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Computational Agents, Design and Innovative Behaviour: *Hetero Economicus*

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Abstract

For too long, a majority of economic stories speak of perfectly informed, fully rational optimisation within a purely materialistic world – leaving a lack of evidence and explanation regarding human decision makers and entrepreneurs revolutionising the decision space. Strands like game theory and institutional economics have already adopted a more practical view. Evolutionary and behavioural economics were finally able to establish the necessary links to other disciplines – like psychology and informational science. This paper recaps selected parts of the literature that favour a conceptional view of computational agents. Firstly, we invite economic modellers to question the microfoundation of their assumptions with regard to the individual or to an aggregate level of human behaviour that they truly refer to. Secondly, we illustrate the potential, as well as the limitations, that computational agents exhibit – with regard to the incorporation of creativity as the main source of innovative behaviour. Thirdly, this rather superficial collection of ideas serves as a position paper for future approaches.

Keywords: computational economics, *hetero economicus*

JEL classification: D01, D90, B91

1. Introduction

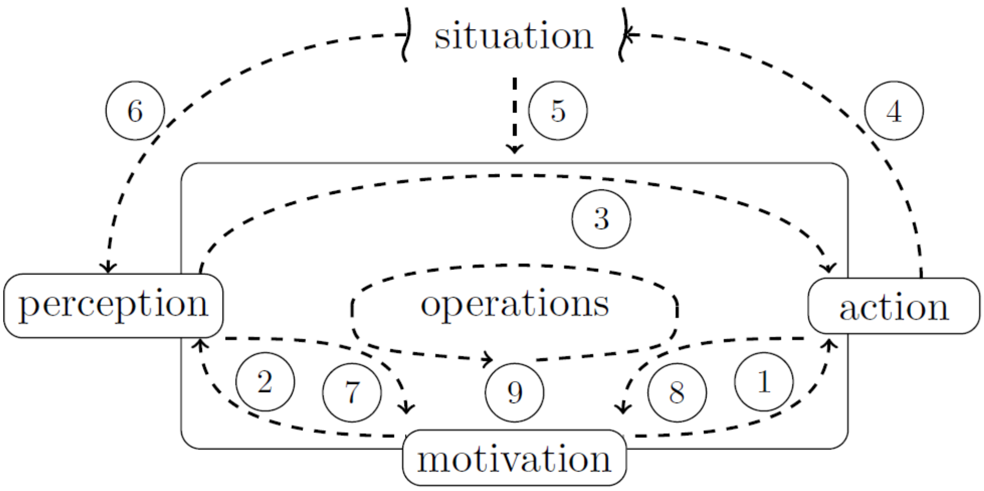
Arguments in favour of agent-based modelling often relate to corresponding critiques of other, more common, approaches in economic science. To benefit from the advances provided by agent-based models, therefore, we need a fundamental change in perspective – not least on economic agency. According to Jason Potts (2001, p. 111), engendering 'a plausible and scientifically interesting model of economic agency' is what 'orthodox microeconomics' has never accomplished. His attempt to substitute the one-dimensional *homo economicus* with his scheme of *hetero economicus* certainly requires a new evolutionary perspective. But with regard to its formalisation and representation, it still suffers from the constraints of economics.

Fifteen years before Potts, Herbert Simon (1976a, p. 66) indicated that a real change in perspective implies that 'an economist should acquaint himself with the psychological literature on human cognitive processes or human choice'. Now, fifteen years since Potts and thirty years since Simon, I intentionally do not tie in with their formalities, nor do I directly aim for a new, formal description of economic agency. Instead, I allow myself to step outside existing boxes and remain conceptional: to pick up some ideas from other disciplines and sketch their potential relevance for agent-based models. I capture and name considerations that modellers may – or at least should – have in mind when they design computational agents representing socio-economic entities (see section 2). It may help to critically question the extent of individual or aggregate human behaviour that a certain model can truly capture, and which assumptions it explicitly, or – especially by neglect – implicitly, refers to. Because creativity is one of the key features that differentiates artificial intelligence from the human mind, I add some considerations with regard to the potential (and limitations) of incorporating innovative behaviour (see section 3). The whole paper can be seen as a hint about how far the economic discipline will, in the future, incorporate computational agents, design and innovative behaviour. My focus on computational agents is based on the belief that simulations are the most important way to model the complexities arising from adopting more realistic assumptions about human behaviour (cf. Novarese, 2004, p. 23), which must form the basis of economic agency.

