Modelling Capability and Affordance as Properties of Human/Machine Resource Systems

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Keywords: Capability, Affordance, CPN, Critical Affordance Factor, Affordance Mechanism, Affordance Path, Affordance Chain.

Abstract: Understanding how and why the capability of one set of business resources, its structural arrangements and mechanisms compared to another works can provide competitive advantage in terms of new business processes and product and service development. However, most business models of capability are descriptive and lack formal modelling language to qualitatively and quantifiably compare capabilities, Gibson's theory of affordance, the potential for action, provides a formal basis for a more robust and quantitative model, but most formal affordance models are complex and abstract and lack support for real-world applications. We aim to understand the 'how' and 'why' of business capability, by developing a quantitative and qualitative model that underpins earlier work on Capability-Affordance Modelling – CAM. This paper integrates an affordance based capability model and the formalism of Coloured Petri Nets to develop a simulation model. Using the model, we show how capability depends on the space time path of interacting resources, the mechanism of transition and specific critical affordance factors relating to the values of the variables for resources, people and physical objects. We show how the model can identify the capabilities of resources to enable the capability to inject a drug and anaesthetise a patient.

1 INTRODUCTION

Capability is complex, with wide variations in meaning and evaluation. Capability can refer to the human action ability to do something, (Prahalad and Hamel, 1990) (Gallouj and Weinstein, 1997). Capability also refers to an object's abilities (Beimborn et al, 2005) and the ability of groups of resources to perform a task (Grant, 1991) via a process (Makadok, 2001). Capability relates both to tangible visible transformations, (eg manufacturing an object) and intangible transformations, eg teaching, where information is transferred and tacit knowledge is created (Michell, 2013). The ability to transform resources is the basis of business competitive advantage, where the product resources have greater monetary value than the input resources and cost of work done.

1.1 Paper Objectives and Layout

Our focus is: modelling the capability of a system of business resources to identify how and why it is able to meet a specific capability goal. Such a model enables comparison/selection of the best system of resources for a specific task (Michell, 2012). It also aids understanding the resource properties and dispositions required for a capability-affordance system to achieve a goal. The paper is in 6 sections. Section 2 Introduces affordance and effectivity to formalise the capability model. Section 3 reviews formal affordance models and their shortcomings in relation to capability affordance modelling. Section 4 develops a proposed model for capability analysis using CPN. Section 5 provides an example application of the model. Section 6/7 discusses the use and benefits of the model and our conclusions.

Michell V. and Roubtsova E.
Modelling Capability and Affordance as Properties of Human/Machine Resource Systems.
DOI: 10.5220/0005424500740083
In *Proceedings of the Fourth International Symposium on Business Modeling and Software Design (BMSD 2014)*, pages 74-83
ISBN: 978-989-758-032-1

1.2 Definitions

Table1: Definitions.

Environment E	A business environment *E* comprises a set of *{resources Ri}*. The set of *resources* {Ri} have perceivable features whose value at any point is called a disposition
Agent	An *agent* resource is a resource object that can perceive its own environment through sensors and acts on the environment according to their self-motivations through effectors. (eg human or autonomous machine)
Active/Passive Resources	*Active resources* eg a nurse, are capable of exerting a change of state on other object resources in a transformation (note driving resources must be active resources) and have a disposition q. *Passive resources* require other agents to realise their capability ie they are inert and not capable of their own motion or change of state and have a disposition p (eg a syringe).
Action	An *action* is a discrete physical transformation event between active and passive resources that can change the state of a system of resources in an environment to a desired goal state G.

1.3 Capability

A Capability *Cv* results from transformation interactions between two or more resources that achieve a business goal, typically to increase the business value of the transformed resources with respect to a business client. *Business capability is the potential for action to achieve a goal G via an action/series of actions in a process P resulting from the interaction of 2 or more resources, in a transformation that produces business value for a customer.* (Michell, 2011). For example, resources *R1* and *R2* in state *s1* and *s2* interact in the transformation and produce a new state of the system which matches the goal state requirements *G* and in which *R1/R2* may be different. The resources may be combined into a third resource (an input resource is consumed/combined) or *R1* and *R2* remain, but the physical states or *R1* and *R2* are changed. Capability represents the potential of a system of input resources being able to effect a transformation to meet a goal state G and a corresponding system of output resources. For example, a laboratory technician mixing two drugs with a goal to form a new drug, or two doctors discussing a diagnosis. In both cases energy has been expended and a physical state change has occurred. In case *1*, two drugs have been mixed to create a different drug *R3,* but *R1* the drug mixer remains, but in a different state – having the transformation experience. In case *2* information has been passed between clinicians altering their states, i.e. perceptions and memory (biochemistry/ memory state change) *R1* to *R1'* and *R2* to *R2'*). Both transformations add 'value' to the process; a new higher value drug is formed or a patient diagnosis is understood. For the transformation to occur at least one resource must be 'active' and capable of exerting forces and energy via some form of 'mechanism' to transform the other resource. It may be a human or autonomous machine. Other resources may be passive, e.g. drugs, materials etc or also active – another agent or machine. We seek to identify what are the properties of the interacting resources that enable this capability.

