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The Structure and Logic of Interdisciplinary Research in Agent-Based Social Simulation

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Abstract

This article reports an exploratory survey of the structure of interdisciplinary research in Agent-Based Social Simulation. One hundred and ninety six researchers participated in the survey completing an on-line questionnaire. The questionnaire had three distinct sections, a classification of research domains, a classification of models, and an inquiry into software requirements for designing simulation platforms. The survey results allowed us to disambiguate the variety of scientific goals and *modus operandi* of researchers with a reasonable level of detail, and to identify a classification of agent-based models used in simulation. In particular, in the interdisciplinary context of social-scientific modelling, agent-based computational modelling and computer engineering, we analyse the extent to which these paradigmatic models seem to be mutually instrumental in the field. We expect that our proposal may improve the viability of submitting, explaining and comparing agent-based simulations in articles, which is an important methodological requirement to consolidate the field. We also expect that it will motivate other proposals that could further validate, extend or change ours, in order to refine the classification with more types of models.

Keywords:
Interdisciplinary Research, Social-Scientific Models, Multiagent-Based Models, Verification and Validation

The Interdisciplinary Character of Simulation

1.1

After the consolidation of the multiagent paradigm in computer science, the role of multiagent-based simulation has been acquiring importance in a variety of scientific disciplines. In particular, the sources of analogy between agent-based technologies and models of actual social systems have created an intense interdisciplinary effort, opening new interfaces of research across various disciplines under the umbrella of a new scientific field, which may be called Agent-Based Social Simulation (ABSS) (see *e.g.* Conte, Gilbert and Sichman 1998).

1.2

This interdisciplinary character has brought together researchers from several scientific fields, sometimes with different backgrounds. But, since this convergence has only emerged recently, the identification of the extent to which the variety of interdisciplinary goals may be instrumental to each other is not straightforward. As a result, the vague definition of the structure and boundaries of simulation has been limiting the analysis of its research goals and technical frontiers, delaying the consolidation of methodologies and, to some extent, its recognition as a fruitful scientific activity.

1.3

Indeed, the conditions that made this effort possible seem to be easier to identify than its consequences. As for the conditions, these may be stated as (i) the wide interpretative scope of the theory of agency, which seems to facilitate the interchange of multiagent models between different scientific fields; (ii) the advances in computer capability such as processing power, distributed technologies, expressiveness of programming languages and human-computer interfaces, which have amplified the communicative and interpretative room to confront models intersubjectively. Nevertheless, the way agent-based simulation is organised around different research goals, ontological and methodological assumptions is still not clear.

1.4

At the same time, it appears that the area has acquired an autonomous scientific character with its own scientific problems, solutions and even some traditions. The profusion of conferences and journals, as well as the results of the survey that we will describe here, seem to indicate that it indeed has. And these indicators do not contradict the fact that simulation is, and will possibly remain, a highly interdisciplinary field.

1.5

But this raises a set of methodological dilemmas. The viability of comparing models based on presumably different assumptions is frequently not assessed, nor are those models classified according to a standard set of common assumptions – "methods and instruments" is rarely an explicit section in the published articles. For instance, if agent-based models enhance the potentialities of computers to simulate social phenomena, or if the latter prove useful for building multiagent-based computer technologies, do the assumptions behind those approaches differ in any substantial way? How are theories transferred between the computational sciences and the social sciences?

The SimCog Survey

2.1

It can therefore be suggested that the research community is organised to a significant extent according to a variety of research goals, which use different methodological assumptions to verify/validate their models. To make this puzzle more intelligible we should try to compose a descriptive picture of the area, hopefully on the way to building a more comprehensive picture of the field. Specifically, in the short term, we should be able not only to identify the diversity of scientific goals and procedures but also to investigate the organisational structure of scientists and developers around those issues. In this context, there are at least three topics that deserve analysis:

- *domain of interest*: the profusion of motivations associated with different areas of research and/or development. For instance, pure scientific and research-centred; educational; or application-centred, such as engineering, industrial, policy making;
- *type of model*: the kinds of model associated with different kinds of targets. For instance, of an abstract nature; of a natural, social or technological nature. Different models will probably

ask for distinct interpretative references, based on varying assumptions, which call for different research logics;

- *technological requirements*: the need to identify or extend requirements of software packages according to this variety of motivations.

2.2

This article reports an exploratory statistical survey structured around the three topics. The survey, completed at the end of 2002, involved the contribution of one hundred and ninety-six researchers (196) through an on-line questionnaire. It was prepared in the context of the SimCog project (SimCog 2003). The survey results allow us to disambiguate with a reasonable level of detail the interdisciplinary complexity of ABSS, especially with respect to the interaction between the roles of social-scientific modelling and agent-based computational modelling.

2.3

We will present the layout of the questionnaire and the survey methodology in section 3. The layout is described in line with its three distinct sections, which are a classification of research domains, a classification of models, and an inquiry into the appropriateness of certain software requirements to design computational platforms. Sections 4 and 5, investigate the structure of research in the area, based on the correlation both between different models and domains and between different models and software requirements. The survey results allow us to present in section 6 the final classification of models, and to analyse the roles of those models in relation to the logic of scientific research in simulation.

