The Capability-affordance Model
A Method for Analysis and Modelling of Capabilities and Affordances

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Abstract: This paper builds on an earlier paper modelling business capabilities as a function of resources and process to support enterprise architecture decision making. This paper develops the earlier capability model by using a realist perspective to apply the theory of affordances and the Z specification language to show how capabilities and their actualisation can be modelled as a tuple or set of resource affordance mechanisms (AM) and affordance paths AP subject to critical affordance factors. The paper identifies and develops the concept of objective and subjective affordances and shows how these relate to the capability resource model. We identify an affordance chain by which affordances work together to create a capability. We define the affordance modelling notation AMN as a method of representing the affordances in a system of interacting resources. A medical case study (based on interviews at a local hospital) is used to show how capabilities can be identified and modelled using the theory of affordances. We also propose a model of affordance efficiency, effectiveness and quality that enables the performance of a capability and its constituent affordances to be measured and modelled.

1 INTRODUCTION

The performance of a business enterprise has become increasingly important, especially in recessionary times. The term capability has been widely used in enterprise architecture and other business as a concept describing the ability of a set of business resources to perform, but it is difficult to pin down and measure (Michell, 2011; Curtis et al, 1995). Analysis of capability has been mainly at high level (Grant, 1991; Hafeez et al, 2002; Josey et al, 2009; Merrifield et al, 2008; Beimborn et al, 2005). Without a more reproducible model of capability it is difficult to consistently understand existing business capabilities, or to use the concept to measure the relative performance of the various resources and business structures. This makes it difficult for an enterprise to make critical resource investment and divestment decisions and to understand and develop core competences that are vital to maintain and grow competitive advantage (Liu et al, 2011).

1.1 Capability

An earlier paper (Michell, 2011) sought to reduce this gap by building on resource theory to identify a definition of the capability of business resources of an enterprise for use in enterprise architecture. The following section re-iterates and develops the definitions using and adapting Luck and d'Inverno's work on agent frameworks and *Z* Notation (Luck and d'Inverno, 2001). We defined the *business environment E* to comprise a set of objects we called *business resources* R_i, where i= 1-n:

Environment E = {resources R_i}.
Env = = $\mathbb{P}$ Resource

Each resource is what Luck et al call an *object*. Hence we use the term *object resource*. The set of object resources $\{R_i\}$ have what Ortman and Kuhn (Ortmann and Kuhn, 2010) call qualities *q* that can be divided into perceivable features and facts about the object e.g. size, weight, chemical composition etc., what Luck calls 'a collection of attributes'. Another class of quality is what Luck calls *capability* and Ortman calls *affordance*. We will

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discuss the difference and their relationship later in the paper.

We identified *agents* as either *human intelligent* or *artificially intelligent*. We now extend this by defining a human agent by combining the artificial intelligence definition (Stoytchev, 2005) with Luck and d'Inverno's definition to give: *A human or artificially intelligent agent is a resource object that can perceive its own environment through sensors and acts on the environment according to their self-motivations through effectors*.

We identified passive resources as resources requiring other agents to realise their capability ie they are inert and not capable of their own motion or change of state which relates to Luck's lower level definition of an object (Luck and d'Inverno, 2001). We identified the concept of a driving resource in a process to refer to object resources actively enabling and driving a business transformation compared with those (objects) passively used in the transformation involved in a business process (Michell, 2011). Driving resources in a business process are autonomous agents (human/artificial) controlling a range of transformations. Our scope focuses on business activities where all the entities in a business environment are object resources to be used by a business enterprise. We defined *capability* as: *a property of a resource (tangible or intangible) that has a potential for action or interaction that produces value v for a customer via a transformation process that involves the interaction of the resource with other resources* (Michell, 2011). We use Luck's definition of action as 'a discrete event that can change the state of an environment' (Luck and d'Inverno, 2001). The tangible and intangible resources in a business environment undergo transformations and a change of state as a result of an action of one resource interacting with another. Each of these resources has a capability of adding benefit of a specific value dependent on what resource and process is used to execute the capability i.e. *Cv* (*capability of value V*) = *f (resource, process P)*. We adapt Ortman and Kuhn's definition of value, to business value is the result of any action that is of benefit to the business/client (Ortmann and Kuhn, 2002). The Capability Cv results from transformation interactions between two or more resources that increases the business value of the transformed resource (with respect to a business client), i.e. the capability process contains value transformations as defined by Weigand et al (Weigand et al, 2006).

Cv = f (resource interaction, process of interaction).

At the detail level each driving agent resource in the sequence of transformations will be driven by what Luck et al call motivations to achieve an outcome or goal state G (Luck and d'Inverno, 2001), which the transformation aims to achieve. We can say that this goal state has attributes and a value to the driving resource that is greater than the value before the transformation. Using Z notation we can say a resource R is transformed between a state a and a' such that actions are an effect on the environment that result in a partial change in the environment. We identified the process as a sequence of actions. A process is what Luck refers to as a total plan where Totalplan ==seq Action. To develop the resource capability model we need to use a structured method that enables an action level perspective of capability as the interaction between object resources.

