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ORIGINAL PAPER

Technologies, Inbetweenness and Affordances

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Abstract
Categorization of technologies by the order of their inbetweenness is a useful device for parsing complex structures info fundamental parts and understanding the application of a technology. This promises a coherent foundation for explaining how we deploy technologies in design, in particular with respect to the affordances they create. By connecting the categorization of technologies to the matching of user effectivities to features of the environment in affordances, the paper proposes an approach to the transparent description of the assemblages produced by design in terms of which technologies are involved and how they connect to each other, to the wider environment and to users. For affordances, this improves specificity concerning the features of the environment that are directly relevant to an interaction and the connections between these features and the rest of the environment. With respect to technologies, it helps understand not only why a technology may be used under certain circumstances but also abuse and underperformance. Finally, it supports design by providing means for parsing complex situations into chains of technologies between animals and environments. This helps explain how technologies modify effectivities, environments or relations between the two and how this affects design performance.

Keywords Affordance · Artefact · Design · Effectivity · Environment · Inbetweenness · Technology

1 Introduction

1.1 Technologies and Design

The relatively recent proliferation of computing technologies and their ubiquitous presence in most aspects of daily life have raised awareness concerning the extent

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to which they mediate in our actions. The novelty of computing and its differences from precedent technologies obviously attract much attention and produce insights into their character and function. Such insights, however, must be generalized if we are to understand the fundamental characteristics of all kinds of technologies. This is particularly important for design disciplines: these combine various technologies, increasingly both analogue and digital, frequently interchangeable and inevitably belonging to different generations, into artefacts and environments that accommodate the activities of their users and satisfice their needs, in the sense of Simon (1996): good enough without being optimal. The complexity and multiplicity of available technologies add to the burdens of design and increase its sensitivity to both the interoperability of technologies and the capacities of users. This raises the already high probability of designs that, regardless of aesthetic or morphological (formal) value, can be poor concerning user interaction (function) and performance (Galvao and Sato 2005; Norman 2013; Tweed 2001). Designers, therefore, need sharper tools for anticipating the impact of technologies in their designs, based on a transparent and coherent theory of how interconnected technologies operate as parts of an environment, including as mediators in user interactions.

1.2 Users, Affordances and Representation

Some attempts to move away from the axiomatic and stereotypical view of users that has marred design thinking about interaction and functionality until late in the twentieth century have sought a foundation in affordance theory (Gibson 1979, 1983). What an environment affords to its users forms a promising basis for evaluating interaction and usability because it takes into account dynamic processes of interaction beyond basic ergonomics (Galvao and Sato 2005; Tweed 2001) and helps explain differences between the intentions behind a design and its actual use (Koutamanis 2006; Maier et al. 2009; McGrenere and Ho 2000; Norman 2013; You and Chen 2007).

Many design studies hold abstract views of affordances, which promote high-level aggregations, e.g. that a building affords shelter, and focus on how designers recognize relevant general possibilities in a design situation (Maier 2011; Maier et al. 2009; Rietveld and Kiverstein 2014). The present paper proposes that such views should be complemented with an understanding of designs as assemblages of technologies. In these assemblages, design decisions are taken at a variety of levels and from different perspectives. If the structure of the assemblages remains opaque, decisions often have limited coherence and consistency (Koutamanis et al. 2021; Turk 2016). For affordances this means that many of relevant features and relations are ignored, with persisting bad performance as a result. For example, too many accidents occur on stairs (Blazewick et al. 2018), even though stairs are both heavily regulated and points of attention in designing.

A better understanding of affordances and related design challenges requires descriptions that provide overview and transparency beyond what most current design representations. Emphasis on convention and geometry, as evidenced in architectural drawings (Cosgrove 2003), hampers transition to symbolic representations that make explicit entities and relations, including user interactions (Koutamanis 2022). This calls for a fresh way of parsing designs, one that accommodates the perspectives of both users and designers.

1.3 Parsing Environments

Floridi's categorization of technologies by the order of their inbetweenness (Floridi 2013, 2014) is proposed here as a complement to affordances, through which the complex assemblages that constitute designed environments can be parsed into fundamental parts and relations (the building blocks of symbolic representations). This addresses a key question in design affordances: *how features of a design that are relevant to a particular interaction connect to the rest of the environment*. Answering this question helps comprehend the complexity of environments in which we conduct our daily activities, as well as connect design intentions and goals with the structure and use of design products. For example, design affordance studies often focus on points of conscious interaction like the handle of a door (Norman 2013). These are obviously critical for the operation of the door but how a handle connects to the rest of the door and to how we use the whole door in pedestrian circulation, visual or acoustic separation etc. are at least equally important.

The next section introduces the two perspectives (affordances and Floridi's approach to technologies), which are then combined in Sect. 3, in an exploration of their joint capacity to provide analytical, coherent descriptions of environments. Sect. 4 moves on to the second main contribution of Floridi's view of inbetweenness: the precise connections between various parts of an environment through protocols and interfaces, which add specificity to the analytical descriptions of the previous section. Finally, Sect. 5 summarizes the conclusions of the paper with respect to the questions that motivated it.

2 Two Complementary Perspectives

2.1 Affordances and Effectivities

Gibson introduced the term "affordances" to describe the possibilities for action an environment presents to an animal, which moreover the animal perceives directly even though not always correctly (Gibson 1979, 1983). Affordances can be beneficial or harmful to an animal: a step affords climbing to a higher level but also hazardous falls. Similarly, sunlight in the form of ambient light affords visual perception but bright sunlight also affords discomfort or even damage to the eye. Utilizing the affordances of an environment depends, firstly, on the animal's ability to perceive them and, secondly, on the *effectivities* of the particular animal: its capabilities for action (Chemero 2003; Turvey 1992).