2. The Agent's Design

Agents, in agent-based models, are confronted with decisions and solve them according to certain rules and procedures. Describing an agent, therefore, requires more than an itemisation of its final choices. Especially with regard to economic behaviour, the visible, end choices probably represent just the final steps within a more comprehensive series of considerations. According to Simon (1976b, p. 130) we must carefully consider the deliberation process that the agents perform in order to make their decisions, before making assumptions and related explanations.

Figure 1 The operating structure of an agent



In 1974, Wersig (pp. 55–57) suggested a corresponding idea for agent design by applying Stachowiak's (1964; 1965) approach for a cybernetic model of the human organism. Neither Wersig nor Stachowiak had an economic focus, but implicitly identified the importance of an operating structure as the central point of contact (see figure 1). Picking up and just slightly adapting this so-called Kybiak-model, internal operations have to process individual perception in order to prepare autonomous actions. This is one kind of operation – internal to the agent (①②③⑦⑧⑨) – to be discussed later. The term 'operation' thereby captures different procedural connections within the agent's operating structure. One human decision maker is just one subsystem of an economy formed by many. Further operations, therefore, have to be considered that deal with the interaction and interdependency among them (④⑤⑥). They link the individual agent to the situation of the world an agent is embedded in, and part of. External feedback can affect both the situation collectively shared within the agent's environment, and the situation as it is individually perceived. So far this suggests an intelligent agent, situated in an environment, perceiving and acting 'in order to achieve its delegated objectives' (Wooldridge, 2013, pp. 4–5). It is these delegated objectives that underline that there has to be a guiding reason for perceiving and acting in a certain way: the agent's *motivation.*

In order to avoid any confusion of terms, I will refer to several particles of information available, recorded and processed in a model, and thereby in the operating structure, as 'informational elements'. The selection of informational elements to be considered for the set of an agent's perception, motivation, operations and action space – depends on the individual model.

2.1 Motivation – Roots, Renunciation and Recurrence

As Wersig (1974, p. 56) himself stated, the consideration of motivation as a term is not least founded on psychological theories. Probably the most important theory of motivation available in those days was the hierarchy of needs by Maslow (1943; 1954; 1969). Treating needs as key motives at that point seemed adequate – not only for psychologists. A corresponding connection to economics was identified even earlier in time by Brentano ([1908/1924] 2003) and, probably more famously, by Gossen (1854). Unfortunately the latter is remembered in mainstream economic theory nearly exclusively with regard to utility and maximisation. It is utility maximisation also that represents the sole motivation – as well as operation – of an agent called *homo economicus*. At least implicitly, this agent is the main actor in mainstream microeconomic teaching. The narrowness of its operating structure may be shown by a simplified, but typical example with regard to the previously mentioned design (see figure 1): facing resources and market characteristics ⑥; restricted to the choice of output level ①; endowed with the goal of profit maximisation ②; calculating the optimal amount to produce ③; providing it in favour of aggregate supply ④.

Whether it is profits, utility or welfare that the agent of interest tries to maximise, the rather deceptive conclusion remaining says: microeconomics is about the optimal use of scarce resources (cf. Estrin, Laidler, and Dietrich, 2008, p. 1; Snyder and Nicholson, 2008, p. 6; Pindyck and Rubinfeld, 2009, p. 27). This conclusion is in no way wrong, but its exclusivity disclaims several strands of specialisation within the economic discipline. Focussing soley on optimisation refuses to acknowledge the roots of economics in general. As it is still written in introductory literature today, economics – and thereby economic science – deals with those human activities that serve the satisfaction of needs (Wöhe and Döring, 2008, p. 1). This is the fundamental level where microeconomics has to step in.