1.2 Affordances

Gibson (Gibson, 1979) defined the term *affordance* based on the root 'phenomenon in gestalt psychology (cited in (You and Chen, 2003)). Gibson's ecological approach saw 'affordance as an invariant combination of properties of substance and surface taken with reference to an animal' and 'what the environment offers and animal or intelligent agent'. The theory of affordance provides a perspective on the interaction of objects in an environment that supports the capability approach. Stamper (Stamper & Liu, 1994) expanded the concept of affordances using behavioural norm concepts into organisational semiotics and the idea of affordance relating to the invariant behaviour of both physical objects and intangible entities such as social behaviours and concept models such as ontology. Norman (Norman, 2004) refers to the term 'perceived affordance' for the concepts to describe the interaction of objects with people and design implications of man-made objects such as handles optimised for pulling via a gripping section or plates for pushing (Gaver, 1991). Norman sees affordances as 'referring to both potential and actual properties of a designed device'. You and Chen identified the difference between the semantics of design resource objects and affordance theory (You and Chen, 2003). Ortman and Kuhn (Ortmann and Kuhn, 2010) see affordances as one part of a set of qualities of an object which separately include physical qualities or facts about the objects such as size, temperature etc. Turvey (Turvey, 1992) developed a mathematical model of affordances as a property of a pair of things e.g. object and agent where the affordance is wholly dependent on the nature of the system of interaction. Unlike physical qualities of an object resource, an affordance is a property of the interacting object resource systems manifested only when they are interacting. Turvey's model highlights the criticality of the interaction between the two object resources. This suggests we should really refer to the term 'affordance pair' as the affordance interaction property of two systems. Using Turvey's notation and the capability notation from the previous paper an affordance between two resources R_p and R_a, where R_p is the passive resource with property p and R_a is an active agent resource with property a can be represents as Af_p. Af_{pa} is a tuple of a passive resource and a driving agent and represents the interface interaction or affordance of the pair of object resources. This interaction property is different from the properties of the separate object resource systems. The affordance Af is represented as an ordered pair. However, in this paper we use the rule that the active or driving resource should precede the passive resource undergoing transformation (in cases where this is perceptible), in this case a human agent based on Turvey's order in the stair example. We use the notation: $Af_{ap} = f(R_a,R_p)$. However, there is a dichotomy in views of affordance as Gibson (Gibson, 1979) reminds us that an affordances is at once both an objective property of an object independent of perception and a subjective property depending on the perception of the viewer. Our capability definition is a function of the resource objects and of the actions (process) by which the resources interact and affordance theory relates to the mechanism of the resource interaction. This echoes Montesano et al's view of affordances 'capture the essential world and object properties, in terms of the actions the agent is able to perform' (Montesano et al, 2007). We adopt a realist perspective with physical, cognitive and in particular geographical reality relating to Gibson's ecological affordance view (Smith and Mark, 1998). We use the theory of affordances and *Z* notation as a formal language and frame of reference to represent the capability-affordance model, focusing mainly on physical affordances. In the following we attempt to discuss and relate these two views and show the relationship between capability and affordance.

2 OBJECTIVE AND SUBJECTIVE AFFORDANCES

This section focuses on objective and subjective affordances, as already mentioned.

2.1 Objective Affordances (OA)

Affordances that exist independent of perception are inherent objective or 'passive 'structural properties of the environment or object resource. For example a solid floor objectively and passively affords support of objects placed on it vs. the perceptive view of affordance which relies on an agent identifying how an object resource could be used. We suggest these passive objective affordances (OA) are what keep object resources in an unchanging, ie motionless state of equilibrium. Also these affordances are not perceptions or possibilities of what might happen – the possibility has already happened and we are observing executed affordances. The interface relationship has been 'actualised' and the affordance is acting in a state of equilibrium. Using Luck's state approach and Ortman and Kuhn's quality approach we can say that objective affordances relate to the qualities of a passive resource in stable equilibrium at a externally perceived level, i.e. we exclude semiotics at a microscopic level as Noth's view (Noth, 1998) to avoid problems with motions of microscopic organisms etc. We therefore suggest a resource has a set of state determining qualities that are required to be balanced in order to execute a passive objective affordance. This would comprise for example the force experienced by an object, its spatial position and other quality attributes. Objective affordance then relates to actual physical qualities or properties that relate to the natural behaviour of the object resource such for example the laws of natural science such as physics (Newton's laws) chemical and biological laws etc. The passive objective affordance is a stable state where:

- Transformation forces on the object are balanced
- The object's special position is unchanging
- The object's attributes are not changing (chemical composition, dimensions etc.)

