A Strategy for Limits-aware Computing

Jay Chen
New York University
Abu Dhabi, UAE
jchen@cs.nyu.edu

ABSTRACT

Research on computing within limits explores the design of computing technologies that will be appropriate for a future where availability of resources is drastically reduced. In an effort to define the scope and goals of limits-aware computing, early papers discussed how such a future may come about, what challenges this future may present, and the kinds of technologies we should design given these scenarios. In this paper, we posit that these future challenges already exist today in their incipient forms. We propose that limits-aware computing research should focus on these problems to make a difference today while preparing for further future collapse.

CCS Concepts

•Human-centered computing → Human computer interaction (HCI); •Computer systems organization → Dependable and fault-tolerant systems and networks;

Keywords

Limits; Collapse; Crisis Response; ICTD; Sustainability

1. INTRODUCTION

In this paper we use the term "limits" to mean limits to economic growth caused by fundamental planetary resource or ecological constraints as first coined by Meadows et al. in "The Limits to Growth" [29] and updated in later publications [30, 28, 51]. The concerns of limits are succinctly described by Silberman [48] to include:

[The] depletion of nonrenewable resources, especially fossil fuels; climate change, ocean acidification, desertification, sea level rise, increased frequencies and severities of floods and droughts, and freshwater and food scarcity; pollution; and degradation of ecosystems and biodiversity loss. However, these resource and ecological limits are not "hard", but rather seen as undesirable consequences of growth. [...] The main exception is the depletion of nonrenewable resources, especially fossil fuels, which directly power the economy.

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At the inaugural LIMITS workshop several papers argued for an urgent shift in computing research toward limits futures [48, 38, 45, 21]. Other works considered what limits-aware computing research would entail, such as: specific computing needs, the properties computing technology should have, and rough sketches of such technologies [12, 43, 52]. However, one of the biggest immediate challenges facing limits research is that it is hard to design for a context that does not yet exist. Silberman [48] describes this problem as follows:

Effective trans-scalar responses to global change will require that the global networked information-industrial society become a fundamentally different society and one cannot fully map the road from here to there from here, as if from above; rather, the process is one of "navigation", in which we discover the road as we walk it: "any successful quest for sustainability will be a collective, uncertain and adaptive endeavor in which society's discovering of where it wants to go is intertwined with how it might try to get there [20]."

In other words, if a system were to be designed beforehand, it would likely be inappropriate given the inevitably different social, political, economic, and technological landscape. Also, the limits scenarios we expect may not occur in the time frame or in the manner that we expect. In these cases, our preemptive efforts and increasingly precious resources would be wasted.

This observation appears to directly oppose the planning of any long-term strategy for limits research. However, we absolutely must make progress despite the difficulties designing for uncertain futures. Silberman [48] concludes that:

The solution is to support other limits-aware activities – especially those that seek to transform existing social arrangements. This answer is simple and actionable: we should help other people trying to respond effectively to global change. Specifically, "community" organizations, including non-profits, small businesses, and local government and initiatives that aim to support increasing social capital and the growth of local economies.

We make a slightly different argument to resolve this paradox. We argue that we should contribute to the facets of limits-aware research that already exist: crisis response, development, and sustainability.

To motivate actionable research for limits-aware computing, previous works drew parallels between development (and crisis) contexts and future limits scenarios in terms of the infrastructural, social, or technical challenges [12, 45]. Thus, these contexts were thought to provide a useful basis for imagining limits futures. Tomlinson et al. [56] linked collapse informatics with development, quoting:

"The view that global crisis will occur in the future reflects a parochial, developed-world perspective. For two-thirds of the world's population, crisis of scarce resources, inadequate housing, deplorable conditions of health, and starvation are already at hand" [27].

Here, we build upon this idea and posit that rather than thinking of these contexts as being *like* limits scenarios, we should consider these contexts to *be* limits scenarios and within the immediate scope of our research. Thus, crisis, development, and sustainability problems are not only useful contexts for limits-aware technology design, but instead provide tangible problems for, respectively, responding to collapse, resisting collapse, and preventing future collapse.