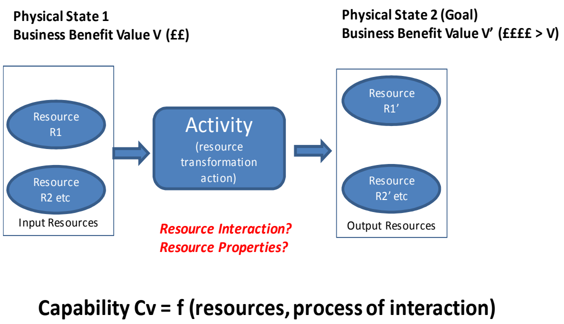

Figure 1: High Level Capability Model.

2 AFFORDANCE / EFFECTIVITY

2.1 Affordance as Environment Ability

Gibson (Gibson, 1979) defined affordance as' the 'property that the environment or physical system offered the animal to enable a possible useful transformation for the benefit of the animal' (Greeno, 1994) Gibson saw affordances as object properties that could be perceived as well as intrinsic properties of the way the object was – its disposition. Affordance represents opportunity for potential action by– visualising what an object can do. Affordance also represents the interaction relationship between the animal and its environment, Gibson's ecological approach identifies action as a result of what the animal or agent can do. Affordances refer to descriptions of (verb-noun) object abilities such as a road is 'walkonable' or the 'cup affords drinking' (Gibson, 1979) indicating that the structure/disposition of a road or cup enables it to be walked on or drunk from. Affordance is the 'relational' property of the agent environment system that provides the potential for interaction and transformation. It focuses on the possibilities of how the object could be used by the animal or person. However, the animal must also have an ability to use the object and have the correct disposition of properties; otherwise no useful interaction can take place.

2.2 Effectivity as Animal Capability

Shaw (Greeno, 1994) identified that environment ability or disposition, must be complimentary to the animal's disposition and ability. Shaw defined this ability of the animal to compliment the affordance properties of the object as 'effectivity' ie the 'capability of the animal' to use the object in a transformation. Wells (Lenarcic, 2007) suggests effectivity relates to 'the functional state of the animal' and its possible movements. Hence an effectivity; 'can walk', refers to the human ability to meet the goal of walking (Kim et al, 2010). We can think of effectivity as the driving agent ability or the human potential functional characteristics and features that enable them to effect a transformation.

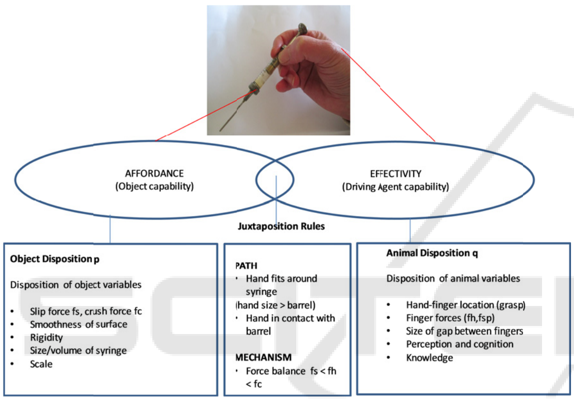

Figure 2: Affordance-Effectivity of 'Grasp'.

2.3 The Affordance-effectivity Dual

The disposition of the animal, its effectivity, must compliment the disposition of the object; its affordance, in order for an interaction or transformation to take place. The term affordance-effectivity dual refers to the complement and one cannot exist without the other (Ortmann and Kuhn, 2010). For example to hold an object, such as syringe, a person's hands must fit around the object and the fingers must be in a position to prevent it moving and slipping by applying forces via the fingers, sufficient to lift and hold, but not to crush the object. These are properties of the persons' effectivity in grasping the object. For the object to be held in a hand it must fit inside the hand (volume property), must not be too heavy or slippery, It must also have places that the fingers can grip on to, – properties of the object's affordance. The affordance-effectivity dual refers to the capability of a driving agent to configure (dispose) itself to complement an object's configuration (disposition) to achieve a transformation. The configuration of the agent refers to finger and force location, magnitude, size of hand etc. The configuration of the object refers to its size, weight, slipperiness, functions and features etc. The disposition is a specific set of values of the configuration of object/agent at the point of interaction. A mathematical model is needed to enable quantitative and qualitative definitions for comparison and use of capabilities and their dispositions.

The next section briefly describes mathematical models of affordance and effectivity and their limitations that motivate this paper.

