# On the Capabilities of Digimaterial Artifacts
## *Structures, Symbols, Actions*

Lars Bækgaard
*Department of Business Development and Technology, Aarhus University,*
*Birk Centerpark 15, DK-7400, Herning, Denmark*

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Abstract: The purpose of the paper is to propose and discuss three types of capabilities of digimaterial artifacts like laptop computers, cameras, cars, robots etc. Digimaterial artifacts are material artifacts that combine digital and non-digital elements by bearing one or more digital artifacts. Digital artifacts are linguistic expressions like, say, binary sequences of 0's and 1's. Software and databases are examples of digital artifacts. Paper pieces with digital inscriptions and cars with data and software are examples of digimaterial artifacts. Digimaterial artifacts can bear, and potentially manipulate, digital artifacts. We describe and discuss digimaterial structures and the capabilities that are enabled by these structures. And we describe and discuss the plastic nature of such structures and capabilities. We expect that our work can be used to understand digimaterial capabilities and to analyse and design digimaterial structures that possess a relevant set of capabilities.

# 1 INTRODUCTION

The purpose if this paper is to define and discuss three types of capabilities that can be used to characterize the similarities and dissimilarities between artifacts like cameras, laptop computers, printers, smartphones, robots, and cars. Such artifacts may have capabilities that are based on a combination of digital and non-digital elements. A smartphone has storage capabilities for digital data, technology for processing of digital data, and a material body. Similarly, a camera may be constituted by digital storage and processing technology and material components like glass.

Terms like IT artifacts (Orlikowski and Iacono 2001), digital artifacts (Kallinikos, Aaltonen et al. 2013), digitalized artifacts (Yoo 2010), and digital technology (Yoo, Henfridsson et al. 2010) can be used to denote different aspects of artifacts that combine digital and material elements. The term IT artifacts can be used to refer to a totality of information and technology (Goldkuhl 2013). The term digital artifact can be used to refer to digitally represented data and software (Kallinikos, Aaltonen et al. 2013). The term digital technology can be used to refer to technological artifacts with digital storage and processing capabilities (Yoo, Henfridsson et al. 2010).

In order to avoid term ambiguity, we distinguish between digital artifacts and digimaterial artifacts. We use the term *digital artifact* to denote information artifacts like binary expressions and bar codes. Digital artifacts can be viewed as non-material artifacts that can be materialized by material artifacts that bear them (Faulkner and Runde 2011, Faulkner and Runde 2013). A piece of software may be viewed as a digital artifact that is constituted by a binary expression, i.e., a sequence of zeroes and ones. This sequence is, in itself, a conceptual, linguistic entity. It is non-material. A hard disk or a USB drive may bear a representation of the software. These artifacts are examples of digimaterial artifacts. An e-book is a digital artifact that is constituted by binary expressions. An e-book reader that bears the e-book is a digimaterial artifact.

We use the term *digimaterial artifact* to denote material artifacts that bear (and potentially manipulates) one or more digital artifacts. We present and discuss essential characteristics of digimaterial artifacts.

Our conceptualization can be used to understand the digital artifacts that are beared by and processed by means of digimaterial artifacts. Also, it can be used to understand how the potential capabilities of digimaterial artifacts depend on a combination of



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digital and non-digital elements.

The paper is structured as follows. In Section 2, we define the notion of digital artifacts. In Section 3, we discuss the notion of digimaterial artifacts. In Section 4, we define and discuss three types of capabilities that digimaterial artifacts may possess. In Section 5, we discuss the plastic nature of digimaterial artifacts. In Section 6, we discuss our findings, conclude the paper and suggest directions for future research.

# 2 DIGITAL ARTIFACTS

In this section, we discuss essential characteristics of digital artifacts like databases, text files, software etc. The purpose is to create an understanding of the roles played by digital artifacts in artifacts like laptop computers, cameras, robots, cars etc. In order to distinguish between digital and material aspects of such artifacts we distinguish between digital artifacts and the digimaterial artifacts that bear digital artifacts.

We view a *digital artifact* as a linguistic expression that is based on set of discrete symbols. In the present paper, we focus solely on binary digital artifacts where information is represented by means of sequences of bits (binary digits). Usually, the symbols 0 and 1 are used to represent binary digits in the binary numeral system in which sequences of bits are used to represent numbers that in turn may represent software, images, text, music etc.

The syntax and semantics of the binary numeral system can be represented by written expressions on, say, a piece of paper and the same holds for binary expressions. The piece of paper can be called a bearer of the expressions (Faulkner and Runde 2011, Faulkner and Runde 2013). Bearers and the expressions they bear represent a material aspect of language. Databases, software, configuration files, digital music files, digital image files, digital text files etc. are examples of digital artifacts.

Binary expressions can be viewed as non-material artifacts (Faulkner and Runde 2011, Faulkner and Runde 2013). However, digital artifacts become material-like when material artifacts bear them (Leonardi 2010).

