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Keeping users in the flow: Mapping system responsiveness with user experience

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Abstract

User immersion in computing happens not only in entertainment, gaming, and virtual reality but whenever users are "in the flow", completing their work and communication without thought to the technology that is making it possible. When a user is in the flow, and poor performance brings attention back to the technology, the user is pulled from that immersive experience to focus on computer performance in a negative way. System response time (SRT) is the amount of time that elapses from when a user submits a request until the result is returned from an interactive computing device. Empirical and theoretical literature has repeatedly demonstrated that SRT is a key factor that can dramatically affect user satisfaction. Although it has been suggested that SRT issues would become obsolete with the technological advancements in hardware and software, the amount of literature in this field and its effect on user experience (UX) is a clear reminder that SRT continues to be problematic. Specifically, there is a lack of comprehensive metrics that quantitatively correlates user satisfaction to SRT. This paper will discuss SRT and its influence on *user-perceived* performance. It will describe how the concept of flow is an essential factor influencing user satisfaction, especially with highly interactive devices. In addition, it will explore how time perception, attention, and feedback can impact users' perception of flow. It describes why the little things (seemingly small or short-duration characteristics of the experience) have the most impact on users' perception of flow. Finally, a new framework for categorizing and mapping UX and SRT's will be presented along with the three guiding principles that dictate this relationship. This new framework provides a systematic approach to enable the objective measurement of flow, and hence, a new user-centric approach to computer performance evaluation.

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1. Introduction

User experience (UX) is a multifaceted construct. Many factors contribute and interact to enable an experience. Some of these factors are easier than others to define and objectively measure, and contribute more or less to an overall experience. In the case of highly interactive devices, system response time (SRT) is one of the key factors that predict user satisfaction. SRT is the amount of time that elapses from when a user submits a request until the result is returned from a computer system [1]. Although processors have continued to improve, advances in software computations, input modalities, and new functionality has continued to make SRT a challenge for developers. Unfortunately, there is a lack of comprehensive, quantitative metrics that correlate user satisfaction to the wide variety of SRTs. These specifications are necessary for driving UX quality into product development, validation, reliability, and benchmarking efforts.

This paper will discuss SRT and its influence on user-perceived performance. It will describe how the concept of flow is an essential factor influencing user satisfaction, especially with highly interactive devices. In addition, it will explore how time perception, attention, and feedback can affect users' perception of flow. An argument will be presented describing why the little things (seemingly small or short-duration characteristics of the experience) have the most impact on flow. Finally, a new framework for categorizing and mapping UX and SRT's will be presented along with the three guiding principles that direct this relationship. This new framework provides the groundwork to translate UX into a language that engineers can understand and apply, enabling a user-centric approach to design and testing that focuses on what users will really notice and value.

2. User-perceived performance: It's the little things

Traditionally, computer performance has been measured using metrics such as frequency, throughput, and response times of compute-intensive operations. With advancements in software and new input modalities like touch [screens], the same rules for performance measurement are not adequate to predict UX, or flow. In particular, the shorter operations like menu navigation, or touch gesture interactions, like scrolling or pinch/zoom, are not captured in traditional evaluation tools. It is these shorter interactions that make up the majority of what users experience in everyday usage of smart phones and tablets, which are growing in popularity and it can take very little delay for users to notice and become annoyed [2]. Tolia et al. [3] agree that one of the most critical measures of user-perceived performance is the crispness of interactive responses. They note that it is the trivial or short interactions that are most critical to user perception of system responsiveness. Such trivial interactions include those visual cues that keep the flow of interaction feeling fast; the system responses that show the system is responding to inputs and reacting precisely to actions the user has directed. However, it is these small response times that are often the most challenging for computing devices to complete quickly and reliably.

2.1. Background

For decades prominent researchers have strived to increase our understanding of computer responsiveness and the role it plays in facilitating optimal UX. These researchers took slightly different approaches. In 1968, Miller [4] began looking at human-computer interactions as "conversations," consisting of human commands and computer responses. Miller's work was motivated by mainframe computer usage where human memory was the influencing factor for setting responsiveness requirements. Although Miller's taxonomy was not based on empirical investigation, it provided a good starting point for research on how fast computer systems should respond to user actions, and his work kicked off multiple research inquiries into system responsiveness.

