

Capabilities

Eric C. MERRELL^{ab1}, David G. LIMBAUGH^{ab2}, Peter M. KOCH^{ac}, Barry SMITH^{ab}

^a*National Center for Ontological Research Lab*

^b*University at Buffalo, Department of Philosophy*

^c*Villanova University, Department of Philosophy*

Abstract: We propose a definition of **capability** as a class intermediate between **function** and **disposition** as the latter are defined in Basic Formal Ontology (BFO). A disposition inheres in a material entity and is realized in a certain kind of process. An example is the disposition of a glass to break when struck, which is realized when it shatters. A function is a disposition which is (simply put) the rationale for the existence of its bearer. To say for example that a water pump has the function to pump water is to say that the pump exists *because* something was needed that would pump water. Capabilities are a special sort of disposition in that that, like functions, they can be evaluated on the basis of how well they are realized. They differ from functions in that their realizations are not the rationale – not the primary reason – for the existence of their bearers. Thus, a water pump may have many capabilities, including to be weatherproof, to run without lubricant, and so forth, but only one function. All functions are capabilities on the view we defend, but not all capabilities are functions. We develop a series of axioms to distinguish capabilities formally from both dispositions and functions and provide examples of the use of ‘capability’ in a variety of domains.

Keywords: capability, disposition, function, interest, Basic Formal Ontology

1 Introduction

A capability of an entity is, intuitively, the potential for that entity to do something useful. We often speak of software capabilities, the capabilities of athletes, the capabilities we will develop by taking guitar lessons, and so on. Our purpose here is to further elucidate the meaning of the term ‘capability’.

¹ Corresponding author, Eric Merrell, Department of Philosophy, University at Buffalo, 135 Park Hall, Buffalo, NY 14260-4150, USA; E-mail: ericmerr@buffalo.edu

² David Limbaugh’s contribution to this research was supported by an appointment to the Intelligence Community Postdoctoral Research Fellowship Program at the University at Buffalo, administered by Oak Ridge Institute for Science and Education through an interagency agreement between the U.S. Department of Energy and the Office of the Director of National Intelligence.

Some entities can perform activities that are helpful or desired. My car can take me places I want to go. My feet and legs can propel me forward, thereby enabling me to walk. My phone can broadcast my voice over long distances, thereby enabling me to talk to people who are far away. Because of sand's malleability, I can sit comfortably on the beach while I enjoy the sound of the ocean. Knowledge of the potential for such activities is helpful when making decisions and when seeking to accomplish goals. Thus, it is often helpful to know what kinds of activities the entities available to us are able to perform.

In Basic Formal Ontology (BFO), a widely used international standard top-level ontology, the potential for some entities to perform an activity is captured with the term 'disposition' [6]. Dispositions are real potentials; materially grounded features of things that are *realized* in changes in the world. For instance, my car has the disposition to take me places and this disposition is realized in the processes of taking me places. It also has the disposition to hold a certain quantity of mass in the form of passengers and luggage, which is realized in the car's preventing that quantity of mass, when loaded, from continuing towards the ground. My car also has the disposition to scare away racoons with the sound of its horn, and this disposition is realized in the horn's *sounding* and in the racoons' *scattering* in fear.

Among the dispositions of my car is its BFO function: the disposition whose realizations provide the reason why my car exists [2], again: in order to transport myself, my passengers, their luggage, and so on. For an artifact the BFO function is the disposition that is realized in those activities that the artifact was designed to perform. But there are also functions that are the product of evolutionary selection. For example, my heart's function (or one of its functions) is to pump blood because an organ for pumping blood contributed to keeping my ancestors alive. Plantinga famously described the idea of proper function. He notes that central to this idea is ... the notion of a design plan:

we must look further into this idea of design: it is much richer and more complex than it initially looks. A thing's design plan is the way the thing in question is 'supposed' to work, the way in which it works when it is functioning as it ought to, Computers, automobiles, and linear accelerators have design plans, but so do plants, animals, hearts, livers, immune systems, digestive tracts, and the like. There is a way in which your heart is supposed to work: for example, your pulse rate should be about 55—80 beats per minute when you are at rest, and (depending on your age) achieve a maximum rate of some 180 beats per minute when you are exercising. If your resting pulse is only 10, or if it goes up to 250 upon walking slowly up a short flight of stairs, then your heart (or something in your circulatory system) is not functioning properly; it is not functioning according to the design plan for human circulatory systems [27].

The realization of a **function**³ of its bodily parts is, now, something in which an organism has an interest. But this captures only a small portion of those dispositions in whose realization someone or some organism might have an interest. Consider: while a flat head screwdriver has the function *to drive slotted screws using torque*, it also has the disposition *to open paint cans*.

It is to account for this wider set of cases that we introduce a new subtype of **disposition**, which we call **capability**. Capabilities are essentially the potentials (dispositions) that people (and other entities) have to perform activities which help us to achieve our goals, including the evolutionary goals of reproduction and survival.

2 Background

The field of applied ontology focuses on creating controlled vocabularies, which can be used to tag and organize large amounts of data in order to promote more successful finding and comparing and querying of data. Ontologies provide also a logically consistent set of terms that all of those working in a given domain can use in order to promote the interoperability of their respective data systems. Basic Formal Ontology (BFO) is a top-level ontology, by which we mean that it is an ontology that is domain neutral in that its terms refer to the most general categories, such as *object* or *process* [1]. BFO is widely used in bioinformatics, and is increasingly being used in manufacturing, and in the defense and intelligence industries [4][8][9][10]. BFO already has terms that allow us to describe what entities have the potential to do. However, we will see that, to do justice to what we have called ‘capabilities’, an expanded account is required. First, we describe briefly the relevant parts of BFO, and then show where the BFO description of the potentials of entities needs further elaboration.

2.1 BFO

We focus on a specific branch of BFO, the branch whose root is the class, **realizable entity**, illustrated in Figure 1. Note that BFO, like all ontologies, rests on an open-world assumption. Thus, it is possible that further subtypes of realizable entities will be incorporated into the BFO framework in addition to those represented here.

³ We shall from here on use **bold font** for classes in an ontology.