Digital artifacts can be divided into connected components (Parnas 1972, Bækgaard 1990, Henfridsson, Mathiassen et al. 2009, Kallinikos and Mariátegui 2011).

*Data Components* can be based on media files (Kallinikos and Mariátegui 2011) or databases (Codd 1970, Chen 1976). Media files like images, videos, text etc. can be divided into data components and distributed on a number of digimaterial artifacts. Likewise, databases can be divided into data compoments and districuted on a number of digimaterial artifacts.

*Software Components* can be procedures based on procedural programming languages. Also, software components can be parameters that represent software properties in a way that can be used to change selected software properties without changing the source code itself (Bækgaard 1990).

# 3 DIGIMATERIAL ARTIFACTS

In this section, we discuss essential characteristics of digimaterial artifacts. We view a *digimaterial artifact* as a material artifact that bears one or more digital artifacts. Binary expressions constitute the digital core of contemporary digimaterial artifacts. No material artifacts are completely digital. There will always be non-digital elements in material artifacts. A digimaterial artifact may (but does not have to) contain technology that can process digital artifacts.

## 3.1 Components

A digimaterial artifact is constituted by a set of material components. At least one of the connected components must be a digimaterial artifact. Some components may have no digital elements. For example, the front glass plates on many smartphones are purely non-digital. Digimaterial components combine material and digital aspects.

## 3.2 Connectivity

*Mechanical Connections*. Material components may be connected by means of mechanical connections. For example, car components like doors and car bodies may be connected be means of mechanical connections between the components.

*Electrical Connections*. Digimaterial components may be connected by means of a combination of mechanical and electrical connections. For example, car components like steering wheels and driving wheels my be connected by means of a combination of material and electrical connections between components.

*Digital Connections*. Electrical connections can be used to establish digital connections by interpreting binary electrical signals as binary information. This makes digimaterial artifacts communicable (Yoo 2010) by facilitating sharing of binary information across digimaterial artifacts. Individual digimaterial artifacts or groups of digimaterial artifacts can be selected as targets because they are addressable (Yoo 2010).

*Digital Associations*. Digital components may be associated by means of relationships between data elements (Codd 1970, Chen 1976) or by means of hyperlinks in, say, Web 2.0 structures. Digital components may be related to and identified with other entities (such as other artifacts, places, and people) based on certain commonly shared attributes. Digital associativity is enabled by tags, keywords, or affiliation patterns (Yoo 2010).

Connectivity enables the distribution of digimaterial components on a variety of locations and distribution of digital artifacts across a variery of digimaterial artifacts (Kallinikos, Aaltonen et al. 2013).

# 4 DIGIMATERIAL CAPABILITIES

In this section, we create a vocabulary that captures essential similarities and dissimilarities between digimaterial artifacts. We propose three types of digimaterial capabilities. We suggest that the capabilities of digimaterial artifacts can be classified as structural capabilities, symbolic capabilities, and action capabilities.

## 4.1 Structural Capabilities

Digimaterial structures can be viewed as capabilities in their own right. Digimaterial artifacts can possess such structural capabilities. A car can keep driver and passengers in fixed positions on seats while the car is driving. A robot can grap an object and keep it in a fixed position. An elevator system can keep a car at a fixed position in a hoistway. The spatial distribution of a digimaterial artifact distributes access to the artifact.

## 4.2 Symbolic Capabilities

Digimaterial artifacts can possess symbolic capabilities. Often, the symbolic capabilities of digimaterial artifacts are based on the digital artifacts they bear. Binary information stored on hard disks can represent sound, text, images, movies etc. The information can be presented on, say, displays in ways that are relevant for human beings.

The symbolic capabilities of digital artifacts are the basis of information systems that capture, store, manipulate and present information (Checkland and Holwell 1998, Avison and Fitzgerald 2006, Alter 2008). A digimaterial artifact can use action capabilities like control, modify, sense, and move to process digital artifacts with the intention of manipulating their symbolic capabilities.

## 4.3 Action Capabilities

Digimaterial artifacts can possess action capabilities. An action capability is a type of action that a digimaterial artifact can perform. Below, we focus on four types of such action capabilities: *Control*, *Modify*, *Sense, and Move* (Bækgaard 2006, Bækgaard 2011, Bækgaard 2016).

*Control* is an action capability that makes it possible for a digimaterial artifact to request that a target object executes a specified action (Bækgaard 2016). Digimaterial artifacts can control (digi)material artifacts. For example, a smartphone with suitable apps can be used to control heating devices and drones.

*Modify* is an action capability that makes it possible for a digimaterial artifact to modify the state of a target object (Bækgaard 2016). For example, 3D printers can transform ink into 3-dimensional objects. And programmers can modify software. Many digimaterial artifacts can process binary expressions. Binary expressions can be used to control the manipulation and transformation of binary expressions.

*Sense* is an action capability that makes it possible for a digimaterial artifact to sense aspects of the states of target objects (Yoo 2010, Bækgaard 2016). Digital cameras can sense light waves. Digital watches can sense movement.