The Survey Design

3.1

The SimCog survey is an exploratory statistical survey. The target population was the ABSS research community. Data was collected through an on-line questionnaire, from September to December 2002. The full questionnaire is found in Appendix B.

The Survey Variables

3.2

Thirty four variables are considered in the survey: (i) domain of interest; (ii) type of model; and (iii) thirty-two software requirements. These are nominal variables that give qualitative information and do not allow rank ordering.

Domain of Interest

3.3

This variable reflects the area in which the respondent expresses interest in using simulation. The following options were available, in a closed multiple-choice question: *research*, *education*, *engineering*, *business*, *industrial* and *policy*. This set was presented with a low specificity because there are innumerable sub-domains within each domain. Each domain has its own characteristics that should deserve attention. The domains of research and education are general in scope and usually associated with projects in universities, government institutions and think tanks. The remaining ones tend to be application-centred, demanding more practical results.

Type of Model

3.4

This variable describes a number of idealisations that depend on several ontological assumptions with respect to a target and/or the different formalisms that may be used to model it. The relationships between ontological assumptions and modelling formalisms can be found in the literature in a variety of forms.

3.5

For example, the belief that the social context of individuals is dependent on socio-cognitive individual representations (*e.g.* norms), can suggest the use of modal logic to model the agents (*e.g.* Conte and Dignum 2001). Meanwhile, a large number of simulations tend to model complex systems through interacting agents specified with very simple rules (*e.g.* Epstein and Axtell 1996). Different formalisms may be the result of various considerations such as availability of theoretical frameworks or computational scalability. Goldspink 2000, for instance, discusses the appropriateness of the functional theory of autopoesis to model complex socio-cognitive phenomena, rather than relying on representational approaches based on formal logic, for reasons of both ontological adequacy and computational scalability.

3.6

While various criteria can be adopted to identify relevant types of models it is nevertheless possible to observe certain patterns in the literature. We provided four options in the questionnaire, and an open question that invited respondents to suggest other types of models. Thus the respondent could identify himself/herself with different proposals or suggest others.

3.7

In the remainder of this section we will explain the interpretations underlying each option. Since some models may be compatible with multiple options, we will provide examples found in the literature. The data analysis suggests that the respondents understood the meaning of the options, as we will report later.

3.8

A. Artificial social models: *To model and simulate artificial societies that do not necessarily reference a concrete target or specific theory about the real world, but only some theory or proposed idea of abstract nature*.

3.9

The level of abstraction within this trend is often purely theoretic, where the researcher is free to abstract any arbitrary relationships of a mathematical, physical, social or psychological nature. If this approach is adopted radically, with no connection at all to what we conceive actual or objective in the "real world", then there is a single empirical reference to the model put forward in the simulation: the behaviour of the simulation, *i.e.,* the program executions themselves. Thus, the emphasis of research is directed to the verification of certain specifications against the program executions in the computer: to what extent is the theory interpreted according to the observed behaviour of the program executions determined by the specified model?

3.10

It is more usual, however, to have the models confronted with the real world other than the simulation itself, even if at a very suggestive level. The more meaningful the model outside the simulation is, the less it is likely to be classified as a pure artificial social model. At different levels, the level of relationship between the following models and the real world varies, albeit somewhat subjectively: the Daisyworld parable of an imaginary planet whose temperature is an emergent property of growing flowers (Lovelock 1992); the Shelling 1971 model of segregation; the Axerlrods model of culture dissemination (Axelrod 1997), or the Sugascape model (Epstein and

Axtell 1996), which attempts to model human behaviour through simple rules of cultural transmission or sexual reproduction. At any rate, the intention is not to base the model on strong empirical relationships to any target system, but to establish relationships at a more or less suggestive level.

3.11

B. Social-scientific models: In this trend, researchers use the theoretic framework of social and/or environmental sciences to model social and environmental phenomena. The target systems are directly observable, or those for which there is some meaningful evidence about their existence. Two main directions can be detected: socio-cognitive and socio-concrete models.

3.12

B.1. Socio-cognitive models: *To model socio-cognitive or sociological theories and implement computational animation of logical formalisms, in order to refine/extend social theories and check its consistency*

3.13

This type of model is usually founded on the computational animation of logic formalisms, which represent agents and social structures according to a specific theory. The animation serves the purpose of checking the consistency of and refining theories. It has been considerably influenced by the experimental tradition of Artificial Intelligence, characterised by the use of cognitive agent architectures that represent explicit knowledge, such as those based on SOAR (Laird, Newell and Rosenbloom 1987).

3.14

One example is the DEPNET system (Conte and Sichman 1995), based on the Theory of Dependence and Social Power. The authors explore a social reasoning mechanism where the agents can represent social dependence relations in accordance not only with their goals and plans, but also with what they believe to be the other agents' goals and plans. The use of cognitive architectures is motivated by the idea of exploring how society is implemented within the minds of its members, the exploration of the "*footprints that a multiagent system leave not only on the behaviour of its component members, but also in their minds*" (Conte and Castelfranchi 1995, p.2). These models seem to fit well with logic-based formal specifications.