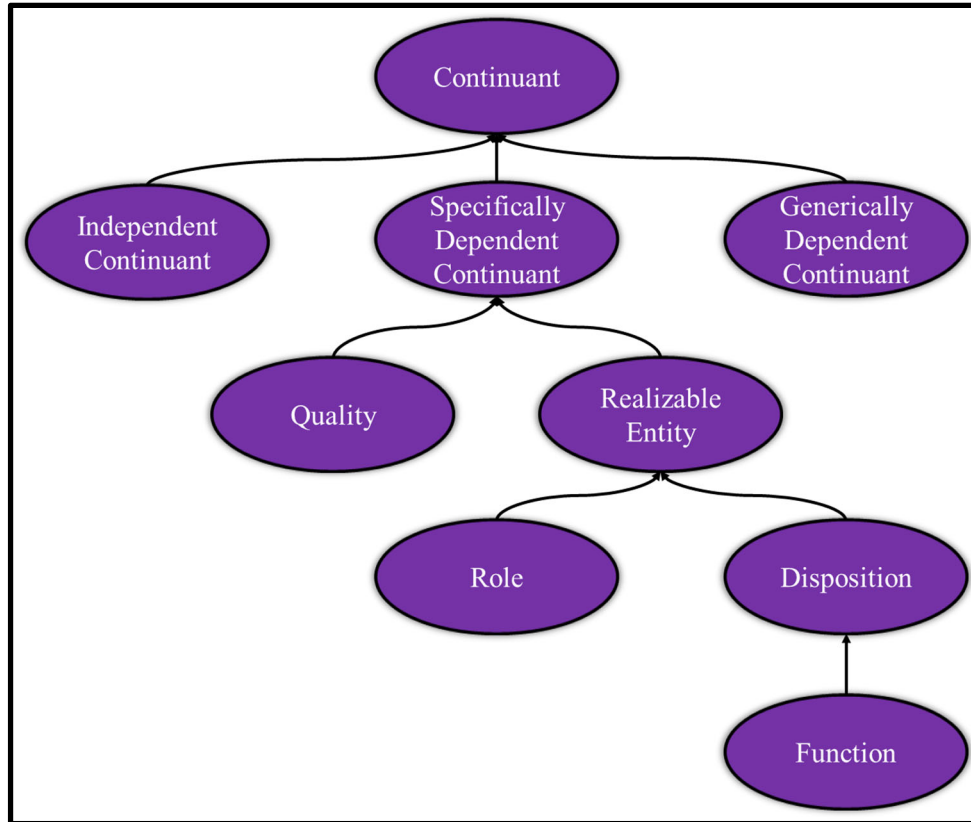


Figure 1: Fragment of the BFO Continuant Hierarchy

To understand ‘continuant’ we start out from the all-embracing BFO term ‘entity’, which we elucidate⁴ as follows:

ELUCIDATION: An *entity* is anything that exists or has existed or will exist. Examples include: Julius Caesar, the Second World War, your body mass index, Verdi’s *Requiem*.

Entities that are fully present at every time that they exist are called ‘continuants’:

ELUCIDATION: A *continuant* is an *entity* that persists, endures, or continues to exist through time while maintaining its identity. Examples include: a human being, a baseball, a cave, a region of space, someone’s temperature, someone’s diabetes, and so on. When you hold a baseball in your hand it is entirely there, no

⁴ We draw a technical distinction between ‘elucidation’ and ‘definition’. Elucidations are descriptions provided to help fix the referent of primitive terms; definitions express necessary and sufficient criteria for an entity to fall under that definition.

portion of it is missing in time. This is in contrast with a baseball *game*, only part of which may exist at any given time.

An independent continuant is a continuant that does not depend on anything for its existence.⁵

DEFINITION: *b* is an *independent continuant* =Def. *b* is a *continuant* which is such that there is no *c* such that *b* depends on *c*.

Consider again the baseball. It has a shape and that shape can change – perhaps the pitcher compresses the ball to make his pitches harder to hit. However, as the shape of the ball changes, the ball remains in existence. A baseball is independent of its specific shape, mass, velocity, and so on.

Dependent continuants, in contrast, are those entities which depend upon some other entity in order to exist. For example, shapes, masses, colors, and so forth. These are called **specifically dependent continuants (SDCs)**, since each is such that it depends on some specific bearer or carrier for the entirety of its existence. If a baseball ceases to exist, then so too does its shape, color, mass, and so on.

BFO recognizes also **generically dependent continuants (GDCs)** [11], such as items of information. If one burns a document that is the only carrier of some item of information, then that information is lost. An item of information is however only *generically* dependent on its carrier, since it can be emailed, or copied from one document or hard drive to another.

A GDC is an item that can be copied in such a way as to migrate from one carrier to another, in a process that is illustrated for instance by every form of communication.

ELUCIDATION: a *generically dependent continuant* is an *entity* that exists in virtue of the fact that there is at least one of what may be multiple copies; it is the content or the pattern that the multiple copies share.

⁵ On the idea of dependence at work here see [6]. The use of ‘dependent’ here should not be taken to imply causal dependence. An apple is, of course, causally dependent upon the apple tree which caused its existence. However, the apple does not depend on anything for its existence – and is in this sense independent in that it could still continue to exist even if the apple tree from which it fell, and everything else in its surroundings, should go out of existence.

For example, there are many copies of *Moby Dick* carried by many composites of paper and glue, on many individual shelves. However, there is only one generically dependent item of information called *Moby Dick*, and each composite of paper and glue, on each shelf, carries that very same item of information.

Specifically dependent continuants (SDCs), in contrast, are defined as follows:

b is a *specifically dependent continuant* =Def. *b* is a *continuant* & there is some *independent continuant c* which is not a *spatial region* & which is such that *b* *specifically depends on c*

2.1.1 Realizable Entities

Two subtypes of SDC are currently recognized by BFO, namely **quality** and **realizable entity**. Qualities are features such as redness and shape, which are overtly present (are manifested) at all times at which they exist. Examples are: the color of this tomato, the ambient temperature of this portion of air, the length of the circumference of your waist, the shape of your nose, the mass of this piece of gold.

Realizable entities, in contrast, are SDCs which are in need of some further process through which they are realized.

ELUCIDATION: *b* is a *realizable entity* means: *b* is a *specifically dependent continuant* that (a) *inheres* in some *independent continuant* and (b) is not a *spatial region* and (c) is of a *type* some instances of which are *realized in processes* of a correlated *type*. Examples: the role of being a doctor, the role of this boundary to delineate where Utah and Colorado meet, the function of your reproductive organs, the disposition of your blood to coagulate, the disposition of this piece of metal to conduct electricity.

