Published in: *Philosophical Inquiry* (2015) 39, 26 –37.

Scientific Simulation as Experiment in Social Science

Wolfgang Balzer, University of Munich (LMU)
balzer@lrz.uni-muenchen.de

Introduction

The method of computer simulations has arrived in the social sciences as well. In the last 25 years, many paradigmatic systems of social systems have been applied, such as (Schelling, 1971) or (Axelrod, 1984) and also some early, general approaches have been phrased, e.g. (Gilbert and Troitzsch, 2005), (Balzer, Brendel, Hofmann, 2010). In addition to the ethical and economic problems, which plague the social sciences, there is also a purely scientific problem, which is not as pronounced in other disciplines. In a general formulation the problem can be described as follows. It is hard to collect and organize the data for a social theory, because there are simply so many of them and thus it is difficult to put them in some interesting order.

In this paper, we firstly want to formulate the problem scientifically and clearer, secondly we want to introduce a new method, with which the problem can be approached, and thirdly we want to mention the reason for this contribution. The department of philosophy at the University of Athens is one of the few departments, which runs, next to its core *business*, the philosophy in an Aristotelian, Greek way. In this department also other disciplines (like social science) are thought through philosophically. Professor Anapolitanos, to whom this volume is dedicated, has a condign share in this development.

We will use the frame of the structuralist theory of science (Balzer, Moulines, Sneed, 1987), (Diederich, Ibarra, Mormann, 1989, 1994), even if our considerations are described in an informal way.

1 Theories and Theory-Nets

Set-theoretic details of the appertaining definitions are found in many different places in the scientific literature, for instance, in (Balzer, Moulines, Sneed, 1987), (Balzer, 1985) and (Balzer, Lauth, Zoubek, 1994). An *empirical theory* T contains the *core* K of T, the *approximation apparatus* A, and the set I of *intended applications* of T. The core K consists – among other things – of a class M of *models*, and a set L of *links*.

Each model x of M has the form

$$x = \langle D_1, ..., D_m, A_1, ..., A_k, R_1, ..., R_n \rangle.$$

$D_1, ..., D_m$ are the *base sets* of x, $A_1, ..., A_k$ the *auxiliary base sets*, and $R_1, ..., R_n$ the *relations* of x. Each relation R_i has a special *type* such that R_i can be set-theoretically constructed by the elements of the base sets.

Three kinds of relations can be distinguished, namely *constants, functions* and *proper relations* (which are neither constants nor functions). In a model therefore can be found five kinds of sets, which we call, in general, the *components* of the model. Each model must have at least a base set, and a relation. In empirical theories the models normally contain all five kinds: base sets, auxiliary base sets, constants, functions and relations.

In a theory, the components of a model are bound together by sentences, which describe these components set-theoretically. There are two kinds of sentences: *hypotheses* und *data*. A hypothesis normally contains at least two relations, functions, or constants. A datum is described by just one relation (or function, or constant) or by some special 'constant', which works like a name for an object (an element of a base set).

An intended application y for a theory is a substructure of the structure of a model x, and, furthermore, it has a special property which cannot by described formally. An intended application 'is' a real (actual, substantial) system, which is perceived by a group of scientists using a special conceptual frame. Such a group has internalized this frame, and has the intention to investigate this application. It is easy to transform an intended application into a set of data. Virtually, an intended application consists of a *finite* set of data.

In this structuralistic approach a theory cannot be described by a set of sentences. But from the core and the intended applications of a theory the *empirical claim* of the theory can be defined by the relation of embedding: the set of intended applications is an element of a complex set defined by the core. Relative to one intended application and relative to one model this relation can be easily expressed by saying that the intended application is a substructure of the model. In empirical theories this kind of embedding must be generalized, because an intended application cannot always be embedded into a model. For instance, the data from the application can be inconsistent or the data and the hypotheses together are inconsistent. The embedding of data will be possible only if the model is transformed into a set of *potential* (possible) models. A potential model can be found in the surrounding of the model. In this way the data are *approximately embedded* into a model. This kind of embedding uses statistical, often complex methods, which are well known.

Between different theories there are connexions, which we call *links*. Pairs of models of the two appertaining theories can be described by a link. From one theory there can be several links to different other theories. In this way we come to *nets of theories* and *nets of models*.

Among these models there are special models, which we call *measuring models*. If a pair of models from a link, the first component is not only a model, but also a measuring model, we call this link a *determining link*. A determining link has the function, to transport data from an intended system of one theory T_1 to another theory T_2. This special function has many uses in scientific networks, e.g. in Bayesian networks.