3.15

The translation of formal logic to computational algorithms, however, seems to be a problem to semantic scalability. As a result, most simulations tend to relax the semantics of their original models, where the agents' internal architectures become more rudimentary and mental objects become segments of algorithms "in which logistic and social information are conditions for the application of given routines" (Castelfranchi, Conte and Paolucci 1998). Moreover, while the theoretic role of formal logic is certainly appealing, it does not imply the ontological conception of socio-cognitive human activity, or sociological phenomena, in terms of logic-based representations and reasoning.

3.16

For example, in contrast with the modal logic-based specification of (Conte and Dignum 2001), the work of (Staller and Petta 2001) simulate a model of social norms based on the appraisal theory of emotions. Caldas and Coelho 1999 use simple evolutionary rules to simulate the aggregated performance of various institutional and normative systems.

3.17

It should be nonetheless be borne in mind that, according to the theory of computation, there will always be a first-order language that can simulate any execution of a program that terminates. At any rate, it is obvious that socio-cognitive and sociological models represent a considerable part of current work in ABSS, regardless of whether or not they are specified with the aid of logical formalisms.

3.18

B.2. Socio-concrete models: *To model and simulate concrete social systems based on direct observation and statistical data, in order to understand social and institutional processes and phenomena*.

3.19

This type of model should represent observations of social and institutional concrete processes. The goal is the use of simulation to describe observed social systems, or to capture the sometimes conflicting perceptions of the social system by stakeholders and other domain experts, such as the modelling of socio-economic and environmental systems (see, for example, Moss's claim in Conte *et al.* 2001).

3.20

In principle, the intention is to establish substantive relationships between the simulation and the target, which typically implies the existence of empirical data about the target. If that is the case, the empirical data should guide the development of the model specification, and should be compatible with the outcomes of the simulation as well. Unfortunately, even though this confrontation is desirable, it is rarely possible to close this circle, since most complex systems are difficult to specify and produce outcomes sensitive to initial conditions. Hence, many simulations simplify the process and concentrate the validation efforts either on the specification or on the outcomes. For instance, the model proposed by Dean *et al.* 1999 uses hypothetical conditions to specify a simulation in order to produce outcomes that may be compared to empirical knowledge about the patterns of extinction of the Anasaki population in the U.S.A. over the period 800 to 1300 A.D.. The specification in this case is not confronted with empirical data.

3.21

Other alternatives have proposed a weaker form of empirical validation, suggesting the development of participatory-based simulations, whereby a set of stakeholders, such as domain experts or the simulation end-users, negotiate the validity of the specification and the outcomes (see *e.g.* Barreteau, Bousquet and Attonaty 2001).

3.22

C. Prototyping for resolution: *To model and simulate multiagent systems to explore multiagent system requirements and intended behaviours, for use in real environments and general-purpose engineering*.

3.23

The main purpose is to simulate abstract conditions or technical figures from real world technologies, usually by prototyping intended computer applications based on multiagent technology. In some cases the agents in the simulation may interact with humans. An example is the ARCHISIM project, which aims at both simulating a realistic traffic evolution and making the behaviour of the simulated drivers credible for a human driver placed in a driving simulator (El Hadouaj, Drogoul and Espié 2000). Thus the simulation of the traffic situation should be the most realistic possible so as to give the driver the illusion of being in a real traffic situation. Other projects involve, *e.g.*, (i) the simulation of multiagent systems interacting with other agents simulating the behaviour of real people, in order to save energy in intelligent buildings (Davidsson and Boman 2000); (ii) the exploration of technological solutions inspired by real world scenarios, such as the implementation of behaviours in robots that play football (RoboCup 2003). The modelling emphasis is thus essentially normative, insofar as the quality of the simulation is validated according to the relatively arbitrary evaluation of the system end-users.

Software Requirements

3.24

Another section in the questionnaire asks the researchers about their preferences with regard to the set of requirements with which ABSS computational platforms should comply. There are currently a large number of computational systems for constructing agent-based social simulations. While analysing such systems, it is possible to detect several technologies, but amongst this diversity there are certain groups of requirements that characterise different kinds of technologies. Such groups will be called facilities (see Decker 1996).

3.25

We identified four facilities: technological, domain, development and analysis (Marietto *et al.* 2002; see Appendix A). Meanwhile, there are a number of requirements that we do not believe are systematised adequately. Most are related to the need to balance the effort spent on the verification and validation of unexpected outcomes. In other words, the importance of validating unexpected outcomes weighted against the target, and the importance of verifying those same outcomes against the model specification and the program executions. We have clustered these services in a new group called exploration facilities.