Where qualities are *actuals*, realizable entities are *potentials*. More precisely, they are SDCs which are or can be realized in processes. For example, there is some feature of an apple that allows it to float in water. The apple always possesses this potential, even when it is not floating. Similarly, people possess many social attributes such as being a lawyer, a parent, or a teacher. These attributes are manifested when they are realized in processes, such as the lawyer's presenting a case in court, a parent's caring for his child, or a teacher's instruction of her students. BFO currently

distinguishes two different kinds of realizable entities, namely **dispositions** and **roles**. **Functions** are further recognized by BFO as forming a subtype of disposition. We shall see, however, that there is a need in certain application areas to acknowledge, between disposition and function, a third kind of realizable entity, namely **capability**.

2.1.1.1 Dispositions

Dispositions are realizable entities that are internally grounded – meaning a physical change is required in order for a disposition to begin or cease to exist. A disposition is a real possibility, and it is dispositions that give the BFO ontology the ability to represent modal aspects of reality.

ELUCIDATION: *b* is a *disposition* means: (a) *b* is a *realizable entity* & (b) *b* is such that if it ceases to exist, then its bearer is physically changed, & (c) *b*'s realization occurs when and because this bearer is in some special physical circumstances, & (d) this realization occurs in virtue of the bearer's physical make-up

An example of a disposition is, again, the disposition of an apple to float in water. There is something about the internal construction of the apple that allows it to float. Similarly, an apple has a disposition to roll down a declining surface. This disposition to roll is realized when the apple is placed in the proper environment – a sloped surface. The apple owes its disposition to roll to its internal construction – namely that it has grown into a rounded shape.

2.1.1.2 Functions

BFO elucidates **function** as follows:

ELUCIDATION: A *function* is a *disposition* that (a) exists in virtue of the bearer's physical make-up and (b) this physical make-up is something the bearer possesses because it came into being either through evolution (in the case of natural biological entities) or through intentional design (in the case of artefacts), in order to realize processes of a certain sort.

As stated earlier, each function exists in virtue of the fact that its performance is the reason for the existence of its bearer. This can come about in two ways: through evolution or through design. The disposition of the heart to pump blood is an example of an evolved function. Over countless generations, organs of the type *heart* organ were selected for based, *inter alia*, on their ability to circulate blood.⁶

Artifacts, on the other hand, are entities which exist because they were designed intentionally to realize a certain disposition. This disposition that it was designed to realize is that artifact's function. A toaster, for example, has the function to toast bread. The reason why the toaster exists can be traced back to the desire for toasted bread, and the creation of a machine (the first toaster) to fulfill this desire. If no one wanted toasted bread, there would be no reason for the toaster to exist. Similarly, tools, appliances, cars, cell phones, computers, tables, houses, and most other things that human beings create have functions. They were each created in order to realize specific processes, and the reason for their existence can be explained adverting to these processes. Moreover, the effectiveness of each one of these artifacts can be measured in terms of how well it realizes its function. A well-made car is well-made because it fulfills its function well.

2.1.1.3 Roles

Unlike dispositions and functions, which are internally grounded, roles are realizable entities which are externally grounded. That is, they owe their existence to an external state of affairs, which is most often some feature of social reality. BFO 2.0 elucidates the term 'role' in the following way:

ELUCIDATION: *b* is a role means: (a) *b* is a realizable entity & (b) *b* exists because there is some single bearer that is in some special physical, social, or institutional set of circumstances in which this bearer does not have to be & (c) *b* is not such that, if it ceases to exist, then the physical make-up of the bearer is thereby changed. Examples: the lawyer role, the parent role, and the teacher role.

Someone is a lawyer, parent, or teacher only if they stand in the right kind of social relationship to relevant other people and institutions. At the moment when a person becomes a lawyer, nothing changes about her physically. It is

⁶ For a more detailed account see [3].

even possible that someone becomes a lawyer without knowing that they have acquired this role, for example if the document that confirms their passing of the bar exam is still in the mail.

2.2 The Need for ‘Capability’

For our purposes here, a capability is what an entity is able to do in virtue of its *material constitution*. Thus abstract entities such as algorithms have no capabilities in the sense here intended. Another use of the term which falls outside our purview involves reference to what people have the *authority* to do in a given social context in virtue of their roles in that context, as when we say that the mayor has the capability to fire the police chief.

The term ‘disposition’ captures a broad array of what things can do. The term ‘function’ captures the much narrower array of what things can do which are at the same time what they were evolved or designed to do. But how can we capture that subtype of dispositions whose realizations someone cares about but which are yet not functions – as for example in the case of the infant’s use of a finger to represent a tree by daubing paint on a canvas, which is just one of many examples of dispositions whose realizations we may find useful or desirable but which yet cannot be classified as functions?

2.2.1 Biomedicine

Applied ontologies have already been applied with great success in the realm of biomedicine and bioinformatics [4]. By placing capabilities into an ontology, we can have a means of dealing with ontologically important qualitative data regarding a particular patient’s preferences and well-being. The ontologically enhanced data can then be shared, for example, between the patient and a healthcare institution.

The wellbeing of patients is a primary objective of the medical profession. As such, medical professionals must be able to clearly communicate information about the wellbeing of their patients to other medical professionals within their own institutions and to those of others institutions and networks. This information includes the patient’s interests, values, and lifestyles, and thus goes beyond the mere biological health of the patient [28].

Part of the needed information pertains to what various parts of the body, medications, treatments, and so forth, as well as the patient herself, *are able to do*. For instance, the drug Remdesivir was originally developed to treat hepatitis C and was then repurposed to treat Ebola. Remdesivir was not designed to be used to treat COVID-19 [12], yet research suggests that it could be effective in treating this new disease [25]. Assuming that this is the case, it will follow that the portions of Remdesivir used in this research have a disposition to treat COVID-19. This disposition is

not a function, and nor is it a mere disposition, of the sort it might have, for example, to give off a certain odor when wet. Rather, as argued in [28], it is a capability.

2.2.2 Engineering

2.2.2.1 Industrial Ontologies Foundry (IOF)

The IOF is a suite of ontologies that is being developed to provide ontologies that can be used to support more effective access to data used in manufacturing [7]. It includes terms such as: *product, material, processor, machine tool*, and so on. What many of these terms have in common is that they refer to entities that have both functions and added capabilities. The machines and tools used in manufacturing all have functions; but they are also capable of being used for purposes that are not a part of their function. Some of them are capable of being used, for example, under very hot or very cold running conditions. To run at different temperatures is then not a function of a machine, but rather a capability, one of many capabilities included in the list of specifications used in its design.

Materials, by contrast, often have no function, especially before they have been processed in any way. Matter that is still lying in the ground has no function in either the biological or artifactual sense. If I dig up some portion of the matter in order to use it, for example, to heal the rash on my face, and if it has a real possibility (disposition) to do so as is proven over time by trials with other, similar portions of matter, then portions of such matter may serve as raw materials in a manufacturing process the outputs of which will realize a corresponding function.