Card [5] and his team joined the conversation in 1983 when they began analyzing computer tasks, proposing that each task was composed of sub-tasks that could be broken down to the keystroke (or mouse-click) level. Their research also looked at the pace of the human-computer interaction and noted that delays were acceptable at certain points as long as they did not disrupt the pacing of the interaction. Their work led to the development of the GOMS (Goals, Operators, Methods, and Selection rules) model of human-computer interaction which showed that quality UX included the smooth interchange of actions and reactions. The GOMS model also attempted to define the detailed microstructure of tasks in order to predict usability based on the number and complexity of interactions to accomplish those tasks.

In 1987, Shneiderman [6] proposed that because different tasks had different levels of complexity, they required different levels of system responsiveness to satisfy a user. He suggested the complexity of a task needed to be evaluated when determining a range of acceptable SRTs and proposed a four-tier, task focused model as defined in Table 1 below. Like Miller, he viewed human-computer interactions as conversations and concurred that a certain pace was required to sustain them. He observed, "The maximum acceptable time taken to prepare a response depends on the nature of the response; thus, responsiveness is relative to the type of interaction."

Table 1. Shneiderman’s response time categories based on complexity.

Task Complexity	Response Time
Typing, mouse movement	50 – 150 ms
Simple frequent tasks	1 s
Common tasks	2 – 4 s
Complex tasks	8 – 12 s

Table 2. Seow's response time categories based on expectations.

Expectations	Response Time
Instantaneous	100 – 200 ms
Immediate	.5 – 1 s
Continuous	2 – 5 s
Captive	7 – 10 s

Unlike Shneiderman, Seow [7] did not attach response time guidelines to specific tasks or to task complexity. He believed task complexity was relative to the user's expectation of how long that task should take (a longer delay for a more complex task is acceptable). For his model, Seow proposed that interactions with a computer be categorized based on user expectations. He also suggested that a user's tolerance of a system delay had more to do with the type of interaction and the user's expectation for that task than with the complexity of the task. Seow's four-tier model of SRTs (see Table 2 above) provides response time guidelines that emphasize the importance of the end user's "conversational" interaction with the system, showing that delays within limits are tolerated per the pacing of the interaction and the user's expectations. Seow’s model tends to be more suitable to developers because he incorporated the perceptual element into his model and provided a more intuitive way to assign SRTs to categories.

These models were useful as a step in guiding engineering requirements; however, there is still a need for going beyond the 10-12 sec range since most user interactions or workflows are comprised of both shorter and longer interactions that together influence perceived flow. When measured response times do not fall directly within these ranges, it is unclear what the impact is to UX. Moreover, understanding and quantifying the impact of 100 ms vs 200 ms on UX is needed since with some types of interactions, these differences are significant; depending on the degree of impact throughout a workflow, many small delays can add up to large UX impact.

Tolia et al [3] offer a set of guidelines around the impact of interactive response times on user satisfaction and task productivity. Their guidelines were developed based on a careful review of over 40 years of literature on this topic. They too focused on short interactions (those within 10 sec) and defined such SRTs as perceived to require very little to no processing. They suggested that 1) a crisp response is one below 150 ms, where user productivity is not impacted; 2) users tend to notice response times between 150 ms to 1 sec; 3) they would prefer response times to be as close to 150 ms or below, and 4) users become unhappy and frustrated with response times above 1 sec unless cleverly masked. Tolia et al's guidelines come closer to detailing a quantified relationship between SRT and UX but only for what Seow would consider the instantaneous category. Researchers have also found the perception to latency to be as low as 64 ms and performance to be impacted by even lower latencies [8], which suggests that even more stringent mappings between SRT and UX is required to accurately measure flow.

This paper describes an expansion of Shneiderman’s and Seow’s work, with categories in the non-attentive range. In addition, it proposes that within each category, regression models can be defined to quantify the precise relationship between UX as a function of SRT. It is with these models that UX predictions can be made throughout a workflow to measure user-perceived performance – flow. Next, an overview of flow, time perception, attention, and feedback will be presented as they pertain to interactive device experience.