In summary the affordance transformation mechanism in objective affordances is in a state of stable passive equilibrium. An example is the weight of a cup due to gravity is balanced by the structural strength and reactive force (due to Newton's Third Law) of the surface on which the cup sits. The equilibrium is stable as the potential transformation mechanism e.g. the forces are in balance and the cup resource object is a passive resource and therefore possesses no means of motive force or transformation mechanism capability of its own. We can say that the interface mechanism between the two resources; cup and table is stable and has no active transformation mechanism. This suggests that affordance depends on the mechanism of transformation at the interface of the affordance pair. In this case the affordance interface mechanism is the force of gravity modelled by Newtonian mechanics i.e. F=ma to stably maintain the cup in contact with the table. Objective passive affordance relates to what Norman (Norman, 2004) calls the intrinsic properties of things (Norman's 'actual properties) and innate affordances. This passive objective affordance exists without the need for perception. This relates to Turvey's (Turvey, 1992) focus on an environments capability to support an activity. Then Affordance = the disposition (of the object) i.e. force balance on table. Effectivity = the complement of the disposition i.e. cup supported as a result of the transformation mechanism being achieved ie force balance. This equilibrium state of object resources continues unless acted upon by an external force (e.g. Newton's First Law) which brings us to subjective affordances.

2.2 Subjective Affordances (SA) and Perceived Actions

Ortmann and Kuhn suggest 'Perceiving affordances generates possibilities for action.' (Ortmann and Kuhn, 2010). We suggest that subjective affordances (SA) depend on perceived actions. This uses the 'perceived design affordance' (Norman, DA14) that relates to users understanding of the possible ways (affordances) of using designed features in designed objects. Our term refers to active resources such as a driving resource i.e. an agent intelligently perceives the affordance or possibility for using a resource object to make a substantive transformation and has an intention to use it. We include the term *action* here as the intention is to do physical substantive work, and we us this term to differentiate from non-substantive actions relating to knowledge and semiosis. We also include the term *subjective* as it depends on the driving resource's goals and motivations in the intended action and also critically on the selection of the path of action or process from our earlier definition. This relates to Gibson and Uexkull seeing affordances as perciptibles (Ortmann and Kuhn, 2010). It is these perceived 'action affordances' that relate to planned actions in business processes, activities or human visions and conceptual models of possibilities for action. Subjective affordance depends on an agent's perception as to how the properties or qualities of the object can be envisaged to be used to achieve a goal. The intention or goal of the outcome must complement the affordance (Ortmann and Kuhn, 2010). The goal; also helps a) to define a set of best action paths or processes that could be used and b) to define the value or client benefit of the result expected to be achieved on completion of the action. However, the affordance depends on the interface between an affording object and the driving agent that is attempting to use it. In its simplest form active affordance is the property of interaction of two entities or systems that enable an action to achieve a goal or transformation. The affordance relates to a mechanism for a potential action achieved by a transformation mechanism that changes an object resource state from state a to a' in *Z* notation.

- This may be physical e.g. a force form an agent (active resource) sliding a cup between two positions on a table i.e. cup-table affordance pair affords sliding
- This may be chemical e.g. sugar dissolves in water i.e. sugar-water affordance pair affords dissolving due to chemical forces.

2.3 Objective Affordance – A Multiplicity of Options

Any resource in a business environment is a collection of capability options or opportunities or affordances which depend on how the resource is related to another resource and what affordance mechanism is to be employed to achieve the state transformation and meet the goal. For example a simple passive resource such as a brick can be used as a doorstop (weight affordance mechanism Af_1), as a missile (kinematic mechanism of a thrown brick affordance Af_2), as a structural support component in a wall (rigidity and bonding affordance mechanism Af_3).

i.e. $R -= f \{Af_{ij}\}$

This type of affordance depends on identifying an object's potential for action when an active agent or driving resource can visualise the way in which the object can be used in conjunction with their end effectors and senses. Turvey (Turvey, 1992) in his nest building argument provides support for the driving and passive resource view (Michell, 2011) in his view of disposition and complement by differentiating between the properties of an animal (or agent) affordance which seeks to identify the affordance properties of the environment i.e. how the resources can be used by the person, (i.e. via manipulation, construction, imagination etc.). This relates to Turvey's focus on the animal's capability to perform an action. So, *effectivity* equals the disposition i.e. the effectiveness of the transformation mechanism in meeting the transformation goal (to be discussed later). And *affordance* equals the capability of the transformation mechanism necessary to achieve the goal. In our capability terms the agent driving resource in a process seeks to identify the disposition of the resources (objective affordance) to achieve the transformation action required by the process.

2.4 The Relationship between Objective and Subjective Affordances

In summary, objective affordances refer to executed and operational affordances ie an on-going system interface relationship where the mechanism of transformation becomes an equilibrium mechanism and the path is completed and meets the goal eg affording structural support. In contrast the subjective affordance has to be perceived or planned and therefore the mechanism and path may change and so may the outcome or actualisation and the goal which is dependent on both of these as below.

