**Alsmith, Adrian**

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# The concept of a structural affordance

**Adrian Alsmith**
Centre for Subjectivity Research, University of Copenhagen, Denmark
*asmith[]hum.ku.dk*

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**Abstract**

I provide an analysis of the concept of an “affordance” that enables one to conceive of “structural affordance” as a kind of affordance relation that might hold between an agent and its body. I then review research in the science of humanoid bodily movement to indicate the empirical reality of structural affordance.

**Keywords:** Affordances, Ecological Psychology, Embodiment, Embodied Cognition, Motor Control.

One of Gibson’s novel contributions to perceptual psychology is the notion of an affordance. In this article, I provide an analysis of the concept that allows one to think about a kind of affordance relation that might hold between an agent and its body, which I call “structural affordance”. After a brief specification of the latter, I review research in the science of humanoid bodily movement to provide some indication of the empirical reality of structural affordances.

## Gibson’s affordances

Here is the first example of an affordance that Gibson provides:

> *If a terrestrial surface is nearly horizontal (instead of slanted), nearly flat (instead of convex or concave), and sufficiently extended (relative to the size of the animal) and if its substance is rigid (relative to the weight of the animal), then the surface affords support.* (Gibson 1979/1986: 127, emphasis original)

The status of affordances is slightly ambiguous. At first blush, when Gibson says that the surface affords support, it would suggest that he wishes to pick out certain properties of the environment. Indeed, when he introduces the term itself he says that the “affordances *of the environment* are what it offers the animal” (ibid.: 127, emphasis mine). But then he says this: “The verb to afford is found in the dictionary, but the noun affordance is not. I have made it up. I mean by it something that refers to *both the animal and the environmen*t in a way that no existing term does” (ibid., emphasis mine). How could a term refer to both animal and environment? He then offers a third option (which I think is the most sensible), saying what he wants to refer to is something that implicates their relationship, for he insists that the term "implies the *complementarity* of the animal and the environment" (ibid., emphasis mine). So we have a few options for interpreting the term. Indeed, there are two extremes. At one end, the interpretation is that "affordance" denotes a property of the environment which bears a special and particular relationship to an animal.[29] At the other end, "affordance" denotes the (special, particular) relation itself.[30] Although this is a significant matter of theoretical choice, I opt for the latter interpretation; but not entirely without motivation. Treating affordances as relations is the simplest way of capturing the reality of affordances: they are as real as their *relata*.[31]

Interpretive issues aside, there are several things about affordances that are clear. The relations are certainly conditional. They only occur within a certain range of possibility, denoted here by the explicit contrasts used (nearly horizontal vs. slanted etc.). In this case, and presumably others, multiple conditions must simultaneously obtain in a particular situation for the instantiation of a particular affordance. If a terrestrial surface were nearly horizontal over one period of time, but only sufficiently extended at another, and rigid at neither time, then there would be no time during which the affordance held at that place. And the same point holds, of course, for conditions holding in different places at the same time. It is also clear that the conditions are not necessarily binary phenomena, but are potentially graded; a surface that is nearly flat may do just as well as a surface that is completely flat. This gradation may further dictate the extent to which an affordance holds (and even in part its evaluation as positive or negative). A slippery surface, for instance, might be some grade between an affordance of support and falling; and this might be an instability to be exploited by the right morphology (cf. Pfeifer and Bongard 2007: 99).

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[29] In what follows, I use the notion of a property in the general sense that objects (e.g., pears, chairs) are characterised by their properties (e.g., sweetness, rigidity). I treat them as distinct from relations for the sake of clarity; relational properties are distinct from the relations they instantiate. Most of what I say could be altered to treat relations as properties predicated of more than one individual, but with needless complication. Conversely, one might do away with properties altogether and define the notion of a structural affordance (discussed below) solely in terms of relations (see footnote 5). I will not explore the consequences of this here.

[30] There is of course the possibility that affordances could be both. Norman (1988) aims to provide a distinction between perceived and real affordances. In effect, this is a distinction between the perceived properties of a thing (*viz*. properties that bear particular relations to particular animals) and the actual relation that an animal bears to that thing. It should be noted that much theoretical literature on affordances assumes that affordances are environmental properties that bear particular relations to animals, and occasionally this assumption is made without argument (see Chemero 2009: 135 - 47 for a review). However, others have argued for the view that affordances are properties of an animal-environment system (Stoffregen 2003), or relations between the abilities of animals and features of their environments (Chemero 2003). As the reader can surmise, my preference is for the latter.

