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The changing industry structure of software development for consumer electronics and its consequences for software architectures

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ABSTRACT

During the last decade the structure of the consumer electronics industry has been changing profoundly. Current consumer electronics products are built using components from a large variety of specialized firms, whereas previously each product was developed by a single, vertically integrated company. Taking a software development perspective, we analyze the transition in the consumer electronics industry using case studies from digital televisions and mobile phones. We introduce a model consisting of five industry structure types and describe the forces that govern the transition between types and we describe the consequences for software architectures.

We conclude that, at this point in time, software supply chains are the dominant industry structure for developing consumer electronics products. This is because the modularization of the architecture is limited, due to the lack of industry-wide standards and because resource constrained devices require variants of supplied software that are optimized for different hardware configurations. Due to these characteristics open ecosystems have not been widely adopted. The model and forces can serve the decision making process for individual companies that consider the transition to a different type of industry structure as well as provide a framework for researchers studying the software-intensive industries.

1. Introduction

The consumer electronics industry, i.e. TVs, set-top boxes (STBs), audio and video storage devices and mobile phones, has gone through substantial changes during the last 15 years. From its inception until around 2000, the industry was dominated by a small group of consumer electronics companies. Each company was responsible for the complete design of its products and developed many of the product components. For decades, the cost of designing a product was negligible, compared with the material and manufacturing costs. However, as the functionality increased as the capabilities of their integrated circuits followed Moore's law; the relative design cost became a significant factor. Furthermore, as processors became fast enough to process video and audio in software, it became possible to serve a wider customer base with more product variants from a single hardware platform. This contributed to a shift in the balance of development costs from hardware to software. In order to amortize these development costs more widely, independent software and IC companies emerged, either as spin-offs from consumer electronics firms or as newly created companies, and these became major players.

In this paper we analyze the transitions in the structure of the consumer electronics industry and we introduce a model that describes the different industry structures that we have identified. These structures are presented from the perspectives of software architecture and industry structure. Since the consumer electronics industry structure is still in flux, we draw analogies from the computer industry, which went through a similar evolution. Grove (1996) described the changing structure that took place in the computer industry between 1980 and 1995. In 1980 that industry was dominated by a small group of companies that behaved as vertical silos, meaning that they developed the entire system, from ICs to sales and distribution, see Fig. 1.

By 1995 the vertical silos had been replaced by modular clusters, i.e. groups of companies that were dominant in certain parts, or layers, of the system. This transition was facilitated by the high degree of modularity that was created (Baldwin and Clark, 1997;

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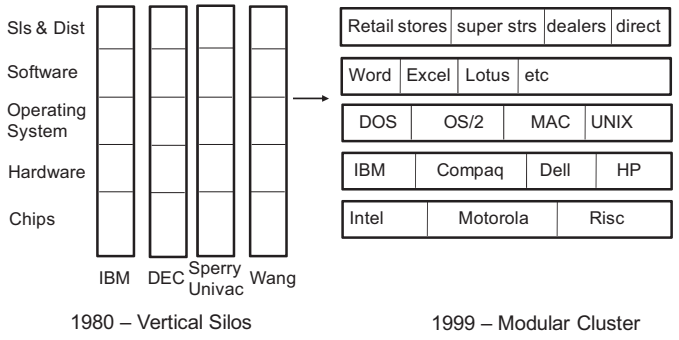

Fig. 1. Changing structure of the computer industry, adapted from (Grove, 1996), p. 44.

Christensen et al., 2004). This transition resulted in an ecosystem, which is formulated by Moore (2006) follows: "An intentional community of economic actors whose individual business shares in some large measure the fate of the whole community".