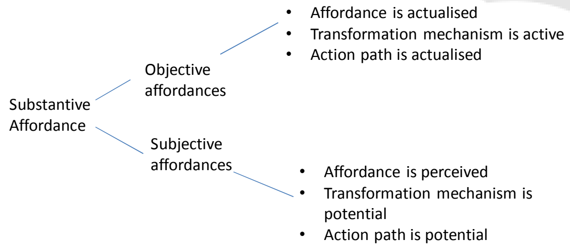

Figure 1: Objective/Subjective Affordance Types.

2.5 Subjective Affordances and Action Paths

However, a subjective affordance does not just depend on the transformation mechanism, it also depends on the way or path taken to actualise or execute the affordance. Consider the often quoted example of 'the cup affords drinking'. It does only if *a)* the cup is grasped firmly without obscuring the opening, *b)* if the cup is brought to an animal's mouth by an action that changes the position of the cup to the proximity of the mouth, *c)* it is tilted to enable gravity to act on the fluid and or the animal sucks to aid the fluid transfer. We will explore this issue of path in terms of our capability model.

3 MODELLING AFFORDANCES

3.1 Affordance Modelling Notation (AMN)

In reality, as we have seen, capability rarely comprises one affordance, but depends on multiple affordances. We will use a medical example of a capability 'to anaesthetise a patient' to explore the relationship between capability and affordance. The goal is to ensure the patient has a controlled unconscious state, the value being that a medical intervention can be performed without adverse reactions (e.g. pain, movement) from a normally conscious patient. For succinctness we will consider a sub-capability a single action of administering a medical injection. We will explore the interaction between the anaesthetist, the syringe and the patient. Using our capability terminology (Michell, 2011) the anaesthetist is the active agent driving a passive resource (the syringe) to execute the capability C_i of injecting an anaesthetic drug into a patient via a process/action P_i that results in the value of 'patient anaesthetised and can be safely operated on'. In the diagram we denote the affordance by the term A_{xy} where *A* is the affordance and *x* and *y* refer to the notation for the two elements in the affordance pair. We use an underline notation to refer to the fact that an affordance relates to a vector dynamic transforming action or a static force balance and hence has magnitude and direction. We use a line terminated by balls in the shape of a dumb bell with each ball resting of the relevant element or component to show the relationship between the two components of the affordance system. The syringe is an example of a designed device (Brown and Blessing, 2005) and can be considered as a system comprising 3 components (excluding cap) a plunger, body and needle which fit together as a passive system of affordances as in the figure below:

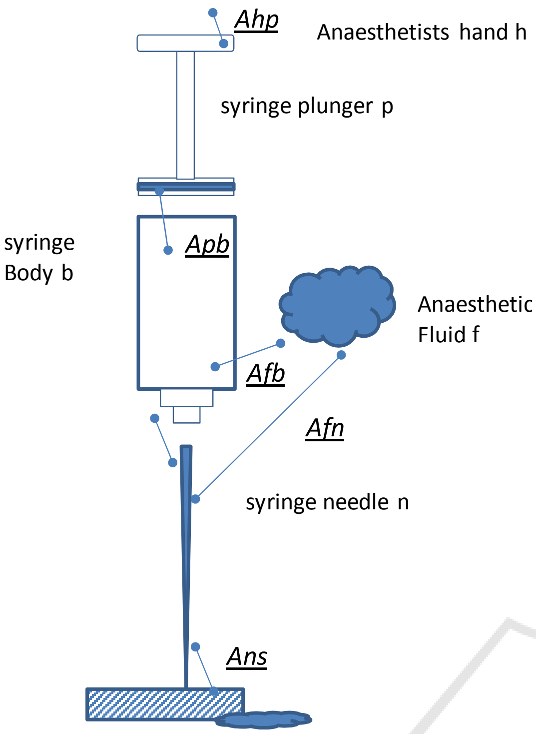

Figure 2: Syringe Affordance Pairs.

3.2 The Affordance Chain (AC) and Objective Affordances

Maier and Fadel identified that multiple affordances can be associated with a particular subsystem (Maier and Fadel, 2006). Thus the affordance of the syringe is a combination of the affordance of the component subsystems comprising the syringe i.e. Af (passive) = f{Af_s} i.e. the passive affordances of the syringe relate to the mechanical structure and engineering mechanics of the syringe in terms of physical science e.g. Newton's three laws. Reviewing the capability model we can see that there are a number of passive objective affordances. The Plunger-Body Affordance – A_{pb} ensures the plunger is retained in the barrel and slides easily up and down it by the affordance pair predicated on the fact that the plunger is designed to interface with the barrel and has only one degree of freedom in an axial direction. The affordance mechanism AM depends on friction and the affordance path is the axial plunger motion. In the Hand-Plunger affordance A_{hp}, the plunger has a tube (with a seal) and top to it which supports the affordance of 'holding' the top of plunger in order to exert downward force (A_{hp}). This downward force acts on any fluid contained by the syringe body (A_{pb}). This affordance (affords force transmission to fluid) is dependent on the properties of interaction of the plunger and body. The plunger must slide and be a secure fit vs. body, must be made out of materials not affected by the fluid to be injected etc. The act of compressing an incompressible fluid forces the fluid out through needle via an affordance Af_n i.e. the needle – fluid affordance. An affordance property of the needle (affords fluid transportation) is that its hollow tubular nature directs the anaesthetic and is chemically inert vs the fluid (a potential negative affordance). A further affordance exists between the needle tip and the patient's skin Af_{ns}. The small surface area at the point enabling a small force on the plunger to be safely and effectively transmitted (due to mechanism of mechanics i.e. pressure = force/area) as a large pressure on the patient skin surface affords penetration of the skin. However this of course is not possible without the subjective affordances of the active driving resource, the anaesthetist who is responsible for identifying the target vein and ensuring the tip of the needle enters a vein etc.