[31] I sideline the further possibility that affordances might be dispositional states (or indeed, properties) of the agent's nervous system (Ellis and Tucker 2000). I do so firstly because it is so far from Gibson's intentions; secondly, because I suspect that the truth of the proposal depends upon the explanatory scope of the notion of representation; and thirdly, because even if it were the case that affordances (in general, not merely Ellis and Tucker's micro-affordances) were representational, the question of what they represent (properties of the environment or relations between animal and environment) would still be at issue, i.e., the central issue would remain unsettled.

Identifying affordances requires identifying relational properties of the environment that are inter-dependent with relational properties of the animal. And they must be identified as such; for only this would give us a handle on the complementary relationship that is putatively at hand in the instantiation of an affordance.[32] But it certainly does not follow from the fact that a *theory* of affordances must identify certain relational properties, that they must be known to the perceiver under that description. In fact this is just what Gibson wished to avoid. If there is anything that is clear about what it means to perceive an affordance, it is that it is precisely not supposed to convey the idea that seeing a surface as affording support involves entertaining (or endorsing) a thought such as:

- The surface I see that is nearly horizontal (instead of slanted), nearly flat (instead of convex or concave), and sufficiently extended (relative to the size of my body) and its substance is rigid (relative to my body) is in such-and-such a spatiotemporal relation to me that the relation affords support.

If anything is meant to follow from Gibson's claim that "affordances *seem* to be perceived directly because they *are* perceived directly", it is that the perceiver need not be appraised of affordance relations under any description of them as such in order to perceive them. (1979/1986: 140)

Nevertheless, in order to *study* affordances one needs to identify the relational properties of the animal that are supposed to stand in an affordance relation with the environment. In the quoted case, size and weight (at least) seem to be important properties. These may be determined in a number of ways, for instance, relative to conventions of measurement designed to approximate objective physical units, or relative to a particular contextual relation with no such design. The crucial difference here is that the contextual relation is symmetric, whereas the conventional relation is asymmetric. The girl being six feet tall depends upon conventional measurements of feet and inches, but conventional measurements of feet and inches do not depend upon the height of any particular individual. There have been some elegant studies designed to demonstrate the importance of contextual (rather than conventional) relations in the instantiation of an affordance. For instance, Warren and Whang (1987) sought to investigate the extent to which an aperture affords walking from one side of a partition to the other by measuring the frequency of shoulder turning in a group of smaller-than-average participants and a group of larger-than-average participants. Unsurprisingly, a decreased frequency of shoulder turning was found to be positively correlated with an increase in aperture width. But when aperture width was determined relative to conventional physical units, the psychophysical functions of the two groups were fairly dissimilar. It was only when aperture width was determined relative to the distance between the participant's shoulders that the psychophysical functions of the two groups became comparable (indeed, strikingly similar).

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[32] By this I mean that in order for a theorist to recognise that an affordance is instantiated, it needs to be identified in some way. This somewhat mundane point is certainly distinct from the claim that affordances need to be identified (and recognised) in order to be instantiated.

## Structural affordances

I now want to argue that there is a particular kind of affordance relation pertaining to the structure of the body, one that can be distinguished from all others. The initial impetus comes from Jose Luis Bermúdez's discussion of a candidate solution to the problem of how to segment the body into parts:

> *Let me now introduce the technical concept of a hinge. The intuitive idea that I want to capture with this term is the idea of a body part that allows one to move a further body part. Examples of hinges are the neck, the jaw socket, the shoulders, the elbows, the wrists, the knuckles, the finger joints, the leg sockets, the knees, and the ankles. The distinction between moveable and immoveable body parts, together with the concept of a hinge, creates the following picture of how the human body is segmented. A relatively immoveable torso is linked by hinges to five moveable limbs (the head, two legs, and two arms), each of which is further segmented by means of further hinges.* (1998: 155)

Bermúdez suggests that his talk of hinges "provides a nonarbitrary way of segmenting the body that accords pretty closely with how we classify body parts in everyday thought and speech" (1998: 156). This is not quite right. It may be non-arbitrary, but it does not exactly capture reference to noses and ears, for example. Still, I want to extract something positive from the idea by noting another point he makes, which is that "awareness of the location of the hinges, as well as of the possibilities for movement that they afford, can plausibly be viewed as an inevitable concomitant of learning to act with one's body" (ibid.: 156). A look around his book would suggest that Bermúdez is using the notion of an affordance here in the Gibsonian sense (cf. Bermúdez 1998: 103 - 29). According to the account of affordances adopted above, affordances are relations. Here the relationship is between a bodily agent and its body. Call this kind of an affordance a ***structural affordance (SA)***, to repeat:

**SA** A structural affordance is a relation between a bodily agent and its body.

This in turn enriches the idea of an (ordinary) affordance relation between an agent and environment. On this analysis, ***agent-environmental affordances*** (leapability, malleability *etc.*) are second-order relations, prior to which are an agent's first-order SAs. Call agent-environmental affordances AEs for the sake of the distinction. One can define the relationship between SAs and AEs as follows; reading $Q$ and $R$ as specific relations, $x$ as an unspecified relation, and $b$ as an individual:

(1). If there are affordances, then there are SAs.

(2). There are affordances that are not SAs.

(3). If $x$ is an affordance in which $b$ is a *relatum*, then either $x$ is an SA relation $R$, or else $x$ is an AE relation $Q$, and $b$ is a *relatum* in $Q$ in virtue of being a relatum in $R$.

The definition of the relationship between SAs and environmental affordances is similar to a seminal definition of the notion of a ***basic action*** (cf. Danto 1965: 142). Here I will understand basic action to mean any instance of an agent trying to maintain or change its bodily comportment. This is nevertheless meant to be along the lines of the typical understanding. A basic action can be in the service of some further (instrumental) action that an agent is trying to perform, but it need not be. Furthermore, *trying* to act requires the following condition: only when actions are initiated (and usually performed) under the impression that the actual performance is *possible* might we say that the agent *tries* or is *trying* to perform that action. This is one side of the philosophical coin paid in a trying-analysis of action, the other side of which is the metaphysical possibility of the action’s total failure. O’Shaughnessy provides a description of this latter:

> *There is a perfectly genuine sense, suppressed by philosophers of a commonsensical orientation, in which no event, including intended act-events, can be foretold as an absolute certainty. That sense is this: the world is known to have harbored freak happenings; this is a permanent potential of the world, and of no situation can it be said: “This situation bears a charmed life, it is guaranteed not to harbor such a freak”.* (1973: 365 - 66)

Here besides the suggestion of the metaphysical possibility of a radically indeterminate world there is the significant insight that when we try to perform some basic action such trying is always engaged in spite of the possibility that reality may not cooperate. Nevertheless, “trying entails the presumption on the agent’s part that success is at least a remote possibility” (O'Shaughnessy 1973: 367). If this is correct then there ought to be some way of specifying the constraints on the action in question. One way of doing so would be to appeal to the fact that the body itself has structure. A positive feature of Bermudez’s hinge analysis is that it forefronts the fact that parts of the body have the relational property of being interlocked with one another. Furthermore, by employing “the idea of a body part that allows one to move a further body part” in the analysis, Bermudez likely intends to indicate the importance of this property in this regard. The assumption being that it is in virtue of the fact that its body parts are interlocked with one another that a bodily agent is able to act. But this cannot be sufficient for the possibility of basic action. It is not so much the interlocking of parts that is important, but rather (as a consequence) the manner in which the parts causally interact, in virtue of their properties. Moreover, in absence of reasons to think otherwise, one ought to allow for the possibility of part-whole causal interaction, in addition to the possibility of part-part interaction forefronted by Bermudez’s hinge analysis.

Here then is a fuller definition, unpacking the notion of a structural affordance further:

**SA*** A structural affordance is a relation between a bodily agent $b$ and the properties $I^P$ and $I^W$ of parts of its body, in virtue of which a basic action $\phi$ is possible for $b$.

- $I^P$ is the property of being causally interactive with other parts $x_1, x_2, x_3, \ldots, x_n$ in virtue of their properties $P_1, P_2, P_3, \ldots P_n$.
- $I^W$ is the property of being causally interactive with the whole body in virtue of its properties $W_1, W_2, W_3, \ldots W_n$.