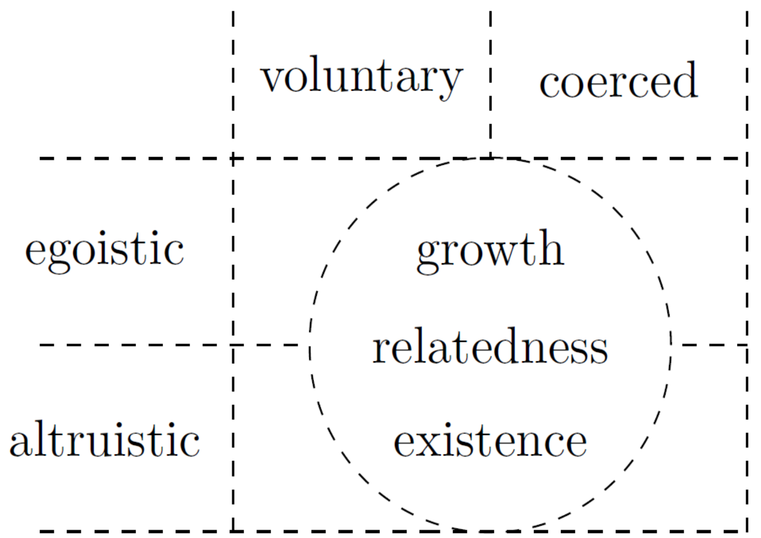
An economic agent's motivation is therefore best described by its key motive: the satisfaction of needs – the distinctive and delegated objective of Potts' (2001, p. 113) *hetero economicus*. It heralds the renunciation of the one-dimensional utility framework. It is not that all modern textbooks totally neglect the existence of needs, other than a person's own material ones (cf. Burda and Wyplosz, 2009, p. 109, Gibbons, 1992, p. 130). However, assuming that all kinds of needs and preferences are transformable into one dimension implicitly assumes that they can all be totalled – as well as substituted. This perspective risks missing the fact that different needs may be of different urgency and require different mechanisms to satisfy them – and that they may even exclude one another. It, therefore, is the consideration of complementary categories of needs that helps us understand the spectrum of motivation by true heterogeneity. Heterogeneous and complementary needs are what the entertainment industry has applied to their computational agents for some time now

(The Sims, Tamagotschi, etc.) – so social and economic science should at least try to close the gap.

When it comes to the categorisation of different needs, another psychologist, Alderfer (1972), refers to three hierarchically ordered types: existence, relatedness and growth. They provide a still-simplified, but thereby feasible, guide for approaching a higher level heterogeneity of motives in economic models (see figure 2). To emphasise the need for such heterogeneity, just think of fundamental economic variables – like final demand and labour supply, or even savings and investment. Accumulation of wealth and the expansion of a business may be suggested by books, or be driven by an individual's desire for power, or just self-actualisation. A job may allow for identification with an occupation and colleagues, or may not; it may allow for individual fulfilment or may not; it may provide a long-term perspective or just be terminable. Consumption also partly serves to define who we are and what social groups we belong to (cf. Giddens, Fleck, and Egger De Campo, 2009, pp. 216, 298, 308, ..., 711, 741–749). Economic decisions are far-reaching and cover the whole spectrum – from existential needs to needs of relatedness and growth.

Speaking of the previous examples, the goods purchased, the amount of hours spent working in a job, and the size of a business – may not be a choice made from an indefinite and continuous decision space. This suggests that we consider the possibility that not all decisions are completely voluntary, and they may not be purely egoistic. Motivational structures are not necessarily restricted to self-interest and free will, but also take the form of altruism, or even coercion (cf. Kasper and Streit, 2005, pp. 61–63). It all helps determine microeconomic behaviour based on certain levels of needs (see fig. 2). Microeconomics, therefore, is more than the derivation of optimal consumption bundles, production levels and corresponding equilibria in markets. The theoretical discussion should, in fact, start with the question – why to produce and consume in the first place.