2.2.2.2 Systems Engineering

The field of systems engineering also makes use of the term ‘capability’ to mean ‘the ability to do something’ [15]. Very many different sorts of capabilities are to be found in the domain of the systems engineer, from the lower-level capabilities of individual humans and individual pieces of equipment to the capabilities that entire systems and indeed entire systems of systems as are used, for example, in the realization of space exploration or military resupply missions. Here too, therefore, it would be useful to provide an ontological treatment of the term ‘capability’, which can account in consistent fashion for the range of different uses of this term. The Systems Modeling Language (SysML), for example, which is widely used by systems engineers does not include ‘capability’ in its language, and although several architecture frameworks that use SysML do include a definition of this term, no rigorous account has been given which would promote common understanding within the domain and thus promote consistent reasoning over systems data.

2.2.3 Defense and Intelligence

When making decisions about national security and defense, it is important to develop and maintain an accurate understanding of the military, economic, and political situation of one's allies, one's enemies, and oneself.⁷ For instance, having up-to-date knowledge of other countries' *nuclear capabilities* is important for national security. Warfighter capabilities are the results of education and training – thus data about capabilities are needed by the military also to support for example outcomes measurement to validate new training programs in the military.

2.2.4 Defense Architectures

The Department of Defense Architecture Framework (DoDAF), which is used to model military enterprises across the U.S. DoD as well as to inform the NATO architecture framework (NAF), includes the term 'capability' in its glossary, reflecting the role played by what we can think of as capabilities engineering in large scale military planning [21][22][23][24]. Accordingly, having a BFO conformant definition of 'capability' that is compatible with other ontologies used by the DoD and NATO will potentially be of benefit to the users of these architecture frameworks.

2.3 Capabilities

Many uses of 'capability' refer to dispositions that contribute toward the success of some plan or goal. The assertion that someone or something has capability x implies that x is useful for some purpose. Thus, we would not ordinarily say that someone has the capability *to fail at a job*, because failing at a job does not serve a purpose. We speak of capabilities as something positive, describing their realizations in terms of achievement and success: the capability to recover quickly from disease, for example, or the capability to succeed in some venture. Capabilities are such that, other things being equal, their exercise produces positive outcomes. Before exploring how, precisely, this idea shall be specified in the BFO framework, we discuss prior attempts to define 'capability' and related terms in the literature.

2.3.1 Nussbaum's account of capabilities

Martha Nussbaum and Amartya Sen have spearheaded an influential treatment of capabilities focusing on capabilities of humans conceived as gradable dispositions that tend to bring about good outcomes. Nussbaum for example, defines capabilities as:

⁷ See [5] for a more detailed description of the intelligence process.

the answers to the question, “What is this person able to do or be?” In other words, they are what Sen calls “substantial freedoms,” a set of (usually interrelated) opportunities to choose and to act [13].

Everyone has the capability to acquire new skills, such as to drive a car or to organize a schedule. The Nussbaum-Sen approach is focused on basic capabilities, which emerge universally among human beings, such as the capability to communicate through language, recognize threats, or tell jokes [14]. Other capabilities may include the capability to enrich one’s life through learning, the capability to earn an income, or the capability to reproduce.

While these are all capabilities of human beings, many other kinds of entities can bear capabilities. Two people might both have the capability to communicate with other human beings, which one realizes through processes of speaking English and the other through processes of speaking French. A tree has the capability to photosynthesize sunlight and grow fruit. A motorcycle has the capability to transport a person quickly and efficiently.

2.3.2 Chemero’s account of abilities

Anthony Chemero uses the term ‘ability’ to refer to capabilities understood in the manner of Nussbaum namely to refer to, namely things that a person (or organism, for Chemero) is able to do. However, he takes a different approach characterizing an ability as an entity whose realization plays a role in aiding the survival of the organism who has it [18]. One interesting feature of Chemero’s account is that abilities are not held to be dispositions. The reasoning goes like this:

- (1) If an entity e is a disposition, then e must necessarily realize any time the triggering conditions for e are met.
- (2) It is not the case that an ability will manifest any time the triggering condition for it are met.
- (3) Therefore, abilities are not dispositions.

The disagreement here may be terminological. Chemero asserts that “disposition, on the other hand, never fail; they simply are or are not in the appropriate circumstances to become manifest” [18]. One could understand this assertion to mean that dispositions either realize in a binary way: either a disposition realizes or it does not realize without any gray area. If this is Chemero’s view (which by our reading, it is), then we take it that Chemero just has a narrower notion of ‘disposition’ in mind than the one adopted by BFO. Accordingly, Chemero’s account of abilities necessarily describes a different kind of entity than what we refer to as capabilities in this paper.

2.3.3 Koch's Account of Capability

Koch offers an account of capability that, like ours, is situated within Basic Formal Ontology. He defines a capability as “A disposition which can be exercised more or less well and which is good for the bearer or the bearer’s wider community when realized” [28]. While much of our analysis parallels that of Koch, we diverge from his account in that 1) we revise the “good for” relation, replacing this relation with one based on interest; 2) we propose additional or restructured axioms in order to elucidate the notion of capability.

3 The Proposal

How, then, should we define the term ‘capability’ in a way that has the required generality of application, and also comes close to the way this term is standardly used and understood by users of English? We now propose a definition of capability that can be applied to all of the above use cases as well as in many other domains that would benefit from a coherent terminology that enables tracking the capabilities of various objects and actors in the world. Our proposed definition reads as follows:

DEFINITION: capability⁸ =Def. disposition in whose realization someone (or some organism, or some group of organisms) *has or had an interest*.⁹

Examples are: a glass jar has the capability to act as a paperweight, my heart has the capability to pump blood, FedEx has the capability to do logistics, a wolf pack has the capability to hunt and kill deer, some people have the capability to play chess.

These are in every case examples of dispositions in whose realization one or more organisms have an interest. I have an interest in my heart pumping blood because its function is to keep me alive, and this is so whether or not I know about the existence of my heart. Wolves have an interest in hunting and killing deer because they belong to a species that has evolved to obtain food in this way.

⁸ Before turning to the elucidation of the relational expression ‘has an interest in’ we note that this definition implies that a function, in BFO terms, is in every case a capability (whereby we note also that this might require a charitable reading of ‘organism’ to comprehend also native inhabitants of distant planets).

⁹ The rationale for the ‘or had’ here is provided in section 3.5 Permanence Axiom below.

