Computational Agents, Design and Innovative Behaviour: Hetero Oeconomicus

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Abstract

Far too long economic stories treat of perfectly informed as well as fully rational optimization within a purely materialistic world. No wonder there is a lack of evidence and explanations consistent with regard to the subject of interest: human decision makers and entrepreneurs revolutionizing the decision space. Strands like game theory and institutional economics partly already take a more practical view. Evolutionary and behavioural economics finally establish the necessary link to other disciplines like psychology and informational science. This paper recaps selected parts of the literature in favour of a conceptional view on computational agents. The latter, first, invites economic modellers to question and argue the microfoundation of their assumptions with regard to the individual or aggregate level of human behaviour they truly refer to. Secondly, the design serves to illustrate the potential as well as the limitations computational agents exhibit with regard to the incorporation of creativity as the main source for innovative behaviour. Thirdly, the rather superficial collection of ideas serves as position paper for future approaches.

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1 Introduction

Arguments in favour of agent-based modelling often relate to corresponding critique of other more common approaches in economic science. To gain from the advances provided by agent-based models therefore also partly requires a fundamental change in the perspective – not least on economic agency. Engendering „a plausible and scientifically interesting model of economic agency“ is what „orthodox microeconomics“ according to Jason Potts (2001, p. 111) never has accomplished. His attempt to substitute the one-dimensional *homo economicus* by his scheme of *hetero economicus* no doubt takes a new evolutionary perspective. With regard to its formalization and representation it yet suffers from the blinders of economics.

Fifteen years earlier Herbert Simon (1976a, p. 66) already indicates that a real change in the 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 even thirty years since Simon's quote, I intentionally do not directly aim on a new formal description of economic agency. Instead I just pick up existing approaches from other disciplines, sketch a general concept, and collect some considerations, modellers may have in mind when they design computational agents representing socio-economic entities (see ch. 2). It may help to critically question the extent of individual or aggregate human behaviour a certain model truly captures and which assumptions it thereby explicitly or – especially by neglect – implicitly refers to. Before I conclude, I add some considerations with regard to the potential and limitations for incorporating innovative behaviour (see ch. 3). The whole paper may be seen as a hint on how far the economic discipline is to incorporate the system entities of interest and thereby economic agency.

2 The agent's design

Agents in agent-based models are somehow confronted with decisions and solve them according to certain rules and procedures. Describing an agent therefore requires more than an itemization of finally made choices. Especially with regard to economic behaviour the visible choices probably represent just the final knots of a more comprehensive series of considerations. According to Simon (1976b, p. 130) assumptions and their explanations therefore have to especially consider the deliberation process agents perform in order to make their decision.

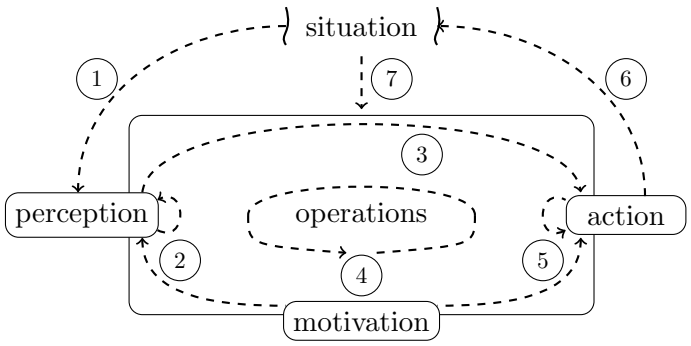

Figure 1: The operating structure of an agent

As old as this request now seems a corresponding suggestion for an agent's design is already seized and edited in those days by Wersig (1974, pp. 55-57) when he applies Stachowiak's (1964; 1965) approach for a cybernetic model of the human organism. Both did not have an economic focus, but implicitly dignified the importance of an operating structure as the central point of contact (see fig. 1). Picking up and just slightly adapting this so called Kybiak-model, internal *operation*s have to process individual *perception* in order to prepare autonomous *action*s. It is one kind of operations internal to the agent (② ③ ④ ⑤) to be discussed later. The term operations thereby capture different procedural connections within the agent's operating structure. Operations external to the agent (① ⑥ ⑦) then 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 in different ways. So far this strongly refers to a meanwhile common sketch of an intelligent agent situated in an environment perceiving and acting „in order to achieve its delegated objectives" (Wooldridge, 2013, pp. 4-5). It is the delegated objectives that underlines that there has to be a guiding reason for perceiving and acting in a certain way: the agent's *motivation*.