3.26

Thirty-two requirements were included in the survey as closed multiple-choice questions. From these thirty-two, four are exploration facilities, and thus represent the authors' personal view about a specific set of desirable requirements for the next generation of ABSS platforms. The other twenty-eight can be found in some form or another in most platforms. The respondents could classify each requirement with the following options: "Imperative", "Important", "Desirable", "Undesirable", "Not necessary", and "Domain dependent".

The Survey Hyphotesis

3.27

We put forward three hypotheses. The first is that the distribution of respondents around the categories of each variable fit certain patterns, reflecting different research motivations. This is basically a univariate analysis, which can give us evidence about the classes of models that are being used in ABSS.

3.28

The second hypothesis considers the correlation between the "type of model" and "domain of interest" variables, where the respondents would be more or less likely to choose a specific model depending on the domain. This should give us evidence about the structure of interdisciplinary research in ABSS.

3.29

The third hypothesis is that researchers prefer different sets of software requirements depending on the type of model. There may be requirements common to various tendencies, as well as different, or perhaps incompatible, requirements associated with different tendencies.

The Survey Methodology

3.30

The target population in the survey was the ABSS research community. Potential respondents were informed that personal identification would be kept confidential.

3.31

Sample selection: We adopted a judgement sample, a non-random sample where the elements are selected according to the judgement of someone who is familiar with the target population (see Fowler 1984)[1] .The sample frame is a list of email addresses comprising authors of articles in scientific publications, key researchers in the field, and the members of five email discussion lists[2] .Elements in the sample were contacted individually by electronic mail. Requests to fill in the questionnaire were also sent to the email discussion lists.

3.32

Data collection: The questionnaire comprises thirty-four closed questions and two open questions. The first open question invites the respondents to describe different types of models when his/her opinion does not match the available options. The second asks the respondent for additional comments or corrections to the questionnaire. Responses were received between September and December 2002.

3.33

Sample size: Response rates vary widely for different types of survey. Because many elements in the target population are members of more than one email list, the number of elements in the sample and the response rate are unknown (for reasons of confidentiality in the lists). Information about the number of completed questionnaires and refusals is found in Table 1. The number of respondents per region is described in Table 2 (number of respondents per country in table A.1 of Appendix A).

3.34

Data analysis: The software used to analyse data was the Statistical Package for the Social Science (SPSS). Complete cross tabulations are found in Appendix A.

Table 1: Number of completed questionnaires. CQ is the number of questionnaires that have been completed (more than 90% answered questions), PQ the number of questionnaires that have been partially completed (between 60% and 90%), R is the number of refusals (respondents who declined to fill in the questionnaire), and NC is the number of non-contacts (if eligible respondents could not be reached with the given email)

Sample Size	CQ	PQ	R	NC
unknown	196	0	22	45

Table 2: Number of respondents per region (according to the respondents institution affiliation)

	Asia & Oceania	Central and South America	Europe & Russia	Canada & USA
Respondents	17	9	116	54

Univariate Analysis

Variable "Type of Model"

4.1

The vast majority of researchers (97.5%) chose at least one available option for this variable. Figure 1 illustrates the percentages of positive responses in each category of the variable, relative to the total number of respondents. Only a minority (11.7%) completed the open question. Of those none proposed alternative models, suggesting that the set of available options was significantly accepted and appropriately interpreted.

4.2

The fact that there is a fair distribution across the four types of models does not mean that the organisation or researchers around this variable is trivial. Indeed, we observed a high level of scattered choices: 28.6% of respondents chose a single option, whereas 48.5% chose two options, 13.3% chose three and 8.2% chose all options. Also, the use of artificial social models is negligible (less than 1%), since only three respondents did not select that option in conjunction with the others.

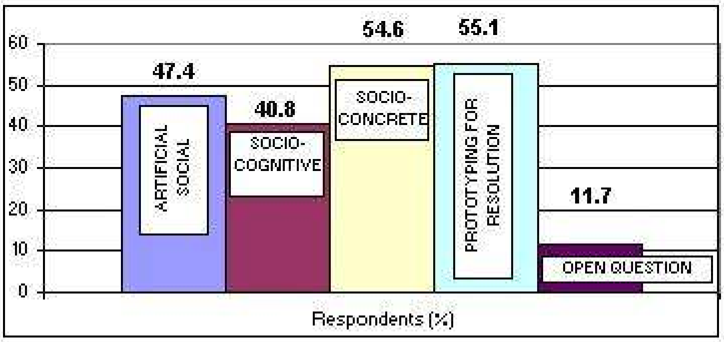


Figure 1: Percentage of positive responses in each category of the variable "type of model", relative to the total number of respondents

4.3

These results enable us to make the following observations: (i) most researchers work with more than a single type of model; (ii) social-scientific models, including both socio-cognitive and socio-concrete approaches, seem to be more common than prototyping for resolution and artificial social models; (iii) the use of artificial social models seems to be no more than a source of inspiration for the other types of models. These observations are useful for hypothesising a classification of respondents according to specific sets of models, instead of just one model.