3 AFFORDANCE MODELS

3.1 Turvey et al.

Turvey modelled possible actions, or affordance-effectivity opportunities, as 'prospective controls', to refer to an animal perceiving whether an action is possible (its capability) and its control of the planned action to meet the goal of using the object. Turvey's affordance model related animal properties Z and properties of other entities X in an environment (Turvey, 1992). The specific animal, Z disposition or arrangement q enables it to join to X, which a complimentary disposition p. Turvey has defined the juxtaposition function j as the subset of all the possible dispositions X and Z possess that make the interaction Wpq possible. So p (the object disposition) is 'said to be an affordance a thing in the environment X' and 'q is the complementary disposition of the animal Z'. At the point of interaction the animal-environment interface possess an interaction property r, which is a property of Wpq alone.

$$Wpq = j(Xp, Zq) \quad (1)$$

Stoffregen (Stoffregen, 2003) developed the model and identified the need for spatio-temporal contact for affordance to be possible (Lenarcic, 2011). This highlights the need for a space-time path to exist between the interacting agent-object resources that form the basis of our model. Warren and others (Mark, 1987) identified that the geometry of the interacting objects is important in affordance, eg the climb-ability of stairs depended on the ratio of riser height to leg length (Warren, 1984). This suggested classifications of affordance by a dimensionless ratio. However, not all affordances can be reduced to one ratio as Mantel et al (Mantel et al, 2012) observed in their study of action modes, their boundaries and degrees of freedom of interaction. This highlights the need to consider a wider set of critical factors that we refer to in our model. Steedman (Steedman, 2002) used linear dynamic event calculus to identify all the possible potential action paths. However, it does not meet our need for modelling the mechanism of action paths to a specific goal. Brooks (Brooks, 1991) Sahin (Sahin 2007) and others have used affordance extensively to develop ecological behaviour based control in robotics, but this is out of scope of our work, which is focused on human-device work interactions.

3.2 Lenarcic - Situation Theory

Lenarcic combined Barwise' situation theory that models the semantics of situations (individuals, information, time, place) (Barwise and Perry 1980), with Gibson's and Turvey's affordance propositions. Lenarcic's situation theory model relates affordances of a set A of objects in the logic (Lenarcic, 2011):

$$A = \{Aatom, Aset, Astate, Asit, Aaff, Aind\} \qquad (2)$$

Aatom is a set of relevant facts, eg nurse, grasp, hold, syringe etc. Aset is the set of objects. Astate is a set of assertions *{w}* that relates individual people and objects as truth assertions *w = {r, t1…tn, E}* eg *<<in, nurse, room, 1>>*, or 'drug is in the syringe': *<<in, drug, syringe, 1>>*. *Asit*, situations, are sets of relationships between states *{w1,…,wn}*. *Aaff* is a set of affordances as a tuple *{Φ, s, i}*, *Φ* refers is the action relating to the affordance, s refers to the situation conditions, *i* is the individual capable of affordance, eg *Φ1 <<inject, injection situation, nurse>>* refers to the agent driving the affordance, the action involved and the state conditions. Aind are individuals with their; name, abilities or possible actions eg inject, grasp and their niche or specific action groups (Lenarcic, 2011). An 'enacting function' representing the juxtaposition function, for the affordance to be possible. Lenarcic's model defines a comprehensive algebra for affordances and situations and their semantic relationships. However, the model is complex and unwieldy for more than a few interactions. It is mainly qualitative and hence difficult to compare capabilities or the mechanism of their interaction.

3.3 Affordance Model Developments

Kim et al (Kim et al., 2008) models affordance using situation theory and finite state automata (FSA) models at different levels of detail called grains. A high level grain model represents a plan of action or process and an atomic model of interaction that provides a level of detail within the process that relates to the CAM model. They define a 12 tuple model for Matom:

$$M = (\{X, Z, W\}, \{P, Q, PA\}, Pr, j, \pi, ta, int, tint) \qquad (3)$$

Where the environment is X and human agent *Z* and *W* the animal environment system (AES) (Lenarcic, 2011)]. *P* is the set of affordances, *Q* the set of effectivities and *PA* the set of possible actions that can take place. Kim et al include *Pr* a perceptual predicate function to account for the fact that affordance must be seen and understood in order to use them. Other variables relate to Turvey's juxtaposition function *J* (the function combining affordance and effectivity) and possible action generation function pi and the goal or target action ta. The tuple concludes with time function for the process level (delta) and the atomic level timing of the affordance-effectivity interaction. Kim et al provide useful examples of the application of the model to a coin in a slot machine and catching a ball. LTL enables notional separation of affordance *p* and affectivity *q* (Lenarcic, 2011). However, Kim's 12 sets of variables make it unwieldy in modelling situations where we wish to compare affordances at a higher level of capability, ie several actions. Also it is not easy to model and specify *p* and *q* explicitly and intuitively, partly because p and *q* are related by the juxtaposition function *J* which is not easily elaborated.