2 Theories in the Social Sciences

Theories of social science differ from theories of other disciplines in several aspects. First, a model in the social sciences usually contains a base set whose elements are human persons (or sets of such). In addition to human persons, also legal persons can occur in a model - but that is not mandatory.

Second, a human person in a model usually has beliefs, intentions, desires and emotions. These complex units are simply suppressed in many models. Without these components such a model is represented very idealized. Many aspects and features, which can be found in reality and can also be relevant in the studies, are not mentioned in the hypotheses of a theory.

The important relations of a model, thirdly, usually apply to relationships between human persons. Often these relationships are expressed normally through words, which are used in natural languages. For example verbs in network models, such as *to like*, are used as proper relations, or nouns are used like *status* and *prestige* (Burt, 1982).

Fourth, the intended applications in social sciences are often represented in a rather coarse way. In contrast to natural science the intended applications are often studied in a purely qualitative way. The main reason for this difference results from the complexity of the objects in these models. Of course an object of the type 'human person' can be split and analyzed in much smaller parts, just like it happens in natural sciences. But the 'component parts' of a person stem from many different dimensions. In the natural sciences is the analysis of an object easier. There, the elements of an object can be represented in fewer dimensions. For example in astronomy, a large object can be described in time and space by a few basic relations ('forces').

Fifth, the probabilistic view of the world causes much bigger problems in social sciences than in natural sciences. In the 'classic' period of the natural sciences the hypotheses could be described deterministically. It was possible to infer from a cause to a definite effect. Today, random events can even be found in quantum mechanics (e.g. β-decay). The studies, in which random events are relevant, are today described by statistic methods in a precise way, but often cannot be understood that easily. Statistic applications cause additional problems for the social sciences. There, many different dimensions gear into each other in only one application, which makes it hard to determine causes and effects. For example, a regression analysis often does not get on the track of the causes.

Sixth, the term of measurement is much more difficult to handle for the social sciences, than for the natural sciences. In comparison with the measurement of a geometric distance in physics is the determination ('measurement') of the dissonance of cognitive elements of persons (Festinger, 1957) much more difficult. In natural sciences experiments can be performed, in which certain measurements can be enforced. Such experiments are hardly possible in social systems. In mechanics a particle is placed on an inclined plane; the particle will start to roll. In contrast, an experiment to determine dissonance requires much more effort, but does not lead to a clear variable, which could be measured.

In the experimental applications of social sciences, seventhly, surveys play the leading part. But these measurement methods have one problem, which is neither really clarified nor discussed. This *measurement problem* arises in an application if a questionnaire, if a basic notion used in a hypothesis is formulated with other words – the basic notion is not used. At this point a derivation gets stuck, see e.g. (Balzer, 2009, 3.6).

All of this leads to practical problems in the application. For surveys or similar methods a large amount of data is required, to gain statistically relevant statements. But this is mostly impossible due to practical reasons: there are no funds or the currently active moral system prevents the application. To fit a hypothesis to data of an intended application, a large amount of data has to be collected, which is not possible due to practical reasons. Therefore it makes sense to put more effort in the hypotheses and models. Instead of focusing on the data, many hypotheses are 'thought through' and compared to each other. In this way the few, available data are compared to many different models. And if it is reasonable, a new method of embedding of the data in a model will be used, which we will now describe.

3 Models, Measuring Models, Links

Special models (for a theory), which we call *measuring models*, are constructed for the sole purpose, to define or measure a special component (or a part of this component) of a model more clearly. At this point it is not necessary to refer to the many different measuring methods which are well known (Krantz et al., 1971), (Balzer, 1985).

In general the following points are important for us. First, a measuring model has the same type as a model. The type of a measuring model can thus always be assigned to a certain theory, which can in special cases also be a measuring theory. Independently, a measuring model can also be in a relation, in a *link*, to another theory. Given a measuring model we call such a link a *determining link*. If a determining link exists, the measuring model from the link can be used for a measurement for a model of other theories as well. It is possible that there are several determining links from one measuring model to different theories.

Second, two set-theoretic disjoint 'parts' of a measuring model can be separated from a measuring model itself. We call the first part the *calculation basis* and the second one the *final result* of the measuring model.