2.2. Flow

The concept of flow as the state of being fully absorbed in an activity was credited to psychology professor Mihaly Csikszentmihalyi in the 1960s. Flow theory took off in the 1980s and 1990s with researchers studying its relation to things like happiness and achieving optimal experiences. Within the HCI (human-computer interaction) community, flow is commonly described as the natural, *fluid state of being productively engaged with a task without being aware of the technology that is driving it*. As such, if successful, technology can become virtually forgotten when a user is immersed in the experience, or is in the flow. Researchers such as Dabrowski and Munson [2] studied the relationship between HCI performance and personal performance and concluded that flow elicited the greatest performance from the user with the fewest errors and the highest satisfaction with the systems. Seow [7] proposed that a certain degree of flow may or may not occur depending on how well a system's responsiveness meets or exceeds user expectations. When a system's performance enables or enhances flow, it has a positive effect on the user's perception of that system's performance. In contrast, when the performance does not enable a good flow experience, it has a negative effect. Flow is broken when there is an interruption to the user's interaction with a technology, such as when there is a system delay that is unacceptable to the user. When flow is broken, this often results in a person becoming annoyed [9].

2.3. Perception of Time

Empirical studies have shown that people perceive time at the start of a delay as longer than they perceive time later in a delay. In one study, it was found that actual download waiting had a direct, positive linear relationship to perceived download waiting when participants were comparing a relatively short delay with a longer delay [10]. However, this relationship leveled off at 30 sec because participants could not reliably differentiate between medium-length (30 sec) and longer-length download times (60 sec). Another study looking at perceptions of shopping-site download delays found similar results [11]. The researchers found a positive but nonlinear relation between actual download times and perceived download waiting. These observations are analogous to a fact observed about many human sensory systems in which human sensitivity tends to be compressive across the range of sensitivity. This means that very small differences in stimuli can be detected in the low and middle ranges of the sensitivity curve, but it takes larger differences to be detectable as the stimuli approach the limits of those senses. When a time duration is within the range of sensitivity, the relationship between *actual* time and *predicted* time is a linear correlation. When the time duration extends past the sensitivity limits, the relationship is no longer linear. Next, the role of the attentional system will be discussed as it influences our perception of time and - hence - our ability to stay in the *flow*.

2.4. Attention

As mentioned above, users judge short durations more accurately, but they also judge the duration of events that hold their attention as longer than less attended events [2,8]. It follows that during shorter attentional tasks people are proportionately more affected by those delays. When users are in the flow they aren't attending to the computer or its functioning; they are attending to the task at hand and feeling progress being made toward their end-goal. Moreover, when users are experienced, their interactions can become automatic which heightens the sense of flow. When skilled performers are asked to shift their attention to the details of what they are doing, this breaks their flow and hinders performance. For example, when skilled typists are asked to pay attention to specific letters and fingers while typing, performance decreases [13].

Since shorter system delays are perceived more acutely and more accurately by the user, it is critical to minimize delays during all of these shorter interactions. Shorter attentional tasks are widely agreed to fall within the 10 sec range [3,4,6,7]. Seow characterizes interactions that are 10 sec or less, as those tasks that people most focus on and therefore influence their perception of computer performance most significantly. For mobile devices like smart phones and tablets, those shorter response times make up the majority of all interactions. That is not to say that the other, longer system response delays are not important. But because the shorter, attentional SRTs have been largely passed over in evaluation tools and the frequency and impact to UX is so high, it is necessary to put an emphasis on them here.

2.5. Feedback

Not all responses can be instantaneous or immediate. In cases where some delay is unavoidable, there are techniques that can help keep a user in the flow, by giving them a sense that there is constant progress. Not only can you trick a user into feeling there is steady progress being made, but feedback can also decrease a user's perception of wait-time and stress [12,14,15]. Overall, feedback reduces users' uncertainty and gives them a sense of control by assuring them the system is acting on their inputs appropriately. Since feedback can have mitigating effects, it must be considered when defining the start and end time of a SRT.

2.6. Influencing Perception: Three Guiding Principles

As Norman [16] points out in his book, The Design of Everyday Things, every system inherently has a model built into it, and every user has a mental model that corresponds to a system model. When devices and products are designed to fit with users' mental models of what they expect of operations and technology - where their instincts about what should happen next and how to make something happen are right- those devices and products will be perceived by the user as intuitive and desirable. Three key psychological principles (see Fig.1) are proposed that influence a user's perception of time and the quality of their experience during the use of an interactive device.