Affordance literature regrettably often reduces affordances to simple relations and metrics for these relations, usually between a single property of the animal and a single feature of the environment. Stair climbability, for example, has been expressed as the ratio of the step rise to the leg length of stair users (Warren 1984). While this ratio is clearly significant and perceivable, affordances involve all relevant features of the environment, as well as all relevant effectivities of the animal. On the side of the stair environment (Fig. 1), this includes not just the step rise but also the tread going and width, the number of steps in a flight, the presence and height of handrails, the overall geometry of the stair, its illumination and other features known to contribute to stair efficiency and safety (Templer 1992). As for animal effectivities, climbing a step requires not only adequate leg length but also sufficient muscular power, joint flexibility and other static and dynamic properties in the animal (Day et al. 2015; Konczak et al. 1992; Meeuwsen 1991; Warren 1984).

The affordance of stair climbability depends on all these features, effectivities and the *matching* of the two sets. In design studies of affordances, the metrics of each relation are collected in matrices that provide overview (Galvao 2007; Hsiao et al. 2012; Maier et al. 2009) at multiple abstraction levels, e.g. grasping a pen to write, writing on paper with the pen and writing a poem with pen and paper (Galvao and Sato 2005; Pols 2012). In the match of effectivities to features, some individual relations may appear to be more critical than others but all contribute with varying significance. The climbability of the same, good stair may change for the same, fit, young adult after even a slight knee injury, if carrying a heavy load or when having to negotiate the stair in absolute darkness. In each case, it is other features, effectivities and relations that become more critical.

It is this complexity that poses the main challenges to the application of affordances in design. Valid laboratory results, such as the ratio of step rise to leg

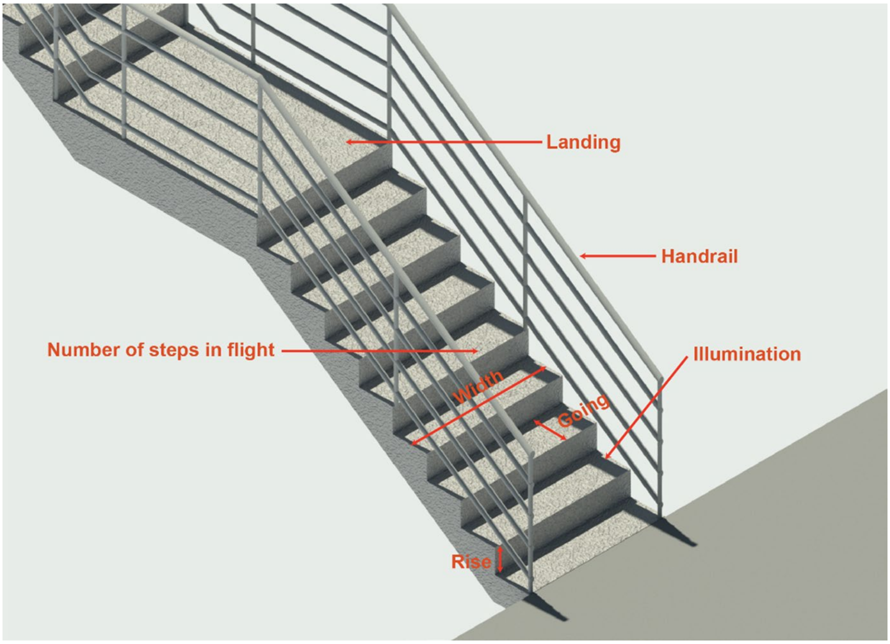

Fig. 1 Some of the affordance-defining features of a stair

length, are only the starting point. We require a large number of such results for all relevant aspects in stair climbing, from handrail graspability to the influence of illumination or eye disorders on accurate step perception, but above all a more coherent and specific structure than matrices for all these relations and metrics. Such a structure would help prioritize relations in the match of effectivities to features, as well as elucidate how design interventions and user choices may affect them.

With respect to users, we should also keep in mind that acting on affordances depends on the effectivities of an animal but remains a matter of choice: when confronted by bright light the animal may brave the discomfort, turn its head, squint, close the eyes, shade them with a hand or a hat, or put on sunglasses. Both effectivities and choices are constrained by the current state and activities of the animal. If the animal is carrying lots of sensitive stuff in its hands, it may feel disinclined to drop everything in order to pick up its sunglasses and put them on, especially if it is not staying long in the bright light.

Taking the animal's activities into account also helps realize that next to the physical dimension, affordances also have a social and a cultural dimension. Stair climbability changes if other animals are also using the stair, by the number and activities of these animals or when the climbing animal is part of a group, e.g. has a small child in tow. Cultural constraints can be even more rigorous, despite often being physically insignificant: if a stair is cordoned off by a length of tape or rope, its climbability may disappear completely. Interestingly, this brings us back to design, as cultural constraints are often signified through design interventions that introduce some technology between users and other things, e.g. a piece of rope between visitors and exhibits in a museum.

2.2 Artefact-to-Artefact Affordances

A subject with particular relevance to the present paper is the notion that artefacts also present affordances to other artefacts (Koutstaal and Binks 2015; Maier et al. 2009). Especially in design studies, this seemed a logical extension: if a chair affords sitting to a user, a floor could be said to afford support to a chair. The notion was further extended to include relations between objects and environments (Hu and Fadel 2012) and relations between objects not only in subsystems but also at the same level (Cormier et al. 2014).

Artefact-to-artefact affordances are appealing as a means of analysing environments and avoiding a narrow focus on single things. Affordance studies often deviate from the Gibsonian emphasis on the whole environment and focus on a single feature, such as a chair, but the sitting affordances of the chair depend not only on its size and shape but also on the relations between this particular chair and its environment, including social and cultural constraints. Making these relations explicit can only help design, provided that they are described with specificity and return a coherent description of the whole environment.

2.3 Technologies and Inbetweenness

In *The 4th Revolution,* Floridi (2014), stresses the inbetweenness of technologies as one of their primary characteristics and applies it as the main criterion for the following categorization:

1. First-order technologies are between humanity and nature
2. Second-order technologies are between humanity and other technologies
3. Third-order technologies remove or replace humanity from the loop

The tripartite structure of technological inbetweenness is illustrated in diagrams (Figs. 2, 3 and 4) and explained through a number of examples, including the wood-splitting axe as a first-order technology (between the human and the wood), the screwdriver as a second-order technology (between the human and another technology, the screw) and the modem as a third-order technology (between a digital computer network and an analogue transmission line). Most examples are clear and convincing but there are some that require further analysis. These are considered in detail in following sections of this paper.