Figure 2 Exemplary categories of needs and motivational structure

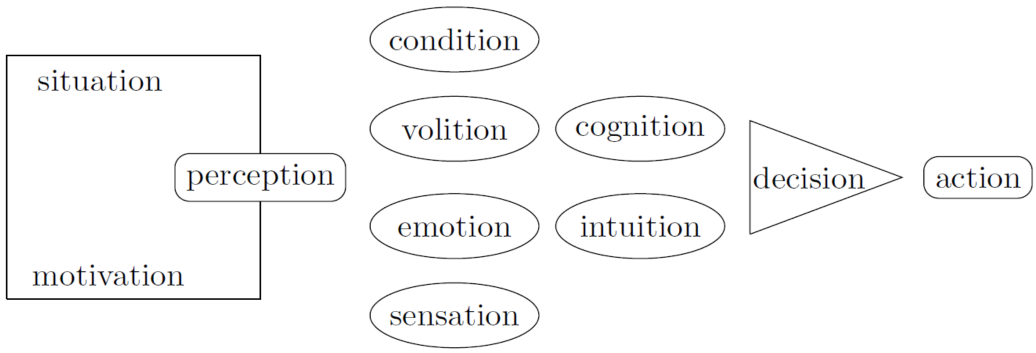


2.2 Operations – Dependencies and Behaviour

Given the motivation of an agent, the determination of an agent's behaviour has to be defined. Again I refer to the operating structure of the suggested design (see figure 1). The first challenge is to consider that an intrinsic motivation may pass some *transduction* or *transformation* on its way to the agent's perception ②. The agent might perceive some vague state rather than a distinct and numbered dissatisfaction of needs. For example, the agent might just sense hunger instead of identifying the exact amount of calories to eat. Speaking of rudimentary motivation systems, as well as *sensation*, the importance of *emotion* cannot be neglected. Applying Murray's (1938) model of human behaviour, the emotion is determined by the combined effects of personal needs and environmental pressure. Emotions then are considered as the interface between those two forces (Heckhausen and Heckhausen, 2010, p. 59). Both sensation and emotion, as well as their partly unsettled evolution over time, are almost never considered in economic models.

Considering sensation and emotion as something feeding the perception of the agent, I am tempted to say that many economic models simply set in one step later. Populated with elaborated and rational agents, these models dare to focus just on the the main task of a human decision maker and thereby represent the intelligent agent: decision making ③ – both reactive and proactive (cf. Wooldridge, 2013, p. 8). According to a common evolutionary perspective, the decision process may be separated according to three principles: the *categorisation* of the perceived and accessed elements, the *prediction* of possible outcomes based on potential decisions, and finally the *selection* of an action (Lesourne, Orléan, and Walliser, 2006, p. 39). All these steps, and maybe more, have to be considered when trying to apply the phenomenon of choice mentioned by Potts (2001, pp. 116–117) in order to describe his *hetero economicus* as an algorithmic man. However, decisions can be made in different ways and be based on different intensities of deliberation. Linking psychology with behavioural economics, Kahneman (2003, p. 1451) provides a useful perspective on human rationality. He suggestions decisions may be based on intuition on the one hand, and reasoning on the other. Intuitive decisions are rather fast, automatic and emotional responses, while reasoning occurs comparatively slowly and with more control. Similarly, but in a little more detail, Rubinstein (2007, p. 1245) differentiates between cognitive reasoning, instinctive behaviour and reasonless action based on random processes. A model of a human decision maker, therefore, must consider both *intuition* as well as *cognition* (see figure 3) to allow the model to build a complete picture of personal typologies based on psychology (cf. Jacobi, 1987, p. 21). Accepting the ability for cognitive reasoning also requires the model to represent the complexity and reflexivity of the agent it implies. The operational structure described so far is not just a one-way, check-in / check-out system. Instead, the psychology of human decision allows for *volition*. This means that the agent is able to form its own intermediate goals – and can perceive and pursue them. In addition, the agent is able to reflect on what they perceive. At least implicitly assumed in economic models and theories (cf. Davis, 2016, p. 2), the complex and reflexive way of processing input is a key feature of human decision makers and their economic behaviour in the aggregate. In order to emphasise this interlinkage between internal and external input, as well as the spectrum from emotion to cognition, models of education and pedagogy also mention social and societal *conditions* (cf. Illeris, 2006, pp. 30–31). While the agent is a complex system of its own, it is highly dependent on the systems surrounding it, and vice versa.