2. REDEFINING COLLAPSE

One probable model of collapse is a gradual failure [53, 15]. As we run out of cheap natural resources and climate change intensifies, economic pressures and environmental shocks will affect vulnerable populations. This future will consist of diminished socioeconomic well-being and decaying infrastructure punctuated by increasingly frequent humanitarian crisis as our current (and future) efforts to maintain growth result in increasingly extreme pressures. When these inevitable humanitarian or economic crisis occur, the affected 'community' will suffer and people will die, survive, or migrate [17].[1][2]

Of the possible post-crisis outcomes, if people die there is a net loss of life, economic well-being, and consumption. If people survive, a community's well-being is reduced until a 'lower' level of function (or dysfunction) is reached.[3] If people are forced to migrate they will add stress to the destination community [17]. As these stresses aggregate and overwhelm a community's capacities they will collapse and spill over to other communities.[4] Unless we drastically alter our course, the frequency and scale of these stresses will increase worldwide due to hysteretic ecological and resource pressures. This process will continue until our global community reaches new equilibria.

Thus far, we have generally assumed that we need to know more precisely about the future contexts in order to properly design a solution to those problems. However, given this failure model, collapse is not a large singular looming disaster, but instead a continuous stream of failures at smaller scales that cause ripple effects to adjacent communities. If we think of collapse in this way, then crisis events are no longer signs of imminent collapse, but rather collapse events themselves. The collapse 'future' is already here. From this perspective, crisis response is a reaction to collapse, development is a reinforcement against collapse, and sustainability is an attempt to prevent future collapse.

3. FACETS OF COLLAPSE

3.1 Crisis Response

Climate change has been identified as the cause of unusual droughts, flooding, and other extreme weather conditions [50, 28]. These events lead to famines, loss of economic well-being, mass migration, and other large scale humanitarian crisis [17]. As we approach global ecological limits, these crisis are expected to continue with increasing frequency, and severity [28]. A recent report by the US Global Change Research Program discusses how these crisis events are likely to continue with long-term impacts on public health [42].

After being struck by a disaster, individuals will try their best to cope with the resources and measures they may have prepared. At any point in the fight for survival organizations may be able to reach people who need help and save their lives or provide relief. Maitland et al. [25] summarize:

When disaster strikes the response occurs in what is generally seen as 4 stages: 1. emergency or rescue, 2. relief, 3. recovery and 4. reconstruction or development. During the first stage action is taken by local organizations whereas the second stage, relief, may be carried out by hundreds of organizations from both near and far. During this second stage the primary goal is to see to the short-term needs of survivors, including health care, food, shelter and clothing. The organizations involved in relief are diverse and consist of governmental (including military), inter-governmental (IGO) and non-governmental organizations (NGO).

Unfortunately, the operational goals of these entities are generally separated, particularly the stages of relief and development (as are their respective communities). Crisis efforts are focused on performing triage and are often not mandated, funded, or equipped to offer long-term aid. Eventually, the task of reconstruction or development must be transferred to another organization (or division within the same large organization).

The role of ICTs as the "central nervous system" [22] for coordinating relief efforts has been extensively studied and found to be highly beneficial [24]. Messaging through networking technology can be useful in identifying individuals who need assistance [16] or for large scale informatics [49, 7, 34]. Also within computing, climate modeling is a field in and of itself, but is focused primarily on modeling with only secondary effects that affect change through policy and awareness. Some models and climate data have been applied to famine and other early warning systems [3], but unfortunately these warnings are often ignored by policy makers, donors, and governments themselves.

There are many other interesting challenges within crisis response that have not been deeply examined from a computing perspective including rapid deployment of infrastructures, crisis coordination, and logistics problems. Specific to limits, it could be interesting to consider crisis response technologies that are easily deployable, self-sustainable, extensible, and compatible with existing infrastructure.

3.2 Development

Information Communication Technology for Development (ICTD) attempts to confront some of the extant socio-economic inequities in developing regions through the design and deployment of Information Communication Technologies (ICTs). The domain that ICTD researchers concern themselves with is defined by the socio-economic condition of poverty, which generally corresponds to some combination of low infrastructure, meager education, deficient healthcare, unreliable food supply, weak or corrupt government, etc.