2.4 Prompters Replace Affordances

Floridi's tripartite scheme bears structural similarities to the bipartite match of animal effectivities to features of an environment, in a way that suggests complementarity: affordances focus on the two sides on the match and Floridi on what comes between them. *The 4th Revolution* uses the term "prompter" for what leads to the use of a specific technology (Floridi 2014): bright light prompts humans to place sunglasses between their eyes and nature, while a screw prompts using a suitable screwdriver. However, in an earlier version of

Fig. 2 First-order technology—after Floridi (2014)

Fig. 3 Second-order technology—after Floridi (2014)

Fig. 4 Third-order technology—after Floridi (2014)

his account of the inbetweenness of technologies, Floridi had used "affordances" instead of "prompter" (Floridi 2013). An endnote in *The 4th Revolution* clarifies that affordances were abandoned to avoid confusion stemming from the use of the term in other, unspecified contexts. The change appears to have been a direct substitution: the later (book) version is practically identical to the earlier (journal) version but for the use of "prompter" instead of "affordances" in the text and addition of the diagrams that illustrate technologies of different orders (Figs. 2, 3 and 4).

Admittedly, affordances are used in different senses in a variety of fields and having a prompter on one side of a technology creates a nice symmetry with the user on the other. Nevertheless, as affordances in the sense of Gibson and his epigoni in the field of ecological psychology focus on the mutuality of animal and environment, they form a suitable framework for understanding why and how technologies are deployed. As one can clearly see in first-order technologies (Fig. 2), the introduction of a technology alters the relation between animal and environment by creating new affordances, e.g. to the ability to split wood with precision and efficiency.

While accepting Floridi's preference for the term "prompter", this paper is an attempt to *include affordances in his description and classification of technologies.* The underlying assumption is that by combining the tripartition of technologies with the bipartition of affordances we can enrich both. Affordances state that a road can accommodate various forms of locomotion, while Floridi analyses this into a first-order technology (the road) that prompts various second-order technologies (cars, bicycles etc.) one can use to travel on the road. Consequently, we can use Floridi's approach to parse environments as suggested in Sect. 1.3 and to formalize the matching of effectivities to features of an environment in the comprehensive manner outlined in Sect. 2.1.

The insights produced by the combination are significant for users but even more for designers and engineers, who must arrange technologies to produce new environments that attain certain required performances. Of particular importance are:

1. *The order of a technology,* which helps reveal the chain of technologies involved in a process. This makes evident prerequisites and infrastructures that should not be ignored in design, and rids affordances of aggregate platitudes such as "a building affords shelter" or "a plot of land affords a building".
2. *The inbetweenness itself:* is a technology truly in between or does it affect one side more than the other? This is important for realizing the true subject and the effects of a design.
3. *The connections* between technologies, users and environments: how precise or tolerant are they? Their constraints are significant for the arrangement of technologies in designing, as well for the performance of design products.

The first two are discussed in the next section, on order and categorization. The third is the subject of Sect. 4 ("Interfaces and protocols").

3 Order and Categorization

3.1 Modifying Affordances and Effectivities with Technologies

Affordances and prompters both relate to specific actions. There are, however, key differences: as Floridi points out, bright light is not an affordance *for* the hat but protecting from bright light is an affordance *of* the hat (Floridi 2014). An animal recognizes both the harmful affordances of the bright light and the related beneficial affordances of the hat and combines them to mitigate the former. One could therefore argue that, similarly to perceiving affordances by matching effectivities to features of the environment, we match affordances in the environment (in this example, the bright light) to the affordances of some technologies. The latter match acts as a prompter: it calls for the deployment of these technologies, so as to improve the affordances of the environment, i.e. reduce some harm or increase some benefit.

A fundamental reason for the deployment of any technology is that affordances are not the unchanging product of a match between fixed environments and fixed effectivities. Animals are not just users of environments; they also have the capacity to modify environments. In an encounter with a branch hanging low over a path, an animal may duck to pass underneath, brush the branch aside (temporary modification) or break it off (permanent modification of the environment). Such modifications are the starting point of design and construction activities that add technologies to the environment, creating a highly modified version, full of new affordances and prompters for other technologies. Animals are also capable of modifying their own effectivities, for example train in order to be able to climb higher steps or carry heavier loads. Quite often, the redesign of the self is done by technological means: grabbing a stick increases the animal's reach, while pulleys and wheelbarrows increase its lifting and carrying capacities.

All kinds of modification affirm the inbetweenness of technologies, which appear between the animal and the environment. There are, however, significant differences in how different technologies attach to what. Following Gibson (1979), we can distinguish between three main kinds:

1. *Attached* technologies, firmly connected to features of the environment, e.g. roads and bridges. These tend to be so firmly embedded in the environment that they become infrastructure, practically indistinguishable from unmodified parts.
2. *Detached* movable objects, with a non-permanent relation to features of the environment, e.g. chairs or wood-splitting axes. Some are also clearly part of the environment but with the difference that they form adaptable, superimposed layers (e.g. furniture). In many cases, they function in ways that accentuate their inbetweenness, becoming microenvironments with clear boundaries with the rest of the environment, e.g. airplanes during flight. Other detached technologies effectively become part of the animal, e.g. extensions of its perceptual systems. When feeling around with a stick, the animal actually perceives with the tip, the far end of the stick, rather than at the near end it is holding (Richardson 2013; Simpson 1974).

3. *Wearables:* a particular kind of detached objects that are at least semi-permanently in close contact to the body of an animal, e.g. clothes and sunglasses. These are not just parts of the animal; they are often indistinguishable from it. Clothes are as closely connected to a body as roads to the ground. When an animal wears sunglasses, the sunglasses become part of the visual system. The animal hardly perceives them, it mostly sees *through* them.

