Advancing Non-Linear Design Thinking

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ABSTRACT

In prior non-archival work, Blevis and Blevis, 2022 [5] cite a notion from marketing research about linear and non-linear thinking. In the marketing research, we learn that people oftentimes expect linear relationships when non-linear relationships hold. These expectations can lead to poor business decisions. These same principles apply to interaction design and supply the theoretical underpinning for a framework we call non-linear design thinking. Non-linear design thinking is a method for re-framing design problems and spaces in a manner that avoids the errors in thinking that arise from assuming that relationships between design factors are linear when they are not. Our contribution is a framework for thinking about non-linear relationships in design and how to design taking these into account, illustrated with examples.

This paper is a full-length extended version of the shorter non-archival article [5] with added authors, examples, background, and details. About 40 percent of the material is new.

CCS CONCEPTS

• **Human-centered computing → Interaction design theory, concepts and paradigms**;

KEYWORDS

Non-Linear Design Thinking, Design Thinking, Design Theory, Sustainability, AI

Figure 1: Carried Away, 2022

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1 INTRODUCTION AND CONTRIBUTIONS

Things are not always as expected. In our teaser image of Figure 1, a young woman appears to be carried skyward by her umbrella. This is an illusion. She has in fact jumped in the air and has been photographed just at the right moment to give the impression of being carried away. This is a familiar photographic technique (e.g., Baldessari's [1] 1973 photograph titled *Throwing Three Balls in the Air to Get a Straight Line: Best of Thirty-Six Attempts*). Aside from tempting the reader's attention–that is after all the point of a teaser image–the image is connected to the substance of this paper because this paper concerns thinking about design differently. It concerns challenging assumptions and noticing how things can *appear* to be one way and yet actually be another. It concerns looking for other possible design strategies, beyond the obvious. In this paper, we develop and illustrate one strategy for thinking differently about design, namely *non-linear design thinking*. We define it at length below.

The contributions of this work are:

- A framework for thinking about non-linear relationships in design and how to design taking these into account, illustrated with examples;
- A full length version of a successful, but limited length non-archival article with additional authors and insights;
- In addition to the *non-linear design thinking framework* itself present in Table 5, we present simple accounts of three examples of the framework in action, namely *climate care actions and awareness* (Table 6), *energy aware settings and personal choice* (Table 7), and *climate care and SHCI* (Table 8). These first three accounts are thought experiments created in order to work through the framework in the first place;
- As a matter of method, we invited new co-authors to this work and asked them to apply the framework in contexts within their own design expertise to see how easily others can apply the framework. This leads to two contributed accounts related to sustainability, namely *migration choices and climate change* (Table 9), and *fishing and sustainable practices* (Table 10). These contributed accounts were then discussed among and refined by all authors;
- Our collected examples show how the framework can be utilized to re-frame several design spaces for broader impact in the contexts of sustainability and design. The contributed examples show that the application of the framework can become quite a lot more complex than the original thought experiment examples. This confirms something that is not often said about design frameworks, but should be. That is, design frameworks are not necessarily as simple for others to apply as they are for framework inventors to construct. Noticing this is another contribution of this work. Inviting new co-authors to apply the framework can turn out to lead to new insights to refine the framework or guidance about when the framework applies or does not.

Note: In order avoid interrupting the logical flow of the paper, some of the discussion of related work appears towards the end of the paper in the section "Multidisciplinary Basis."

2 LINEAR AND NON-LINEAR DESIGN THINKING

"The 'A causes B' way of thinking is one-dimensional and linear whereas reality is multi-dimensional and non-linear. One has only to think of one's own life to see how absurd it is to think everything can be explained as a simple linear process of cause and effect" -James Lovelock [18]:15.

From marketing research, we learn that people oftentimes expect linear relationships when non-linear relationships actually hold. These expectations can lead to poor business decisions. These same principles apply to the notion of climate care.