This is closer to being satisfactory.[33] Now the main work is in showing that reality of structural affordances is plausible. I will do this by means of a potted review of research in motor coordination. The aim is to make some piecemeal progress by picking out at least a few candidate *P*s and *W*s (marking them as *(P)* and *(W)* as I go along). In doing so, I hope to highlight some of the causal processes on which SAs are dependent. I will also minimally address how something might count as a bodily agent, and thus how something can count as a basic action of a bodily agent (when I do that it will be obvious I am doing so). My treatment of these will be somewhat cursory, but sufficient to indicate the direction I think a treatment of SAs should take.[34]

## The empirical reality of structural affordances

A significant property of multi-jointed agents is ***motor redundancy*** (see Figure 1). Latash summarises a favourite example, which he attributes to the father of the concept, Nikolai Bernstein:

> *Touch your nose with your right index finger. Now try to move the arm without losing the contact between the fingertip and the nose. This is easy to do. This means that one can touch the nose with very many combinations of arm joint angles. Nevertheless, when the task was presented, you did it with a particular joint combination.* (Latash 2008: 35)[35]

His point is that your arm has the *(P)* property of being highly redundant in a certain sense. A glance at Figure 1 can help clarify. Assume an idealisation of your arm as having only four joints (shoulder, elbow, wrist and first knuckle), where each joint has only one degree of freedom. In order to reach endpoint E, you could assume angles a, b, c and d. But you could also reach E by assuming a', b', c' and d'. Indeed, you could also reach E by assuming a'', b'', c'', d'' *etc*.

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[33] An alternative (suggested to me by Sascha Fink) would be to describe structural affordances literally as structures with sets of relations defined upon them. This would be something like the following:

**SA**** A structural affordance is a relation between a bodily agent *b* and the relations *I* and *J* governing the set of *b's* body parts, in virtue of which a basic action $\phi$ is possible for *b*

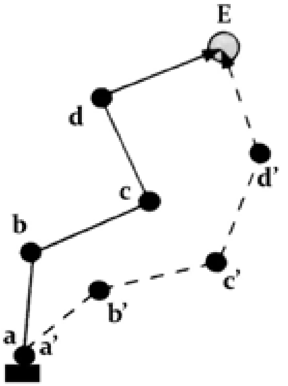
- *I* is the relation of part *x* causally interacting with other parts $x_1, x_2, x_3, \dots, x_n$
- *J* is the relation of part *x* causally interacting with the whole body

An interesting line of future research would be to explore the implications of this and other alternative ways of defining structural affordances.

[34] There is in fact a large literature on the study of agent-environmental affordances that I leave aside for the sake of brevity (See, e.g., Ellis and Tucker 2000; McBride, Sumner, and Husain 2011). Suffice to say, if the concept of a structural affordance picks out something real, it ought to figure in a full explanation of the phenomena revealed in these studies.

[35] Latash makes something of an understatement here. He is well aware that there are not just "very many combinations of arm joint angles" that will bring the finger to the nose. As he notes later, potentially the number of combinations is infinite (Latash 2008: 36).

**Figure 1– Redundancy in a four joint limb**



See main text.
Adapted from Latash (2008: 36).

Redundancy thus described, gives rise to a very simplified instance of what is often known as ***Bernstein's problem***. As Michael Turvey notes, when considered as a *(W)* property of the whole body, motor redundancy is all the more complex:

> *As characteristic expressions of biological systems, coordinations necessarily involve bringing into proper relation multiple and different component parts (e.g.* $10^{14}$ *cellular units in* $10^{3}$ *varieties), defined over multiple scales of space and time. The challenge of properly relating many different components is readily illustrated [...] There are about 792 muscles in the human body that combine to bring about energetic changes at the skeletal joints. Suppose we conceptualize the human body as an aggregate of just hinge joints like the elbow. It would then comprise about 100 mechanical degrees of freedom each characterizable by two states, position and velocity, to yield a state space of, minimally, 200 dimensions.* (1990: 938)

Suffice to say that a 200-dimensional space of possibilities (which itself is a simplification) is of mind-boggling complexity. Biological movements regularly trace a path through the high-dimensional spaces that Bernstein's problem reveals. But, interestingly, they regularly exploit the variety of options; they trace *different* paths to reach the same goal. And this is the case even in stereotyped movements performed by highly trained individuals. As Latash conveys, Bernstein discovered this himself in a careful study of labour workers (Latash 2008: 31). He attached small light-bulbs at key points on the bodies of blacksmiths, as well as on their familiar hammer. Then he photographed their movements using an innovative high-speed shutter, whilst they performed a typical hammer-strike. What the photos revealed was that across strikes there was much less variability in the movement of the tool than in the various individual joints moving it. This suggests a simple and smart solution to Bernstein's problem: treat the system as if it had fewer degrees of freedom by lumping components together. J. A. Scott Kelso illustrates the idea nicely:

> *During a movement, the internal degrees of freedom are not controlled directly but are constrained to relate among themselves in a relatively fixed and autonomous fashion. Imagine driving a car or a truck that had a separate steering mechanism for each wheel instead of a single steering mechanism for all the wheels. Tough, to say the least! Joining the components into a collective unit, however, allows the collective to be controlled as if it had fewer degrees of freedom than make up its parts, thus greatly simplifying control.* (1995: 38)

This solution motivates a fairly autonomous conception of components of a motor task, where "elements of a system are not controlled individually, like segments of a marionette's body by attached strings, but united into task-specific [...] *structural units*" (Latash 2008: 53, emphasis original). According to this gloss, ***task-specific structural unity*** is a *(P)* property of the blacksmith's arms. Parts of the blacksmith's arm work in cooperation, stabilising and compensating for one another's variable behaviour to consistently reach the target.

Task-specific structural unity can also be seen as a *(W)* property of the whole body in an activity like locomotion. To give an intuitive illustration, consider how one might approach the design of systems capable of human-like walking. Humans, like all three-dimensional objects, have a minimum of three degrees of freedom: a body can pitch forward and back, roll side-to-side, and turn (yaw) left or right. If a locomotive body is treated as a structural unit then it might be possible to keep the number of its degrees of freedom fairly close to three. Pitching and rolling are less technically known as leaning. Too much leaning can lead to falling over, so leaning whilst walking ought to somehow be stabilised. The problem can be conceived by imagining the walker as an inverted pendulum on either the sagittal or frontal plane. The aim is to keep the ball of the pendulum roughly perpendicular to a flat walking surface (idealized as having no incline or decline). What is required is to achieve a sustained natural pendular motion by instantiating the *(W)* property of stably coupled components. One way of doing this would be to make sure that pressure exerted upon the walking surface is kept within a safe area inside the foot edges, by making sure that the foot of the stance leg remains flat on the floor whilst the swing leg is brought forward (Wisse 2005: 113- 14).[36] But this is harder than it sounds. All potentially destabilising elements would require continuous monitoring and control, which adds considerably to the basic three-dimensions.

Enter the ***wild-walker***. The Delft Biorobotics lab have developed a simple construction that they call ***Mike***, to demonstrate that the task specified above can be more simply executed by coupling components to one another such that they collectively produce a self-stabilising behaviour. Mike has two symmetrical pairs of legs, each leg in a pair is fused to the other, one pair moves outside the other, and each pair has a knee joint (see Figure 2A). To facilitate movement on a flat (rather than a declining sloped) surface, Mike has oscillatory pneumatic actuators, called ***McKibben muscles***, either side

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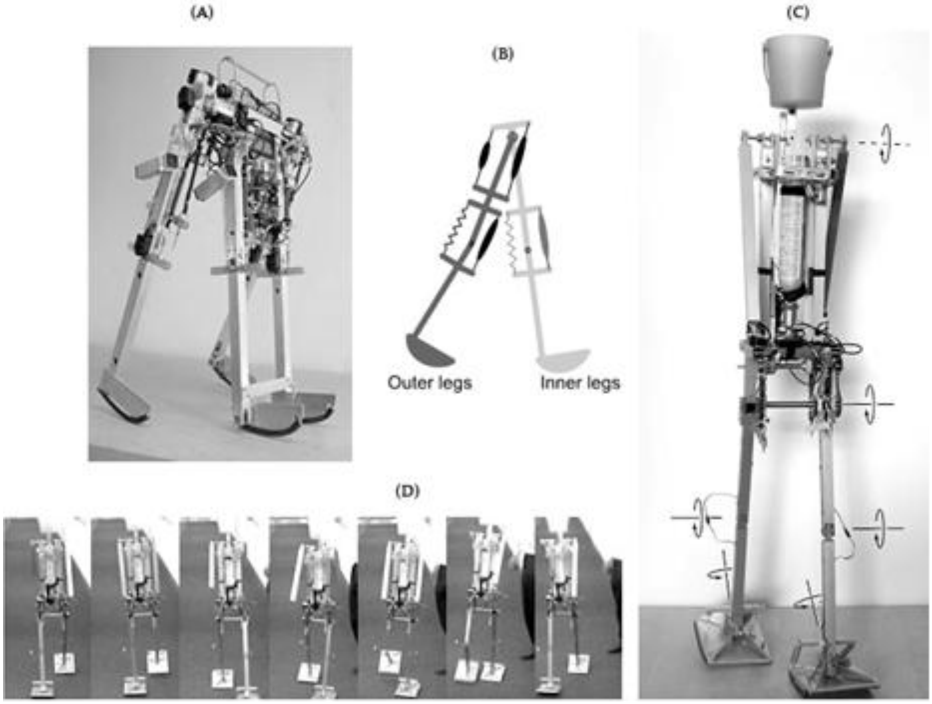
[36] As the expression flat-footed connotes, this is not in fact how most humans ought to place their feet. As Wisse and van Frankenhuyzen (2006: 144) point out, the shape of typical human feet actually channels the centre of pressure forwards in the progression of the step cycle. This fact has been reflected and exploited in the design of prosthetic feet, and wild-walkers since McGeer's early prototypes.