Third – and central – the final result in a measuring model is clearly determined by the calculation basis and the hypotheses, which characterize the measuring model. For a theory, in which numbers are used in an essential way, and which does not have the property of uniqueness, we can force uniqueness by forming equivalence classes. In easy cases parts of a measuring model can be separated in following ways. In a first case the final result is identical to a components of the model and the calculation basis with a substructure of the model, which does not contain this component. The final result can be uniquely determined by the hypotheses of the theory, to which the measuring model belongs to, and by the remaining components of the model. In a second case there is a component from the measuring model, which has the shape of a function, and the final result has the form of a function value of this function. The calculation basis contains parts of this function and can also contain other parts of other components.

Fourth, as with almost all theories – at least with all empirical theories – the ideal form of uniqueness is reached only in two steps. Initially it will be checked, whether the final result can actually arise from the (or any) calculation basis. In the second step, based on the calculation basis, the range of different possible final results is examined. The ideal uniqueness condition is valid only, if in a measuring model there exists just one single, final result. This ideal condition can almost never be found in empirical theories. In these theories statistical estimations are made, which however can often be described very precisely. With that many possible final results can be limited, based on the calculation basis. Often the calculation basis is varied in this way as well.

Fifth, the uniqueness is often only achieved through theoretical detours. The calculation basis of the measuring model is derived from a calculation basis of a different model of a different theory. Often, several theories are used for that (Schurz, 2013), (Heinrich, 1998). The calculation of a final result is in these cases often made by *chains of measuring models* (Balzer, 1985, Chap. IV). The final result is quasi inductively constructed by a sequence of calculation bases, whereby these bases result from tree-like arranged measuring models. One branch of such a 'tree' is a chain of measuring models. In a first measuring model of a chain of measuring models the final result of this model is transferred to the 'next' measuring model from the chain. This result and possible others, which result from chains of measuring models, form a part of the calculation basis of the 'next' measuring model. In this way finally the sought value in the terminal node of the tree, in the highest situated measuring model, is calculated. Usually, units for quantities are used in the initial model of a chain of measuring models. Such a unit belongs to a quantity (a function)1 which can be found in the calculation basis of a measuring model.

Sixth, we eventually get to a point, which cannot be described through formal methods only. In short, it is about the question, how dependent the application of a measuring model and the uniqueness of the final result are from the activities of persons – apart from the 'direct' observation of course, which is made by the persons in these applications. We call these activities – apart from the observations – *interventions*. In an application the experimenter can intervene more or less in a measuring model. In natural sciences there are experiments, in which the intervention can be minimized in a given range of application. For example, the deviation of a light beam in the Michelson-Morley experiment will appear, no matter if people are watching this deviation or not. On the other hand there are experiments in physics, in which interventions are possible. It is often discussed, whether a Stern-Gerlach experiment in quantum mechanics, would work without observers in the same way it does with them. This applies in an even more particular way to social sciences. Especially in sociology an intervention in a measuring model happens, if the measuring model is applied to a whole society, in which the observer-scientist lives as well.

With measuring models we can build a bridge between the hypotheses and the data for the theory. The hypotheses should match the data as good as possible and vice versa. Matching arises, if the hypotheses can be confirmed through the data. Here, a central point comes into play. On the one hand there is an amount of already existing, 'somehow' produced or collected data for a given system. On the other hand there is an amount of *possible data*, which *could* be measured in the system. For example in a model of the theory of gravitation, there is an infinite number of possible positions of a particle. But only a finite number of positions are examined, on which the particle is located at a certain points of time. In newer theories data are not observed directly, but derived through chains of measuring models of other data of other theories. In this form the set of possible data is expanded.

Before there was the method on computer simulation, a theory was developed in two directions. First, for the given hypotheses there were found and produced more, 'new' data. Second, for given data different hypotheses were used, to describe the range of applications more suitable. This leads to a historic dynamic, in which firstly time for observations and the production of new 'suitable' data is spent and after, if these are of no avail, a new amount of hypotheses are brought into play. This dynamic oscillates back and forth between these two poles.

In some disciplines the hypotheses are more important and in others the data. Without giving good arguments, we suppose, that one discipline is more interested in hypotheses, if its models are more complex. For example a theory of kinematics is simpler than a theory of quantum mechanics. How this looks beyond the limits of disciplines has hardly been discussed.

The more data are needed, to find suitable hypotheses, the harder it gets to confirm these hypotheses. The finding of data needs capital, so that it can be weighed more precisely, whether it is worth to determine new data. Looked at it in economic terms the final utility moves toward zero, if the fitting of a hypothesis does not change by one single datum. In other words, for every intended range a set of found data can be separated from an only vaguely described set of *all possible data* for a real system. The more complex the hypotheses of a theory get, the harder it gets to find new, real data.