3.1 The ‘interest in’ relation

We take the *has an interest in* relation to be primitive, which means that we cannot specify a set of jointly sufficient and individually necessary conditions which would need to be satisfied for this relation to obtain. We can, however, specify that the domain of this relation is: *all organisms and groups of organisms*, and that the range is **process** in BFO terms, specifically all processes that are the realizations of dispositions. At one extreme are the interests of organisms and groups of organisms in survival and reproduction, and all the interests that flow therefrom (in obtaining food, evading predators and so forth). I have an interest in drinking water if I am thirsty. Trees have an interest in acquiring sufficient sunlight to realize photosynthesis. A cancer patient has an interest in eliminating her cancer.

Human organisms and groups of human organisms have interests not directly related to survival and reproduction, for example: A lawyer has an interest in obtaining evidence that supports her case. A scientist has an interest in proving her theories. A student has an interest in getting good grades. A church restoration company has an interest in making money by restoring old churches.

Finally, we can assert that the ‘has an interest in’ relation obtains only when the conditions expressed in any of the following four axioms are satisfied.

3.2 Biological Axiom

Biological Axiom: If a part of an organism has a function, then that organism has an interest in the realization of that function.

Every organism has an interest in the realization of the functions of all its parts – where again: a biological function is that subtype of BFO function whose instances were selected for according to the organism’s evolutionary history. For example, I have an interest in my pancreas realizing its function to produce insulin, I have an interest in my gallbladder realizing its function to store bile, and I have an interest in the nephrons inside my kidneys realizing their function of filtering out wastes and toxins from my blood.

Biological functions entail a corresponding interest in their realizations because the existence of each and every biological function is explained by its contribution to the survival of the organism. For this reason, tumors, for example, do not have functions, precisely because they have not evolved to contribute to the survival or reproduction of the organism that has the tumor.

3.3 Prescription Axiom

Prescription Axiom: If a person or group of persons has a plan, then it has an interest in the realization of all the processes and process-combinations prescribed by that plan.

The term ‘plan’ here should be understood in a very general sense. For example, when someone has an objective – that is, when they intend to accomplish some goal x – then there is present also at least a minimal *plan* of the form: I plan for x to occur. A more complex plan will specify a number of process-combinations – it is not enough to realize, separately, all the processes specified in the plan; one must realize them in the specified order, and under specific conditions, and within specific constraints.

To illustrate, in order to successfully launch and operate a space station many dispositions would have to be realized: dispositions of various rockets and spacecraft in order to get the parts of the space station into orbit; dispositions of various tools in order to assemble the station, dispositions of parts of the space station itself for example to circulate and filter oxygen and other gases, protect the astronauts from solar radiation, maintain a stable orbit, and so forth. Each of these dispositions is a capability. Some of these capabilities will be functions that the various artifacts used to build the station possess. Others would not, such as the capability of some electronic component to warm an astronaut’s cold hands, or the capability of the station to house 11 astronauts.

3.4 Facilitation Axiom

Facilitation Axiom: If (a) x has an interest in the realization of a disposition y , and (b) the realization of disposition z facilitates the realization of disposition y , then (c) x has an interest in the realization of disposition z , where by ‘facilitates’ we mean that the realization of z is either (1) required for y , or (2) would contribute positively to the grade of, y ’s realization.

As an example of (1), consider Ellie, who has an interest in streaming movies on Netflix. This means that her computer’s disposition to stream Netflix is a capability. As an example of (2), consider the capability of a car with power steering. The power steering mechanism in the car have the disposition to make it easier to turn the wheel, thereby improving the realization of capability of the car to be steered using the wheel. Although the power steering mechanism is not required for the realization of the capability of the steering wheel, this mechanism still bears a capability because it improves the quality of another capability’s realization.

3.5 Permanence Axiom

We hold that the status of a disposition to be a capability is *permanent*, in the sense that, once acquired, this status will exist for as long as the disposition exists. This feature of capabilities is introduced in order to preserve what is for the purposes of our account here the formally very useful treatment of **function** as a special case of **capability** (this will in fact turn out to be a theorem on our approach). A BFO function, too, exists for as long as the real possibility of its realization exists [2]. Thus your heart still has the function to pump blood, and it still has the capability to pump blood, even if, as during heart bypass surgery, its pumping has been temporarily stopped.

Accordingly, we formulate the following axiom to capture the permanence of capabilities:

Permanence Axiom: If x has an interest in the realization of a type of disposition d at time t , then d is a capability at t and at all subsequent times.

Some dispositions in whose realizations someone has an interest at one time might at some later time be of interest to no one. For example, while a Betamax player still has the *function* (and thus the *capability*) to play Betamax tapes, it is possible that no one today has an interest in realizing this function. The device then has what we can think of as an obsolete function [2], and we here introduce a terminological convention to the effect that there are also *obsolete capabilities*, namely: those (formerly full-fledged capabilities) whose realizations are *per accidens* no longer of interest.

That all functions are capabilities is then implied by the definition of ‘function’, and by the Biological and Prescription Axioms, since these implies that all functions are realizable by a process in which there is an interest *at some time*. This holds trivially for biological functions. That it holds also for artifact functions follows from the fact that, from the Prescription Axiom, it is impossible for someone to design an artifact with a purpose without having at least a minimal plan that *prescribes* the artifact’s purpose – that is, which prescribes the realization of that artifact’s function.

To see how this works in a specific case, suppose that an ancient screwdriver is discovered that was designed to be used with a particular type of ancient screw. Suppose further that screws of this type have not been made (or heard of) for two millennia. It is then likely that, prior to the discovery of the ancient screwdriver, there is no one alive that has an interest in the realization of its function. However, it is still true that the designer of the ancient screwdriver

had an interest in the realization of this function; and, by our lights, this is sufficient for the function of the ancient screwdriver to be called a ‘capability’.

4 Discussion

4.1 Gaining and Losing Capabilities

Capabilities can be acquired in two ways. On the one hand, because capabilities are dispositions, a material change in the bearer can cause an instance of a capability to be created. For example, if the end of a stick is sharpened, it may acquire the capability to skewer and roast marshmallows. This capability would be gained when the stick acquires the *disposition* to skewer a marshmallow, a disposition which is triggered by someone developing a corresponding interest. As concerns the way in which an entity may lose a capability, we draw on the BFO treatment of functions, which (by the Permanence Axiom) can be lost only as a result of the fact that the bearer is physically changed in such a way that the relevant disposition no longer exists – or in other words there is no longer a real possibility that the function/capability will be realized.