We define an *affordance chain* (AC) as *a connected and related set of affordances (and hence affordance mechanisms) acting together as a system at a point in time to achieve a specific goal of enabling a new macro affordance mechanism, i.e. the capability*; Ca = AC = f ($A_{1,2}$, $A_{2,3}$, $A_{3,4}$ …$A_{i,j}$) where j= i+1 in a sequence from driver to final resource. The idea of affordance chain allows us to link the micro level affordances to the actions that we define as part of the process referred to in our definition of capability.

3.3 Subjective Systems of Affordances

There are three affordance pairs within the capability that depend on the interaction of a passive with a driving active resource. <u>Aph</u> refers to affordance between the plunger and the anaesthetist's hand. By definition of the syringe structure the plunger must be depressed to work according to its design parameters. The needle in contact with the patient's skin provides another affordance pair <u>Ans</u>. One half of the affordance pair comprising the anaesthetist and patient can both act dynamically, deontically and independently, unlike the passive syringe which requires interaction with both these active resources, one of which – the anaesthetist, is driving the overall capability transformation. Another affordance may be the anaesthetists second hand resting on the patient to steady the needle – this is a subjective agent affordance, but is not illustrated for clarity. The third affordance pair <u>Afp</u> is the interaction between the anaesthetic fluid f and the patient's body physiology p. Here the driving resource is the anaesthetic which has a sleep inducing transformation mechanism, if of the right fluid composition and if the delivery or action path – i.e. into a vein is efficacious.

4 LINKING CAPABILITIES AND AFFORDANCES

Based on the above discussion we can rewrite our original capability model:

Capability = f (resource interaction, process of interaction) i.e. any capability depends on a transformation based on the affordance mechanism and an affordance path, both of which are functions of the set of resources $\{R_i\}$ needed to deliver the capability: Capability = f (Affordance mechanism AM(R_i), Affordance path AP(R_i)).

4.1 Affordance Mechanisms

The affordance mechanism should describe the potential transformation mechanism at the interface between the two object resource systems R_p and R_q and its properties that enable the transformation. Mathematically the affordance mechanism is a transfer function that describes the transformation in terms of input resource properties and output resource properties that defines the transfer between input and output qualities. Affordances are actualised by an affordance mechanism AM that represents the transformation. Our affordance mechanism transfer function relates to what Turvey calls *Function j* in his crystal refraction (Turvey, 1992). He shows a light ray *Z* capable of refraction (q) interacts with a crystal *X* capable of refracting the ray (p) to give transformation of light ray to a refracted or bent ray and a new position as a result of a Function j – which we call the affordance mechanism which can be represented as a mathematical function or refraction equation. However, this transformation is subject to critical affordance factors f_c being within the correct window to enable the affordance to actualise or manifest itself. Refraction is dependent on the affordance path i.e. if light ray strikes crystal to obliquely it will be reflected – dependent on the critical affordance factor – the angle of the light with respect to the normal to the crystal surface. Kornhauser's example (Turvey, 1992) of the affordance actualisation of bird flying into a branch depends on the affordance mechanism for 'fracturing'. This is the law of conservation of momentum that transfers the bird's momentum to the branch and results in an impact reaction - impacts its organs. However the actualisation also depends on the affordance path where exactly the bird hits the branch, how far it travels and what absorbs the momentum.

4.1.1 The Critical Affordance Factor

The bird's velocity (assuming a straight unimpeded flight) has a safety envelope that determines unsafe momentum transfer. This should include a lower level of speed to ensure the bird does not miss the branch. The speed is the critical affordance factor in the affordance mechanism that will determine the safe actualisation of the affordance. In Warren's stair climbing the riser height is a critical affordance factor (Warren, 1984).

4.2 Affordance Paths (AP)

The affordance path should describe how the resource systems must be acted upon to be brought together to enable the interface transformation mechanism specified by the affordance to occur. It is the path followed by actions to enable affordances.

An affordance path AP is the set of possible actions that could be taken to enable the affordance mechanisms to act and execute the capability.