2.6.1. Users' expectations

Flow is resilient to some delays, especially if the delays align with user expectations. It's important to consider the average target user's expectations for determining the appropriate SRT category. Users may have different amounts of experience with certain products. Depending on their technical knowledge and their familiarity with the technologies, their internal, conscious, and unconscious expectations get established more or less firmly. The versions and design of the tools they use also contribute to form their expectation regarding how technology "ought" to behave. Past experiences with related usages also play a role in expectations that are formed over time. For instance, pressing a hard button to play music on a stereo usually results in very reliable and instantaneous feedback in the form of music playback. When playing music from a computer application, users tend to expect the same results. User expectations can change over time so new research on performance perception will always be required. It's likely that task SRTs at the upper end of the shorter-task range (7-10 sec) will eventually become unacceptable to users. Even now, in e-commerce, user expectations have become so stringent that a few seconds can feel too long to wait for a webpage to load that was once acceptable taking up to 10 sec.

2.6.2. Perceived complexity

Depending on how complex or compute intensive an interaction is perceived to be, a user may be more or less tolerant of waiting for an operation to be completed. For example, the more perceived complexity of a given task - the more forgiveness there may be for longer delays, and therefore it would take more change in time to shift the UX. This was clear in Anderson et al's [17] research findings where user ratings varied according to the type of

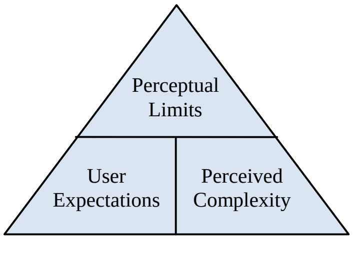

Fig. 1. Guiding principles influencing time perception and experience.

event and is also consistent with Shneiderman's taxonomy. In addition, if a user anticipates that an operation is more complex, they may start that operation, change focus and attend to something else. Shifting attention away from the response of that operation decreases the ability of the user to perceive time accurately as well as reduces the chance that users will become annoyed since their attention is focused elsewhere.

2.6.3. Human perceptual limits

Humans have a sensory threshold for the brain to cognitively process stimuli. A stimulus that falls short of this threshold will not elicit any sensation, and the person will not notice or experience the stimulus. Different methods are used to measure thresholds depending on the sense under study and the research questions being asked. Two common sensory thresholds that have been defined are called the absolute threshold and differential threshold. Absolute threshold is the lowest level at which a stimulus can be detected. This threshold can vary for different individuals depending on things like age, past exposures, training, etc. Differential threshold, also known as "JND" (Just Noticeable Difference) is the level at which an increase in a detected stimulus can be perceived. It is important to take human perceptual limits into account when setting requirements because spending engineering resources to reduce SRTs below these sensory thresholds will not improve flow.

3. Mapping user experience to system response time

MOS (Mean Opinion Score) is a subjective assessment methodology and International Telecommunications Union standard traditionally used in the multimedia industry to measure perceived quality [18]. It provides the techniques to transform subjective user feedback into objective, quantitative scales that estimate average user perception. Research methods associated with MOS require high scientific rigor and are rooted in careful experimental design. In the case of the single-stimulus method, user ratings are collected using a five-point scale, where '1' is the lowest perceived quality (poor) and '5' is the highest perceived quality (excellent). Participant ratings are averaged for each treatment in a study, resulting in a MOS (or average user rating) for each treatment. This data can then be used in various statistical analyses, including analysis of variance (ANOVA) and regression analyses where a mathematical formula can be defined to predict perceived quality from one or more predictive variables. Similar methods can be used to map the sensitivity of user perception to changes in time. This approach can also be combined with performance testing (i.e., Fitts' Law) and JND testing to define precise perceptual thresholds and to inform the slope of those regression curve fits.

3.1. A new SRT framework

The categorization seen below in Table 3 is an adaptation and expansion of the four-tier SRT classification that Seow introduced in 2008. It goes beyond the attentional 10 sec range and includes more discrimination of task times.

Table 3. SRT framework category names, time range, and descriptions.

