Abstract
This paper presents an interdisciplinary analysis of time in life-critical human-computer interaction (HCI). How can a human or a computer provide the right information at the right time and in the right format to support appropriate situation awareness, decision-making and action taking? Time management is both constrained and facilitated by technology, organizations and people. Technological time depends on response speed and the types of processes involved (open-loop or close-loop). Organizational time depends on the types of interaction models (supervision, mediation or cooperation by mutual understanding). People’s time depends on expertise, experience and familiarity.

Author Keywords
Life-critical systems; time; HCI; taskload; cognitive functions, automated and controlled processes.

ACM Classification Keywords
H.5.m. Information interfaces and presentation (e.g., HCI): H.3.4. Context.

General Terms
Representation of time, time is space, time adaptation.
Introduction

Time is usually represented as an arrow (from left to right). For example, the evolution of a parameter $x$ as a function of time $f(t)$ is typically represented on a two-dimensional graph, $x = f(t)$. When $x$ is 2-dimensional, it can be represented as a surface evolving in time using perspective. The problem is that we are limited in the number of dimensions. A 3D parameter can be displayed as a dynamic vector as it is currently done on aircraft head-up displays for example. This introduces the problem of displaying synchronous versus asynchronous data. In this paper, we will focus on both types of data knowing in the case of static data sets, we can use animation to discover new insights by “turning around or into” it.

Time is very difficult to model because experimental data are context-dependent. Psychological (perceived) time is therefore different from real physical time. For example, durations can be perceived very differently according to individual, organizational, environmental and contextual conditions. In other words, time awareness depends on both people’s internal and external conditions. I will use my experience in aerospace to present the various concepts related to time in life-critical HCI, i.e., in systems where task performance can be time-constrained.

In this paper, I analyze task-related time in terms of technology, organizations and people (the TOP model: Boy, 2012). Technology has its own temporal attributes such as response time, amplitude of effects that it generates, and delays. Organizations also have specific temporal attributes related to various types of interconnections and interactions among agents. Finally, people have their own temporal attributes with respect to physiological, psychological and/or social dimensions.

Time and tasks

In life-critical systems (LCSs), a distinction is made between required time (RT) and available time (AT) for task performance. This leads to a definition of taskload, commonly used in timeline analysis. For a given task, taskload (TL) is approximated by the ratio RT/AT. AT mainly depends on work planning. RT mainly depends on expertise and skills of the user. Methods have been developed to assess HCI effectiveness such as GOMS (Card, Moran & Newell, 1983) and MESSAGE (Boy & Tessier, 1985), but they were limited to fixed RTs. People often operate under time pressure, and need to adapt both RT and AT. It may also happen that they execute tasks in parallel instead of in sequence.

TL is often used to measure human workload, which is a very difficult variable to grasp (Broadbent, Baddeley & Reason, 1990). It can be considered as both output and input of human activity. The more one has to do, the more one is loaded. The more one is loaded, the more one will be able to achieve, but up to a point after which one will have to change strategy and reduce your amount of work. Human performance oscillates between two limits: vigilance and stress. Perception of time between these two limits can be very different. Close to the vigilance lower level, required time to do something can be expanded; close to the stress upper limit, required time to do something can be shortened.

Time is not processed in the same way when people perform tasks sequentially or in parallel. In normal conditions, some tasks can be performed in parallel. They are automated, in Shiffrin and Schneider’s sense
Properly trained and experienced people know how to harmonize RTs and ATs of these automated tasks. However, in some abnormal or emergency situations, they may have to cancel parallel processing to focus on single tasks sequentially. They must readapt RT and AT at all times.

**Technological time**
Perception of technology response time, or processing time, can be different with respect to its time range. Around 0.1 sec ($10^{-1}$) nothing is perceived because the average scanning time of the visual sensory memory is about 0.25 sec. From an HCI point of view nothing has to be done. Around and beyond 1 sec ($10^0$), a delay is perceived. From an HCI point of view a symbolic time progression should be indicated to the user (e.g., usually a watch). Around and beyond 10 sec ($10^1$), the user may experience frustration and will need to be informed about what is going on (e.g., a short statement about what is going on and an explicit time progression must be displayed).