In order to avoid 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 practical selection of 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. The probably most important theory of motivation available in those days was the hierarchy of needs by Maslow (1943; 1954; 1969). Treating needs as key motives did seem adequate not only for psychologists. A corresponding connection to economics was identified even earlier in time by Brentano ([1908/1924] 2003) and probably more famous Gossen (1854). Unfortunately the latter's tracks in mainstream economic theory nearly exclusively regard to utility and maximization. It is utility maximization also that represents the only motivation as well as operation of an agent called *homo economicus*. At least implicitly this agent is the main actor also in mainstream microeconomic teaching. The narrowness of its operating structure may shown by a simplified, but typical example with regard to the previously mentioned design (see fig. 1): facing resources and market characteristics ①, endowed with the goal of profit maximization ②; restricted to the choice about an output level ⑤; calculating the optimal amount to produce ③; providing it in favour of aggregate supply ⑥.

Whether it is profits, utility or welfare that the agent of interest tries to maximize, the partly 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 by no way wrong, but its exclusivity would disclaim not only several strands of specialization within the economic discipline. Focussing on optimization only would also disclaim the roots of economics in general. As it still can be read in introductory literature, 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 from the utility framework of one dimension. It is not that all modern textbooks totally neglect the existence of needs others than the 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 all are capable to being totalled as well as substitutable. Such perspective risks to miss the fact that different needs may be be differently urgent and ask for different ways of satisfaction

that may even exclude one another. It therefore is the consideration of complementary categories of needs that enriches the spectre of motivation by true heterogeneity. Heterogeneous and complementary needs is what even the entertainment industry applies for their computational agents since long (The Sims, Tamagotschi, etc.) – so social and economic science should at least try to close the gap.

When it comes to categorization of different needs another psychologist, Alderfer (1972), at least refers to three hierarchical ordered types: *existence*, *relatedness* and *growth*. They may provide a still simplified but thereby feasible guide for approaching a higher level heterogeneity of motives in economic models (see fig. 2). To emphasize 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 instead driven by an individual desire for power or just self-actualization. A job may allow for identification with an occupation and colleagues or may not, may allow for individual fulfilment or may not, may provide a long-term perspective or just be terminable. Consumption partly also 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 spectre from existential needs to needs of relatedness and growth.

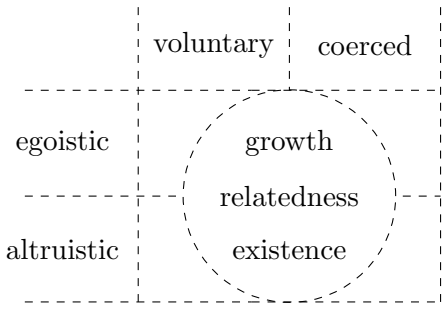

Figure 2: Exemplary categories of needs and motivational structure

Speaking of the previous examples, the goods purchased, the amount of hours to work in a job, and the size of a business may not be a choice out of a indefinite and continuous decision space. This suggests to consider that not all decisions are completely *voluntary* as well as they may not be purely *egoistic*. Motivational structures not necessarily restrict to self-interest and free will, but also take the form of *altruism* or even *coercion* (cf. Kasper and

Streit, 2005, pp. 61-63). All of it determines microeconomic behaviour. Microeconomics therefore is more than the derivation of optimal consumption bundles, production levels and corresponding equilibria in markets. The theoretical discussion then rather starts with the question why to produce and consume in the first place.

2.2 Operations – dependencies and behaviour

Given the motivation of an agent, it has to defined how it determines an agent's behaviour. Again I refer to the operating structure of the suggested design (see fig. 2). The first challenge thereby is to consider that an intrinsic motivation may pass some *transduction* or *transformation* on its way to the agent's perception ②. The agent may rather perceive some vague state than a distinct and numbered dissatisfaction of needs. For example, the agent may just sense hunger instead of identifying the exact amount of calories to eat. Speaking of rudimentary motivation systems, besides *sensation* also the importance of *emotions* can not be neglected. Applying Murray's (1938) model of human behaviour, the latter is determined by the combined effects of personal needs and environmental pressure. Emotions then are considered as the interface between those two types of forces (Heckhausen and Heckhausen, 2010, p. 59). Both, sensation and emotions, as well as their partly unsettled evolution over time are so far hardly considered in economic models.