This principle is elegantly expressed by De Langhe, Puntoni, and Larrick [11] in their article Linear thinking in a nonlinear world. Writing in Harvard Business Review, De Langhe, Puttoni, and Larrick provide a simple whiteboard graph to illustrate the disconnect between individual concern for the environment and purchase decisions that take environmental effects into account. They point out that it would be natural to expect that the more individuals are environmentally concerned, the more likely they will be to make purchase decisions that take environmental effects into account. They further observe that this expected relationship does not hold. In fact, only the most environmentally concerned individuals actually make purchases decisions that take environmental effects into account. They give several other examples of how actual behaviors are not linearly related to attitudes, some with more explicit data sources than some others.

Inspired by De Langhe, Puntoni, and Larrick's account, we consider the relationship between environmental awareness and environmental actions. These are more general notions than concerns and purchase decisions. In the linear case (Table 1), we may be tempted to assume that environmental awareness leads to environmental actions in a linear way.

Following the reasoning of De Langhe, Puntoni, and Larrick, Table 2 illustrates that the relationship between awareness and actions may be non-linear. That is, only the most aware individuals take sound environmental actions. To the degree that this holds for general environmental actions as it does for environmentally sound purchasing decisions in the perspective of marketing, any improvements in prompting environmental actions of those who are a little less aware present the greater challenge, compared with focusing on those who are already very aware.

What is needed as a design goal in line with climate care is that our designs prompt the majority of people to take environmentally sound actions, even with a modicum of awareness. This is illustrated by the non-linear graph of Table 3 that inverts the curve of Table 2 to denote the greatest opportunity space for impact.

How can we expect to make design decisions that prompt the larger effects that the left side of Table 3 suggests? To do this, imagine an ideal that seems even more unattainable than what is needed. That would be a straight line (Table 4) denoting that people always take appropriate actions for climate care regardless of levels of awareness. In other words, abandon the possibility of a relationship between actions and awareness, altogether. Stated another way, can we design to prompt sound environmental actions regardless of awareness?

Table 1: Linear relationship between awareness and action

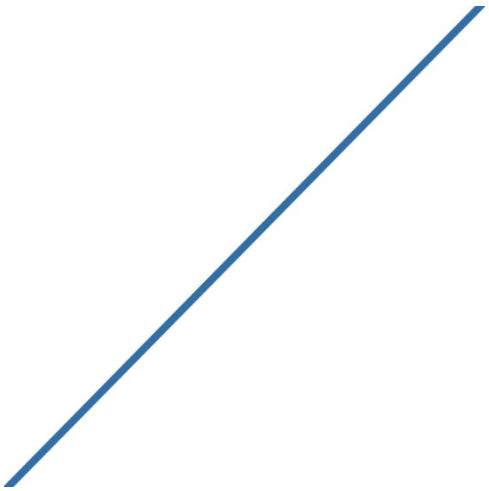
Linear
actions  awareness

Table 2: Non-linear relationship between awareness and action

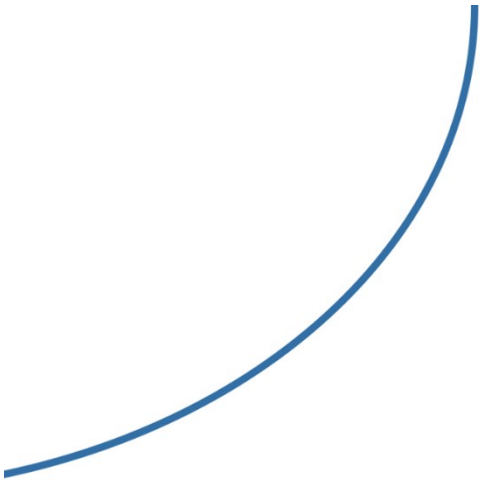
Non-Linear
actions  awareness

Table 3: Needed/imagined relationship for greatest impact

Needed
actions  awareness

Table 4: Ideal decoupling between awareness and actions

Ideal
actions awareness

3 THE NOVACENE

Table 2 above certainly appears at first sight to be an unattainable goal. Can such a state exist? In Novacene: The Coming Age of Hyperintelligence, centenarian and visionary James Lovelock [18] speculates that human awareness will not be a factor in a sustainable future, in keeping with Figure 4. He writes *"I am pretty sure that only Earth has incubated a creature capable of knowing the cosmos. But I am equally sure that the existence of that creature is imperiled. We are unique, privileged beings and, for that reason, we should cherish every moment of our awareness. We should now be cherishing those moments even more because our supremacy as the prime understanders of the cosmos is rapidly coming to end."* –James Lovelock [18]:5.