When technology supports a complex dynamic system such as a car, an airplane or a factory, dynamics should be displayed for situation awareness, decision-making and action purposes. Dynamics can be seen either open-loop (e.g., system’s input is not influenced by system’s output) or close-loop (e.g., system’s input is regulated by system’s output). This distinction can be used to develop three types of interaction models: (1) interruptible systems without conditions (e.g., a coffee maker); (2) interruptible systems under certain conditions (e.g., a car); (3) uninterruptible systems (e.g., an airplane). Time perception can be very different according to the type of model (Boy, 1993).

People manipulating systems interruptible without condition usually have enough time to react in case of failure. Danger is never high. No specific skill is required to handle this kind of systems. Systems that are interruptible under certain conditions require certain skills and knowledge to be learned. They are usually easy to handle except in some abnormal or emergency situations where time can become a real issue because of danger and therefore emerging stress. Uninterruptible systems require much longer training. They are typically close-loop, where loops cannot be broken. This kind of situation may cause additional parallel activities that require time-sharing processing.

**Organizational time**
Today, computers have cognitive functions like people. A cognitive function can be described by its role, context of validity and a set of associated resources (Boy, 1998). Cognitive function analysis can be used to optimize interaction, and more specifically time-wise, in human-computer systems. Thus time management can be improved through appropriate organizational setups.

People and machines interact using three types of interaction models: (a) supervision (e.g., the army model); (b) mediation (e.g., interaction between two countries through diplomacy); and (c) cooperation by mutual understanding (e.g., the Orchestra model: Boy, 2012). Time perception can be very different depending on the type of interaction model.

In the supervision model, human and/or machine agents barely can, or cannot, interact with each other without referring to a supervisor. Related interactions typically require substantial amounts of time. This is typically the case of someone who is looking for
guidance in a computer manual (playing the role of a supervisor) in order to interact with a basic computer. Supervision can be handled either by technology (e.g., online user manuals, tips and context-aware tools), organizations (e.g., cooperation with fellow workers) or people (e.g., an expert user). Interaction speed depends upon quality, connectivity and availability of supervisors.

In the mediation model, human and/or machine agents can interact with each other using a mediating interface that includes mediating agents (e.g., WYSIWYG interfaces, metaphoric agents). Users interact with the mediating interface and not directly with the core system. Related interactions are typically faster than in the supervision model.

In the cooperation by mutual understanding model, agents interact with each other using mental representations of the others and their environments (e.g., typical interactions between people). Each agent incrementally learns about the others to build an appropriate and effective mental model. Interaction speed depends on the level of maturity of the various mental models.

**People time**
One of the main assets of people is adaptation. Usually, one adapts, even when systems are not well designed. Adaptation may require a substantial amount of time and is not always guaranteed to be correct. In addition, people perceive and use time differently according to abilities and conditions. For example, when one experiences fatigue or a high workload, his/her performance may decrease substantially.

In HCI, the user can be novice, occasional or expert. It is clear that a novice will take more time to perform a given task than an expert. The main difference is in the way people anticipate their actions and organize their available cognitive functions to perform the task. Up to now, cognitive functions were internal, i.e., inside the user's brain. Today, with software and network capabilities, cognitive functions have become massively external, i.e., outside the user's brain. Consequently, access time to these cognitive functions can be different with respect to maturity of practice. If people are very well acquainted with external cognitive functions, performance can be much better than before in term of time. However, performance will be worse if it is not the case. Familiarity is one of the metrics that can be used to measure the amount of adaptation and coordination of cognitive functions involved in the interaction.