Regarding technology solutions in ICTD, Chen [12] summarizes:

[1]Here, we use the term 'community' to denote a group of people of arbitrary scale, e.g. an individual, a village, a city, or entire countries. This definition of community and its relationship with other communities within greater communities is meant to be thought of as fractal.

[2]Norris et al.'s comprehensive theory of "community resilience" provides a useful model of crisis response [33].

[3]Though higher equilibria may be achieved through increased productivity, this will be less likely in a limits future.

[4]It is possible that communities employ isolationist policies, which would leave others to carry the load.

Computing research in ICTD typically emphasizes the design of technologies that are low cost [41, 23, 6, 36, 18], require little infrastructure [11, 46], and are usable by people who have less formal education or experience with technology [31, 13, 14].

These technology features along with the concerns of ICTD are all generally in line with a limits future. The specific technology requirements for a limits future may be uncertain, but the constraints are generally understood to be low cost, low infrastructure, self-sustaining, and scalable technologies. Of these requirements, self-sustainability and scalability are two areas where ICTD could benefit from limits-aware ideas. Other major challenges in ICTD are adoption and lack of interoperability with mainstream technologies.

In the case of networking, delay tolerant networking (DTN) has a wide body of literature [10], but very little actual adoption other than of a few concepts behind DTN because there is no convenient road to adoption and interoperability.[5] Similarly, rural wireless networks are difficult to deploy and require a wide range of expertise to sustain. The recent commoditization of wireless hardware [5] and availability of simple planning tools [4] help facilitate rural network deployments, but there are still problems to solve before these systems can be easily scaled out.

In the case of human-computer interaction (HCI) in ICTD, technology interventions are thoughtfully considered, but they are few and rarely scalable. Interactive voice response (IVR) systems appear to be one of the more promising platforms for solving real ICTD problems [57]. However, it remains to be seen whether this kind of technology will be widespread.

Many specific challenges exist in ICTD independent of limits concerns, but the deployment and maintenance of infrastructures for food, water, transportation, health, education, governance, and the Internet are all in common with limits priorities.

3.3 Sustainability

Sustainable development was defined by the UN as " meeting the needs of the present without compromising the ability of future generations to meet their own needs" [9]. Penzenstadler et al. [40], drawing from Tainter and others, summarize the concerns of sustainability research:

Ultimately, sustainability depends on the public at large, so common conceptions of sustainability must be acknowledged. People sustain what they value, which can only derive from what they know [54].

Blevis et al. considers how to incorporate sustainability concerns into design research [8]. Penzenstadler et al. [37] (again, referring to Tainter) suggest that it is useful to pose the four questions with regard to sustainability:

1. *Sustain what?*
2. *For whom?*
3. *How long?*
4. *At what cost?*

To help think about the kinds of technologies that could be useful in the future, Penzenstadler et al. present a set of imagined future scenarios of what sustainable systems could look like in 15 years [40]. These scenarios and systems serve as inspiration for imagining the kinds of considerations we could expect.

In relation to the sustainability of ICT systems, much of the initial research has focused on measuring first-order (energy use, e-waste production, emissions, etc.) effects. Malmodin et al. among many others consider the life-cycle cost of ICTs [26]. Hilty et al. consider how to model the sustainability of technologies as they are introduced [19]. Naturally, second and third order effects (e.g. changes in user behavior and broader societal changes) are more challenging to measure and remain open problems [37].

To help motivate future directions for sustainable HCI, Silberman et al. point out that most of the substantial past contributions to sustainability research (e.g. smart cities, green computing, and waste management) have not been from HCI [47]. Pargman and Raghavan are also critical of the recent boom in sustainable computing and sustainable HCI research for ignoring seminal writings from the past several decades, and defining sustainability so broadly that it has become meaningless [35].

Perhaps as a response to these critiques, several creative ideas have recently emerged. Tomlinson et al. explore a novel design of self-obviating systems for sustainability [55]. Raghavan et al. consider how computation can assist in sustainable agriculture [44]. While Silberman argues that, we should "focus on the social and ecological benefits, risks, and consequences of real sociotechnical-ecological practices, not on novel technologies per se." [48], these proposals are particularly noteworthy for capturing both attributes.

4. BENEFITS

There are several benefits to considering collapse as the union of the existing fields of crisis response, ICTD, and sustainability.