3.4 The Capability-affordance Model

Our model identifies capability as a property of any resource combination animal-animal animal-machine, machine–machine (Michell, 2011). This enables both business capability to be modelled as well as the capability of interacting resources without human intervention eg chemical reactions (necessary as part of industrial processes). Capability requires affordance-effectivity interactions to take place. We take a Gibsonian stance, but unlike Gibson's pure affordance, which relates to possibilities of any resource interactions happening, we are concerned with how and why useful business interactions can happen. Hence goals will be specific to those adding value. Our focus is on determining the conditions and resource specifications for which a specific capability is possible. We illustrate this with the example 'injecting a drug' in a clinical process. Using Gibson and Turvey, we decomposed the affordance-effectivity disposition or possibility for action (Lenarcic, 2011) into (i) a space-time or path disposition and (ii) a mechanism disposition (Michell, 2012). At the point of transition Turvey's juxtaposition function *J* must be represented by both a path and a mechanism, both meet critical affordance factor values that make the state transition possible. The capability of a system of agents and objects is the sum of all the affordance-effectivity interactions within the system. This is equivalent to *W*, the AES- animal in environment system in Kim (Kim et al., 2008). The affordance-effectivity interactions are part of a process where paths represent the what Kim calls 'high grain' interactions and affordance chains represent parts of agents or objects eg syringe components such as the plunger and the barrel interacting.

3.4.1 Affordance Path

The affordance path relates to the space-time affordance-effectivity dual interaction requirements that if the agent and object don't spatially come into contact or a region of influence with each other, affordance won't occur (Lenarcic, 2011). Hence part of the animal disposition *q* and the object disposition *p* conditions must relate to space-time rules regarding the contact/interaction geometry between object and animal. In the syringe example, the syringe position and orientation (*p* variables) must match the hand/finger positions (*q* variables). If the structural spatial arrangement or disposition of the interacting resources do not complement each other, the interaction and capability will not be present, ie if the syringe is too big to fit in the hand or lacks grip and leverage points.

An affordance path *AP* is the set of possible space-time movement and geometric configuration conditions that must exist to enable the affordance mechanisms to act and execute the capability. (adapted from Michell, 2012) At the interaction point between resources, the space time path of animal and object must be the same. Movement and dynamics of the agent in its previous states must be such that it leads to the special agent spatial disposition *q* which matches the special spatial disposition of the object *p* at time *t* of transformation. This becomes a more difficult problem of kinematics when both animal and object are moving and the geometry changes, as in Kim's ball catching example (Kim et al., 2010).

3.4.2 Affordance Mechanism

Having the right spatial disposition alone is not enough. There must be an energy and interaction mechanism to get the resources into contact and to enable the desired cause and effect. For the syringe to be gripped, the hand must exert force on it through the fingers to prevent slipping and crushing. The use of forces in this case is the 'mechanism' or what enables the transformation – to hold the syringe. The affordance transformation mechanism refers to the laws of nature that must hold for the cause and effect interaction between the resources to take place. The most common mechanism in substantive interactions is force, supplied by an animal or machine agent. *The affordance mechanism is the cause and effect transformation at the interface between the two or more interacting resources and its properties that enable the transformation* (adapted from Michell 2013).

Mechanism refers to the behaviour and properties of the energy transfer that drives the transformation eg human energy, chemical, electrical etc. This fits with Gibson's ecological approach. Other mechanisms exist. Chemical mechanisms, enable a substance eg sugar to dissolve in a fluid, if the sugar has appropriate properties ie sufficient surface area and if the sugar's bonds can be broken by a fluid such as water. This represents an object-object transformation between the water and sugar. The mechanism of electric induction depends on the properties of a wire and electromagnetic field and enables an electric current to appear in a wire. This mechanism is necessary for affordance and capability of an electric motor ie a motor affords rotation. Without it the motor has no capability or affordance. Mechanisms are not confined to substantive actions, but include human cognition sense making – or semiosis (Stamper and Liu 1994). The mechanism for the nurse holding the syringe includes the need to perceive the situation (position of the syringe) and the affordance of the object (can the syringe be held – how big/heavy is it, will it fit?). Holding the syringe 'to give an injection' requires different knowledge and skill (repeated affordance experience) than a simple grasp (Andre, 2011) to actualise the affordance–effectivity action of 'inject'. Hence mechanisms should ideally include cognitive resources in terms of 'know what, how and why' that enable the agent to make intelligent decisions to enable the resources to interact. The complete capability model should include perception, cognitive behaviours (Michell, 2013) and capability mechanisms that will affect whether the animal is able to a) perceive and b) understand and bring the resources appropriately together with the right disposition to enable the path and mechanism to effect transformation. For space reasons we only include a brief perception example.