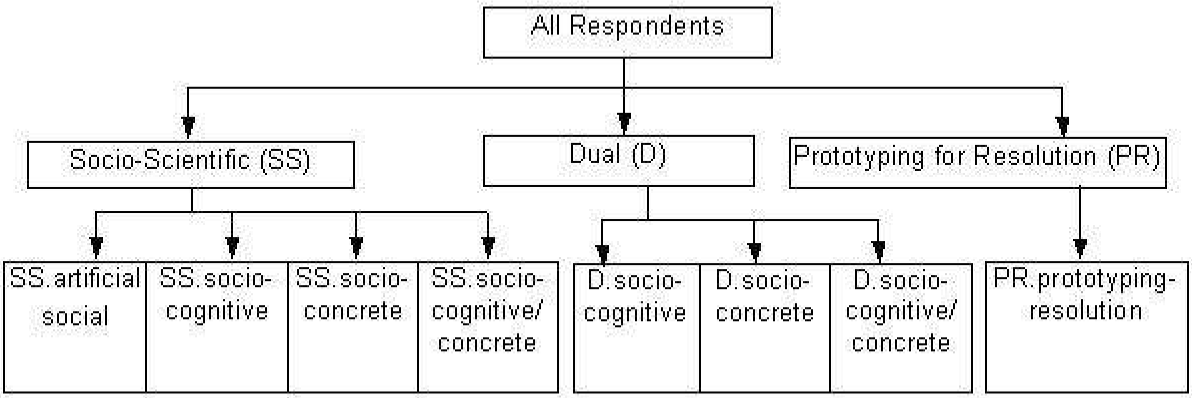
4.4

Figure 2 gives the pattern of responses organised around a tree-based classification of choices, and the corresponding number of respondents for each branch and leaf. The resulting organisation was structured according to three branches, namely:

- social-scientific (SS): comprises respondents who chose social-scientific models (i.e., socio-cognitive or socio-concrete), with or without the artificial social model, and did not choose prototyping for resolution;
- prototyping for resolution (PR): respondents who chose prototyping for resolution, with or without the artificial social model, and did not choose social-scientific models;
- dual (D): respondents who chose both social-scientific and prototyping for resolution models, with or without the artificial social model.

4.5

All leaves are a specialisation of branches SS, D or PR. For instance, the leaf D.socio-cognitive/concrete aggregates respondents whose options were socio-cognitive and socio-concrete and prototyping for resolution models, including or not the artificial social model. Statistical results indicate that there is a significant difference between the frequencies observed in the leaves (Chi Square Goodness of Fit=58.73, DF=7, $p<0.05$). Figure 3 shows the distribution of respondents according to all branches and leaves.



branch SS (85) – Researchers with a social-scientific approach
SS.artificial social (3): artificial social
SS.socio-cognitive (22): socio-cognitive, with or without artificial social
SS.socio-concrete (35): socio-concrete, with or without artificial social
SS.socio-cognitive/concrete (25): (socio-concrete *and* socio-cognitive), with or without artificial social
branch PR (50) – Researchers with a prototyping for resolution approach
PR.prototyping-resolution (50): with or without artificial social
branch D (58) – Researchers with a dual approach
D.socio-cognitive (11): socio-cognitive *and* prototyping-resolution, with or without artificial social
D.socio-concrete (25): socio-concrete *and* prototyping-resolution, with or without artificial social
D.socio-cognitive/concrete (22): (socio-concrete *and* socio-cognitive *and* prototyping-resolution), with or without artificial social

Figure 2: Hierarchical organisation of respondents according to the categories of the variable "type of model". Only 193 respondents were considered because three respondents did not choose any available option

4.6

We will close this section by making the following comments:

- Pure social-scientific models (branch SS, 44.0%) seem to be more common than pure prototyping for resolution models (branch PR, 25,9%), but there is a significant number of researchers using both in branch D (30.1%). Branch D is probably where the interdisciplinary effort between the computational sciences and the social sciences is more intense, and where agent-based theories are more often transferred between different domains. We will give evidence for this in section 5;
- Socio-concrete models seem to be more common than socio-cognitive models, in both social-scientific (SS) and dual (D) branches.