4.2 Functions and Capabilities

4.2.1 Are all functions capabilities?

We have proposed that all BFO functions are capabilities, and our adoption of the Permanence Axiom, makes this a theorem of our approach. According to the Biological Axiom, every biological function is a capability, since the host or bearer organism has in every case an interest in its realization. In a similar way, when an artifact function comes into existence it is always the case that it is a capability, since the creation of an artifact goes hand in hand with an interest in the realization of its function.

To judge such cases aright, however, we may have to pay attention to different groups of *instances* of a given artifact kind. The drug Remdesivir, for example, was originally developed to treat Ebola, and since it can effectively treat Ebola, this means that the original batches of the drug had the function to treat Ebola. It was however recently discovered that Remdesivir also has the capability to treat COVID-19 [25]. A corresponding interest then came into being, and so all existing batches of the drug thereby acquired the capability to treat COVID-19 (while no batches had this capability before the disease emerged). At the same time only those batches of Remdesivir manufactured for the purpose of treating COVID-19 had the corresponding *function*.

4.2.2 What are ‘functional roles’?

The term ‘functional role’ is typically used to refer some process or activity that must be performed – typically within an organization – in order to keep that organization functioning. Functional roles are not functions within the framework of BFO, rather they are simply roles. However, they are roles which are restricted to bearers that possess certain capabilities. A mayor fulfills such a functional role in this sense, and to do so, there are certain requirements that she must meet. If she is to serve as the mayor of the city of Buffalo, for example, then she must be able to speak English, because she would otherwise not understand the documents that she would be required to work with. Similarly, a hammer might have the function to hammer nails, but if it is used as a paper weight outside, it would acquire the role of being a paper weight. It can only fulfill this role because the hammer is heavy enough to keep the paper from blowing away in the wind.

4.2.3 Secondary functions

The notion of a secondary function, introduced by Miles [19], is a function that an object (usually an artifact) bears in order to enable it to perform its primary function [19][20]. For example, the primary function of a car engine is to turn the wheels. However, one can design engines that accomplish the same primary function by realizing different secondary functions. An internal combustion engine will turn the wheels by transforming the energy from combusting gasoline into kinetic energy. An electric engine, by contrast, will turn the wheels by transforming the potential energy in a battery into kinetic energy.

Miles’s account coheres well with our treatment of capabilities. Both the car and its engine are artifacts, and as such the functions that these artifacts bear are a result of their intentional design. Thus, secondary functions are functions according to the BFO definition. Our treatment can actually contribute to the framework developed by Miles. As already mentioned, both capabilities and functions are dispositions that are *gradable* – they can be realized more or less well – but unlike functions, capabilities do not have to be designed either by an agent or by having an evolutionary history. According to Miles, the usefulness of the distinction between secondary and primary functions is that it provides us with methods for achieving the same primary function in order to reduce the overall cost in the engineering process [19]. The *capabilities* of the artifacts we design may similarly be taken into account when determining the costs involved in its production.

For example, a car with an internal combustion engine can heat the cabin at no additional energy cost. The heated cooling fluid in the engine simply diverts to a heat core, which blows warmed air into the cabin. An engine of this sort has the capability to produce heat, even though the capability of this engine to produce heat is neither a primary nor a secondary function of the engine. The *heating core*, on the other hand, does have the function to *divert heat* from the engine and into the cabin. Many electric vehicles, by contrast, do not on their own produce enough heat to heat their cabin in the winter, and they must therefore drain additional power from the battery for heating purposes.

4.3 Gradeability

For many entities there are types of dispositions that are ‘normative’ in the sense that their realizations may be better or worse, as for example the disposition of a bicycle that is more or less well oiled may provide a more or less comfortable ride. In such cases we have realizations that can be measured according to some scale [2][17].

Formally, we can say that:

disposition *d* is *gradable* =def. *d*’s realization can be measured according to some scale.

For example, the capability of my TV to produce accurate colors is gradable because it can be measured according to the scale used by rtings.com. Similarly, the capability of my pulmonary system to deliver oxygen to various parts of my body is gradable because it can be measured according to the VO2 max scale. The standard of gradeability for both functions and capabilities depends on the associated interests, and thus on context. We are surrounded by persons and objects with dispositions relevant to our goals whose gradeability is repeatedly established through the development of corresponding scales. All tests and examinations carried out in training and educational establishments serve the purpose of grading the realizations of corresponding capabilities on the part of subjects being tested (see 4.8 Training and Human Capital).

4.3.1 Degraded Functions and Capabilities

When we speak of artifacts becoming degraded, we often mean that an artifact loses its function. If one’s stereo system degrades, for example, it loses its capability to play music and might instead emit a horrid screech. On our account, both functions and capabilities are lost all at once: an object bears the function, *F*, until the time when the relevant disposition (real possibility) goes out of existence – which typically means destruction of the relevant moving parts (or, for organisms, something like death).

4.4 Overlapping Interests

Since having an interest in some realization of a disposition d can be satisfied either by an organism having a goal which that disposition helps to bring to fruition (prescription axiom), or because it is a biological function (biological axiom), it is possible for both axioms to be satisfied at once. For example, water has the capability to quench my thirst both because I have the goal of quenching my thirst but also because achieving this goal addresses a biological need.

Thus, for a given object as the domain and a given object as range, there are at least three ways that interests might be satisfied:

- (1) An organism has an interest in the realization of a process according to both the Prescription and the Biological Axiom; the thirst quenching case above is an example of this.
- (2) An organism has an interest in a realization according to the Prescription but not the Biological Axiom. Suppose, for example, that Sam is a heavy drinker. If Sam forms a plan to go out drinking heavily, she then has an interest in drinking heavily according to the Prescription Axiom. Sam does not have a Biological interest in drinking heavily.

or

- (3) An organism has an interest in a realization according to the Biological but not the Prescription Axiom. Suppose that, after an extended period of heavy drinking, Sam becomes an alcoholic. If she forms thereupon a plan to quit drinking, then from the Prescription Axiom she acquires an interest in not drinking, which means that she loses her interest in drinking heavily. At the beginning of her journey to sobriety, however, she may still have a Biological interest in drinking while the process of weaning herself off her alcohol dependence is still on-going.

4.4.1 Too many Capabilities?

Given the account so far, it would seem that many, perhaps even most, dispositions turn out to be capabilities *in some context*. Initially, this seems fine. There are lots of things that objects and people can do in which some organism has an interest. However, this can raise some puzzling questions. For example, suppose that I have enemies who have an interest in my death; then it would be true that a cancerous tumor *has the capability* to kill me. This seemingly counter-intuitive result follows directly, however, from the fact that different human beings have many, often conflicting, goals, and there are many dispositions in the universe that allow us to achieve those goals. We should then not be surprised if the class of capabilities covers an extremely large terrain.