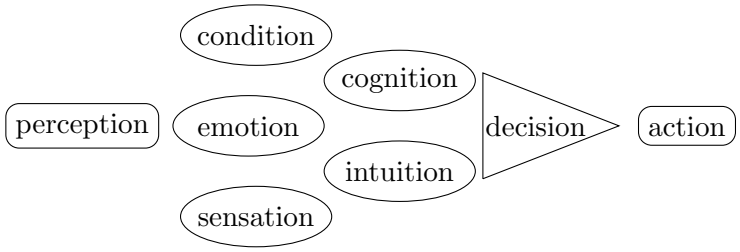

Figure 3: Exemplary dimensions adressed by internal operations

Considering sensation and emotions as something feeding the perception of the agent, I am tempted to say that economic models simply set in one step later. Populated with elaborated and rational agents economic models dare to focus just on the the main task of a human decision maker and thereby the representing intelligent agent: decision making ③ – reactive and proactive as well (cf. Wooldridge, 2013, p. 8). In a view once again lent from psychology it is *cognition* and *intuition* that completes a sketch in favour

of personal typologies (cf. Jacobi, 1987, p. 21). Considering the broadness of those terms, decision making as the link from perception towards actions is just one specific facet captured by them. In order to address and structure the internal operation focussed therefore further terms are required. 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 it is tried to apply the phenomenon of choice mentioned by Potts (2001, pp. 116-117) in order to describe his *hetero economicus* as an algorithmic man. Considering the probably restricted role of rationality, I have to emphasize that decision can be made in different ways and based on different intense of deliberation. Once again, linking psychology with behavioural economics Kahneman (2003, p. 1451) provides a gainful perspective on human rationality. Following this perspective the hereby discussed category of operations may be further divided in those referring to decisions based on intuition on the one hand and those referring to decisions based on reasoning on the other hand. Looking on operations as decision processes intuitive decisions are rather fast, automatic and emotional responses, while reasoning occurs comparatively slow and controlled. Similar, but a little bit more detailed Rubinstein (2007, p. 1245) therefore differs between cognitive reasoning, instinctive behaviour and even reasonless acting based on random processes.

After sketching the continuous spectre amongst intuitive and cognitive decision making, the comprehensive spectre of cognition itself has to be explored further. With regard to its evolution, parts like learning, memory, and introspection play an important role worth considering. Internal operations responsible for *conservation* or *mutation* not only refer to the process of saving and adapting informational elements in the individual data store representing an agent's knowledge and keeping its internal state (cf. Salamon, 2011, p. 77). They also are responsible for changing the set of internal operations itself, as the operating structure itself thereby has to be seen as an partly endogenously evolving and changing system. There is the link to another part of cognition picked up in more detail in the second chapter: imagination, creativity and problem solving. When a human decision maker is hindered to execute an action or the actual outcome of an action does not equal the outcome expected, there are more options than bullheadedly following once fixed algorithms of behaviour. Instead mutation allows to generate new candidate solutions to conserve. Potts (2001, pp. 117-124)

talks about 'dynamic operators as genetic algorithms' and 'mechanisms governing the process of evolution' also with regard to preferences as well as skills or competence adopted by an agent. In order to emphasize the interlinkage to external input, besides the spectre from emotions 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, they are highly dependent on the systems surrounding them.

Another economically important example for this interdependency may be given by fundamental laws, norms and institutions 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 be not only perceived, but over time even adopted as sort of intrinsic value, or influence the agent in terms of external pressure already mentioned. Anyway, the agent's operating structure may exhibit some explicit or implicit value system consistent with its set of motives that directly affects their decision making and corresponding acting ⑤. A practical example may be that some need for relatedness can exclude the execution of some condemnable deeds. Corresponding operations then may derive a set of actions that is consistent with a *permission* and *obligation* 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 strobed complexity of cognitive processes, such dominant tendencies may refer to the will and beliefs of an agent.

All together hints on the fact that the perception serves as a recipient for inner impulses and datas as well as for stimuli from outside the agent's organism. Those stimuli, however, are causal and path dependent effects and outcomes themselves. An operation external to the agent determines the effect an *action* indeed has on the *situation* ⑥. Similar it is an operation external to the agent that determines which informational element describing the situation also finds its way into the set of an agent's *perception* ①. So far the regular external feedback loop is described. However, another category of operations has to define the immunity of the operating structure itself against or its dependence on external situational influences ⑦. Such influence may affect several operations internal to 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. Such an operation therefore may addressed by the term *manipulation*. With regard to human decision makers a colourful example is given by drugs or other causes for physical derogation. Other stress factors may be provided by special physical or psychical treatment or the neuro-

logical activation of certain areas in the human brain. With regard to all discussed operations and a potential instability of them neuroeconomics may give important insights and suggestions for incorporation (cf. Glimcher and Fehr, 2014). While considering forces for an instability in an agent's set of operations seem 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), trying to approach a model of a representative of human decision makers, would by naive to neglect the vulnerability of an agent's autonomy.