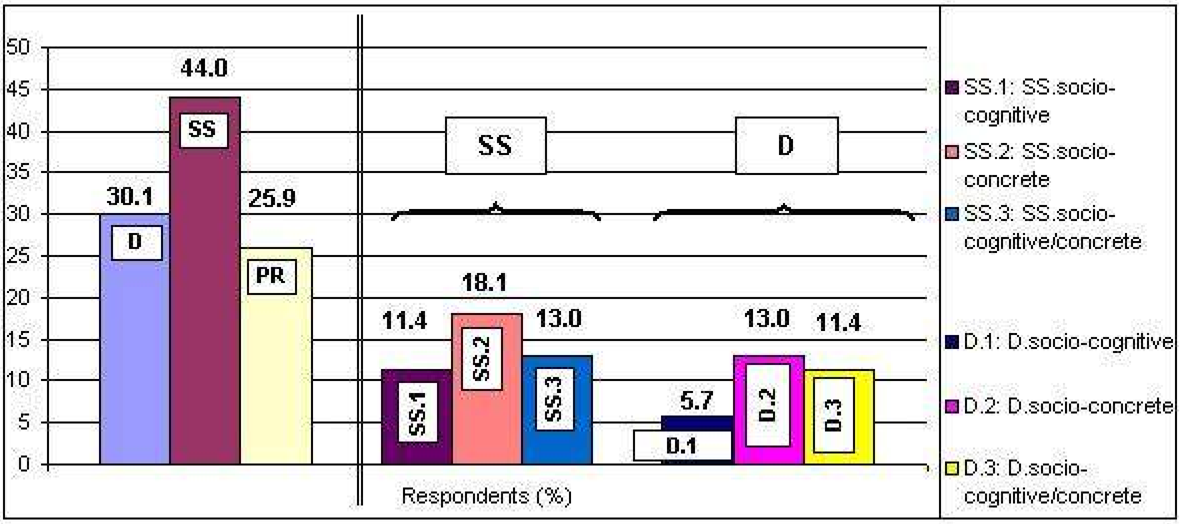


Figure 3: Distribution of respondents according to all branches and leaves of Figure 2

Variable Domain of Interest

4.7

Figure 4 illustrates the percentages of positive responses in each category of the variable "domain of interest". The graphic shows that the vast majority of responses included research as one of their interests (96.4%). A significant percentage of researchers revealed interest in education (33.2%), while each of the application-centred domains (engineering, policy, industrial and business) merited less interest.

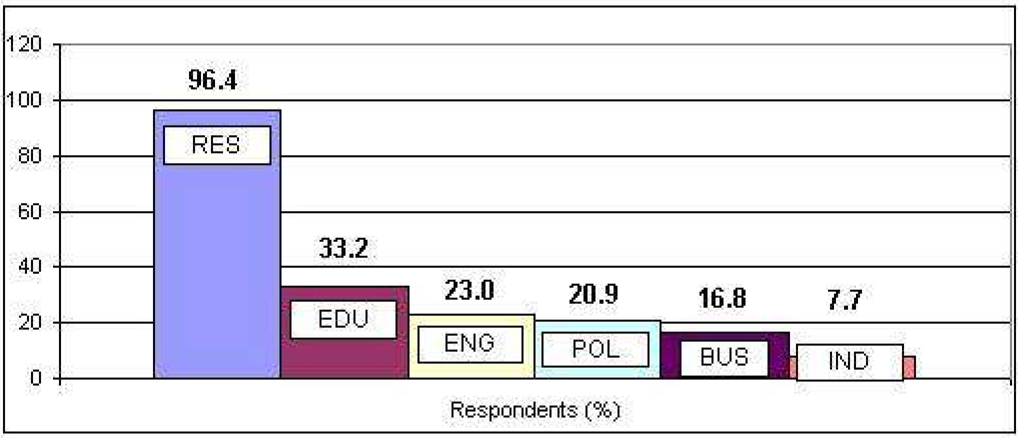


Figure 4: Percentage of positive responses in each category of the variable "domain of interest"

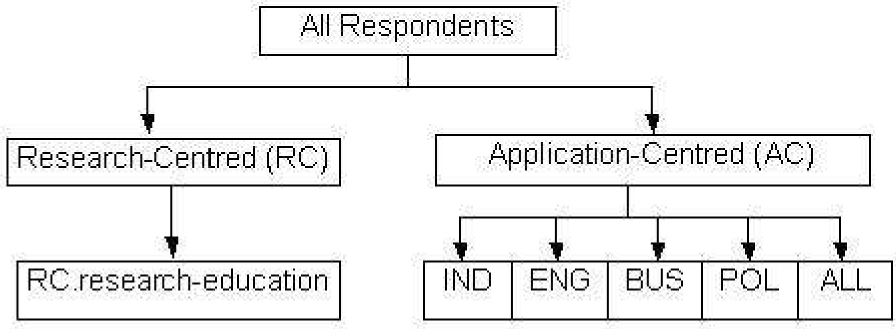
4.8

In Figure 5 we give the pattern of responses organised around a tree-based classification of domains. The classification was based on the following observations: (i) the vast majority of respondents selected research as one of their options; (ii) most respondents who selected education also selected other options. The classification is organised according to the following branches:

- Research-centred branch: all respondents who selected research or education but did not select any other domain;
- Application-centred branch: all respondents who selected at least one of the following domains: engineering, policy, business or industrial.