3.4.3 Critical Affordance Factor

In both path and mechanism there is a linked set of critical values of the variables relating to the functions that define the path and mechanism. that enable interaction. These critical affordance values effectively encompass any critical ratios (such as those defined by Warren, 1984) and other factor values that will affect the possibility of the transformation occurring. We define the factors that have critical values attached to them as critical affordance factors, CAF (Michell, 2012). CAFs refer to the values and/or range of values for the disposition of both object and agent to interact ie values of *p* and *q* in Turvey's notation. So in the syringe example they might refer to the range of force (ie critical mechanism values) values to hold the syringe without crushing it and the location/position of fingers within which the syringe can be held (critical path values). This is analogous with Kim's conditions – C (Kim et al., 2008). Identification of critical affordance factors and their ranges are important for both quantitatively comparing existing capabilities and requirements for the capability to exist and in designing new devices and products to meet new capabilities and performance goals.

3.4.4 Affordance Path and Chain

For designed objects, to work, a sequential set of affordances for the interacting components, needs to interact in unison in an 'affordance chain' (Michell, 2012). For example, a syringe has a barrel and needle and plunger with a seal that fits inside the barrel. The action of pressing the plunger results in the plunger pushing the air or fluid out of the barrel – eg into a patient. We can say the 'syringe affords injection of a drug'. In an affordance chain (Michell, 2012), the parts are locked together by virtue of their affordance/effectivity properties. An affordance chain also occurs when an agent is holding and manipulating objects, ie the object or tool becomes an extension of the person's hand due to the chain of interactions at object-hand and object-object interfaces. An **affordance chain is a contiguous interaction between affordances acting at the same time.** In contrast the **affordance path refers to a time sequence of related affordances that together produce the conditions for a capability**, eg the capability of injecting a patient.

3.4.5 Resource Properties

Other properties of object and agent are required for affordance-effectivity. For the syringe to be used effectively it needs some kind of scale so that the volume of fluid/drug inside it is known depending on the position of the plunger on the scale. This is an additional necessary resource property of the syringe that enables the affordance-effectivity transformations.

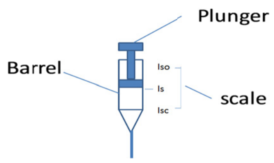

Figure 3: Resource Properties for a Syringe.

3.4.6 Relationship to Other Models

We model the capability affordance model at two levels of Kim's grains, process level for the actions and resources and atomic level for the affordance-effectivity and disposition details (Kim et al., 2008). At the point of affordance-effectivity interaction, the mechanism and path relate to the juxtaposition function. The path represents the space time rules of the juxtaposition function for the affordance-effectivity dual to work. Typically, this will involve the need for objects to be touching, in the same position and specific orientations needed for the transition. Both the object and agent share path spatial conditions. In the syringe example the syringe position and orientation (*p* variables) must match the hand/finger positions (*q* variables). The mechanism represents the action forces (biomechanical, chemical, electrical) etc that enable the transition or change in physical state to occur at the juxtaposition point. Both the object and the agent share mechanism conditions. The critical affordance factors refer to the variables of the path and mechanism and their range values for the affordance-effectivity and hence capability to work. (see Capability-Affordance Model (CAM) below).

4 CAPABILITY SIMULATION

4.1 Model Requirements

Based on the previous discussion, a capability model should enable;

a) modelling of Affordance Paths (process level) at a business process level from initial state to the goal state; representation of affordance path/position and their functions at atomic level, which characterises transitions on the paths.
b) representation of the Mechanism/Force and their functions, at atomic level, which characterises transitions on the paths.
c) modelling of critical affordance factors at atomic level (the values and ranges of their variables) and relationship to path and mechanism functions.
d) The model should show a number of actions at the process and the atomic level that supports a capability without excess complexity. The above are all logical or mathematical constraints and hence a simulation type modeling language with functions and rules is required. Requirements b), c)) rule out traditional BPMN process models and a),d) rules out Kim and Lenarcic's approach. However, Colored Petri Nets (Jensen, 1997) have been widely used to model activities, states and processes. CPN makes the conditions necessary for alternative affordances visible. These conditions are important for capability system analysis. Given our focus on modelling the why and how of capability we propose making them visible as guards of CPN transitions. As we show later the critical affordance factors presented as guards are great tools for simplification of affordance models. Our approach combines CPN with the Capability Affordance Model (CAM) described earlier that allows us to abstract transitions and simplify the model.

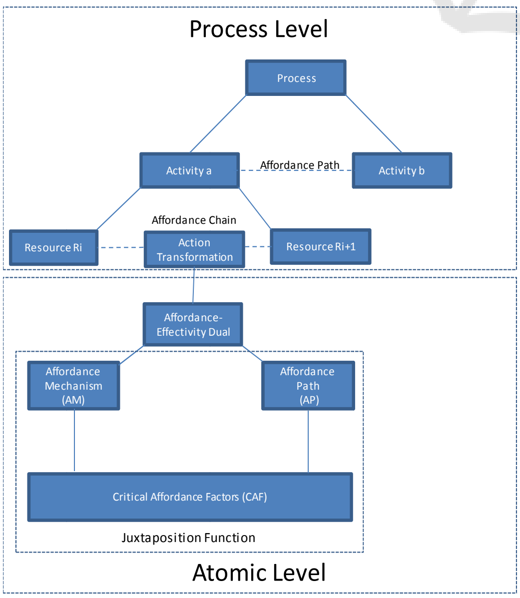

Figure 4: Capability-Affordance Model (CAM).