In Lovelock's vision, the Anthropocene—the age of human industrialization over the past 300 years—is coming to an end and will give way to the Novacene—an age of intelligent electronic agents. He sees such electronic forms as becoming fully autonomous and intuitive. AI (or AIs) will solve the issues of climate change more easily and more quickly than we can, essentially removing the need for human awareness from the equation for climate care. According to Lovelock, this is good news even if it is not under our human control. The intelligent electronic agents of the Novacene will have an interest in keeping the planet to manageable temperatures just as organic life does. To these agents, relatively slowly thinking humans will form part of the biosphere just like frogs or trees—useful to keep the Earth cool in keeping with the needs of intelligent electronic agents and organic lifeforms alike. These agents will develop intuition and learn on their own at superhuman rates.

If this seems far-fetched, we recommend reading Lovelock's visionary text first hand to make your own judgements. Writing in the London Review of Books, Meehan Crist [8] offers a balanced review that we can also recommend. Regardless of how Lovelock's vision is received, it is easy to see that nowadays AI pervades everyday life in ways that are not easily predicted by its original human designers and in ways that are increasingly autonomous. We are not arguing here that Lovelock's prediction is or is not sound. Rather, Lovelock's prediction serves our reasoning as an example of decoupling. We explain this below.

4 THE ROLE OF INTERACTION DESIGN

Without claiming to be able to see as far ahead as Lovelock is uniquely qualified to see, interaction designers may realize that they have more power than they think. By understanding that relationships are non-linear, interaction designers can design systems that reward climate careful actions over climate careless actions, regardless of if and how awareness and actions align, or other salient relationships to actions such as, for example, influence, empowerment, universality, or resilience. We can propose a reasoning framework that some may find useful in their design work as a means of applying this discussion. Let's call it a *non-linear design thinking framework* tabulated in Table 5

Using this framework to summarize all that precedes, we have the instantiated frame of Table 6.

We are not arguing that these steps are necessarily easy to implement. There may be some relationships that are in fact linear. It may be hard to know what the actual non-linear relationships are.

Table 5: Non-linear design thinking framework

Linear	*typically assumed relationships*
Non-linear, Actual	*actual relationships, to the extent they are known*
Non-linear, Needed for Impact	*opportunities for greatest impact*
Decoupled	*decoupling or re-coupling relationships to remove or realign needs*

Table 6: Climate care actions and awareness

Linear	*we may expect that the more awareness, the better the climate actions*
Non-linear, Actual	*actually, only the most aware take climate care actions*
Non-linear, Needed for Impact	*design to prompt those who are not the most aware to also take climate care actions*
Decoupled	*remove the need for climate actions to depend on human awareness, by–for example–imagining that intelligent systems may be better able to safeguard the climate than we are*

It is easier to create designs for people who are already aware than for those who are either unaware or reluctant to prioritize climate care actions over their own everyday pressing concerns. There may not always be a way to eliminate the need for a factor like human awareness as in Lovelock's account. Nonetheless, we are arguing that this framework is one way to understand and augment design possibilities for greater impact. Thinking about smartphones and tablets and computers and other digital devices, here is a less abstract instantiation to illustrate the utility of our non-linear design thinking framework for interaction designers per Table 7.

Apropos of Table 7, consider the screen displays from the Ecobee (www.ecobee.com) app given in Figures 2 and 3. The system does not default to the most sustainable energy use settings. Rather, the owner needs to proactively enable "eco+" mode along a choice of four dimensions (Figure 3). The reward for enabling "eco+" mode and turning on all four dimensions is an email summary of performance congratulating the owner (Figure 2). The screens in both figures are nudges (see [16], [23]). Nudges are prompts to actions,