4.9

The application-centred branch was further subdivided in five leaves, including industry, engineering, business, and policy. The leaf ALL comprises respondents who selected more than one application-centred domain. Statistical results indicate that there is a significant difference between the frequencies observed in these leaves (Chi Square Goodness of Fit=185.735, DF=5, p=0.00).



branch RC (101) Research-Centred
RC.research-education (101) : research *or* education *or* (research *and* education)
branch AC (95) Application-Centred
IND(4): industrial *or* (industrial *and* research) *or* (industrial *and* research *and* education)
ENG (28): engineering *or* (engineering *and* research) *or* (engineering *and* research *and* education)
BUS (12): business *or* (business *and* research) *or* (business *and* research *and* education)
POL (22): policy *or* (policy *and* research) *or* (policy *and* education *and* research)
ALL (29): all others

Figure 5: Hierarchical structure and number of respondents according to the categories of the variable "domain of interest"

4.10

It is now obvious that approximately half of all respondents are application-centred, reinforcing the hypothesis that ABSS has acquired a dynamic of research that involves not only an interest for pure theoretical research but also applied research. In Figure 6, the engineering and policy domains seem to be the most preferred, and it seems that industry does not currently attract a significant number of researchers. The percentage of respondents of leaf ALL tells us that there is a considerable number of eclectic-type of respondents.

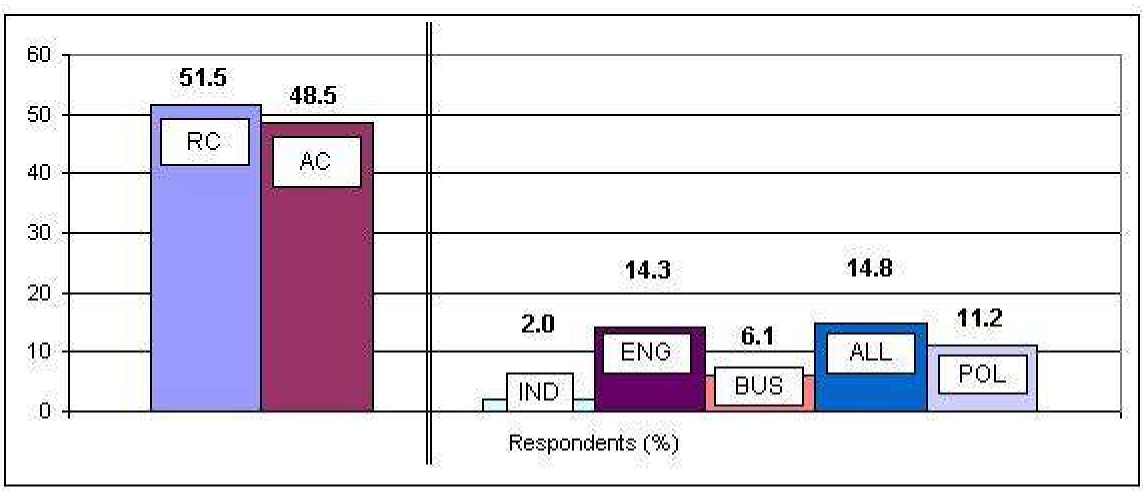


Figure 6: Distribution of respondents according to all branches and leaves of Figure 5

4.11

Finally, it must be said that there may be other domains of interest that were not available in the questionnaire, and we deliberately did not provide a specific open question for this variable. Even so, some respondents proposed the following domains in various contexts of the two open questions: complex systems (4), natural sciences (2), philosophy (1), road traffic (1), computer science and engineering (1), negotiation (1), anthropology (1), demography (1), training (1) and economics (1). It is clear, however, that most of these domains may be considered as sub-classes of those available in the questionnaire.

Software Requirements

4.12

Considering both the "Imperative" and "Important" options as indicators for identifying requirements that deserve special attention, Table 3 illustrates the set of sixteen requirements that were selected as such by more than fifty percent of all respondents (this table is a subset of Table A.4 in Appendix A) Note that the group cannot be interpreted as indicating a common core of desirable requirements for any ABSS computational platform, since some requirements may be important only for a particular set of models.

Table 3: The group of sixteen requirements that were selected as "Imperative" or "Important" by more than fifty percent of all respondents. Acronyms A, T, DO and DE stand respectively for membership of Analysis, Technological, Domain and Development facilities

Requirement	Facility	%
Observe Behavioural Events	A	83.2
Manage Communication	T	81.1
Control Tracking	A	75.5
Define Scenarios	A	72.4
Manage Agents Life Cycle	T	71.4
Manage Scheduling Techniques	T	70.4
Provide Graphical Interface	A	69.9
Model Scalability	T	65.8
Observe Cognitive Events	A	64.8
Provide Graphical Representation of Domain(s)	DO	61.2
Provide Sensitivity Analysis	A	59.7
Develop Agent Architectures	DE	57.7
Use Groups	DE	56.6
Use Roles	DE	53.6
Launch Agents	DO	51.0
Provide Data Analysis	A	50.5