4.5 Specificity of Capabilities

Capabilities, like dispositions, can be more or less specific. For instance, my car has the capability to drive me places. It also has the capability to drive me to my sister's house. My digestive system has the capability (and the function) to digest food in my body. It also has the capability to digest tiramisu. The more specific capability is in each case subsumed by the more general.

It now follows that, just as capabilities can be more or less specific, so too can what it is there is an interest in. The specificity of what one is interested in will determine the range of realizations of corresponding capabilities. For instance, a general might have an interest in winning a war, and there is, then, a very general interest, which his army possesses. A more specific interest might be winning the war with minimal loss of soldiers' lives, or winning the war before Christmas, winning the war through shock and awe, and so on.

4.5.1 Composable Capabilities

Sillitto introduces a treatment of capability for application in a military context, in which capabilities can be generated on the basis of the configuration and composition of their elements [16]. For example, one warfighter be trained to use GPS targeting equipment and another to operate ground to air missiles. Each alone does not have the capability to shoot down enemy aircraft, but when their capabilities are combined, the capability to shoot down enemy aircraft emerges. It is accordingly not only the relation *has an interest in* which has *group of organisms* in its domain, but also the relation *has capability*.

On Sillitto's account, individual warfighters, support personnel, vehicles, weapons, and other equipment, form what he terms "Capability Components", which are joined together into what he calls "Force Elements", which are then bearers of composed capabilities. Force Elements can be joined together in turn to form greater Force Elements at higher levels and eventually entire Task Forces. Force Elements can be established and dissolved as dictated by the needs of the operational environment, which allows a commander to reorganize her forces in such a way that it produces in the force the right kinds of capabilities to best respond to a given adversary in a given situation.

In our account Capability Components would be classified as instances of either BFO **object**, for warfighters, tanks, and so forth, or BFO **object aggregate**, for Force Elements at successively higher levels. Capabilities at the lowest levels are then composed to allow complex capabilities to be created at higher levels. This implies also a division into levels of the *training* that is required to create and sustain the corresponding capabilities, and as

recognized by the Department of Defense [26] it would have implications also for planning, acquisitions, technology, logistics, sustainment, recruitment, as well as for program analysis and evaluation.

4.5.2 Capabilities of Groups, Teams and Organizations

Capabilities of groups are created where multiple humans are needed to work together in order to realize a given goal. Examples are the capability needed to lift a car, or the capability needed by a group of pilots in order fly in formation. These examples further demonstrate the need to distinguish ‘capability’ from ‘function’. The pilot, as a result of her training, has the *capability* – but not the *function* – to fly a plane. They raise also the question as to whether groups of organisms – as conected with single organisms, can have functions. It seems acceptable, for example, to recognize a Force Element – an organizational entity that has been designed and created for some specific purpose – as having an *artifact function* to realize this purpose.

4.6 Must Capabilities be Known?

4.6.1 Conscious Awareness of Capabilities

One might think that, in order for a disposition to be a capability, some organism has to *recognize* that the disposition can be used to obtain something in which that organism has an interest. How, after all, can a disposition be drawn upon to achieve a certain goal if its beneficial realizations are not thought to be helpful in a given circumstance. If, for example, I am unaware that WD-40 has the capability to eliminate the squeak of my door hinge, I will never go looking for WD-40 when I have a squeaky door.

Lack of awareness of a disposition does not, however, entail that the disposition loses its status as a capability. WD-40 has the capability to eliminate the squeaking of the door hinge even if I am not aware that it would be helpful for this purpose. This position is consistent with the formulation of our three axioms:

- 1) The *Biological Axiom* entails that every organism has an interest in the realization of the function of every one of its functional parts. Thus, if the function of some part of a poison ivy plant is to cause pruritis in mammals, then poison ivy has an interest in causing pruritis in mammals, even without any conscious awareness.
- 2) The *Facilitation Axiom* states that if x has an interest in y , and process z facilitates y , then x has an interest in z . This means that if I have an interest in participating in the *Tour de France*, and the realization of the function of my tire beads prevents me from getting a flat tire, then I have an interest in the realization of the function of my tire beads, regardless of whether I am (or ever have been) consciously aware of my tire beads.

- 3) Finally, the *Prescription Axiom* entails that if I have a plan that prescribes x , then I have an interest in x . This is so even if I fail to notice that my plan prescribes x .

4.6.2 Discoverability of Capabilities

Given that every function is a capability, and that biological functions can be discovered (for example in result of advances in biological science), it follows that some capabilities can be discovered. The function of the pineal gland, for example, was not always known; it had to be discovered.

If we do not have to be aware that a given disposition *is* a capability in order for it to *be* a capability, it should not be surprising that capabilities can be discovered. Edison, for example, was one of those who discovered that a certain type of metal filament could be heated to create light.

Because capabilities are *discoverable*, we can go out into the world and discover new dispositions; discover, in other words, that the bearers of these dispositions can be used for various ends. Because the realizations of these undiscovered dispositions can bring about (or facilitate the acquisition of) what there is an interest in, they are capabilities, and this is so regardless of whether we know about them or not.

4.7 Bodyguard Capabilities

We have in the foregoing used many examples of capabilities – to play guitar, to eat, to walk – which involve a realization involving some process of change. Yet we often speak of capabilities, such as to protect, to shield, to shelter, which are precisely capabilities to prevent change. Bricks, for example, have a capability to withstand intense heat. Skyscrapers have the ability to withstand significant amounts of windshear. Tooth enamel has the capability to protect your teeth from physical, thermal, and chemical forces that would otherwise cause injury to your dental pulp. Nightclub bouncers and police protection forces possess the capability to protect locations and persons from those who wish to do them harm. All of these are what we call bodyguard capabilities; their common feature is that they are capabilities that allow either their bearer or some other continuant entity to resist change of some kind.

4.8 Training and Human Capital

Capabilities are central to education, training, and even so-called talent acquisition for government and private organizations. These fields relate to each other within a system. Organizations both public and private have an interest

in acquiring competent individuals who can further their goals and agendas. However, to acquire these skills these individuals need to be educated through school and universities, and sometimes also trained through institutions such as vocational colleges and military bootcamps.