Attention	Category Name	SRT Range	Category Description
Attentive	Instantaneous	< 300 ms	User feels like they are in a closed-loop system; as if they are in direct control.
	Immediate	300 ms – 1 sec	Processes perceived by user as easy to perform.
	Transient	1 sec – 5 sec	Perceived by user as requiring some simple processing but user feels that they are making continuous progress (appropriate feedback required). It is unlikely a user would disengage from task flow.
	Attention Span	5 sec – 10 sec	Perceived by users as requiring more processing/wait time but user needs useful and informative feedback to stay closely engaged.
Non-Attentive	Non-attentive	10 sec – 5 min	Perceived by users as requiring more complex processing. Users would be likely to disengage and multi-task during this process. Feedback of progress is necessary.
	Walk-away	> 5 min	Perceived by users as requiring intensive processing. Users would not stay engaged with this task. Feedback of progress is necessary.

The time ranges for each category only represent a general range of acceptability; they are meant to guide the assignment of an SRT, not to assign a UX score. Predictive models are needed within each category to provide more precise engineering targets and measures of UX. These models are also necessary to accommodate the many differences in SRT perception and acceptability. A variety of factors explain these differences, such as the context of use, mode of input, feedback, etc. For instance, depending on the input modality (mouse, keyboard, touchscreen, air gesture, speech, etc.), the perception of what a user would consider instantaneous will vary. The mode of user interface feedback (visual, audio, haptic) can also cause the same SRT to be perceived as faster or slower [19]. For example, in the case of speech recognition and natural language interaction, it may not be necessary to reach SRTs as fast as touchscreen interaction, since we naturally pause between utterances in a conversation and a slight pause better aligns with user expectations [20]. Multiple models are necessary to accommodate these considerations but once a collection of these models are developed for each category, subsequent SRT’s can be assigned to these based on user expectations, perceived complexity, and perceptual limits that govern user perception. Additional studies will only be required to develop new models if these principles are unknown or to understand how user expectations shift over time.

By providing a quantitative mapping of SRT to user perception (MOS), the appropriate trade-offs can be weighed and informed decisions can be made based on the goals and value propositions of a given interactive experience. These UX predictions will also provide the ability to quantifiably aggregate a series of SRTs that make up a *workflow* to then calculate an overall score.

4. Conclusion

The field of HCI focuses on the seamless and intuitive experience users have with technology. When fully immersed in the flow of the interaction, users are focused on their work without being aware of the technology, which results in a strong positive perception of the system and its performance. A disruption of this flow, however, shifts users' attention to the technology, leaving them with a negative perception of the interactive device and a less than optimal experience. Engineering standards and product design processes are now incorporating UX quality considerations to ensure system performance improvements that add value to users, but these practices remain a challenge in many cases because it is often difficult to translate "good" UX into quantifiable and actionable requirements. This paper describes a new approach to measuring system performance from an end-user’s perspective; proposing a more comprehensive mapping of UX from an existing performance metric, system response time. By incorporating those shorter, attentional SRTs for highly interactive devices, it will provide the necessary building blocks to ultimately measure flow.

5. Future research

One SRT, alone, does not usually make or break flow since flow is a feeling that happens over time. The measurement of flow will be based on the *accumulation* of a number of interactions. The research suggests that longer, non-attentive SRTs are non-linearly correlated to user perception, compared to the attentive SRTs that users are more sensitive to and better able to predict accurately. More studies are planned to develop these predictive models until there is a sufficient collection in each category to cover a range of interaction types and input modalities. These can then be used to assign to new SRT requirements using the three guiding principles, 1) user expectations, 2) perceived complexity, and 3) perceptual thresholds.

Research is also planned to study how these individual perceptions add up to generate an overall experience. Traditional performance evaluation tools take an average of the longer operation times to calculate overall scores. When it comes to user perception, however, the same scoring approach is not appropriate. Past research shows that users' negative experiences are weighted more heavily than positive experiences [21,22]. For example, Anderson et al. [23] and Oliva et al. [24] report that the relationship between attribute-level and overall product evaluations is asymmetric. These researchers and Oliver [25] also found that attribute-level dissatisfaction had a larger weight than attribute satisfaction in its effect on overall product evaluation. Moreover, in studies of perceptual salience's effect on memory, researchers found that negative information was more perceptually salient, was given more weight, and elicited a stronger physiological response than positive information [26]. Careful consideration of these and other factors will be important to predicting user-perceived performance with the help of new user-centric evaluation techniques such as presented in this paper.

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