3.2 Tripartition Revisited: Compounding and Perspective

Looking back at the tripartition of animal-technology-environment, one could extend Floridi's diagrams to also express affordances and how technologies modify them by:

1. Explicitly including the environment in all categories, so as to ensure that the whole chain of technologies is present between the animal and the environment
2. Compounding technologies with the side (animal or environment) they are strongly connected to (as modification of either effectivities or environments)

With many first-order technologies, we can distinguish between the attached ones that become parts of the environment and can therefore be compounded with the environment, and those that remain detached. Wearables and detached technologies that are in close contact with the animal can be compounded with that side (Fig. 5).

With second-order technologies, the distinction between sides is often similarly clear. The prompting first-order technologies are usually compounded with the environment, while for the prompted second-order technologies there are two options: either compound them with the animal or keep them separate from the animal and the environment (Fig. 6).

Concerning affordances, the diagrams help understand what should be considered as environment, which effectivities are modified and how technologies either supply the particular features that determine affordances or prompt for

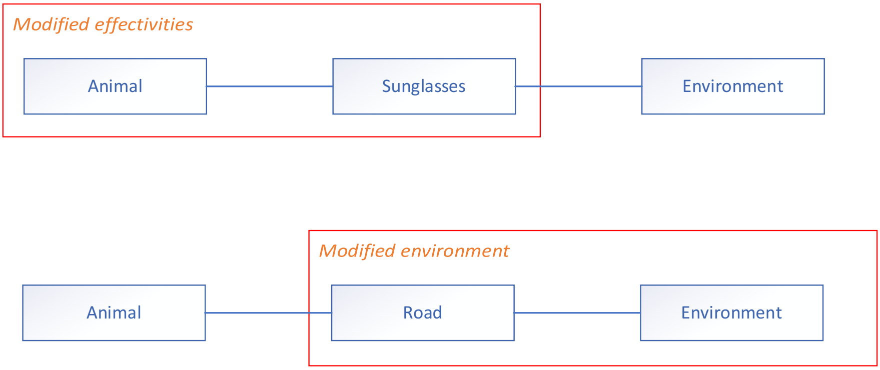

Fig. 5 First-order technologies compounded with either the animal or the environment

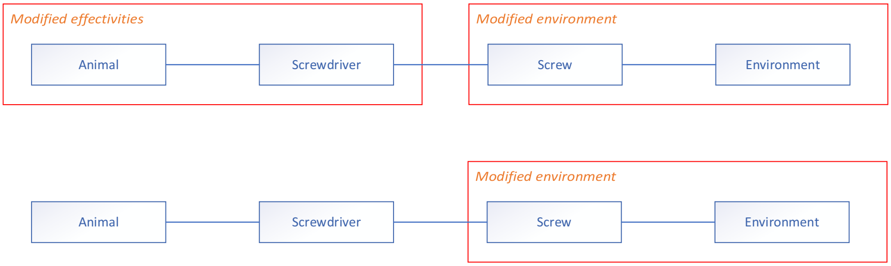

Fig. 6 Compounding second-order technologies with the animal or the environment: two alternatives

specific technologies, without which the affordances are limited or even not available. For example, a road is the feature that usually determines locomotion affordances, while a rail track limits the affordances to a specific kind of wheeled vehicle, e.g. a train or a tram. The resulting transparency in the connection of effectivities to features of the environment is significant for using affordances for design guidance and analysis: it makes impossible to ignore what a designed environment should include and for which use.

For the inbetweenness of technologies, the presence of the environment adds to the clarity of the technology chains and ensures their completeness. For instance, it matters if a screw is driven into a tree trunk or a car door panel. In the latter case, the environment must be analysed further to make explicit another technology: the expanding anchor the screw enters and possibly also the hole for the anchor in the car door frame.

Compounding technologies with the environment or with each other is compatible with Floridi's reasoning: he suggests that the chain of linked technologies can be expanded to include any number of second and third-order technologies without producing technologies of the fourth or higher order. Any chain can be reduced into a series of triples, each belonging to the first, second or third order. Explicit compounding improves consistency in this parsing of technologies. For example, Floridi considers the drill a second-order technology for the drill bit but the drill and bit should probably be treated as a first-order compound, not a temporary tandem like the screwdriver and the screw. Even though bits are interchangeable, the bit remains part of the drill and does not become embedded in the drilled environment.

The view of the drill as a second-order technology comes from focusing on the technology itself and excluding the environment in which it is used. Such narrow focus can be useful in e.g. a comparison to a drill with a fixed bit, which explains the evolution of the drilling technology. It does not, however, address use of the drilling technology. The compounding of the drill and the drill bit furthermore agrees with another example used by Floridi: the assault rifle, which he categorizes as a first-order technology between two animals (animals being part of the environment, too), without reference to the complex chain of parts in the rifle.

3.3 Affordances and Context in Categorization

The previous section discussed how the explicit presence of the environment and the compounding of technologies are helpful for the inclusion of all relevant parts of a technology chain and their categorization. Categorization also benefits from the resulting description of affordances, in particular with respect to questions of context. Floridi states that categorization depends on the context, e.g. on who uses a pair of scissors and on what. If the scissors are used to cut the stem of a rose, they are of the first order; if used to cut a piece of paper, of the second; if used by a robot to cut cloth in a factory, of the third.

The problem with this example is that different kinds of scissors and their prompters are abstracted into generic categories. If we distinguish between these kinds and their relations to specific prompters and to the affordances of the environment, the picture changes. Flower clippers and pruning shears are used in gardening, arboriculture and similar contexts but are hardly appropriate for paper or cloth. More specifically, pruning shears are applied to branches and stems of a limited thickness, usually less than two centimetres in diameter. It is these particular branches and stems that prompt the use of the pruning shears: a human armed with pruning shears can actualize their cutting affordances on branches and stems with an appropriate cutability (Fig. 7). Similarly, tailor's scissors can be used in context like a tailor's, a garment factory or at home but always on fabric and materials that agree with their cutting affordances. However, no pair of scissors becomes a third-order technology when used by a robot: the scissors remain in the first or second order; it is the robot that constitutes a third-order technology.