4.2 CPN and Capability

Coloured Petri Nets (Jensen, 1997) (van der Aalst & Stahl, 2007) possess all the expressive means needed for understanding and possible measurement of the notion of capability. Coloured Petri Nets (CPN) combine advantages of classical Petri Nets (PN) with the expressive power of complex data types "colors "(Jensen, 1997). An initialized non-hierarchical CPN(net) without time stamps is a tuple: *CPN= (C,B,V,P,T),*
- *C* is a finite set of colors (data types), $c \in C$. For example, the colset:
*Syringe=productSyringeName*ForcePlunger* ForceSlip* SyringeScale* SyringeopenScale* (Fig 6.)
represents types of variable needed to describe dispositions (variables) *p* and *q* of resources. Colors and variables are defined in declarations. We use data types and variables to represent resource types.
-*P* is a finite set of places, $p1, \ldots, pm \in P$, depicted by ellipses (Figure 5). Each place p possesses a bag *bp*.
-*B* is a bag of tokens (values) of colors $c \in C$ represented near places. We use tokens to model instances of resources.
-*V* is a set of variables of colors $c \in C$.
-*T* is a finite set of transitions depicted by boxes (Figure 5). Transitions represent actions and are denoted by verbs.
-Each transition is a tuple *t= (I, g,O):*
-*I* is a finite set of input arcs. An input arc is directed from a place *p* to transition *t*. An arc contains an expression of the color of place *p*.
-g is a guard of transition *t*. Each guard is a Boolean function. By default each guard has value true. We use guards to model the critical affordance factors (space time and mechanism) necessary for the affordance-effectivity dual.
-*O* is a finite set of output arcs. An output arc is directed from the transition to a place *p*. An arc is labelled with an expression of a place *Color*.

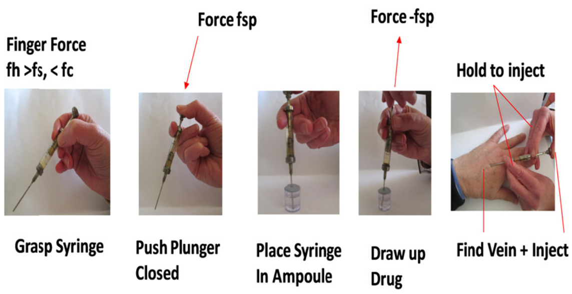

Figure 5: Capability to Inject a Drug Example.

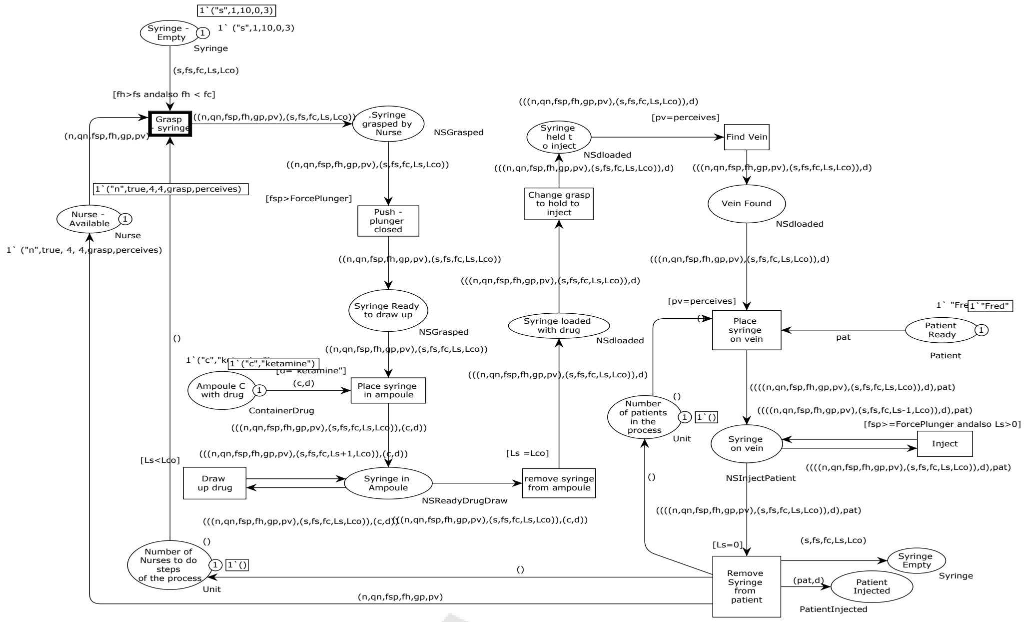

Figure 6: CPN model of Capability - Inject a Drug.