of his outer hip joints. There is also a muscle at every knee joint extending the leg, counteracted by a spring on the other side (see Figure 2B). Muscle activity is regulated by manually tuned timing and a simple switching mechanism in the inner and outer feet that antagonistically couples the hip muscles. So, for example, when the inner foot mechanism switches, the outer knee muscles are deactivated, the muscles at front of the outer hip are activated. The knee muscle is reactivated just under half a second later, and as the outer foot strikes, the mechanism switches the power from the front hip muscles to those at the back. As a result, when set to walking, Mike exhibits a robust gait, with a fairly fast leg motion of even length (see Wisse 2005: 116 - 22; Wisse and Frankenhuyzen 2006). In fact this is the key, as Mike's intrinsic dynamics essentially implement the following two principles: "You will never fall forward if you put your swing leg fast enough in front of your stance leg. In order to prevent falling backward the next step, the swing leg shouldn't be too far in front" (Wisse 2005: 122, italics removed).

**Figure 2– Humanoid walker prototypes**
**at the Delft Technical University Biorobotics lab**



(A) Mike, a quadruped two-dimensional walker with actuated hips and knees.
(B) "McKibben muscles" situated on Mike's hips and knees (see text).
(C) Denise, a biped three-dimensional walker with unactuated knees, a passive upper body, counterswinging arms and an ankle joint modelled on a skate-board truck.
(D) Video-stills of Denise in motion (video available at *http://dbl.tudelft.nl*).

All pictures from Wisse (2005), reprinted with permission from the author.

Mike's structure presents a solution to a tendency for unstable pitching that keeps degrees of freedom low. In fact, he is built to have only three degrees of freedom, one at his hip, and one for each pair of knees. As a result, Mike only moves in the sagittal and horizontal plane. From the side, he looks like someone marching. But from the front he looks like someone shuffling on crutches, for the lateral stability inherent in his inner-outer leg design foregoes the problem of ***lateral leaning***. A slightly more humanoid solution to this would be lateral foot-placement; but a potential drawback is that reducing lateral leaning in this way could lead to an increase in pitching instability. Martijn Wisse suggests a compromise:

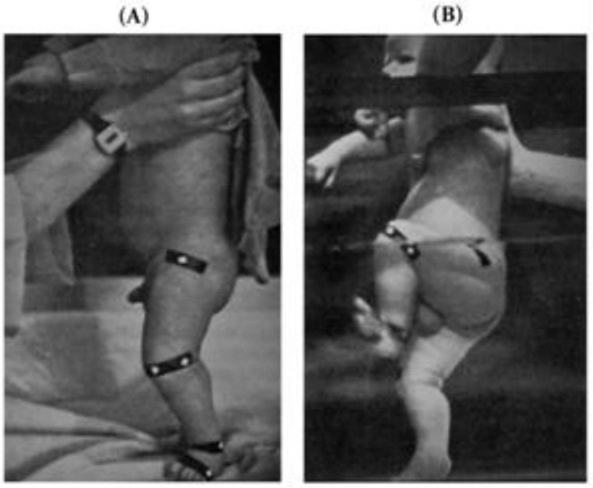
> *Similar to skateboards and bicycles, one could use steering (yaw) to stabilize lean, at least as long as the system is moving forward with sufficient velocity. The same principle is applicable to walking, and can be implemented in walking robots with an ankle joint that kinematically couples lean to yaw.* (2005: 125)

Working on these principles the Delft team built ***Denise***, a three-dimensional walker. Denise only has two feet, she also has a passive upper body, two counter-swinging arms rigidly coupled to hip angle, and a (skateboard-like) lateral leaning ankle joint, resulting in five degrees of freedom (see Figure 2C). Her ankles and knees are entirely passive, and her hip joint reciprocally couples her two legs to one another. Her hip motion is controlled in a similar manner to Mike's, but with less actuation. At each step, a switch in the striking foot activates the contralateral hip muscle, and releases a latch at the knee joint, allowing the leg to bend and then swing back to extension. Because of the ankle joint, each of Denise's steps is slightly laterally displaced. But each step drives her forward to another step: when the right foot strikes, the left knee is released, and the hip muscles start pulling the left leg forward, Denise's weight shifts forwards, the leg extends and the foot lands, repeating the process for the contralateral leg. Consequently, she swaggers along stably at around 2.5 km/h (see Figure 2D).