4.1 Solving Real Problems

It is obvious that in the process of working on crisis and development problems we will be solving actual problems that affect people today. This is an actionable strategy for making progress while preparing for an unknown future.

In the event that limits futures do not occur as we expect, we will still have had a positive impact on people's lives. These fields could all use our help, particularly crisis response, which has relatively few contributions from computing beyond networking (cellular/wireless networks) [2] and climate modeling (early warning systems) [3].

By working with these efforts today to design, test, and deploy useful technologies we can learn quickly what works and what does not in real contexts. If a design fails we can learn quickly from our mistakes and iteratively refine our ideas.

4.2 Achieving Incremental Adoption

As with any new technology, adoption takes time, effort, and motivation. The problem when we design technology without immediately appreciable or foreseeable benefits is that convincing people to use that technology is hard. People generally do not change their behaviors without a compelling reason, rational or otherwise.

Three additional reasons compound the adoption challenge for limits-aware computing. First, limits scenarios are approaching much more slowly than the decision making horizon of the general public. While climate change denial is waning, the disconnect between our individual actions and their delayed consequences is fundamentally difficult for people to intuit. Second, there are also likely to be design and engineering tradeoffs that make limits-aware technologies less performant in today's environments [12]. Third,

[5] Here, it is interesting to note that this body of research has moved forward *despite* adoption, and thus while the initial ideas were very useful, it is unclear how much of the recent DTN research will be relevant to ICTD.

there are inherent structural barriers to changing the status quo [21].

By supporting contexts that actually require the technologies we are designing, we can both navigate our way forward and incrementally scale out the adoption of limits-aware technology. Compared to ambitious infrastructure re-designs, there is a higher likelihood that this approach will work and a lower risk of overcommitting to large scale projects that will not.

4.3 Leveraging Existing Communities

At the research level we need a community that understands and values the contributions we make. We should work with these adjacent fields (crisis response, crisis informatics, ICTD, and sustainable computing), arbitrage valuable ideas, and steer these areas toward limits-awareness. We may even need to go a step further and suffuse throughout computing research, i.e. "the topic of sustainability *should* be central to HCI (both research and practice), computing in general, and most other applied academic disciplines" [35].

In terms of technical knowledge and understanding, these fields have had significant experience working within constraints (low cost, low infrastructure, usability challenges) that can be useful to learn and borrow ideas from. Furthermore, each area is already highly interdisciplinary and thus non-technical knowledge with respect to HCI and intervention design can also be reused.

Finally, by leveraging existing research fields and, if necessary, re-framing problems for limits-awareness we can spend our time more productively than attempting to establish an entirely new research area.

4.4 Identifying New Problems

Beyond the shared types of challenges found in these fields (e.g. low resources and other constraints), these areas are actually highly overlapping and entangled to the point where it is often unclear where one ends and another begins. For example, after a crisis response effort provides a temporary supply of water, food, and shelter some levels of self-sufficiency, quality of life, and resilience against relapse must also be established (i.e. development). Another rarely discussed overlap, is the inherent tension between development and sustainability (cf. Section 5.1).

As is the case for most interdisciplinary fields, from the more holistic vantage point of limits-awareness, we may be uniquely positioned to identify and contribute to boundary problems at the intersection of these fields. For example, rapidly deployable infrastructure solutions are being actively pursued [2]. However, from our perspective, such technologies should be designed to be able to be built upon rather than replaced as conditions stabilize. It would be interesting to explore how to reuse these ad-hoc systems, designing such systems to be compatible with more permanent infrastructures, or designing for a transition toward development.

5. CHALLENGES

There are clearly challenges technical and otherwise in each of the aforementioned fields. Here, we briefly outline the challenges to being an interdisciplinary field across interdisciplinary fields. Some of these challenges are essentially the inverse of the previous benefits.