While the generic scissor type can be considered a first-order technology (a technology for cutting in general), specialized subtypes match the particular affordances of specific things, including first-order technologies like paper or fabric. Subtypes used on such technologies are undeniably second-order technologies but they inherit the generic, first-order affordances of the type. As suggested in a previous section, the prompting for a technology is based on matching affordances of an environment to affordances of the technology. The match does not have to be perfect because affordances often have wide tolerances, i.e. accept a wide range of effectivities and satisfice the requirements of a variety of actions. This explains not only variations in categorization but also abuse, e.g. the use of tailor's scissors in gardening. The cuttability of a plant stem prompts a specific technology but one may use a less appropriate one, at the risk of poor cutting performance and of damage to the scissors because the risk is deemed insignificant or if there are no alternatives. Consequently, we have to consider the whole environment of the cutting activity and its affordances as context in categorization.

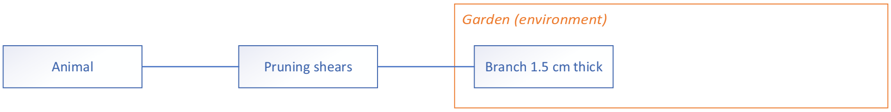

Fig. 7 Use of pruning shears prompted by the cutting affordances of a branch

Another reason for always and explicitly including the environment in Floridi's tripartite scheme is that wider affordances of an environment constrain the prompting or deployment of technologies. A piece of fabric may prompt the right kind of scissors but the environment of the fabric may not afford use of the scissors because the room is poorly illuminated. Although the fabric is a detached object, its relation to the environment and its affordances is binding. In attached technologies, this relation is more evident, as with a road and the mountain on which the road meanders. Road and mountain become one: if the mountain subsides, the road disappears, too. Including the environment in the scheme can therefore explain why a prompter may fail to work or appear. Inclusion of the environment can also indicate the presence of prompters for complementary technologies, e.g. adequate artificial lighting in addition to the tailor's scissors, and so explain indirect relations between technologies.

4 Connecting Users, Technologies and Environments

4.1 Connections and Performance

The descriptions of animal-technology-environment chains we have used so far miss one critical part: the specification of connections between links in a chain. How exactly an animal connects to a technology or a technology to an environment is significant for affordances because it determines the matching of effectivities to features of an environment. It is also a key issue in design because designing involves not only selecting suitable technologies but also arranging and interconnecting them in ways that ensure adequate performance.

Good performance of an artefact or designed environment, as well as afforded abuse, rely on the mutual dependencies between technologies: screws call for screwdrivers and screwdrivers are specialized technologies for screws. However, affordances make this relation not exclusive: screws can also be driven by hand, fingernail or the tip of a knife, while screwdrivers can be used as levers or stabbing weapons, too. There are many examples of inappropriate or creative use, abuse and innovation when technologies meet each other, users or the natural environment. In affordance terms, all amount to a successful match between effectivities and features: anything that roughly matches the drives on the screw head can be used to turn the screw.

While such capacity for creativity and adaptation in an animal is laudable, it also suggests that the design may have failed to support efficient interaction. If there is insufficient room for properly positioning a screwdriver relative to a screw, we are forced to improvise. Such failures are regrettably only too frequent in design products, from uncomfortable chairs to irregular stairs. Users of bad designs generally manage to negotiate inconveniences and even brave dangers but this does not take away the unacceptable performance. Moreover, the persistent production of bad designs suggests that we have to take a closer look not only at which technologies we include in a design but also at exactly how users interact with them to achieve their goals.

As discussed in the introduction, interaction has been a key subject in affordance studies but it has been largely limited to points of direct contact, such as door handles. How the operation of a handle translates into use of the door largely remains a black box (which agrees with the perception of a door by most users), while the relation to the rest of the environment (e.g. if there is sufficient room to open the door) is persistently understudied. The explicit description of chains of technologies between animal and environment, as formulated in the previous section, makes such boxes transparent. What remains is to make connections in these chains similarly transparent and hence predictable and manageable.

4.2 Interfaces and Protocols

Floridi (2014) uses two terms to specify the connections between animals, technologies and environments: *interface* and *protocol.* Interface is reserved for the interaction between a technology and its user, while protocol describes the interaction between two technologies or a technology and the environment (Fig. 8).

The two terms add a welcome specificity to localizing and qualifying prompting or affordances. A screw, for example, calls for a screwdriver but it is the drives on the screwhead that call for a particular type of screwdriver because they agree on a common protocol. Screwdriver types with non-matching tips are inefficient, ineffective or harmful to the screwhead. This match between the demand and supply sides of the protocol underlies many aspects of performance. Using the right screwdriver instead of a fingernail ensures a higher level of efficiency and safety. Moreover, the tip must be properly aligned with the screwhead, so as to connect fully with the drives and allow for effective driving action. In the absence of a screwdriver or room for proper alignment, alternative solutions with a vague match to the screw protocol may be used, especially if the screw role is secondary, e.g. related to a cosmetic part of some flat-pack furniture.

Such deviation from even strict protocols can be explained by affordances: animals are quick to perceive action possibilities and may utilize them even when they are not the best option for local performance. This depends on the goals and objectives of an animal but also on protocols: some protocols are quite specific, as with screws, while others are quite tolerant, for example the relation between a ball and a surface on which the ball can rest or be made to roll or bounce. So long as the surface is relatively flat and smooth, and the ball reasonably inflated, the protocol between ball and surface supports playing games like soccer. The vaguer or more tolerant the protocol, the higher the skill level required for its control. That is why learning to use screws and screwdrivers is much easier than learning to control the interaction between ball and playing field in soccer. The lack of specific skills and knowledge lowers our expectations and

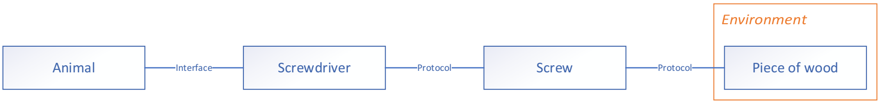

Fig. 8 Interfaces and protocols in a second-order technology

makes us perceive affordances with wider tolerances, not always attuned to the protocols involved, as one can see in any game between novice soccer players.