A capability affordance path is a process or sequence of actions necessary to realise the capability. It refers not just to a set of closed actions (like the affordance chain), but a process of connected sequential actions that typically occur in a business i.e. linked ordered but discrete actions as part of a business activity. This will comprise physical or substantive actions e.g. the act of injecting an anaesthetic as well as non substantive i.e. semiological actions (Stamper et al, 2000) e.g. verbal communication or inspection actions by the anaesthetist as a control on the action of injecting and assurance of the resulting value/goal achievement. We can say:

- AP is set of actions within an ordered sequence;
- AP contains actions represented affordance chains;
- AP contains semiological actions.

Affordance path = $\sum$ substantive affordance chains + semiological affordance actions

The Affordance path also results in a change of the variables AP = f $\triangle$ a $\rightarrow$a'

This relates to Luck and d'Inverno's total plan. I.e. Affordance Path AP =*Total plan* = seq *Action*

Note affordance paths P relate to Brown et al's (Brown and Blessing, 2005) 'operations' to preserve the link to capability. The anaesthetist has an almost infinite range of possible affordance paths. Consider the ways in which the substantive action of injection can be accomplished ie he can hold the syringe with one hand on the barrel and simultaneously resting on the patient to steady it and the other on the plunger. We can simply prod the patient with the syringe etc. The syringe has 1 degree of mechanical freedom – the plunger slides along the axis to afford the delivery of the fluid/anaesthetic. The passive structural affordances (A_{pb}, A_{bn}) at once constrain the motion and also effect the delivery of the capability value i.e. injecting the anaesthetic into the patient. The quality of the action path chosen will impact the efficacy of the affordance mechanism and determine how well the capability transformation is achieved. That is C = f (AM,AP) where AP is the set of substantive and semiological actions as shown in Figure 3.

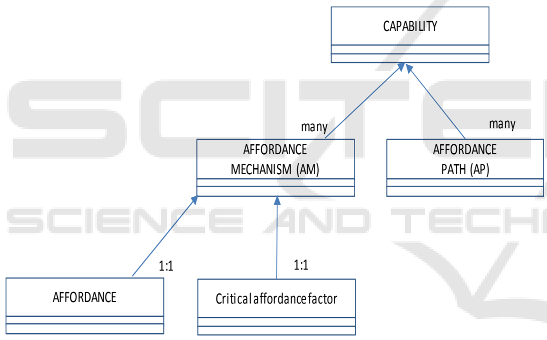

Figure 3: Affordance Mechanism and Path.

5 CAPABILITY-AFFORDANCES: A MEDICAL CASE STUDY

5.1 Drug Injection Capability

Based on structured interviews conducted at a health trust hospital (see acknowledgements) the following analysis was developed. The Capability C_i of injecting an anaesthetic drug into a patient via a process/action P_i results in the value v of 'patient anaesthetised and can be safely operated on'. Capability = f (resource affordance, process/actions of executing the affordance) = f (adding business value). But this capability results from four interacting systems, the anaesthetist, the anaesthetic fluid, the syringe and the patient. The syringe as a designed object resource can be further decomposed into its active components. The syringe is a set of interacting passive objective affordances where the laws of physics hold the assembled component affordances together in a state of equilibrium (ie objective affordance as we have seen). At a more macro or capability model level of what we can perceive, we can say; Capability of anaesthetising a patient = f {resource} = f (A-anaesthetist, S-syringe, F-anaesthetic, P-patient). The capability is dependent on a tuple or affordance chain by which the anaesthetist acts on the syringe which in turn acts on the fluid which in turn acts on the patient through a number of transformation mechanisms. It also relates to further affordance paths related to the semiological affordances involved in inspecting the patient and controlling the syringe action. The syringe affordance chain can be decomposed into its mechanisms and actions as seen in Figure 4.

5.2 Affordance Path & Mode of Action

The syringe tool has a designed way of being used – ie a set of preferred potential affordance paths. The syringe is a passive, but designed resource or a device Ds and must be guided by the surgeon in a specific designed way, at a certain angle to achieve results to meet the desired goal. This relates to refers to Chandrasekaran and Josephson's the mode M(Ds,E) (Chandrasekaran and Josephson, 2000) of deployment of the syringe device. The mode may come from tacit best practice knowledge or following procedures or documents defining usage procedures. For example, the mode of holding the syringe and injecting, the mode of the anaesthetic etc. Hence the mode refers to an optimum affordance path for the affordance chain ACs of the syringe: Mode *M* (Ds, E)= optimum f(affordance paths P_1-P_n OR actions mentioned earlier). But the optimum mode is achieved by the Anaesthetist's sensor affordances (sight/touch etc) and his tacit knowledge/conceptual model of the environment. The mode defines certain action behaviours to ensure the affordance mechanism is optimised eg: ensure syringe is in the correct location to meet a vein, it doesn't slip (negative affordance) and it reaches the correct depth to interact with the vein.