Figure 3 Dimensions addressed by internal operations on the way from perception to action



Many have considered this interdependence as important and suggested ways to identify the ineradicable social element in the economy (cf. Arrow, 1994, p. 2). It is obvious that interaction – like exchange – is an ineradicable social element in market economies, however, there are many more. Market economies are built on institutions like every other social and economic system, and these institutions are highly relevant for the decision process. Some even say that 'rational deliberation is not possible except through interaction with the fabric of social institutions' (cf. Hodgson, 2003, p. 163). So from perception to action – and even motivation, the social framing of the agent is determinant. Simple examples for this interdependency may be given by fundamental laws and norms that an agent is aware of, and confronted with, when it is deciding about its behaviour (cf. Fishbein and Ajzen, 2010, pp. 120–123). These norms and institutions may not just be *perceived*, but over time even *adopted* as an intrinsic, and thereby even motivational, value ⑦. The agent's operating structure then may exhibit some explicit or implicit value system consistent with its set of motives, that directly affects its decision making and corresponding action ①. A practical example may be that some need for relatedness can exclude the execution of some condemnable deeds. And so corresponding operations might derive a set of actions that is consistent with permissions and obligations taken as given. They determine a pre-selection of decision nodes and actions (cf. Dignum and Padget, 2013, pp. 73–77). With regard to the step-by-step complexity of cognitive processes, such dominant tendencies might point to the *will* and *beliefs* of an agent. The operating structure must also consider examples where the decision in favour of an action alone may provide some satisfaction, independent of its actual impact on the situation – ⑧ thereby affecting the motivational state of the agent.

Another category of operations must address the case where the system integrity of the agent is questioned. The agent's design must consider a possible lack of immunity of the operating structure itself against external situational influences ⑤. Such influences may affect several operations internal to the agent, as well as several sets of informational elements – distorting the perception, restricting the practicability of actions or even triggering special needs and thereby motivation. This type of operation could be labelled as *manipulation*. With regard to human decision makers, a colourful example is given by drugs or other dependencies. Other stress factors may be provided by special physical or psychical treatment or the neurological activation of certain areas in the human brain. With regard to all discussed operations – and a potential instability of these – neuroeconomics may give important insights and suggestions for incorporation (cf. Glimcher and Fehr, 2014). To consider forces causing instability in an agent's set of operations seems counter intuitive because they restrict the autonomy of intelligent agents having 'control both over their own internal state and over their behaviour' (cf. Wooldridge, 2013, p. 5). But trying to create a model representative of human decision makers whilst neglecting the vulnerability of an agent's autonomy – would by naive.

When discussing the potential distortion in the set of operations itself, one also has to discuss its evolution: issues like learning, memory and introspection play an important role. Internal operations responsible for *conservation* or *mutation* refer to the process of saving and adapting informational elements in the individual data store representing an agent's knowledge and maintaining its internal state (cf. Salamon, 2011, p. 77). Internal operations can also be responsible for influencing themselves, so the operating structure itself has to be seen as a partly endogenously evolving and changing system ⑨. There is the link to another part of cognition (discussed in more detail in section 3) – imagination, creativity and problem solving. When a human decision maker is hindered from executing an action, or the actual outcome of an action does not equal the expected outcome, there are more options than bullheadedly following fixed algorithms of behaviour. Instead, mutation allows the generation of new solutions. Potts (2001, pp. 117–124) talks about 'dynamic operators as genetic algorithms' and 'mechanisms governing the process of evolution' and discusses preferences, skills or competences adopted by an agent.

All together this suggests that perception serves as a recipient for inner impulses and data, as well as for stimuli from outside the agent's organism. Those stimuli, however, are causal and path dependent and effect the outcomes themselves. An operation external to the agent determines the effect an *action* has on the *situation* ④. Similarly, it is an operation external to the agent that determines which informational element describing the situation finds its way into the set of an agent's *perception* ⑥. So far the regular external feedback loop is described.

2.3 Perception and Action – Assignment and Subjectivity

At this point it is also important to once again emphasise the subjectivity of individual perception. An agent individually deciding in favour of an action does not automatically imply that the action takes place. While an agent perceives that the ability to act in a certain way may be warranted, that action may not actually be carried out. Overestimation of one's own capabilities, unknown circumstances or unforeseeable dynamics may let the agent fail to achieve the desired outcome (Wooldridge, 2013, pp. 5–6). In addition, when agents represent human decision makers, they have to be 'assumed to be autonomous entities, pursuing their own individual goals based on their own beliefs and capabilities' (Dignum and Padget, 2013, p. 60). Both may be restricted or even faulty. That means, even if an action can be performed in the aspired manner, the actoin and its consequences may be perceived differently by different agents (Wooldridge, 2013, p. 15). An agent's perception therefore is subjective – a subjective excerpt of the modelled environment, including all agents and the agent itself.