Interfaces are by their nature more complex because users can have a wide range of effectivities (e.g. hands of various sizes), as well as different ways of interacting with a technology (e.g. different ways of holding a screwdriver). Even more than protocols, interfaces are not only about the precise physical connection between an animal and a technology but also about the frame of the interaction: the actions and goals of the animal, as well as the context of the interaction. Driving a screw in a piece of wood or metal is seldom a goal by itself. Usually, it is a means to attaching one thing to another for some higher purpose. This determines not only affordance tolerances (e.g. by how critical the task is) but also the physical, social and cultural environment in which the task must be performed. Therefore, the interface of a manual screwdriver can be explained by matching animal effectivities to features of the handle, primarily whether the handle is easy to hold and turn, but the explanation has to take into account both specialized types of screwdrivers (e.g. the differences between the tools of watchmakers and carpenters) and the actions of the animal for which the screwdriver is needed. How an animal interacts with a door handle depends not only on its anatomy and other effectivities but also on what the animal is doing and the environment in which this is taking place, including social and cultural constraints. This explains why an animal carrying heavy or delicate stuff may choose to use its elbow to turn the handle.

4.3 Protocol Chains

Social and cultural constraints add to the complexity of activities but even the physical side of an isolated action can be demanding. Holding and turning a screwdriver is part of an intricate whole that is revealed when we consider the complete technology chain: the animal has to control both its own interaction with the screwdriver and the interaction between the screwdriver and the screw, as well as the interaction between the screw and the piece of wood. As already mentioned, detached objects often become extensions of the animal's effectivities (Richardson 2013; Simpson 1974): in addition to its interaction with the handle, the animal also perceives the interaction between the screwdriver tip and the screw. How the shank and the tip of the screwdriver work, and how the screw behaves follow the interaction at the interface, the handle. Reversely, how the connection between tip and screwhead feeds back to how the handle is used. In other words, constraints from interfaces and protocols are propagated along technology chains in both directions, causing adaptations within the tolerances of each interaction.

This constraint propagation becomes quite evident in lengthier chains, such as a door: the animal usually interfaces only with the door handle, the design of which should make its own working (e.g. turning) explicit but the interaction is not limited to the handle. It extends to the whole lockset and from there to the rest of the door and its connection to the frame and the wall, through sequences of protocols. Some protocols may be embodied in special-purpose components, like hinges, that add constraints to the interface. Opening a hinged door combines both turning and

Fig. 9 Interfaces and protocols in taking a baking tin from a shelf at room temperature

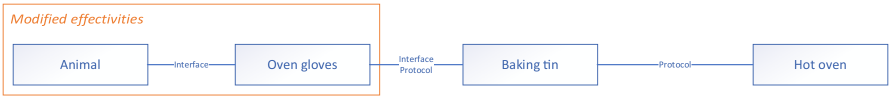

Fig. 10 Interfaces and protocols in taking a baking tin out of a hot oven

pushing (or pulling) the handle in order to respectively activate the lockset and the hinges. The form and operation of the handle should therefore facilitate not only turning but also pushing and pulling, with the turning transmitted through precise protocols to the lockset and the pushing or pulling transmitted in a more primitive manner to the hinges. If the door is locked or the hinges open in the opposite direction, their behaviour is transmitted back to the interaction at the interface, informing the animal of the conflict between its actions and the affordances of the door.

The screwdriver and the door examples illustrate that while interfaces are localized at specific parts of a technology chain, interaction tends to be much broader and deeper. In both cases, handles provide an interface with a prompted or prompting technology. Affordances explain how an animal interacts with these interfaces, e.g. which handle shapes and sizes work perceptually and ergonomically, but also how the animal interacts with the whole chain, i.e. goes through a door. The multiple levels of abstraction involved in these affordances are in turn explained by making explicit the technologies in the chain and their precise connections, compounding technologies as required by the use or design action or operation. One does not have to know the parts in a lockset to open the door; a vague notion of how the handle works and how this affects the door suffices. A designer, on the other hand, may have to pay attention to the lockset and consider it in detail to ensure that the handle functions and performs as required, including with respect to privacy and safety.

Compounding also affects interfaces and protocols. As suggested earlier, technologies are prompted because their affordances match and improve those of the environment. Protocols and interfaces, and their cooperation in a technology chain make explicit how this improvement is achieved. In many cases, the action at an interface becomes translated into constraints at subsequent protocols, as in with a screwdriver (Fig. 8). In other cases, constraints from a protocol may be added to the interface. Consider, for example, the differences between taking a baking tin from a shelf prior to cooking (Fig. 9) and taking it out of a hot oven after cooking (Fig. 10). In the latter action it is safe to assume that the animal uses oven gloves to protect its hands. The way the animal holds and lifts the tin can be identical in both actions but when oven gloves are worn, the interface is enriched with a protocol: a layer of thermal insulation that protects the hands from the heat.

In general, if the technology is compounded with the animal, one can expect that the technology adds a protocol to the interface, as in Fig. 10. In this respect,

Fig. 11 Interfaces and protocols in putting one's sunglasses on a table

Fig. 12 Interfaces and protocols in wearing one's sunglasses

it is important to take into account the transformation intended by an activity and the goal of an action: putting one's sunglasses on a table (Fig. 11) is quite different to putting one's sunglasses on (Fig. 12), even though the interfacing with the sunglasses themselves (the way one holds them) is the same. The difference can be found in the final state of the transformation, i.e. whether the sunglasses come to rest on a table or a face, and the interfaces and protocols in the whole environment at that state. This reinforces the case for including the environment explicitly in all situations and argues for interpreting a technology chain and its affordances dynamically, with respect to the activity it is used for.