To the extent that Mike and Denise provide models of actual walking, they provide nice examples of whole body structural unities that could be constituent properties of an SA. But the presence or absence of an affordance for basic action can be rather labile. An interesting case of this is found in the development of infant locomotion. Most newborn infants exhibit alternate stepping movements if their upper body is supported, though these seem to "disappear" after a couple of months (Zelazo, Zelazo, and Kolb 1972). Beyond this, Esther Thelen and colleagues made several further observations. First is that these movements are "not random thrashings of the legs, but rather organized movements with a recognisable structure in time and space" (Thelen and Smith 1994: 11). Second is that these babies actually exhibit increased movement of their legs in the putative non-stepping period: they become rather fond of kicking their feet in the air as they lie on their back. These are rather striking when combined with a third: that these supine kicking movements exhibit the same kinematic profile (*viz.* structure in time and space) and a similar pattern of muscular activity to their precocial stepping movements (Thelen and Fisher 1982). From these and other data points, Thelen and Smith conclude that "what had previously been considered as distinct and separate behaviors" are in fact "manifestations of the same motor output performed in two different postures" (op. cit.: 11).

So what had changed? Why do these kids stop stepping when they can perform the movement involved perfectly well? A further line of Thelen's research indicates that the affordance fades as they lose the *(P)* property of a delicately balanced force-to-mass ratio. Newborns get fatter faster than their muscles can handle, they are simply not strong enough to keep their (perfectly healthy) chub in check. With this in mind Thelen, Fisher and Ridley-Johnson (1984) compared stepping frequency with the rate of change in newborn infants' body mass over the first month of life. They found that "infants who had gained the most stepped less" than infants who were gaining weight more slowly, suggesting that it was the *rate* at which body mass increased rather than simply body mass itself that caused the stepping reflex to recede (ibid.: 485). To further probe the ways in which muscle strength is an index of the bounds of movement, they investigated the extent to which stepping could be influenced by adding and relieving weight. And, unsurprisingly, after being loaded with the equivalent of an extra two weeks' worth of body mass, infant stepping decreased significantly in frequency and height, whilst submerging them in a bath of warm water (see Figure 3) produced the opposite effect (ibid.: 489).

