Annual Reviews in Control 38 (2014) 1–11

Contents lists available at ScienceDirect

Annual Reviews in Control

journal homepage: www.elsevier.com/locate/arcontrol

Review

From automation to tangible interactive objects

Guy André Boy

Human-Centered Design Institute, Florida Institute of Technology, 150 West University Boulevard, Melbourne, FL 32901, USA

A R T I C L E I N F O

Article history:
Received 16 October 2013
Accepted 12 February 2014
Available online 13 April 2014

A B S T R A C T

Automation led to many innovations for a long time, most of them were developed during the twentieth century. It was commonly thought as a layer on top of a mechanical system. It promoted system management over low-level control. The more information technology evolves, the more it takes a fundamental part in our lives. This article describes a paradigm shift where automation will no longer be an add-on, and where software supports the definition, implementation and operationalization of functions and structures of products from the beginning of the design process. Any design today starts by using computer-aided design tools that enable us to easily draw, modify and fine-tune any kind of system. We can fully develop an airplane and literally fly it as a complex piece of software. Usability and usefulness can be tested before anything physical is built. Consequently, human-centered design (HCD) is now not only feasible but also can drive the overall engineering of products. We have started to design products from outside in, i.e., from usages and purposes to means. We even can 3D print mechanical parts from the software-designed parts with ease. In human–computer interaction, specific research efforts are carried out on tangible objects, which define this inverted view of automation. We now design and develop by using information technology to do mechanical things, and therefore redefine the essence of a new kind of cognitive mechanical engineering. This article is about the revolution that is currently happening in engineering and industrial design due to the immersive influence of computers in our everyday life, and the expansion of HCD.

Contents

E-mail address: gboy@fit.edu

http://dx.doi.org/10.1016/j.arcontrol.2014.03.001
1367-5788/

1. Introduction

This article is an extension of a keynote given during the IFAC Human–Machine Systems conference, held in Las Vegas on August 14, 2013. The title of the initial talk was: "Human Systems Integration: Unifying Systems Engineering (SE) and Human Centered Design (HCD)." Since the keynote explained the shift from automation (i.e., including information technology and control theory into mechanical systems) during the twentieth century, to tangible interactive objects (TIOs, i.e., providing physical shape to and grasp of software artifacts), it was decided to reshape the title of this article, which also follows up the conclusion of the Handbook of Human–Machine Interaction that emphasizes the shift from automation to interaction design (Boy, 2011). However, the unification of SE and HCD remains a major component of the essay.

A TIO is a robotic artifact, ranging from a piece of software to a physical artificial agent, which has reasoning and/or reactive computational features and, therefore a role, a context of validity and appropriate resources (i.e., cognitive functions, later defined in the article). We now find TIOs in various kinds of habitats, vehicles, public places and industry. TIOs are the result of the evolution of computer science and engineering toward ubiquitous and pervasive computing, where computers make themselves invisible buried into appliances and systems of any kind (Mark, 1999; Weiser, 1991). Recent development of *modeling and simulation* (M&S), high connectivity, 3D printing and TIOs enable effective human-centered design, leading to human-systems integration. Making a TIO is no longer automating a previously developed physical object or machine; it is progressively designed, from the start, as a software object that is transformed into a physical entity.

Automation led to many innovations for a long time, most of them were developed during the twentieth century. More than thirty years ago, advanced automation enabled the shift from three to two crewmen in commercial aircraft cockpits and led to the glass cockpit concept (Boy & Tessier, 1985). This article is based on this initial experience as well as on nearly all Airbus cockpit designs and evaluations from the A 300 FF (Garuda) to the A 380 (Boy, 1998a, 1998b, 2011). It is also based on automation experience in other domains such as US Space Shuttle and Space Station procedure following and documentation systems (Boy, 1987, 1991), the NASA Lunar Electric Rover (the LER was renamed Space Exploration Vehicle) design and more specifically its navigation system (the Virtual Camera project; Boy & Platt, 2013), various control rooms in nuclear, telecommunications and aviation industries (Boy, 2011), and most recently the design of an interactive rocket launch control room at Kennedy Space Center. This 35-year experience is the main ingredient for a vision of the shift from automation to TIOs, and analysis of the mutual influence of engineering, information technology, human and social sciences, and design.

The organization of this article is as follows. In Section 2, the evolution of automation is presented. The cognitive function model is described to support a better definition of automation reactions to expected and unexpected events, as well as function allocation and the concept of emergent cognitive functions. In Section 3, human-centered design is explained and reasons are given why it is now possible. In Section 4, it is shown how the V-model can be transformed to integrate HCD and SE. It is shown why the concept of user interface is a wrong concept when it is used at the end of a design and development project instead of starting by analyzing, designing and evaluating technology, organizations and people's jobs holistically from the beginning. In Section 5, the Orchestra organizational model supporting HCD is presented. It is based on a multi-agent approach and cognitive engineering principles. It is very important at this point to operationalize the cognitive function concept. Section 6 is devoted to discussions on the shift. In Section 8, some concluding remarks are given.

2. Evolution of automation

The Bing dictionary provides an interesting definition of *automation* that deals with the "replacement of human workers by technology: a system in which a workplace or process has been converted to one that replaces or minimizes human labor with mechanical or electronic equipment." Automation has several synonyms such as mechanization, computerization and robotics (http://www.bing.com). Automation has lots of advantages such as increasing productivity, quality, robustness, consistency and product returns (mainly by decreasing costs). Sheridan contributed to describe and foster the evolution of automation (Sheridan, 1992, 1997, 2002). Automation also has some issues such as rigidifying practices, increasing complacency of people involved in supervisory control, decreasing and sometime removing human skills (Billings, 1991). Let's further describe automation using a more formal approach supported by the cognitive function formalism.

2.1. Cognitive functions

Automation can be described as a transfer of *cognitive functions* from people to machines (Boy, 1998b). A cognitive function is defined by three attributes: *role*, *context* of validity and necessary *resources* supporting the use of it. A cognitive function enables the execution of a task and produces an activity. Therefore, the input of a cognitive function is a task, and its output is an activity. Using this definition, we can characterize the activity of a human or a system who/that has to execute a task (Fig. 1). This formalism was successfully used to help figure out the various roles that are transferred from people to systems, as well as in what contexts they are valid and what resources they need to perform a given task, e.g., in aircraft automation (Boy, 1998a).

Cognitive functions are very similar to Leont'ev's *functional organs* (Boy, 2002; Leont'ev, 1981). These concepts were developed by the Russian activity theory school, and by Alexei Leont'ev and Victor Kaptelinin in particular. "Functional organs are functionally integrated, goal-oriented configurations of internal and external resources. External tools support and complement natural human abilities in building up a more efficient system that can lead to higher accomplishments. For example, scissors elevate the human hand to an effective cutting organ, eyeglasses improve human vision, and notebooks enhance memory. The external tools integrated into functional organs are experienced as a property of the individual, while the same things not integrated into the structure of a functional organ (for example, during the early phases of learning how to use the tool) are conceived of as belonging to the outer world." (Kaptelinin, 1995).

Cognitive function analysis (CFA) is then a very useful approach and method to better understand how functions can be allocated among humans and systems. CFA was defined and developed

Fig. 1. A cognitive function defined as transforming a task into an activity, and being defined by a role, a context of validity and a set of resources.