4.4 Design and Connections

In the resulting combinatorial networks of technologies and connections, affordances and their links to activities, actions, motives and goals are helpful in abstracting technology chains and identifying prompters, protocols and interfaces. A highway is the prompter for the motor car because it affords transport, especially to wheeled vehicles and even more specifically to motor vehicles capable of certain speeds and equipped with relevant facilities, e.g. snow chains if the road is frozen (physical affordances) or a highway vignette (cultural affordance). Cycling on a highway is generally prohibited (cultural affordance) and actually dangerous due to the motorized traffic (social affordance), even though the road itself is quite suitable for cycling, too.

Compounding technologies in a way that expresses these affordances not only matches the parsing of an animal's activities and actions, it also makes prompters clear and unambiguous through their interfaces and protocols. The prompting of a highway includes all physical, social and cultural constraints in its protocol (including those of the underlying chain), and therefore matches only specific classes of vehicles. The designer of a highway can therefore have a clear picture of what the highway should afford in order to accommodate the intended transport modes and exclude all others.

The comprehensiveness and specificity of resulting descriptions of environments and interactions have advantages over simple relations between animal properties and features of the environment, such as the step riser to leg length ratio in stair climbability, and to matching unstructured sets of effectivities and features. These include the ability to identify and separate different actions in the same situation, and compound them into separate modules that relate to parallel technology chains in the same environment. For example, an open-air tailor working on the pavement of a sunny street may require two distinct technologies: tailor's scissors to cut fabric and sunglasses to reduce glare from the bright sunlight (Fig. 13). The two technologies do not form a single chain: they are related indirectly, through their position between the same animal and the same environment, as well as a common goal, i.e. their complementary contributions to the total affordances of tailoring on a sunny street pavement.

The advantages of such descriptions become evident in more detailed situations, such as driving a car. Even though Fig. 14 is a highly simplified example, missing seats, seatbelts, parking brakes, differentials, starting keys or buttons and many other essential parts, it illustrates how driver interactions with the car and consequent effects on the behaviour of the car can become manageable in a structured manner that facilitates recognition of modalities, clusters and parallel chains at various abstraction levels. In this example, the description focuses on the interface between the driver and the car, compounding other parts into nested nodes that can be easily expanded into detailed technology chains when required. Any change in abstraction level or perspective does not affect the comprehensiveness, consistency or coherence of the description, only the gradients of abstractions in the analysis of how one drives a car or the design of a car.

The specificity of such descriptions helps explain the match between animal effectivities and features of the environment, and so specify interfaces on the basis of affordances. In the car driving example, there are multiple, interrelated interfaces for various body parts, requiring coordinated action on the part of the driver. Organizing these interfaces in an ergonomically and perceptually usable layout, as well as taking into account driver preferences or disabilities, are integral parts of automotive design. Any interface layout should not affect the functioning and performance of the technologies behind the interface. To ensure this, designers can base their decisions and analyses on the transparent connections between the interfaces and the protocols behind them.

The transparency of these descriptions allows designers to deploy technologies in ways that improve effectivities or environments in a focused and guided manner.

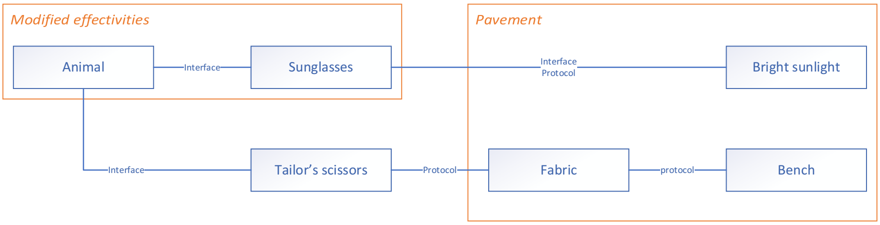

Fig. 13 Open-air tailor under bright sunlight

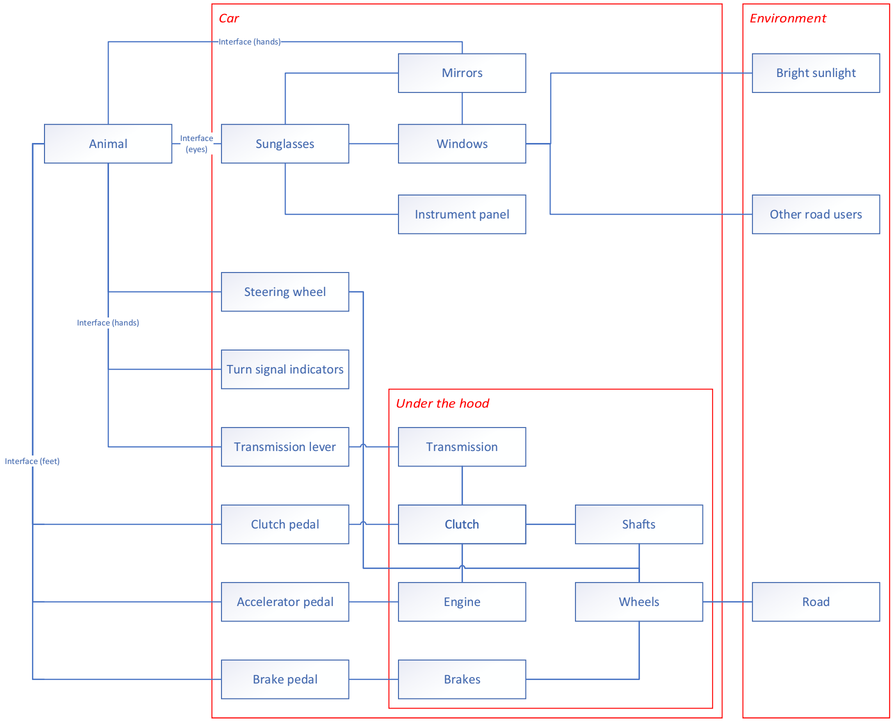

Fig. 14 Driving a car

Any mismatch or potential for improvement can be identified and linked to suitable technologies, including where exactly these technologies can be inserted in a design and how they should connect to others. The overview provided by the descriptions also supports attempts at innovation that radically reform a class of designs, such as one-pedal driving and drive-by-wire in electrified vehicles. These simplify technology chains and therefore reduce construction, operation and maintenance costs, while largely retaining familiar interfaces and improving overall performance. An earlier example of similar innovation is the automatic gearbox: a third-order technology that replaces the user and eliminates the interface in favour of protocols.