5.3 The Affordance Diagram - AMN

As affordances are pervasive we propose a simple affordance modelling notation AMN to provide

Affordance type	Affordance Ref.	Affordance Description	Affordance Mechanism (AM)	Affordance Path (AP)	Variables changed	Critical affordance factor fa
dynamic	Ahp	plunger affords pushing and grasping	apply force Fhp on plunger acting along axis of plunger	move plunger to end of travel (eg1 cm)	plunger location relative to body	Fhp, f1 <Fhp<f2 sufficient to smoothly move plunger& overcome friction
dynamic	Apb	Affords sliding and force transmission	frictional sliding force of plunger seal on syringe body	slider slides 1cm	bottom of body axially to end of travel	plunger travel to limit of body l
dynamic	Afb	Affords containment and force transmission	fluid force containment and expansion towards needle tube	fluid moves down body	fluid moves from body to needle	bursting pressure of plunger and tube
static	Afn	Affords fluid path transmission	fluid force expansion towards needle tip/skin	fluid moves down needle tube	pressure on fluid	bursting pressure of needle tube
static	Ans	affords skin penetration	pressure = force/area at the tip, where force Fns achieves steady penetration	needle penetrates skin to a depth d	skin penetrated	force magnitude Fns, f1 <Fns<f2
dynamic	Afp	Affords anaesthesia (anaesthetic body interface)	induced sleep via chemical interaction between anaesthetic and nerve/brain centres	anaesthetic induced sleep	conscious => unconscious	anaesthetic reaction kinetic factor tba

Figure 4: Anaesthetic Affordance Table.

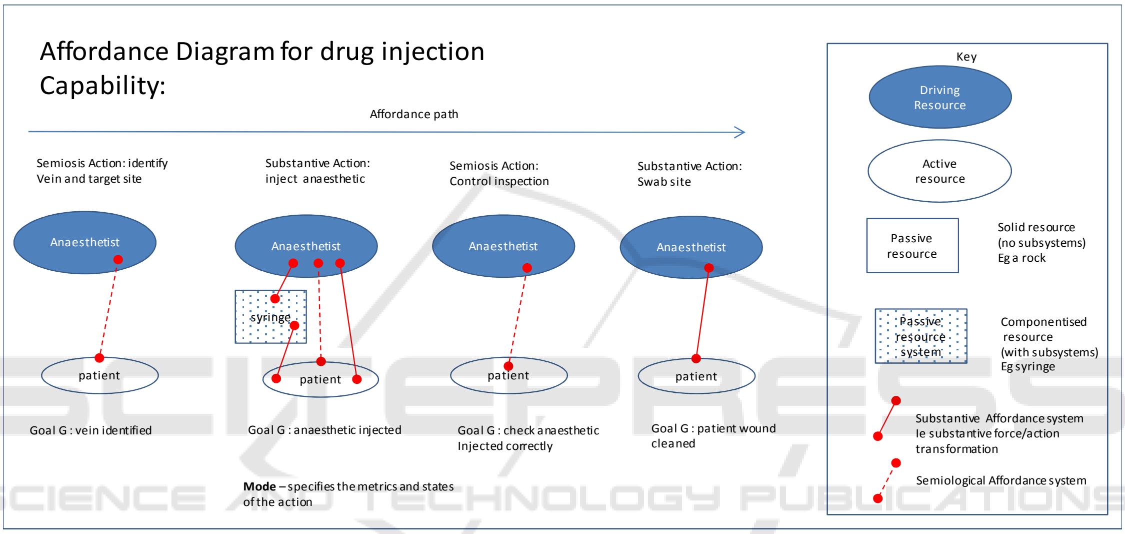

Figure 5: Anaesthetic Affordance Diagram.

succinct visibility of the affordance and system interactions. We use ellipses for active resources and differentiate between driving agent resources as a solid colour. Passive resources are represented as boxes with designed passive resources made from components identified by a shaded box. We also distinguish between action affordances modelled using the solid dumb-bell notation and intangible semiosis driven affordances involving perception e.g. anaesthetist identification of vein and control actions via a dotted line as on Figure 5.

5.4 Mode Representation

The mode specifies the ideal and optimised metrics and states of the action involving a designed object resource, e.g. the syringe as represented by procedures for using the syringe. Similar procedures are expected to exist for the identification of the vein and control inspection of the injection process, although these may be in the form of tacit knowledge and experience. The sequence of actions and the mode actually used vs the optimised mode in the procedures may vary greatly (and does in practice between anaesthetists). This corresponds to the anaesthetist using the syringe in a different way and perhaps using different resource affordances, which may not deliver the desired transformation goal of anaesthetised patient and the value they require to perform the medical intervention.