Accordingly, capabilities and the grades achieved in realizing them – expressed in diplomas, warranties, or baseball statistics tables – are vehicles through which organizations are able to express and fulfil their needs. Not only humans but also equipment and facilities can be viewed through the lens of what capabilities they bring to an organization or through lens of what capabilities can be used as resources which can be counted, assigned a value, and traded in the market. Human capital, in particular, is a matter of capabilities, and the consulting industry exists in no small part to enhance the capabilities of the organizations which they serve.

Conclusion

We have proposed the introduction of a new class, called ‘capability’, as a subclass of BFO **disposition** and a superclass of BFO **function**. The class of capabilities in many respects similar to that of functions: both span the realm comprehending organisms and artifacts, both rest on the BFO idea of a disposition as a real physical possibility. Yet we do not at this stage recommend the inclusion of this new class into BFO. Rather, we invite users of BFO to review critically the ideas suggested in the foregoing and to suggest improvements.

References

- [1] Smith B. Basic Formal Ontology 2.0. Available from: <https://github.com/BFO-ontology/BFO>, last accessed April 6, 2019.
- [2] Spear AD, Ceusters W, Smith B. (2016) “Functions in Basic Formal Ontology.” *Applied Ontology*. 11(2):103–28.
- [3] Millikan RG (1989) In defense of proper functions. *Philosophy of Science* 56:288–302.
- [4] Hoehndorf, R., Schofield, P. N., & Gkoutos, G. V. (2015). “The role of ontologies in biological and biomedical research: a functional perspective.” *Briefings in Bioinformatics*, 16(6), 1069–1080. <https://doi.org/10.1093/bib/bbv011>
- [5] Joint Publication 2-0. Joint Intelligence, 22 October 2013.

- [6] Arp, Robert; Smith, Barry; Spear, Andrew D. (2015) *Building Ontologies with Basic Formal Ontology*. MIT Press.
- [7] Kulvatunyou, Boonserm; Wallace, Evan K.; Kiritsis, Dimitris; Will, Chris. (2018) “The Industrial Ontologies Foundry Proof-of-Concept Project”. *National Institute of Standards and Technology*.
- [8] Smith, Barry; Malyuta, Tatiana; Rudnicki, Ron; Mandrick, William; Salmen, David; Morosoff, Peter; Duff, Danielle K.; Schoening, James; Parent, Kesny (2013), “IAO-Intel: An Ontology of Information Artifacts in the Intelligence Domain”. *Proceedings of the Eighth International Conference on Semantic Technologies for Intelligence, Defense, and Security*.
- [9] Kulvatunyou, Boonserm; Wallace, Evan; Kiritsis, Dimitris; Smith, Barry; Will, Chris (2018) “The Industrial Ontologies Foundry Proof-of-Concept Project.” *NIST*
- [10] Open Biological and Biomedical Ontology Foundry Web Site – <http://obofoundry.org>, last access 2020/8/29.
- [11] Smith, Barry; Ceusters, Werner. (2015). “Aboutness: Towards Foundations for the Information Artifact Ontology”. In *Proceedings of the Sixth International Conference on Biomedical Ontology (ICBO)*.
- [12] Stephens, Bret [2020] “The Story of Remdesivir”. *New York Times*. Available at: <https://www.nytimes.com/2020/04/17/opinion/remdesivir-coronavirus.html> last accessed: 202-/8/29.
- [13] Nussbaum, Martha. (2011). *Creating Capabilities*. Cambridge, MA: Harvard University Press.
- [14] Brown, Donald E. (1991). *Human Universals*. Philadelphia, Pennsylvania: Temple University Press.
- [15] Henshaw, Michael, Lister P, Harding AD, Kemp D, Daw AJ, Farncombe A, Touchin M. (2019). “Capability Engineering – an Analysis of Perspectives”. Fishare. <https://hdl.handle.net/2134/9944156v1>.
- [16] Sillitto, Hillary G. (2013). “Composable Capability – Principles, Strategies and Methods for Capability Systems Engineering.” *INCOSE International Symposium 23*(1). DOI: 10.1002/j.2334-5837.2013.tb03050.x
- [17] Artiga, M. (2011). “Re-organizing organizational accounts of function.” *Applied Ontology*, 6, 105-124.
- [18] Chemero, Anthony (2009). *Radical Embodied Cognitive Science*. Bradford, MIT press.
- [19] Miles, Lawrence D. (1989). *Techniques of Value Analysis and Engineering: 3rd Edition* (p. 62). Lawrence D. Miles Value Foundation. Kindle Edition.
- [20] Roseke, Bernie. (2020). “What is Value Engineering?” Project Engineer.Net. Available at: <https://www.projectengineer.net/what-is-value-engineering/>. Last accessed: Oct. 6, 2021.

- [21] Miranda, G.M., Almeida, J.P.A., Azevedo, C.L.B. & Guizzardi, G. (2016). “An ontological analysis of capability modeling in defense enterprise architecture frameworks.” *In Proceedings of the 8th Brazilian Symposium on Ontology Research (ONTOBRAS 2016)*, Curitiba-PR, Brazil, October 3–6, 2016 (pp. 11–22)
- [22] Gabriel M Miranda, João Paulo A Almeida, Giancarlo Guizzardi, Carlos LB Azevedo. (2019). “Foundational Choices in Enterprise Architecture: The case of capability in defense frameworks”. *IEEE 23rd International Enterprise Distributed Object Computing Conference (EDOC)*. 31-40
- [23] DoDAF: DoD Architecture Framework Version 2.02, 2010. URL: <https://dodcio.defense.gov/library/dod-architecture-framework/>
- [24] NATO Architecture Framework Version 4, 2018, URL: https://www.nato.int/nato_static_fl2014/assets/pdf/pdf_2018_08/20180801_180801-ac322-d_2018_0002_naf_final.pdf.
- [25] NIH Covid-19 Treatment Guidelines. “Remdesivir”. Available at: <https://www.covid19treatmentguidelines.nih.gov/therapies/antiviral-therapy/remdesivir/>. Last accessed: 12/31/2021.
- [26] Joint Defense Capabilities Study Team (2004) *Joint Defense Capabilities Study: Final Report*, https://web.archive.org/web/20090116210345/http://www.acq.osd.mil/jctd/articles/JointDefenseCapabilitiesStudyFinalReport_January2004.pdf. Last accessed 4/19/2022.
- [27] Plantinga, Alvin (1993). *Warrant and Proper Function*. Oxford University Press.
- [28] Koch, P. M. (2016). *A theory of patient welfare*, Dissertation, University at Buffalo. Retrieved from <https://www.proquest.com/dissertations-theses/theory-patient-welfare/docview/1844987126/se-2?accountid=14169>.