Table 7: Energy aware settings and personal choice

Linear	*we may expect that the more personal choice offered, the more people will make the optimal choices for energy use settings*
Non-linear, Actual	*actually, only the most climate aware people will make the effort to choose optimal energy use settings*
Non-linear, Needed for Impact	*default to the most economical energy use settings, rather than rely on people's efforts or motivations to choose their own settings in a climate aware manner*
Decoupled	*remove the need for people to understand optimal energy use settings altogether, by having the system default to the least amount of energy use that will do dynamically with the situation*

but they are not defaults. There is an opportunity here to design differently. The idea of having systems default to their most environmentally responsible settings is described in Preist et al. [21]. Thermostat design has been and continues to be a staple of SHCI and interaction design more generally. There are politics to the logic of Table 7. That is, there may not be a one size fits all design that delights those who prefer autonomy and control in their energy use practices and those who prefer to require everyone to minimize energy use as a matter of concern for the commons.

The framework may also be applied inwardly to the research on and practice of Sustainable HCI (SHCI). Consider Table 8.

5 CONTRIBUTED EXAMPLE: MIGRATION CHOICES AND CLIMATE CHANGE

Global environmental changes are affecting the frequency and severity of weather-related events such as floods, hurricanes, heatwaves, and wildfires. Such extreme events can exacerbate water scarcity, harm crops, increase prices, and eventually trigger forced migration. Millions of people will be displaced from access to food, water supply, and other essential resources.

Despite this scenario being a widely repeated prediction, there is not a linear relationship between involuntary migration and lack of resources to stay in place. According to the Intergovernmental Panel on Climate Change, the impact of alterations in weather patterns is not spatially consistent over time [19]. For example,

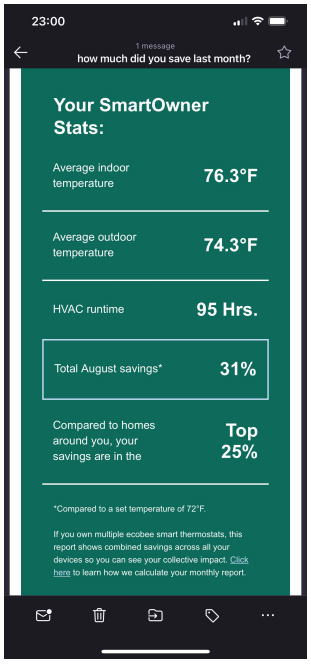


Figure 2: Monthly report from Ecobee smart thermostat, 2022

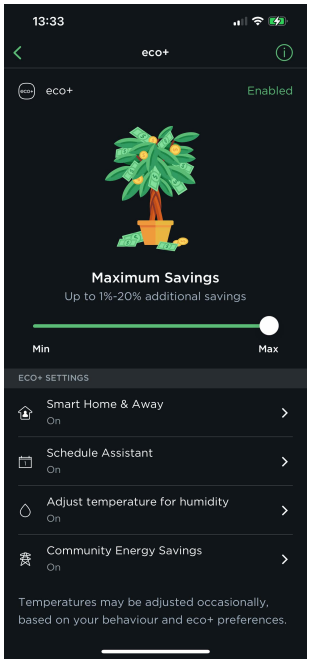


Figure 3: Economy settings in the Ecobee smart thermostat App, 2022

land productivity, habitability, energy security, and employment opportunities could be temporarily affected by an extreme weather event, followed by a period of recovery. Hence, some people may

Table 8: Climate Care and SHCI

Linear	*we may expect that the more interaction designers understand SHCI, the more they will design for climate care*
Non-linear, Actual	*actually, only some interaction designers care about climate care and only those who care a great deal will focus on design with climate care in mind*
Non-linear, Needed for Impact	*rather than require specific knowledge of SHCI, seek and integrate broader appeal and impact into everyday interaction design decisions without requirements for such specific expertise*
Decoupled	*popularize design methods that encode climate care actions automatically, not unlike automated accessibility checking*

Table 9: Migration choices and climate change

Linear	*we may expect that people choose to migrate in proportion to the progressive effects of climate change*
Non-linear, Actual	*actually, people may prefer to stay in place in temporary accommodations, until local conditions improve or the resources are available to allow them to stay in their current location*
Non-linear, Needed for Impact	*rather than wait until the eleventh hour or resign to permanent migration, put infrastructure in place (e.g., MANY) to accommodate the short term needs of people who may be only temporarily displaced*
Decoupled	*recognize that decisions to stay or migrate are complex and may not owe solely to local conditions or the availability of resources to continue to live where one is living*

endure crises and resist migration with the hope of returning to normal in the near future.