Table 2: CPN-CAM Path and Mechanism Sequence.

Ref	CPN TERMS: P =place, T = transition	PATH (at point of affordance-effectivity)	MECHANISM	CRITICAL AFFORDANCE FACTORS (path/mechanism)	RESOURCE CONDITIONS
P1	Syringe			fs=1N, fc = 10N,	Empty/clean
T1	**GRASP SYRINGE:** The empty syringe is grasped without slipping, then pushed closed to draw up the drug. The The critical affordance expressions are shown by the guard conditions on 'grasp syringe'. hands fit round syringe, grasp force fs must be greater than slip force (1N) but less than crush force (10N).	hands fit round syringe	grasp forces fh	fh > fs, fh< fc, hands fit round syringe, grasp force fs must be greater than slip force (1 N) < crush force (10N)	Syringe s slip and crush forces, scale ls = 0 and lco =3cm
P2	Nurse				Nurse
P3	Syringe grasped by nurse				NSGrasped - the nurse grasping the syringe
T2	**PUSH PLUNGER CLOSED:** To draw up the drug the syringe plunger is pressed closed by the nurse applying a force fsp > a minimum plunger force. Otherwise the drug cannot enter the syringe.	hand attached to plunger, plunger at end of syringe ls = lsc = 0	plunger force + fsp	fsp1 > forceplunger (min force to move it)	Syringe held in closed position
P4	Syringe ready to draw up (plunger in closed position)			ls =0	NSGrasped - with
P5	Ampoule C with drug			drug type - ketamine	ContainerDrug - an
T3	**PLACE SYRINGE IN AMPOULE:** containing the correct drug. If not in drug no drug will be drawn up (capability failure). The mechanism here is the gasp force holding the syringe and the ampoule - not shown	syringe needle immersed in drug	nurse grasp forces on syringe & ampoule	d=ketamine	ketamine is the correct drug/label for patient
P6	Syringe in Ampoule			ls = 0	NSReadyDrugDraw
T4	**DRAW UP DRUG:** Plunger is pulled back to draw up drug to the correct amount in increments of ls + 1 . Mechanism here is pulling force on the plunger creating a partial vacuum and atmospheric pressure forces the drug into the syringe.	Hand on plunger moved to end of syringe ie ls = Lco = 3	negative plunger force = -fsp	fsp1 > forceplunger (min force to move it), ls = 3	-fsp applied (not shown) ls = ls +1 until ls = 3 on scale
P6'	Syringe in Ampoule			ls = 3	NSReadyDrugDraw
T5	**REMOVE SYRINGE FROM AMPOULE:** The draw up drug continues until ls = 3.= Lco. Incorrect amounts = capability failure / patient not anaesthetised			ls = 3	syringe not in ampoule
P7	Syringe loaded with drug			ls =Lco	NSdloaded
T6	**CHANGE GRASP TO HOLD TO INJECT:** Nurse's finger tip locations/forces adjusted for safe drug injection at correct angle. Failure risks patient injury and not/partly injecting the drug	Grip pattern (position of fingers) = hold	grasp forces fh	fh > fs, fh< fc, GripPattern = hold	Syringe constrained in'hold to inject' position with no slip
P8	Syringe Held to inject			gp = hold	NSdloaded
T7	**FIND VEIN:** A vein on the patient is perceived, based on the nurse' knowledge. Mechanism is nurse' perception/cognition, visual ability (No vein, incorrect site = capability failure)	Visual path: ie nurse can see the patient and the site of injection	perception-cognition mechanism (Pv)	Pv = true	Nurse - has updated knowledge - Vein is found
P9	Vein Found			pv = perceives	NSdloaded
P10	Patient Ready			pat = Fred	Nurse sees the vein
T8	**PUSH SYRINGE IN VEIN:** at correct angle and position			pv = perceives,pat = fred	Correct patient vs drug
P11	Syringe in Vein			ls >0	NSInjectpatient
T9	**INJECT:** Plunger pushed closed at correct injection site to ensure drug is transferred to the patient, (otherwise no anaesthesia and capability fails)	syringe plunger location ls = 0	fsp	fsp > min, ls > 0	Syringe held in closed position
P11'	Syringe in Vein			ls = 0	NSInjectpatient
T10	**REMOVE SYRINGE...** - Inject contintues until ls = 0 (syringe can be withdrawn)			ls= 0	Syringe not in patient
P12	Syringe Empty			ls= 0	Syringe
P13	Nurse Available				Nurse
P14	Patient Injected				Patient Injected