5.1 Unifying Goals

From the view of collapse described, we need to articulate our goals and determine the best path toward our desired future. There are many possible deeper moral and ethical discussions that can be had, but are beyond the scope of this paper [32]. As articulated earlier by Penzenstadler, answering the four questions of "sustain what", "for whom", "how long", and "at what cost" is a good starting point for our community. Pargman and Raghavan offer a valuable foundation for defining *sustainability* for computing research (and limits) and outline a possible set of goals [35]. Here, we assume that there should be some balance between two basic goals: 1) avoid collapse (sustainability) and 2) maximize quality of life (development). Where (1) can be understood as the same goal as Pargman and Raghavan, but (2) considers more than simply surviving, but also how we live.[6]

From these broad goals, many different technologies can assist in the implementation of these goals. As discussed in previous works, most of the change is not necessarily technological, but rather a change in values and focus shifting away from consumption, profit, and waste. For real change to happen, these changes must simultaneously occur in the general public, in our leaders, and in ourselves.

5.2 Avoiding Fragmentation

While the strategy presented in this paper provides a pathway to incrementally scale out limits-aware technologies, we must also avoid fragmentation of technologies and ensure generalizability and interoperability. As we gradually replace infrastructures in pockets of the world, we should consider whether there are critical issues with our designs at scale. Perhaps, as in networking, common protocols can be designed to ensure cooperation and coordination between the various systems and infrastructures.

An analogous challenge of avoiding fragmentation occurs at the research community level. While being interdisciplinary offers the benefit of borrowing from each constituent field, maintaining cohesion and communicating ideas across disciplinary bounds requires substantial effort. This workshop and others [39] are a good start, but we will have to continue to exchange ideas. To avoid fragmentation within our community, we should solidify our research field while engaging with other communities. Perhaps someday when the ideas within limits become so obvious as to be core values within all academic fields of study, we may become self-obviating and disband.

5.3 Enabling Transition

As identified in previous works, desirable properties of limits systems are: resilience, fractal, etc. [12, 43]. Since a wholesale replacement of our existing infrastructure is unlikely, we should focus on designing incrementally deployable systems that allow a migration path toward an ideal state. Networking and systems researchers should be well-positioned to tackle this kind of problem. However, such a deployment must not only be technically feasible, but also make sense for all stakeholders, which is an area where HCI can substantially contribute.

There are known research challenges in crisis, development, and sustainability. From the limits perspective, however, these fields rarely consider the boundaries and transitions between each other: crisis response computing is not meant to be a permanent solution, development may not be sustainable, and sustainability may be too focused on preserving developed-world norms of the present. Transitioning between crisis response and development has been observed to be a very challenging socio-technical and organizational problem [25]. Our efforts will be especially valuable when directed at these kinds of transition problems.

[6]Pargman and Raghavan do suggest that development may be the eventual focus after we have achieved an ecologically sustainable society. However, aggressively achieving sustainability while ignoring quality of life consequences seems impractical (and potentially unethical).

5.4 Shifting Perspectives

Because of their nature, each interdisciplinary field within collapse already has their own complex mixture of perspectives. For example, ICTD is mired with ideas about politics, international aid, public awareness, and the media. This difficulty will be even greater when these separate fields are combined. Gaining acceptance for limits problems within each of these research communities is another major challenge [21].

There is also the problem of convincing the public that limits is important. This will likely be solved not through technical means, but through advocacy and a gradual shift in social consciousness. Efforts to address the problems of climate change, peak oil, and other limits-related scenarios will only mount in proportion to the problems they cause. The Paris climate talks [1] and climate change as a campaign issue in the 2016 US presidential primaries are some hopeful signs that these problems are beginning to be taken more seriously.

If our society does dramatically shift toward a limits-aware direction then our job will be made easier in that the systems we design will face fewer adoption challenges. Consequently, additional resources will be devoted to limits-aware research and we may then have the luxury of focusing only on the technical problems. It is, however, still possible that superficial 'guilt assuagement' technologies will become the norm; this is another pitfall we must avoid [21].

6. CONCLUSION

In this paper, we redefined collapse as a continuous fractal process rather than a singular critical tipping point. Unlike the previous notion of catabolic collapse, we explicitly consider the facets of collapse to be crisis, development, and sustainability. Through this wide framing, we can take immediately actionable steps toward design, development, and deployment of computing solutions to the problem of collapse. By working with these communities we can solve real problems, share our experiences, and discover new problems. Most importantly, we will have a clear adoption strategy towards a limits-aware future.

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