Given the non-linearity of relationships in this context, providing flexible infrastructure and resources offers alternatives to forced migration. For example, MANY is an online platform designed by Keller Easterling [12] that aims to facilitate the exchange of needs in times of temporary displacement. Presented as part of the U.S. pavilion at the 2018 Venice Biennale, the app builds upon existing networks, such as short-term visas and paid opportunities around the world, and offers shorter project-based journeys and global credentials. Due to the periodic nature of some of the environmental drivers for migration, MANY is a dynamic resource needed for impact in times of constant change.

From the decoupled perspective, one could argue that resource scarcity does not have an impact on forced migration. Black et al. [2] proposed a conceptual framework in which they mapped out the barriers and facilitators of migration on three levels: micro level (personal and household characteristics), meso level (social capital and local communities), and macro level (economic, political, and environmental). If conditions on the micro and meso level are met, it could overturn the decision of migration despite drivers on the macro level. Therefore, the severe impact of climate-related conditions on fulfilling basic needs does not solely drive the decision to migrate. People are forced to migrate for reasons other than resource scarcity, and sometimes they have to choose to stay, despite a lack of resources.

6 CONTRIBUTED EXAMPLE: FISHING AND SUSTAINABLE PRACTICES

Dominant economic frameworks use the gross domestic product (GDP) to measure the economic sustainability–that is, the long term economic prosperity–of each country; GDP is a monetary measure of the market performance often in one year. If we assume a linear relationship between the two, economic sustainability will not be achieved unless there is sustained growth in GDP.

In reality, however, there is a non-linear relationship between GDP and economic prosperity. Some natural resources have limited reserves and cannot be replenished, and some renewable resources cannot regenerate at the same pace as human extraction. In the short-term, constant use of natural resources will increase GDP. However, the continued exploitation of these resources will lead to an irreversible decline in economic prosperity.

Table 10: Fishing and sustainable prosperity

Linear	*we may expect that economic sustainability is related to productivity as a general matter*
Non-linear, Actual	*actually, over-fishing leads to irreversible damage to long term economic sustainability*
Non-linear, Needed for Impact	*play the long game– don't over-fish in order to always be able to fish*
Decoupled	*decouple short term metrics of productivity from long term sustainable practices, as in the "no catch investment" strategy*

To introduce a nuanced perspective, we can also envision a non-linear, impactful relationship between GDP and economic prosperity. The monetary measure of the market value overlooks the temporal dimension of economic prosperity that extends over decades. There is a need for an indicator that considers new measures, such as the amount of preserved resources for future generations, in its calculation of economic prosperity.

In the context of decoupling, periodic intentional downturns in GDP could lead to economic prosperity in the long term. A case in point, No Catch Investment [7], which requires a periodic decrease in fishing, is a strategy deployed in some European countries as a growth strategy in a sustainable economy. This strategy is an attempt to counter years of over-fishing that have left fish stocks with potentially irreversible damage; thousands of jobs and tons of food supplies have already been lost. Although implementing the temporary cessation of fisheries will negatively impact GDP, the short-term costs of No Catch Investment could be overcome with a relatively small investment to support fishermen who lose their income during periodic decreases in over-fishing [7]. No catch investment is a mechanism that decouples short term metrics from long term sustainable practices.

7 MULTIDISCIPLINARY BASIS

In this paper, we have privileged the analysis of De Langhe et al. [11] and the vision of Lovelock [18], focusing on the distinction between linear and nonlinear thinking. There are many related sources that should be mentioned. We review key work here to contextualize the present project. We begin with the notion of multidimensionality. Recall from the opening quote Lovelock's claim that "reality is multi-dimensional and non-linear." Our graphs are too simple for a complete analysis. Climate care actions are not related to just, or possibly decoupled from, awareness but also other dimensions such as influence, empowerment, universality, and resilience, as stated earlier. A more ambitious framework than the one we propose here would take multidimensional relationships into account.