2.3 Perception and action – assignment and subjectivity

At this point it is also important to emphasize the subjectivity of individual perception. An agent individually deciding in favour of an action does not automatically imply that the action takes place. While in the perception of an agent the ability to act in a certain way may be warranted, it actually may be not. 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 automonous entities, pursuing their own individual goals based on their own believes and capabilities“ (Dignum and Padget, 2013, p. 60). Both may be restricted and even faulty. That means, even if an action can be performed in the aspired manner, itself 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 a 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 organizations 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 synonymous to 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 sort of agents too.

2.4 Situation – objectivity and consistency

The term situation in the operating structure then somehow refers to the highest systemic level as well as the objective correspondent – 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 gets relevant just in case of 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

One of the cognitive operations discussed above refers to mutation. One way of mutation may be to directly learn from others. In this case there already exists a routine more sufficient compared to an up to now applied one. The agent just has to preconceive the alternative, mutate in the up to now applied algorithms and then conserve the newly set routine. This is what may 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 founds the diffusion of the more sufficient 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 thereby 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). Shortly spoken creativity allows for the imagination of alternatives unknown so far.

With regard to computational agents creativity then seems to be a operation itself that alternates and especially extends 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, creativity then extends the variety of possible choices. In other words: 'an innovation corresponds primarily to an evolution of decision spaces' (Blaseio, 2016, p. 2). Explicitly defining an algorithm altering and extending an actual set of solutions, however, implicitly already determines the potential sets in the future.

Assuming creativity to be not more than a fixed algorithm somehow presumes that upcoming inventions are predetermined by a given operating structure of human mind and stepwise extended knowledge. This in turn would imply that the only cause for research to take years then is the limited processing power of the human mind. To some extent there really exist such creative tasks where machines employed with genetic algorithms excel the capabilities of humans (cf. Füllsack, 2009, p. 109). However, in that cases machines have to be also comprehensively fed with information translated into readable code first. In principal computers have to be told what to do and every performable action has to be anticipated and planned by programmers (Wooldridge, 2013, p. 4). To this effect they may be helpful looking for symmetries or qualities observable in the code. They, though, cannot interpret and understand a non-codified content (Blaseio, 2016, p. 7). Creativity and the process of research therefore also 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. Using algorithms also for modelling inventiveness seems to be a pragmatic but also effective way defining the evolution of the decision space (cf. Dosi, Fagiolo, and Roventini, 2006, p. 19 to Dosi et al., 2016). It does not claim to explain or represent the task of creativity. According to psychological theories such task must rather be open-ended and must not be purely algorithmic (Amabile, 2012, p. 3). Instead the implementation has to focus on the result: an invention that extends the decision space. When such invention stands certain claims – like the profitability test in economic models – is may be an innovation. The decision in favour of a preferable element in a once alternated decision space then is just the outcome of assumptions and axioms aside from creativity.

3.2 Determinants - potential for endogeneity

However, creativity and therefore inventiveness are not independent from those elements addressed by the agent's design. Creativity and the success of creativity depends on 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 once more emphasizes domain-relevant skills, task motivation and the social environment as main determinants (Amabile, 2012, pp. 3-4). Stretching the bow back to the agent's design the most fundamental determinants of human behaviour have to be mentioned also with respect to creativity: needs. Referring to previously mentioned psychologists it is growth needs, the need for self-esteem and self-actualization that impel a person to be creative also in a productive way. In addition creativity is not only driven by certain needs, but also depends on the satisfaction of other needs as well. 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 implemented in economic models.

Determinants of creativity are to some extent also determinants of inventiveness and therefore determine the probability of an invention and its potential for an innovation. The agent's design allows to implement several factors that can foster or hinder creativity on individual and organizational level – factors that are intensively discussed and reviewed in psychological and managerial literature (cf. Shalley and Gilson, 2004). Economic models of innovation are well advised to consider such factors when they want to claim explanatory worth 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 suggested in the first chapter is to force modellers to identify and reconsider several relevant parts at several levels. It does not deny the potential that isolated and simplified examinations of economic issues may bear. The scope for detailing illustrated by the operating structure thereby has not to be fully employed, but with regard to the economic agent and 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). Hereby the operating structure helps and invites to keep the big picture in mind and gives a first verdict about 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 disclose 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. The operating structure, though, bears some points of contact to reasonably implement determinants of successful creativity if wanted so.

After all, the agent's design suggested helps to build any economic agency and stories about such on more solid ground. It does not rule out simplified concepts like embodied by *homo economicus*, but the operating structure somehow asks for a more reasonable description and argumentation of the applied entities. It thereby ma help to approach an urgent requirement of stories told by economists: consist of identifiable characters in meaningful adventures (cf. Potts, 2001, p. 2) – human decision makers perceiving and interacting according to their motivation and within situational conditions.

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