**Figure 3– Stepping reflex in the human infant**

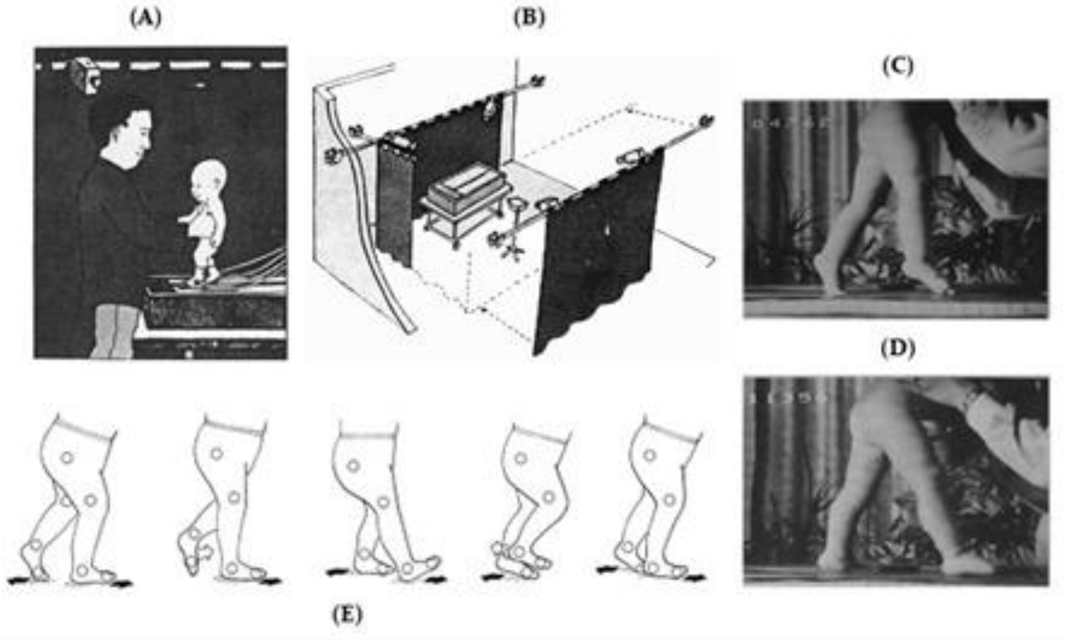


(A) 3-month old tested for stepping with feet on table; infrared light-emitting diodes are visible on the hip, knee, ankle and toe joints.
(B) Stepping reflex induced in the same 3-month old when submerged in warm water.
Both from Thelen& Smith (1994: 12).

However, if this is to be attributed as an action, it needs to exhibit the requisite task-specific flexibility. Some indication of this again comes from Thelen's work. She discovered that 7-month-old infants (*i.e.*, infants who might otherwise be thought to be at a non-stepping age), if provided with upper body support, produced pronounced and smoothly coordinated stepping movements as soon as they were placed on a treadmill (Thelen 1986). Soon after (inspired by studies on quadruped gait) Thelen, Ulrich and Niles (1987) placed infants of the same age on a split-belt treadmill (see Figure 4A & B), and observed smooth adjustments of swing and stance when the belts were run at different speeds. This work has been followed up more recently in an elegant study by

Yang, Lamont and Pang (2005). From their sample of 5-12-month old infants they report that the majority could not only rapidly adapt to belts running at 2:1 ratios, but could also produce coordinated stepping on belts running in opposite directions (see Figure 4E)!

**Figure 4– Treadmill stepping patterns in pre-walking infants**



(A) Infant being supported on a split-belt treadmill.
(B) Split-belt treadmill filmed from four angles with infrared cameras (see curtain rails) and an ordinary video camera (positioned on the floor beside the treadmill).
Both from Thelen& Ulrich (1991: 49).
(C) Toe-strike stepping.
(D) Flat-foot stepping.
Both from Ulrich (1997: 326)
(E) Bidirectional split-belt stepping: left leg steps forward, whilst right leg steps backward. Solid arrows indicate belt-motion and foot-motion during stance. Open arrows indicate foot-motion during swing.
From Yang, Lamont, & Pang(2005: 6874)

Typical adult stepping involves a rolling foot motion in which the heel strikes the ground first, moving through the flat of the foot to the toe. By contrast, neonatal stepping often involves toe-first strikes (see Figure 4C) and the occasional flat-footed contact (see Figure 4D). To investigate the intermediate stages more closely, Thelen and Ulrich (1991: 36ff.) looked for individual differences that might predict the emergence of stable treadmill stepping in the first year of life. They discovered a trend of poor treadmill performance associated with toe-first striking and/or inward foot rotation, whereas good swing and stance came with flat-footed contact. Only in the latter posture can the stance leg be pulled back far enough for a sufficient frequency of muscle spindle impulses to loop through the spine and activate the antagonists, so the leg can then swing far enough in front for a stable step. And, as Thelen and Smith explain, the flat-footed postural arrangement is only available given the *(P)* property of well-balanced relative tension of antagonistic muscles.[37] In particular, the tension of flexors needs to be within a certain range:

> *[If] the tension [in flexors] is too loose, the treadmill will not impart sufficient stretch to overcome the inertia of the leg and it will not swing forward [alternatively, if the flexors are too tight] the treadmill will not impart enough pull to stretch it. In neither case will the stretch receptors be sufficiently activated for reciprocal phasing.* (Thelen and Smith 1994: 112)

With that I hope to have sufficiently illustrated the delicate balance of *(P)* and *(W)* properties in virtue of which basic actions are possible, and thereby given a rudimentary sense of what structural affordances actually are. This is little more than a beginning of the study of structural affordances, for although (as reviewed above) the relational properties which they typically involve are well understood, the relations themselves are rarely identified as such.

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[37] The developmental story perhaps runs more fully as follows:

*Newborn infants have a characteristic flexor bias in their limbs; legs and arms are held tightly to the body [...] probably partially as a result of the tightly packed fetal position [...] the limbs are relaxed only over many months, and indeed extensor strength in the lengths lags behind flexor strength throughout the first year.* (Thelen and Smith 1994: 112)

It is likely that it is for these reasons that “[h]ighly flexed individuals and those who did not have sufficient extensor strength” could not put their foot flat on the belt, and consequently “did less well in treadmill stepping” (ibid.: 112).

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