Since computers are now everywhere in our lives, it is time to better understand how human and computer cognitive function networks work. This is why cognitive function analyses are always suited in LCS's analysis, design and evaluation (Boy, 1998, 2011). It is not only a question of human-computer interaction in the classical sense, but also a question of interaction among human and computer agents in the social sense. Computers agents can be supervisors, mediators or smart agents (as can people). Depending on the interaction model, people's time management can be very different in terms of RTs and ATs.

Interaction time can also be affected by the way the relation between people and technology is supported. In life-critical systems, operational procedures are developed and used to that end. Operational
procedures are a special kind of automation: automation of people, as opposed to technology automation (Boy, 2012). Both types of automation tend to simplify and speed up interaction, but also rigidify it, maintaining people on preprogrammed interaction tracks. However, in some unplanned cases, people need more flexibility. They need to solve problems that are neither supported by automation nor operational procedures. Real-time problem solving is often time-demanding and requires specific skills and knowledge.

Discussion
Life-critical systems (LCSs) can be cars and airplanes, but also smart phones. As a matter of fact, if you lose your smart phone, you will experience a life-critical loss (e.g., life-critical information included in this external memory system). The Cloud can be seen as a technological solution to this problem. LCSs are now at the heart of our lives. Consequently, human-computer interaction needs to be considered in a broader scope than the traditional emphasis on office automation and telecommunication systems.

Externalization of (previously human) cognitive functions is one of the key factors of our recent socio-technical evolution. Access time has to be considered in various kinds of situations, including system failure and loss. Failure can come from technology (e.g., your cell phone or Wi-Fi access fails), organizations (e.g., your phone or computer network is not working) and people (e.g., human error). In our highly interacting world, externalization of cognitive functions tends to save time when the overall systems is working (relying on automation), but can lead to exponential processing time when it fails (requiring problem-solving). This is why it is important to anticipate failures and crisis management.

Anticipation enables us to maintain a reasonable taskload, i.e., keep RTs within ATs either by optimizing RTs or by maintaining a good situation awareness of ATs. Anticipation is planning RTs and ATs ahead. Problems come when interruptions occur. When people are interrupted in their interaction with an utterer, whether a human or a machine, they have to decide to continue what they were doing ignoring the interruption, or switch to another thread of actions to react to the interruption. This is always a matter of priority. Issues come into play when people change their thread of actions too many times, and/or when they forget to return to what they were doing before.

Even if multi-tasking can be preprogrammed, in real-world operations people often have to handle complexity in real-time (Loukopoulos, Dismukes & Barshi, 2009). Complexity management can be supported by supervision (i.e., an agent handles the various tasks and coordinates the cognitive functions involved), mediation (i.e., a set of agents mediates interactions among the other agents) or cooperation (i.e., all agents have appropriate internal representations of each other and their environment). Time management among involved cognitive functions is always facilitated by redundancy and/or recovery strategies learned in advance, either to compensate failing systems or human errors.

Conclusion
Timely information is crucial in life-critical systems. How can a human or a machine provide the right information at the right time in the right format? This
The paper presents an interdisciplinary approach of time for situation awareness, decision-making and action taking in life-critical human-computer interaction.

Referring to task planning, execution and feedback, required time (RT) should be compatible with available time (AT). RT and AT can be decreased or increased, but what matters is the optimization of TL, the ratio RT/AT. In addition, chronology of tasks can be thought of as either sequential or parallel, which also contributes to optimizing task time. In any case, anticipation enables to plan ahead best strategies for task time optimization.

There is a lot to be done on time in life-critical HCI. The purpose of this paper was to open a discussion on this topic within the HCI community as well as in the LCS community. I took the concept of taskload, as required time on available time, to portrait some of the issues involved in the interaction with LCSs. Analysis cannot be done on technology only; organization and people have to be taken into account concomitantly. For that matter, models of dynamics, agent interaction and people’s knowledge and skills are required to better understand the various issues presented in this paper.

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References