To sum up we can say, that at the time computer simulation did not yet exist, science had the aim to fit a real range of data to hypotheses.

4 Constants

The constants, which are used in models, have a different weight in the applications of different disciplines. In natural sciences, where the presentation of a model almost always contains numbers and sets of numbers, the 'natural constants' are put into focus. The reason can easily be understood. Such a constant stays the same in many real, intended systems in different theories. It binds together several relations and functions in a model, by combining different relations in a mathematical equation of numbers. In addition to these natural constants three further types of constants play an important role in science.

First, the units are important. A specific unit (like meter) is used to measure the corresponding quantity (like the distance function). For example a certain function value of the quantity is determined. In theories, in which quantities were used historically for the first time, the quantities were determined by fundamental measuring methods. For example in classic kinematics, the distance of two positions and the distance of two points of time are based on fundamental measuring methods. For that a distance is fragmented in several (distance-) units (e.g. with a tape measure and a clock) and then, the number of the perceived units are counted.

In the network of theories these units are introduced into the theories 'lying at the bottom' as constants. This process can be described as follows. A special argument of a given function is taken. This argument receives a prominent name, and the function value of this argument is fixed conventionally. This special argument is an element of a base set of a model. For example the unit (an object) for *meter* was a piece of metal, which was (and is) stored in Paris. The function value of this object receives the number one.

In most theories such units are only used in a theoretical way. If a value of a quantity is needed, which does not appear in a model component of the theory, it will be imported through a link from another theory. The used quantity will thus only be used in the background; it does not belong to the theory currently used. In general the units in chains of measuring models of underlying theories are transported to more general ones.

In reconstructions units are often left implicit or not even mentioned. This is because the size on a unit is represented as a number and thus becomes structurally unimportant for a certain theory. The hypotheses for a model do not change, if another number is used for the unit. In this case the structure of models stays invariant. But this only applies relatively to one single theory.

Conventionally a commission of scientists determines a unit, whereby it is made sure, that the size of the unit, fits the other units harmonically. For example they make sure, that a unit for a first quantity should not be related, for instance, to 106 units for a second quantity.

A second type of constants occurs in applications, in which a hypothesis is confirmed and brought into relation with data. In the easiest cases there is a numeric function f in a model, which can be compared to data of the same kind: $f(a_1), ..., f(a_n)$.

Often the following inequality

$$| f(a) - 1/n\Sigma_{i<n} f(a_i) | < \varepsilon$$

is used. $f(a)$ is a theoretical value from a model and $1/n\Sigma_{i<n} f(a_i)$ is the mean value for a set of real data. The inequality implies that the theoretical value differs from the mean not more than ε.

If the number of data is set identical to the number of objects of this model, it even can be determined, how likely it is, that the theoretical value is in the vicinity of the mean. In those cases the number ε could be defined explicitly. But in an empirical theory the number of basic elements of a model is usually not specified. In most cases ε is not clearly defined, but conventionally determined. The number ε is used like a constant.

In general the surroundings of models and potential models for a theory are only used in a structural way, to formulate an empirical claim for the theory – and perhaps to verify it. In structuralist theories one can find the formulation, that *there is an environment*, in which a model (or a complex entity) lies. On application level the existential quantifier '*there exists*' has to be expressed through a certain number, a constant. We thus find another type of constants, which are important in empirical theories.

A third type of constants is discussed even more rarely. Such a constant expresses the number of objects, which lie in a base set of a model. In the formulation of the structure of a model it is mostly only said, that a base set in a model is finite or infinite.

For a finite base set a 'reduced' probability can often be used, if the probability can be expressed through a relative frequency. Thereto, on the one hand the number of elements of the base set has to be known, on the other hand the number for elementary events of a given kind, which really did take place, also has to be known. For example it is often assumed, that the elementary events are distributed equally. In non-deterministic applications a base set from a model is used to construct a probability space, with which the probabilities can be examined.

In an infinite base set the probability about this number is expressed by a density. In such a case, the base set is often represented by a real interval, so that the interval has an upper and lower limit. These limits function like constants in a model. In a model the limit of an interval is not changed; the basic elements lie in this interval.

For us these constants are particularly interesting, because on the one hand they can hardly be determined more precisely and on the other hand, because they change only in dynamic processes between models. For example a natural constant is examined in a time-variant network, whereto the certification levels of different claims are compared.