Some authors, e.g. van Genuchten (2007) and Suoranta (2006), predicted that the consumer electronics industry would follow an evolution similar to the computer industry. So far, however, this state has not been achieved and in this paper we will show why this is not the case. To explain the current industry structure and its evolution, we have developed a model consists of five industry structure types:

Type 1: Vertically integrated firms
Type 2: System integrators and specialized suppliers
Type 3: Supply chains
Type 4: Closed ecosystems
Type 5: Open ecosystems

In this paper we show that the evolution in the consumer electronics industry followed a structured, logical pattern and, at the time of writing, a software supply chain is the dominant industry structure. The industry has not evolved to type 4 or 5 due to the characteristics of the products, i.e. the need to make optimal use of system resources, the high degree of variability and the high rate of innovation. The consequence of this is a lack of industry-wide standards and hence a limited degree of modularity.

The key contributions of this paper are twofold:

1. We introduce a model consisting of five industry structure types which captures the evolution of software development for consumer electronics. This model is developed using a case study research method, with case studies from digital televisions and mobile phones.
2. We describe the forces that govern the transition between types and the consequences for product line architectures. These forces can serve the decision making process for individual firms for selecting the most appropriate industry for their business.

The remainder of the paper is structured as follows. In Section 2 we present background and related work, followed by a section concerning our research method. Section 4 presents a high level overview of the case studies of digital televisions and mobile phones, from which we build our industry structures model that is presented in Section 5. Sections 6 and 7 provided an elaboration of the case studies, focusing on the rationale behind the transitions and the consequences for software architectures. This paper concludes with a comparison of related work, our conclusions and the identification of areas for further research.

2. Background

In this section we describe the characteristics of embedded and consumer electronics products, and related work on industry structures and transitions.

2.1. Characteristics of consumer electronics products

A consumer electronic product consists of a combination of hardware and software that is designed to perform specific functions, often with real-time performance requirements and constrained computing resources. The products include DVD-players, televisions, cameras and mobile phones. Since different market segments usually have different requirements, a company may develop a range of variants to serve different groups of customers (van Ommering, 2004). Each group of customers receives products that serve their specific needs. The concept of product line engineering is widely applied in consumer electronics (PHOF, 2010). This allows for an efficient creation of variants of product using reusable development artifacts (Pohl et al., 2005).

There is a high pressure on the cost price, so the integrated circuits (ICs) should have the smallest possible footprint. Furthermore, for handheld products, these ICs should use as little energy as possible, given the limited power sources and options for heat dissipation. In order to satisfy these requirements, the amount of software has to be minimized as much as possible and the software must operate as efficiently as possible. As a consequence, an IC usually only contains the software that is needed for the particular product, or a group of similar products, in which it is used.

2.2. Organizational networks and software supply chains

Porter (1980) introduced the term value chain to describe the activities needed to make a product and the value that each of activities created for the end product. Later this method has been extended to analyze value chains in an inter-organizational context, denoted as the value system (Porter, 1985), including the activities of upstream and downstream participants in a supply chain. A supply chain is defined as: "A network that starts with raw material, transforms them into intermediate goods, and then into final product delivered to customers. Each participant consumes logical and/or physical products from one or more upstream suppliers, adds value, usually by incorporating them into more complex products, and supplies the results to downstream consumers" (Lee and Billington, 1994). In the software industry, companies have emerged that are specialized in a certain software product or service (Greenfield and Short, 2004). As an example, consider the supply chain in Fig. 2. There are four links, starting with an audio decoding software vendor and ending with a car manufacturer.

In a supply chain, each of the participants uses components containing variability, combines them with in-house developed components, and delivers specialized components containing variability to its customers. For example, a manufacturer of car infotainment systems uses multiple suppliers for media processing, navigation, and connectivity to create a product line for different car manufacturers.

Jansen et al. (2007) introduced the term software supply networks (SSN) and identified that the software architecture is created based on products and services from other parties in the network. Peppard and Rylander (2006) identified the strong co-operative behavior and relationships between the parties in such a network.

2.3. Industry de-verticalization and creation of software ecosystems

Moore (2006) formulated an ecosystem as follows. "An intentional community of economic actors whose individual business