5 Conclusions

5.1 Affordances and Technologies

The purpose of this paper was to examine the relations between affordances and Floridi's approach to the categorization of technologies, in particular from a design perspective: towards a better understanding of the structure and behaviour of artefacts and designed environments. To this end, Floridi's diagrams of the tripartite scheme animal-technology-environment were adapted to include the environment explicitly in all cases, as well as describe how different technologies are compounded with the animal, the environment or each other.

The results confirm that Floridi was right to replace “affordances” with “prompter”. The two are linked but different: technologies are modifiers of environments or effectivities (or of their relation) that consequently alter affordances. A technology is prompted by matching its affordances to those of the unmodified situation, which normally reveals potential for improvement.

The combination of affordances and Floridi’s categorization has mutual benefits. The adapted diagrams presented here help understand affordances by clarifying what should be considered as environment or as effectivities with and without technological modification, and how the matching of effectivities to features of the environment takes place through interfaces and protocols. The resulting specificity complements analyses of affordances and their traditional focus on interfaces with a transparent description of the technology chains behind the interfaces.

Reversely, affordances help understand why the categorization of technologies can be variable and dependent on actions and their contexts. They explain that the deployment of a technology is bounded not only by interfaces and protocols but also by an animal’s ability to perceive and actualize affordances within an activity. If the only tool available is a knife, if the animal is unfamiliar with screws and screwdrivers and therefore unable to read their protocols or downright careless, using a knife to drive a screw is justified by the affordances of the situation. After all, affordances are possibilities for action, not guarantees of proper use or good performance. This explains abuse, failure and why the same technology can be used as both a first-order and a second-order one.

5.2 Parsing Effectivities and Environments

A key objective of the paper was to elucidate the relations between affordance-defining features and the rest of the environment, including in relation to the notion of affordances between objects. The order and inbetweenness of technologies, and protocols and interfaces help develop structured descriptions that explain interactions in full.

5.2.1 Order

The order of technologies is instrumental in revealing what should be explicit in a chain. Even when we are focusing on the screwdriver, we cannot ignore the screw. We have to specify what kind of screw it is, e.g. for wood or metal, and be explicit about its context (especially the chain of technologies behind it). Similarly, focusing on the screw and neglecting to ensure enough room for the deployment of the right screwdriver is a source of trouble for the planning and execution of actions. Therefore, ascertaining the order of technologies helps elucidate the typically multilayered design problems with the comprehensiveness and coherence they require, regarding both nested subproblems and parallel problems connected by common goals and objectives.

5.2.2 Inbetweenness

Compounding technologies with the animal or the environment returns a clear picture of what amounts to effectivities (modified or not), features of the environment or independent mediators. Consequently, it supports coherent parsing of any interaction and clear definition of scope in choosing a technology, e.g. protecting an animal's eyes with safety goggles versus reducing the fumes that prompt the goggles by adding filters to a machine.

5.2.3 Connections

Protocols and interfaces add welcome specificity to the perception of affordances: they explain *how* the features on which we focus in an interaction work, how they connect to the rest of a chain and how interaction constraints are propagated in both directions in the chain. As such, they are of particular value in design because they deliver unambiguous specifications for any part of a design problem without sacrificing overview of the whole.

Reversely, affordances explain why interfaces or protocols may not be obeyed: an animal may have higher on unrelated goals for its actions, or just lack the capacity to understand and utilize an interaction. In such situations, one must not ignore that social and cultural affordances frequently dominate the physical ones. In design, this supports a deeper understanding of uses and users, including effects of habits, beliefs or disabilities.

5.2.4 Artefact-to-Artefact: Dispositions

Concerning affordances between objects, Floridi's distinction between interfaces and protocols explains that what an environment affords to an animal is not the same as how parts of the environment connect to each other. One could argue that the latter should be called dispositions (Choi and Fara 2021): object properties indicating the possibility of a behaviour under certain conditions. For example, salt is soluble in water and a floor supports detached things up to a certain weight. These behaviours are usually inevitable when the conditions are met, irrespective of the intentions or actions of any animal.

Dispositions are subject to either very specific protocols, as in the case of the screw and the screwdriver, or more generic and fuzzy ones, as between the floor and furniture on it. The latter should not be confused with interfaces, where the variability of the animal's actions is the main reason for variation in the interaction. A floor always supports chairs, while an animal can lift a chair in various ways but may also choose not to do so. The animal is usually aware of dispositional properties in the environment and makes use of them to create affordances, e.g. puts a chair on a floor to modify the sitting affordances of a room. This awareness is explained by the propagation of constraints between interfaces and protocols in the technology chain that includes the chair and the floor.

A complicating factor in distinguishing between affordances and dispositions is that, in the debate on the nature of affordances, it has been argued that affordances are dispositional properties of an environment (Scarantino 2003; Turvey 1992). This, however, is problematic with respect to the definition of affordances as actionable properties, which assumes an agent capable of action. As there is no actor in the relation between a chair and a floor, it seems more consistent to state that, thanks to its dispositions, the floor affords *my* putting a chair on it. Otherwise, we are in danger of pushing affordances into the realm of metaphor and metonymy (Heft 2003).

The confusion between affordances and dispositions suggests that some affordance studies may suffer from narrow framing (Kahneman 2013): they isolate a relation and analyse it as if it were independent from the rest of the environment and the animals that populate it. The explicitness of technologies, environments, interfaces and protocols helps us avoid such narrow frames and consider each relation in its proper context. Therefore, it seems safer to follow Chemero (2003) and define affordances not as properties but as relations between specific aspects of an animal and specific aspects of an environment. *Any relation that involves an interface is an affordance, while relations involving protocols are dispositions.*

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