An agent is not only an operating system but simultaneously an entity of superior economic, social and ecological systems forming the environment – rightfully or wrongly perceived. Other entities may be other individual agents as well as multiagent systems and organisations on a collective or aggregate level – like firms, markets or even societies (Dignum and Padget, 2013, pp. 51–52). The term 'agent', therefore, is used synonymously with 'entity' and may refer to a single subject as well as groups – and thereby formed subsystems. With regard to common economic frameworks then, most informational elements perceived by an agent are somehow assignable to types of agents, too.

2.4 Situation – Objectivity and Consistency

The term 'situation' in the operating structure refers to the highest systemic level as well as the corresponding objective – the general and positive record of all occurrences in the model and all its entities. If a model allows for faulty perceptions, the idea is that for every informational element existing in at least one individual perception, there also exists a corresponding element in the set describing the situation. This element is not only allowed to differ in value, but its value only becomes relevant in cases where there is a difference – as it defines the true determination. The situation – as a set of elements – therefore can be interpreted as the flawless perception of the modeller.

3. Innovative Behaviour

The main objective of this paper is to look at how economic agents are modelled. The operating structure and the set of internal operations discussed previously, aim to remind modellers about the complexity of the subject they are trying to model as well as its facettes, which in favour of simplification tend to get neglected rather than incorporated. One of these facettes is the operations I referred to as mutation and conservation. These are worth focussing on as they determine the evolution of all the remaining set of operations. Mutation, in particular, addresses a characteristic of economic agencies and systems that most classical and neoclassical models hardly consider: ongoing change, challenging every stationary and even steady state – so dearly desired by some theorists.

One driver of mutation might be the direct learning from others. In this case the agent just has to preconceive the alternative, mutate in the originally-applied algorithms, and then conserve the new routine. This can also be called an 'imitation process' (cf. Shone, 2002, p. 415). With respect to the learning agent, this implies a change, and with regard to the aggregate this behaviour forms the foundation for adopting a more efficient routine. The origin of this routine – representing an innovation, though, has to be found elsewhere.

3.1 Origin – Compromise of Exogeneity

In economic terms an innovation generally refers to an invention that stands the profitability test at the market (Kurz and Salvadori, 1995, p. 400). An invention, therefore, is the first occurrence of an idea, while an innovation already refers to the practical and successful implementation of an invention (Enock, 2006). Looking for the origin of an innovation among agents, therefore, means looking for their inventiveness – and, therefore, for creativity. It is creativity that can be seen as the precondition for innovations and inventions in the first place (cf. Scott, 1995, pp. 64–65). Succinctly speaking, creativity allows for the imagination of alternatives so far unknown.

With regard to computational agents, creativity is what enables an operation to alter and especially extend the set of so far imaginable operations. With respect to the agent's design these operations can be understood as algorithms of behaviour. When behaviour is finally determined by decisions, creative mutation then extends the variety of possible choices. In other words: 'an innovation corresponds primarily to an evolution of decision spaces' (Blaseio, 2016, p. 2). Assuming creativity to be no more than a fixed algorithm, though, somehow presumes that upcoming inventions are predetermined by a given operating structure of the human mind and stepwise extended knowledge. Thinking of its practical modelling, explicitly defining an algorithm altering and extending an actual set of solutions would thereby determine all the potential future sets from the starting point.

