). Extending the social ontology methods (Edum-Fotwe & Price, 2009; Hervás & Bravo, 2011) with mapping by sustainability dimensions, development lifecycle and spatial scales might be a useful approach.

A collaborative system would benefit from an open modelling approach (Rahman *et al.* 2004) including model reuse, extensibility and flexibility. Modelling environments should allow rapid creation of environmental models from components (Argent, 2005), with transparency of models to of users being able to probe sensitivity.

- *How can Sustainable Lens encourage and actively support sharing solutions and understandings? (Schümmer et al. 2010; Senge et al. 2007; Chun et al. 2006).*
- *How can we integrate and visualise data from multiple sources across multiple scales of space and time? What are the implications of doing this in real time and in participatory situations?*
- *To what extent should we expose the models used? (Shim & Fishwick, 2008)*
- *What are the requirements for a code of ethics for such visualisations? (Sheppard, 2001)*
- *How can we make use of existing frameworks related sustainability fields: environmental management; decision making; behaviour change? (and so on).*
- *Do emerging models such as social ontology provide a basis for ongoing development?*
- *How can open modelling frameworks encourage an effective and efficient structure for collaborative sharing, reusing and critiquing of elements in a Sustainable Lens worldview?*

A usual assumption of computing development is that problems can be clearly specified. In *The Virtues of Ignorance* Vitek and Jackson (2008) (with many contributors from a research camp) argue that a "knowledge-based worldview is both flawed and dangerous…Since we're billions of times more ignorant than knowledgeable, why not go with our long suit and have an ignorance-based worldview?"

The upshot of this premise is a whole different way of looking at the world: "What would human cultures look like, and how might we interact differently in the world, if we began every endeavour and conversation with the humbling assumption that human understanding is limited by an ignorance that no amount of additional information can mitigate?".

Sustainability is by definition inherently ambiguous. It requires judgement of impacts across generations, species and continents – there are no rules for this, only guidance and values. It is not possible to define sustainable versus unsustainable, indeed Onwueme & Borsari (2007) define perfect sustainability as being unachievable. Unfortunately this uncertainty is usually seen as a basis for "obfuscation or a displacement activity guaranteed to ensure that transformative action is deferred" (Springett & Kearins, 2005). Wals and Jickling (2002), on the other hand, argued that "the very vagueness has "enormous canvassing and heuristic capacity if it is systematically and systemically used as a starting point or operational device to exchange views and ideas".

Even on occasions in which there is no significant scientific uncertainty over physical effects "there may typically be strong ambiguities over the choice of indicators, the framing of metrics, the setting of satisfactory levels of protection, and the relative weighting to place on different forms of harm" . (Smith & Stirling, 2010). Rather than seeing differing understandings as a barrier, (Scoones *et al.*, 2007) argues this should be seen a strength as "various participants in the transition arena will carry their own mental model of the socio-technical system, its key components, major processes of development, their own positioning, and favoured strategies for sustainable transformations, whether proactive or resistant. Actors are situated in diverse contexts, bring contrasting knowledge or experience, and hold contending interests and purposes. Different groups will bring disparate framings of the system, both in terms of its structure and its function" (Scoones, *et al.*, 2007).

- *How can Sustainable Lens support situations where there is no single right answer?*
- *How can Sustainable Lens use make use of multiple understandings to improve understanding?*

Redström argues that technology is inherently persuasive which in turn is inherently of ethical concern (2006). It is clear the *Sustainable Lens* cannot be operate without reflection on values and principles – and this must have a collaborative basis. Any discourse about sustainability is essentially an ethical discourse (Bosselmann, 2008). AtKisson (2008) argues that systems thinking involves much more than understanding simple physical chains of cause and effect. One must also understand the decisions that are taken either to change those causes or to respond to their effects.

- *Should we move to a position where we accept that all technology development is inherently a value proposition?*

Conclusion

This paper has proposed a *Sustainable Lens* as a basis for a research agenda to organise efforts into sustainability in computing.

These research questions can all be applied to a *Sustainable Lens* at multiple levels: a goal for an actual

object (similar to the solder centric SCENICC); a description for wider efforts in sustainable computing; a plea to recognise that all computing needs to be considered as part of a sustainability ethic; or as a conception for an integral heads-up display. For all of these, the imperative is clear and deep-seated- we hope this research agenda provides a way forward. This is a significant step beyond the conservative incremental approaches (Collado-Ruiz & Ostad-Ahmad-Ghorabi, 2010) described by much of the computing literature in the sustainability area.

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