In historic episodes such examinations are often initiated by a constant. A constant is changed a little bit. For example different versions of the classic theory of gravitation have been suggested, in which other coefficients have been used in this equation. Such a coefficient works in a model in the same way as a constant.

So, why shouldn't we use constants as a trigger for scientific change? The constants, which are dispersed over the models in different disciplines, form a *pattern*, which has not been systematically examined much in the theory of science yet. This is different for single disciplines. For example in physics the dimensional analysis is an inherent part of the education. By these preparations we get now to scientific simulations.

5 Simulations as an Experiment in Social Sciences

We will proceed from a theory, a model and from an intended application of the theory, which affects a social system. In opposite to a scientific application without a computer simulation, it is *not* the aim of a simulation to match real data and a model. This does not work for the following – partially already mentioned – reasons. The group of scientists, which examines the real system, out of which the data origins, knows, that the data – and often the hypotheses of a model as well – do not suffice, to display the real system in an interesting way. For example in a sociological examination of armies, the data of the recent past are missing (not to talk about todays condition). In other social examples models are phrased very abstract and intentionally vague, so that it does not make much sense to collect or somehow produce real data. Furthermore there is the problem with social systems to enter into the 'inner world' of the actor. This work alone can become really complex, so that normally there are no funds to actually do this work. Even normal amounts of data can become really large in a social system.

All this means, that the number of the data, which is needed for an examination, is usually not available. The group of scientists does not have the funds to collect these data.2 Often there are also moral problems in social applications, which become virulent e.g. in medical applications.

Given this starting situation a scientific simulation can be described as follows. The hypotheses of the model are reformulated in a computer language. If a theory is described in a completely static way, an additional program module has to be developed, with which the structure of the model can be displayed and perceived as a process. A reduction might be used, if the theory contains many hypotheses. We assume that the data are already available and have the right types for a given model. So we assume, that the theory has been transformed into a computer program.

We have to differentiate in a simulation between three components. First there is the computer run, second, there are repetitions of 'the same' computer run and third, 'a simulation' of a system, which consists of different repetitions with different inputs.

At this point a new aspect comes into play for simulations, namely the generation of atomic sentences, which can be used in a run as additional *quasi data*. In this way the few, real data, which are available for a certain system, can be amended and completed. In the beginning of a simulation program, quasi data are generated in the right form and types for the model. To do so, different constants are used, which have to exist in the program. Out of these constants and different program parts – depending on the program – quite a few new quasi data are generated, which can be used in the original hypotheses with the adequate purpose. If, for example, a function of a special type is used in a hypothesis, one can generate function values, in which the number of possible arguments is calculated in the first step – this number has to exist as a constant. In the second step usually many functional values are randomly generated. In this way the statistical confirmation mechanism can be used more effectively. From a set of real data and a set of quasi data it is investigated by various methods, if the hypotheses match the enriched data or not, and if the program displays the particular real system or not. In other words, new 'worlds' can be examined with computer simulations; systems, which contain partly real data and phenomena and partly manmade ones: *hybrid systems.*

For one run the program is available and the data are loaded. In the run, hypotheses are processed. If the hypotheses involve a time component, time can be recognized also as a main component in the program. In a static model a run has to be programmed, which processes all areas of the model step by step. Since normal computers work deterministic as yet, even if random generators3 are used, there is clearly one specific result, which is somehow handed out in the end.

In this way such a program works like a measuring model. The program generates the final result from the calculation basis. The calculation basis contains, first, all entered data, second, different technical control elements of the program, which at least in a first approach do not have anything to do with the hypotheses of the simulation, and third the potential random elements, like the so called 'seed' – a manually or automatically generated number – which activates a deterministic random generator. In the simplest form we can interpret the final result as a forecast, which has not been explicitly existent in the beginning of the program and in the model. This procedure is even expended, by using quasi data. In simulation, between the calculation basis and the final result a new level is created: a set of quasi data.

Repetitions using the same input lead to different results, *if* the random generator and in every repetition another seed is used for each tun. In this way the different results are analyzed statistically, by e.g. forming type-matching mean values from certain results. Out of these a 'typical model' can be constructed, which shows important aspects of the real system, but which is *not* visible in one single computer run.