Arthur (2009, pp. 124–130) to some extent provides a perspective that supports such a simplified approach, when he says that something novel ‘emerges always from a cumulation of previous components and functionalities already in place’ and ‘to invent something is to find it in what previously exists’. At the same time, though, he adds that the causal history of the new does not imply its appearance is predetermined. A more comprehensive interpretation of Schumpeter’s (1939, p. 63) older and well-acknowledged concept of innovations as new combinations, states that not only does it open a dynamic view of technology and preference space of economic agents, but also ‘allows for a reshuffling of the dimensions of the agents space itself’ (Hanappi and Hanappi-Egger, 2004, p. 4). This reshuffling and, in terms used previously, mutation as a creative task, seems to go beyond computation. According to psychological theories such a task must, instead, be open-ended and must not be purely algorithmic (Amabile, 2012, p. 3). While this, in turn, suggests insurmountable limits for an algorithmic computational agent, to some extent there exist such creative activities where machines employed with genetic algorithms out-perform the capabilities of humans (cf. Füllsack, 2009, p. 109). However, in such cases machines have to be comprehensively fed with information translated into readable code first. In principal, computers would have to be told what to do and every performable action would have to be anticipated and planned by programmers (Wooldridge, 2013, p. 4). So computers may be helpful in looking for symmetries or qualities observable in the code, however, they cannot interpret and understand non-codified content (Blaseio, 2016, p. 7). As creativity goes beyond what can be captured so far by any computer and artficial intelligence, it is a truly open-ended task and cannot be implemented fully endogenously in a model of computational agents.

The origin of inventions in agent-based models of economies, therefore, has to be exogenous. Accepting this, using algorithms for modelling inventiveness is a pragmatic but also effective way of incorporating innovative behaviour (e.g. Dosi, Fagiolo, and Roventini, 2006 to Dosi et al., 2016). Such implementation of creativity does not imitate the true activity, but focusses on its main economic result: an invention that extends the decision space and, more generally with regard to the agent’s design – mutates the set of operations.

3.2 Determinants – Potential for Endogeneity

Creativity and, therefore, inventiveness are not independent from other elements also addressed by the agent’s design. Creativity and the success of creativity depend upon personal factors – like cognitive style, ability and expertise – as well as pressures, resources and other social contextual influences (cf. Csikszentmihalyi, 2002, pp. 313–314, Woodman, Sawyer, and Griffin, 1993, p. 301). There is a whole componential theory of creativity. Besides the already mentioned personal factors, it emphasises domain-relevant skills, task motivation and the social environment as main determinants (Amabile, 2012, pp. 3–4). Returning to the agent’s design, the most fundamental determinants of human behaviour should also be discussed with respect to creativity: needs. In the course of his investigation of the nature of technology and innovation, Arthur (2009, p. 109) states that invention ‘consists in linking a need with some effect to satisfactorily achieve that need’. In addition, creativity is not only driven by certain needs, but also depends on the satisfaction of other needs. All these psychological insights are known and applied by entities of the economic reality, consultants and advisers (cf. Your Coach, Value Based Management, Leadership-Central and others). Therefore, they may also be worth implementing in economic models.

By returning to the agent's design we are reminded of the potential implementian of several factors that can foster or hinder creativity at individual and organisational level – factors that are intensively discussed and reviewed in psychological and managerial literature (cf. Shalley and Gilson, 2004). Those using economic models of innovation are well advised to consider such factors when they want to claim explanatory power with regard to the emergence of innovations. If the model is about the effects of innovation only, however, the excursion into the field of creativity may be spared.

4. Conclusions

The most important potential of the agent's design, as suggested in the first section, is to force modellers to identify and reconsider several relevant parts of the subject of interest at several levels. It does not deny the potential that isolated and simplified examinations of economic issues may offer. If the scope for detailing the full story using the operating system has not been employed then, with regard to the economic agent and to computational simulations, any 'emergent pattern cannot be understood without a bottom-up dynamical model of the microfoundations on the relational level' (Macy and Willer, 2002, p. 143). The operating structure, therefore, helps and invites us to keep the big picture in mind and provides an initial indication of the degree of simplification.

Focussing on the implementation of innovative behaviour, an agent's design that tries to more adequately approach human decision makers does not directly suggest a new concept. The reason is that innovations are inventions in the first place, and inventiveness and creativity are more than algorithms processing a given code. While the challenge of a largely imponderable 'creative act' remains (cf. Arthur, 2009, p. 107) the operating structure can be used to reasonably implement determinants of successful creativity, if desired.

After all, the agent's design helps us to base any economic agency or economic story on more solid foundations. And operating structure does not rule out simplified concepts – as embodied by *homo economicus* – but somehow asks for a more reasonable description and argumentation of the applied entities. It, therefore, may help us to address an urgent requirement of the stories told by economists: that they consist of identifiable characters in meaningful adventures (cf. Potts, 2001, p. 2) – a *hetero economicus* as a model of human decision makers perceiving and interacting according to their motivation and within situational conditions.

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