Our discussion is also related to work in behavioral economics about Thaler and Sunstein's notion of nudge theory [23] and human decision making [16]. Kahneman et al. [16] distinguish between noise (random outliers that are easy to ignore in a rule-based algorithmic sense) and bias (systematic misjudgments that are hard to identify as a matter of human cognition and deep-learning algorithmic bias). This distinction between noise and bias is germane to this discussion as forces that can further complicate understanding the nonlinear relationships between awareness and actions. Cass Sunstein and Lucia Reisch [22] take up the implications of nudge theory for environmentally sound actions. Their work aligns closely with the energy-aware settings and personal choice instantiation of our framework in Table 7.

In Design outside of the arena of sustainable interaction design and SHCI, arguments for climate aware design have a longer history. De Bont [9] gives an account of this history centering on the work of Victor Papanek (e.g., Papanek [20]). In sustainable interaction design and SHCI, Blevis [3] also cites Papanek's work as a primary inspirations from Design, as well as the key work of Fry [13].

In ACM interactions, Blevis and Blevis [4] describe the connection of interaction design to the tipping point for climate change, appealing to Lovelock's earlier and less optimistic work *The Vanishing Face of Gaia: A Final Warning* [17]. In SHCI, Tomlinson, et al., ([24],[25]) provide the more general notion of *Collapse Informatics,* later integrating with a workshop series known as *Computing within Limits* (https://computingwithinlimits.org/) beginning in 2015 and continuing to date. The most recent survey of the SHCI literature appears in Hansson, Cerrato-Pargman, and Pargman [14]. This line of research continues with much yet to be done.

Apropos of decoupling and defocusing humans in responses to climate change as in Lovelock's [18] notion of the novacene, an alternative recent strand of SHCI research takes on an ecologically posthuman agenda. Posthumanism calls for the decentering of the human in design as a strategy to counter the prevailing forces of the Anthropocene era, informed by feminist scholars Haraway [15], who advocates for human-non-human relations and naturecultures, Braidotti [6], who rethinks posthumanism's relation to technology, climate change, and bio-politics, and Puig de la Bellacasa [10], who advocates feminist care ethics as a lens for posthumanism. Similar to this contemporary scholarship on posthumanism, Lovelock's vision of the novacene is posthumanist, even if its motivations and politics differ.

8 IN CLOSING

Our paper introduces a design framework titled the *non-linear design thinking framework* with origins in the literature on marketing (viz., [11]). This framework is of interest to HCI and Design researchers and practitioners as a mechanism for thinking differently about certain kinds of design spaces. The framework is presented in Table 5 and the form of reasoning it prescribes involves moving from linear relationships (Table 1) to non-linear relationships (Table 2) to opportunities for impact (Table 3) to decoupling or re-coupling relationships to remove or realign needs (Table 4). We provide five

examples of the framework in action, namely *climate care actions and awareness* (Table 6), *energy aware settings and personal choice* (Table 7), and *climate care and SHCI* (Table 8), *migration choices and climate change* (Table 9), and *fishing and sustainable practices* (Table 10).

Of these five examples, the first three were instrumental in the reasoning that lead to the framework. The last two were contributed by co-authors who were asked to see if they are able to use the framework. These two were chosen from among several that were contributed based on how well they fit within the framework and then discussed among all authors. We learned that applying the framework works best in the case that (a) there is a linear relationship that might be assumed between two factors that does not actually hold, and (b) that one of the factors (the *response variable*) in each example centers on individual choices or policy choices (i.e., climate care actions, personal choices about settings, taking sustainability into account in HCI, decisions to migrate or stay in place, and decisions about sustainable use of resources). In future work, we plan to ask others to apply the framework in order to further assess its utility, limitations, and accessibility.

Notwithstanding, by borrowing a page from–of all places–marketing research, we may be able to avoid the technocentrism of HCI's preoccupation with technology itself, its centering on the now. The approach we claim here may help think through the broader implications of design decisions–shifting perspectives to deal with time and scale ontologies. That is to say, challenging assumptions, imagining ideals, and decoupling factors may in some cases make the connection between design and futures apparent.

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