So far, a simulation mainly is distinguished from a 'normal' scientific application, by the feature of determinism. But there is one more, new aspect, which has not been used and considered much in social simulations yet. This aspect concerns the constants and their patterns, which we discussed in section 4. For a simulation in a computer program all these constants are required. 'Natural constants' are used in the coding rules, if the hypotheses of the model are expressed through rules. This also applies to models of social sciences. For example, in psychological models numbers are used, which express how many action alternatives are available for one person. Units can occur in every model, even in models for social systems. Constants for approximations are explicitly used in a program. They are entered through 'the programmer' for a certain computer procedure (Balzer, Brendel, Hofmann, 2012). Constants, which express the number of objects for a certain object-type, which are used in the program, are equally important in the simulation. For example in a computer run it is fixed, that 20 (or 10 million) people and 5 (or 93) types of goods are used. In another run different numbers are used.

The new aspect for simulation programs is the pattern of constants. The change of 'real' hypotheses, which we discussed above, needs time. Every alteration, which is created, e.g. also through a constant, has to be compared with the data and confirmed with the data. In a simulation the results cannot always be compared to data, but they can be compared with other results from other runs, in which other constants have been used. In this way the described, historic process is raised to the simulation level, so that a change of a constant, quickly makes clear, if this has positive or negative (or none) consequences for fitting real data to a model.

Even this procedure can further be improved. Through computer programs the procedures themselves can be automated. For this we only needs one additional program module, which works as follows. First, a pattern of constants is replaced with another pattern. Second, with these new constants another computer process is activated. Third, the numerous results from the processes, which thus came into being, are saved. Fourth, the results are processed graphically, so that the scientist can compare the results with his 'naked eye'. The results can be qualitatively different. The result from one run is just different from the previous run. In this case the scientist will examine more precisely, how the difference of the runs came into being. In other words, a new scientific method can be used: the method of *systematic replacement of constants*.

We cannot tell yet how far this method is already used in natural sciences. For us this method is particularly interesting for the application in social systems, because there, as it has been said before, real data are only scarcely available.

References

Axelrod, R. 1984: *The Evolution of Cooperation*. Basic Books, New York.

Balzer,W. 1985: *Theorie und Messung*. Springer, Heidelberg etc.

Balzer, W. 2009: *Die Wissenschaft und ihre Methoden*. Freiburg, Karl Alber (2. ed.).

Balzer, W., Brendel, K. R., Hofmann, S. 2010: A Simple Frame for Artificial Societies. In: (Ernst, Kuhn, 2010), Proceedings of the 3rd World Congress on Social Simulation WCSS2010, CD-ROM.

Balzer, W., Brendel, K. R., Hofmann, S. 2012: How Can We Simulate a Society? *Salzburger Geographische Arbeiten*, Band 48, 111 - 120. (ESSA Kongress 2012).

Balzer, W., Lauth, B., Zoubek, G. 1993: A Model for Science Kinematics. *Studia Logica* 52, 519 - 48.

Balzer, W., Moulines, C. U., Sneed, J. D. 1987: *An Architectonic for Science.* D. Reidel Publishing Company, Dordrecht.

Balzer, W., Sneed, J. D., Moulines, C. U. (eds.) 2000: *Structuralist Knowledge Representation - Paradigmatic Examples.* Amsterdam, Rodopi.

Burt, R. S. 1982: *Toward a Structural Theory of Action. Network Models of Social Structure, Perception, and Action.* New York, Academic Press.

Diederich, W., Ibarra, A., Mormann, T. 1989: Bibliography of Structuralism. *Erkenntnis 30*, 387-407.

Diederich, W., Ibarra, A., Mormann, T. 1994: Bibliography of Structuralism. *Erkenntnis* 41 ,403 - 418.

Ernst, A., Kuhn, S. (eds.), 2010: Proceedings of the 3rd World Congress on Social Simulation WCSS2010 (CD-ROM). Kassel, Germany: Center for Environmental Systems Research, University of Kassel.

Festinger, L. 1957: *A Theory of Cognitive Dissonance.* Evanston Ill., Row and Peterson.

Gilbert, N., Troitzsch, K. G. 2005: *Simulation for the Social Scientist.* Maidenhead, Open University Press (2. ed.).

Heinrich, W. 1998: *Inexakte Messung und Datenkinematik.* Peter Lang, Frankfurt/Main.

Krantz, D. H., Luce, R. D., Suppes, P., Tversky, A. 1971: *Foundations of Measurement Vol.1.* New York - London.

Schelling, T. C. 1971: Dynamic Models of Segregation, *Journal of Mathematical Sociology* 1, 143-86.

Schurz, G. 2013: Criteria of Theoreticity: Bridging Statements and Non-Statement View. *Erkenntnis* (online).

Sneed, J. D. 1991: *The Logical Structure of Mathematical Physics.* Dordrecht, Reidel (2. ed.).