*Move* is an action capability that makes it possible for a digimaterial artifact to change the location of a material target object (Bækgaard 2016). For example, robots can move material objects. Digimaterial objects like drones and cars can move themselves. Digital artifacts cannot be moved. They can be copied and deleted. Apparent movement of digital artifacts can be imitated by means of a combination of sense and modify (delete).

# 5 PLASTICITY

Digimaterial artifacts are plastic in these sense that they can be modified (Bækgaard 1990, Yoo, Henfridsson et al. 2010, Kallinikos, Aaltonen et al.

2013). The plasticity of a digimaterial artifact is to a large extent enabled by the flexibility and modifiability of the digital artifacts it bears.

Digital artifacts like Internet pages (Kallinikos, Aaltonen et al. 2013), image files (Kessler 2009), and search engines (Orlikowski 2007) are modifiable. Digital artifacts are expandable (Kallinikos, Aaltonen et al. 2013) within the limits of the storage capabilities of the bearing digimaterial artifacts.

Programmed rules can be expressed as a combination of software and parameters (Bækgaard 1990). If the software or the parameters are changed, the programmed rules and thereby the logic of the computer is changed and its behaviour is changed correspondingly.

Traditional digimaterial artifacts like computers can be viewed as implementations of Turing machines. A Turing machine is a conceptual model of a programmable machine (Turing 1936). A specific instance of a Turing machine uses a set of programmed rules to transform numbers to numbers. Likewise, a computer uses programmed rules to transform bit sequences to bit sequences.

Usually, the programmed rules are expressed by means of a combination of software (expressed by means of programming languages) and parameters (Bækgaard 1990). If the software or the parameters are changed, the programmed rules and thereby the logic of the computer is changed and its behavior is changed correspondingly.

The plasticity of digimaterial artifacts that is rooted in the flexibility and modifiability of the beared digital artifacts has a number of important implications as illustrated by the following examples.

*Programmability*. Digimaterial artifacts are partially programmable (Yoo 2010). They can accept new logic to modify their structures and the enabled capabilities.

*Late Binding*. Digimaterial artifacts support late binding of properties (Hylving, Henfridsson et al. 2012).

*Weak Coupling*. The structures of digimaterial artifacts are plastic and the coupling between form and function is weakened (Autio, Nambisan et al. 2018).

*Flexible Use*. Digimaterial artifacts possess use plasticity in the sense that there are multiple ways of activating functions and exploring information (Kallinikos, Aaltonen et al. 2013). For example, there are multiple ways to explore the content of databases.

*Flexible Re-configuration*. Digimaterial artifacts can be designed as flexible assemblages, i.e. "... arrangements of different entities linked together to form a new whole ..." (Müller 2015). Typically, the digimaterial artifacts that constitute an assemblage are autonomous and their connections are flexible.

# 6 DISCUSSION, CONCLUSION AND FUTURE WORK

Our conceptualizations can be viewed as a generalization and unification of existing conceptualizations (Orlikowski and Iacono 2001, Yoo 2010, Yoo, Henfridsson et al. 2010, Goldkuhl 2013, Kallinikos, Aaltonen et al. 2013, Matook and Brown 2017).

We have defined a digital artifact as a linguistic expression that is based on a discrete set of symbols like, say, the binary numeral system. And we have defined a digimaterial artifact as a material artifact that bears one or more digital artifacts. Binary digital artifacts (bit sequences) can be stored directly on and by manipulated by contemporary technology with digital capabilities. For example, a laptop computer may be viewed as a digimaterial artifact that bears binary digital artifacts like software and databases. As another example, many cameras may be viewed as digimaterial artifacts that bears binary digital artifacts like image files and image processing software.

We have characterized the plastic structures of digimaterial artifacts in terms of connected and layered components. We have characterized the capabilities of digimaterial artifacts in terms of action capabilities, symbolic capabilities, and structural capabilities. Each capability type applies to the digital as well as the material aspects of digimaterial artifacts. Many digimaterial systems are based on a combination of the three types of capabilities.

The capability types can be used to unite two important applications of digimaterial artifacts. *First*, they can be used to characterize information systems perspective where the symbolic capabilities are at the core. In such systems, the material aspects and the enabled action capabilities support the symbolic capabilities. For example, an ERP system may be based on symbolic capabilities (for example, digitally represented information), action capabilities (for example, capture and manipulation of information), and structural capabilities (for example, distribution of access to the system and its information).

*Second*, they can be used to support the material perspective perspective where structural capabilities and material action capabilities are at the core. In such systems, the digital artifacts support the material action capabilities. For example, a robot may be based on symbolic capabilities (for example, information that represents its actions), action capabilities (for examole, movement of robot arms), and structural capabilities (for example, the ability to hold an object in a fixed position).

Future work includes experiments with the use of our conceptualizations for analysis and design of networks of digimaterial artifacts.

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