Understanding Timing in Mixed-Initiative Interaction

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***Abstract*—Interaction with programming notations happens over time. We are exploring how the rhythm of interaction changes the user's perception of control.**

1. Background

As more programmable capability is introduced to direct-manipulation interfaces, for example in programming-by-example (PBE) systems, this introduces the potential for mixed-initiative interaction. In a typical PBE system, the user demonstrates her intention by manipulating data, or performing other concrete actions in the user interface. At first, this seems very similar to a direct manipulation interface. For example, Allen Cypher's early PBE system Eager [1] observed actions in the Macintosh Finder, and then 'eagerly' offered to carry out further automated actions based on a pattern it had observed.

This strategy could be very helpful, in cases where users might be reluctant to automate their work through programming. Attention investment decisions require the user to evaluate risk that something might go wrong. Direct manipulation is relatively safe, because one thing happens at a time, while programming is risky, because a lot of things can go wrong at once. Burnett's Surprise-Explain-Reward [2] is one strategy that helps the user to overcome perceived risk, by 'surprising' the user with an opportunity to achieve some benefit.

We see an increasing number of systems that do take the initiative in this way, offering benefits to the user that have been predicted through inference on a large data set. A very simple example is the suggested search completions offered by Google, which are derived from (relatively straightforward) statistical inference over the corpus of prior queries. We believe that in future, users will be presented with increasing numbers of opportunities to choose between manual control and automatically inferred behaviour. Many of these may be 'programming-like' in the sense that they employ an abstract notation to specify repetition or selection among possible behaviours [3]. Such decisions are also likely to be 'live' [4], and to occur increasingly rapidly, with micro-abstractions or micro-notations occurring as part of the flow of interaction, in a manner that perhaps shares more with human conversation than with conventional live coding [5].

2. Current Research

The goal of this research is to better understand the ways in which the rhythm of interaction will impact on this kind of back-and-forth flow of interaction. In a mixed-initiative system, the system itself assumes some control, or demonstrates some agency. The user, in trying to express her intentions, will also be asserting control, sometimes under the impression that she is struggling against the expectations of the inference system [6]. Most programming systems assume that the visual environment of the IDE will provide all the information necessary for the user to assess this behaviour and respond appropriately. However, this transient and live-coding-like interaction is as much involved with the time-course of the interaction as with the visual notation.

Our research into timing of back-and-forth interaction is therefore a valuable complement to studies of notation, inspired in part by the role that temporality plays in understanding the human factors of live-coded music performance [7]. In the context of human-computer interaction, we define 'rhythm' as the systematic patterning of interactive events in terms of timing, grouping and accents [8]. Studies in neuropsychology have found that such patterning of stimuli not only stands out as an attribute of a rhythmic process, but also exerts a functional impact on an interaction. By extracting the temporality of interactive events, our brain can form expectations, thereby reallocating our attention and dynamically updating the perceived degree of responsibility that we have [9]. In other words, rhythm can improve the perceived predictability of an interaction, making it less demanding on users' cognitive resources. This could be an encouraging solution to previous observations that higher cognitive load can cause users to experience an impaired sense of agency [10].

In addition to mitigating perceived loss of agency, rhythm also has the potential to improve quality of interaction. When two rhythmic processes interact and adapt to each other, they eventually lock up in a relatively stable synchrony. This 'entrainment' effect has been widely observed in human-human interaction, and has been identified as a key factor that contributes to mutual trust and affiliation, pro-social behaviours, and intersubjectivity [11]. The significance of timing coordination in HCI has previously been identified [12] but has not been thoroughly studied.

Our goal is to explore the potential dynamic benefits of rhythmic interaction.

3. Methodology

Our current research hypotheses are: 1) Rhythm can facilitate HCI, 2) Rhythm in HCI can reduce users' cognitive load and enhance their sense of agency, 3) Rhythm in HCI helps users to form timing expectations, such that violating this expectation can cause a loss of agency. We have designed two laboratory experiments to test these hypotheses. The first presents users with visual stimuli, while the second presents auditory stimuli. Both experiments have the same independent variables: rhythmic stimuli vs. arrhythmic stimuli. We include three subtypes under the rhythmic condition (*computer-paced, user-paced, and user-paced-computer-aligned*) simulating mixed-initiative interaction flows. For the dependent variables, both experiments measure the inter-onset interval (IOI) of mouse clicks, self-report of sense of agency, and task stress (using NASA TLX scale). In the first experiment, we also record how accurately participants recall the shape and location of visual stimuli, in order to explore our hypothesis regarding the effect of rhythm on cognitive load. In the second experiment, we test the intentional binding effect as an implicit measurement of agency using the Libet Clock paradigm [6].

4. Current Results

At the time of writing, we have completed the two experiments with 22 participants. Our current results show that, 1) in Experiment 1, users' task performance was significantly better in *user-paced* and *rhythmic computer-paced* conditions than the other two conditions, 2) in Experiment 1, users' clicking rhythm exhibited a significantly stronger autocorrelation in *arrhythmic computer-paced* condition, while the autocorrelation coefficients in other conditions dropped as more initiative of the interaction was taken by the users (*rhythmic computer-paced, user-paced-computer-aligned, user-paced, users' baseline*), 3) in Experiment 1, the mean asynchronies in users' clicking rhythm was the lowest (approaching 0ms) in *user-paced-computer-aligned* condition, while in other conditions the asynchronies increased significantly as users took more initiative, 4) in Experiment 2, users' time estimation error was the smallest (approaching 0ms) in *user-paced* condition, and the error increased as more initiative was taken by the computer in other conditions, 5) in Experiment 2, the outcome binding effect on users' time perception was the weakest in *user-paced* condition while getting significantly stronger when computer set the pace and behaved arrhythmically, 6) in both experiments, users' subjective ratings on the sense of *control*, *confidence*, *efforts*, perceived *adaptation* and *intention* increased as they took more initiatives in the tasks. The above results have supported our hypotheses above.

5. Implications & Applications

As stated earlier, when the flow of interaction can be initiated by both the user and the system, either in parallel or in turn, timing coordination becomes a key issue in system design. Users are likely to expect the transition of control to happen just in time, without any noticeable overlap (where they try to re-assert agency taken by the system) or gap (when neither claims responsibility). According to Expectation Violation Theory, violating users' expectations, either positively or negatively, will trigger a process of reevaluation and redistribution of efforts and responsibility, and thus impair the perceived transition of control. We hope that our research will provide a quantitative measure of how sensitive users are to the handover of initiative on a millisecond timescale. Moreover, further data analysis will reveal how the user forms and updates timing expectations, and how these influence task performance and sense of agency. We hope that resulting insights, if used to inform mixed-initiative system design such as programming by example and probabilistic programming of end-user automation, will facilitate back-and-forth interaction with inference components.

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