6 AFFORDANCE QUALITY, EFFICIENCY AND EFFECTIVENESS

This section explores how we can measure the performance of the transformation and the execution of the capability. The perceived benefit from the executed affordance and the value added by the executed capability, depend on the way the affordance is executed by the driving agent, i.e. in the process or action of the agent in following the prescribed mode. In each case different parts of the syringe and potentially different designed and non-designed syringe properties may take part in the action, even though the overall capability (to inject an anaesthetic) remains the same. In the interests of medical safety there are appropriate mode guidelines to follow that describe the optimum mode. However the decision on how the substantive action of injection is executed and the affordance path that makes up the capability is deontic – an obligation. The set of actions are subject to variation depending on the behaviour of the anaesthetist. This leads to variation in the efficiency and effectiveness of the capability of the anaesthetist which we will review later.

6.1 Efficiency: Ey

An *efficient action* is *an action (transformation) that uses minimum energy compared with other actions* (Natarajan et al, 1996). E.g., if the drug is over diluted it will be inefficient i.e. drug property has insufficient strength to cause anaesthesia. We define efficiency as the ratio of energy usefully employed vs the total energy employed in an action (or sequence of actions). Affordances which utilise the designed mode M of the device, or that of a specified action or behaviour would be expected to be optimally efficient. In terms of affordances: Negative affordances (e.g. errors) are ineffective i.e. unplanned/unwanted . We can attribute a number (0-1) as a measure of affordance efficiency to represent how close to the design mode of the device or procedure the affordance is. Then the efficiency of an affordance chain is simply the scalar product of the affordance efficiencies of the affordance pairs of the parts of the chain. For the syringe example the overall efficiency for any affordance chain 1-n is Ey of Af (1-n) = E Af12* EAf23*EAf3n.

For the syringe example the efficiency of the injection process depends on the efficiency of the affordance chain between the anaesthetist and the patient receiving the anaesthetic fluid. This involves the respective affordance efficiency of the hand-plunger, the plunger-body, the fluid-body, the fluid needle, the needle-skin and the fluid- patient affordance pairs. The overall efficiency of the chain is the capability efficiency= ∑efficiency of affordance chain actions + semiological action
Eci = EAhp*EApb*EAfb*EAfn*EAns*EAfp.

6.2 Effectiveness: Es

We can say that actions that meet requirements e.g. process goals are effective (Muchiri et al, 2010). *Actions that don't meet process goals are ineffective.* For example, if the wrong drug is used the injection is ineffective. As we have seen, actions depend on the affordance mechanism and the quality of the affordance interface that enables the mechanism to be executed. We can say: a) negative affordances are ineffective (unplanned/unwanted); b) positive affordances not required for the goal are ineffective. Effectiveness therefore refers to the proportion of positive affordances vs total number of affordances experienced. We define Effectiveness Esb as:
Effectiveness = ratio of effective actions/ (effective + ineffective actions)

To calculate the effectiveness of an affordance chain we need to: a) identify effective affordances Afe and b) identify ineffective affordances Afi.

The Effectiveness of an affordance chain is:
Capability effectiveness = sum(Afe)/(sum Afe = Afi).

6.3 Quality: Qas

The overall performance of any system *s* can be defined as its qualify Qs. Quality relates to performance to specifications. Optimal action specifications relate to the mode of operation as we have seen earlier. Quality also relates to performing actions that meet the overall action or affordance chain goals i.e. effectiveness

We therefore define quality of the affordance system as as the scalar product of the efficiency and effectiveness ratios ie Qas= Ey *Es. Hence the quality of an affordance chain of i elements is the Qc = ∑ Eyi*Esi.

6.4 Capability Quality, Efficiency, Effectiveness

We note that the above discussion shows the quality, efficiency, effectiveness of an affordance chain. Affordance chains relate to composite actions where all the resource objects are interacting. However, our original process level definition of capability refers to a sequence of actions. For example the capability of the process anaesthetise patient will include the inject patient action (the composite affordance chain), but also other actions eg communication and message passing between agents and waiting periods where affordances are not active. In this case The capability refers to the affordance path and hence the overall capability quality, efficiency and effectiveness will relate to the affordance chain efficiencies.

7 SUMMARY AND CONCLUSIONS

In this paper we have analysed the original resource capability model in terms of affordance theory of Gibson et al based on a realist approach and the use of *Z* notation. We have shown that capability can be modelled as a tuple of a set of resource affordance mechanism and actions that are dependent on one or more critical affordance factors and how these relate to the work of Turvey and others. The paper has identified and developed the concept of objective and subjective affordances and showed how these relate to the capability resource model and existing theories. We identified an affordance chain of subjective affordances by which affordances work together to enable an action and an affordance path that links action affordances to create a capability. We introduced the affordance modelling notation as a visual method of representing the affordances in a system of interacting resources. A medical case study was used to show how capabilities can be identified and modelled using the theory of affordances. We also proposed a model of affordance efficiency, effectiveness and quality that enables the performance of a capability and its constituent affordances to be measured and modelled.

7.1 Further Work

Further work is now needed to identify the practicality of the approach and to test the method in detail with larger capability sets and including more semiological affordances. Also to provide a complete worked example of affordance mechanism and path and a measure of capability from the system of affordances that constitute it.

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