5 EXAMPLE APPLICATION

5.1 Injecting a Drug

Based on structured interviews conducted at a health trust hospital (Michell, 2012) we model the capability to inject a drug using a syringe. Resources include an active resource; a nurse and patient named Fred and passive object resources; a syringe, ampoule containing a drug (eg Ketamine). The capability to 'inject the drug' depends on a process of actions with the correct disposition of resources to inject the drug. If any actions do not have the correct conditions ie any of the critical affordance factors, path and mechanism are incorrect, there will be no capability. The key actions (See fig. 5) are the nurse grasping the empty syringe and pushing the plunger closed ready to draw up the drug. The nurse places the syringe in a drug container (ampoule) and pulls the plunger to draw up the drug. The nurse holds the syringe in a different way – 'hold to inject' and looks for a vein on the patient. Having perceived the vein the nurse pushes the syringe into the vein at the correct position and angle and then presses the syringe plunger to inject the drug. See Table 2.

5.2 Behaviour of the CP-Net CAM Model

Decomposing this process sequence into actions (CPN transitions labelled T) and situations (places labelled P) enables us to identify the critical state transitions and affordances/effectivities. Figure 6 shows a CPN model of the capability to 'inject the drug.'. The initial state and the goal state of the business process are modelled by places that may contain tokens of given colors. Places are connected via transitions so paths leading from initial states to goal states relate to the capability of the system, ie the CPN simulation reaching the goal state. Tokens - represent instances of business object and agent actions and values for the dispositions of each resource (object or agent) at the point of interaction. Transitions represent the transformation affordance-effectivity interactions. A transition *T* of a CP-net is enabled if places of all its input arcs contain tokens to give values to input expressions of *T,* and the guard value is *true*. The guard values represent the **critical affordance factors**. Eg in *T7,* perceives vein must be true for injection to occur. Each enabled transition *t* can fire. When a transition *t* fires then for each input arc its expression is evaluated by a token from the arc's place. For each output arc its function is calculated using the values of the variables from the input arcs of the transition. The result of the output function is added as a token into the place of the output arc. **Affordance** is represented by properties *p* of the passive resources and environment. Eg Syringe –properties are implied by the token: *(s (name) ,fs (slipforce, fc (crush force), Ls (syringe scale level, Lco (scale zero)).* **Effectivity** is represented by properties *q* of the active resources eg the nurse that acts on the syringe, eg Nurse properties are implied by the token: *(n (name), qn (quality), fsp (plunger force), fh (hand force), gp (grasp type), pv (perceives)).* **Affordance Path** at the transformation point, is represented as a net of transitions from the initial places to the goal state *G*. *G* is represented by the state of resources; patient is injected, syringe is empty, nurse is available. **Affordance Mechanism** is modelled with functions corresponding to guards and functions associated with arcs of transitions, eg the force fh applied by the nurse enable the syringe a) to be held in place to execute the affordance-effectivity and b) a second force *fsp* on the plunger moves it to draw up the drug due to the mechanism of a vacuum created in the syringe. **Affordance Chains** represent the concatenation of resource instances and their disposition variables, we use Cartesian products and a value of token with a product type. Cartesian products relate to the Affordance Chain of agent and component objects (eg syringe plunger etc) needed to enable the affordance-effectivity interaction. For example a nurse *holds* a loaded syringe *(NSDloaded)* or an ampoule containing a drug *(ContainerDrug).* The mechanism, path and critical affordance factors at transitions are shown in table 2.

6 DISCUSSION

The CPN Capability Affordance model provides a precise means of modelling and simulating business resource interactions and their capability properties and quantitative values. The model shows that if no affordance (space time) path to the goal state of 'inject' is possible there is no capability to inject. This is represented by the existence of a complete CPN trace to the end state goal. It also shows that capability to inject depends on the mechanism of forces and perception that relate to real-world interactions and conditions. CPNs are executable. This enables critical affordance factors for forces, locations and positions to be identified and modelled so key actions and required properties of the resources for capability 'to inject a drug' can be identified. For space and complexity reasons not all factors are included. For example; a) the nurse must perceive the drug label on the ampoule and ensure it is matched to her knowledge of what drug should be injected into what patient, b) the patient must be perceived and identified by the nurse as the correct patient.

7 CONCLUSIONS

This paper has shown how capability, affordance and critical affordance factors can be presented in a

CPN model. It shows how capability depends on; a) the existence of a possible path of interaction between the resources (nurse, syringe, ampoule, patient), b) a mechanism of transition (forces and drug interaction in this case), c) specific critical affordance factors relating to the actual value of the affordance and effectivity variables for resources such as people and objects within instances, d) That these variables relate to Gibson's original explanation of affordance disposition and the affordance-effectivity dual relationship. Future work will focus on the detail of a single action and its affordance-effectivity relationship by decomposing this into affordance path, mechanism and affordance factors, including perception and planning as well as control actions.

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