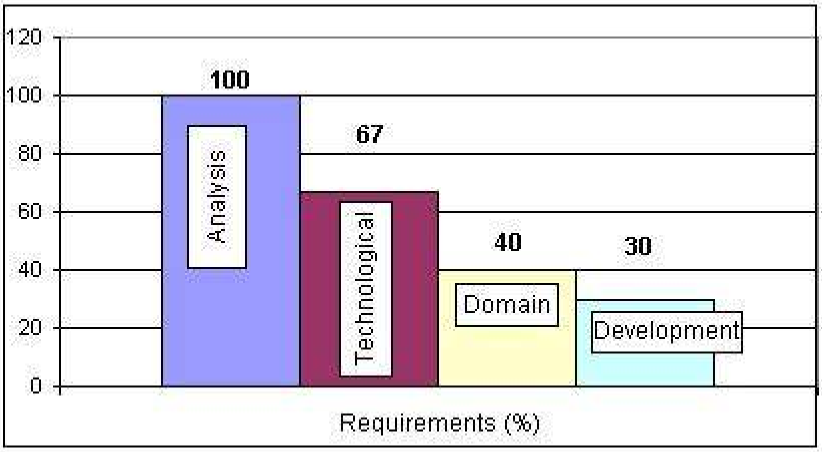


Figure 7: The number of facilities in Table 3 relative to the total number of requirements available in each set of facilities

4.13

It is appropriate, however, to assert some observations with respect to this group. It comprises analysis, technological, domain and development facilities, leaving out exploration facilities. Figure 7 indicates the percentages of facilities in Table 3 relative to the total number of requirements in each set of facilities. All requirements related to analysis are members of the group. This is an expected result, reflecting the importance of providing services to help model the dynamic behaviour of simulations, namely, services to observe and model simulation outcomes – such as "Control Tracking", "Observe Behavioural Events", "Observe Cognitive Events", "Provide Data Analysis", "Provide Sensitivity Analysis", "Define Scenarios" – and services to aid the interpretative knowledge of stakeholders, such as, "Provide Graphical Interface" and "Provide Graphical Representation of Domains.

4.14

Another group of requirements is related to the option "Desirable", which identifies requirements that are useful, though not critical for simulation. On a second level they may give us indications about new trends for ABSS computational platforms. The group is presented in Table 4 (a subset of Table A.5 in Appendix A).

Table 4: The sixteen requirements selected as "Desirable" by more than thirty percent of all respondents. Acronyms A, T, DO, DE and E stand respectively for membership of Analysis, Technological, Domain, Development and Exploration facilities

Requirement	Facility	%
Intervene in Behavioural Events	E	43.4
Intervene in Cognitive Events	E	40.8
Model the Platform Execution Model	DO	39.8
Provide Models of Cognitive Reflectivity	E	39.3
Manage Social Opacity	E	38.8
Manage Intentional Failures	DO	37.8
Use Ontologies	DE	36.7
Provide Translation Mechanisms	DE	35.7
Provide Data Analysis	A	33.2
Develop Agent Architectures	DE	32.7
Use Multiple Societies	DE	32.7

Integrate Controlled and Non-Controlled Environments	DO	31.6
Use Organisational Abstractions	DE	31.6
Adopt Ontological Commitment	DE	31.6
Manage Security	T	31.1
Launch Agents	DO	30.6

4.15

While exploration facilities were not considered critical they are certainly welcome. They account for four entries among the first five in the table. Additionally, the requirement "Model the Platform Execution Mode" merits a considerable interest, suggesting that distributed and parallel execution technologies are welcome to improve the execution of large-scale simulations. In sum, the appeal of services for exploring the behaviour of simulations is highlighted, but the set of development and domain facilities now dominates analysis facilities.

4.16

Overall (i) imperative/important requests stress the need to model observed behaviour of simulations, giving less emphasis to the *a priori* specification and development of intended behaviours; (ii) the challenge to implement services to improve the capacity of exploring unexpected outcomes that would help validate the behaviour of simulations with specifications is highlighted. The results of the survey notwithstanding, the authors believe that both dispositions should be taken as crucial, in order to improve the recognition of the field as a fruitful scientific activity.

4.17

Turning to the option "Domain dependent", only two requirements reached percentages over 25%, namely, "Manage Mobility" and "Manage Security" (see Table A.6 in Appendix A). As for the "Not necessary" and "Undesirable" options, no requirement reached percentages greater than 16% and 5%, respectively (see Tables A.7 and A.8, in Appendix A). These indicators provide evidence for considering the set of requirements in the questionnaire as present and future trends for ABSS computational systems.

Bivariate Analysis

Second Hypothesis: Type of Models *vs.* Domain of Interest

5.1

In this section, we analyse how respondents may be more or less likely to choose a specific type of model depending on the domain of interest. Figure 8 illustrates the distribution of social-scientific (SS), dual (D) and prototyping for resolution (PR) branches relative to each domain[3]. The corresponding cross tabulation indicates that this hypothesis has statistical support (Pearson Chi Square test, PCS=32.058 and p=0.000; see Table A.9 in Appendix A).

5.2

By analysing the set of application-centred domains it becomes clear that there are essentially two extreme patterns. As might perhaps be expected, social-scientific models are more common in policy than engineering, and prototyping for resolution models are more common in engineering than policy. For 68.2% of respondents who chose policy, social-scientific modelling seems to be the exclusive goal, suggesting that the normative character of verifying the behaviour of simulations against the specifications is taken only as an instrumental aid. Conversely, for 48.1% of respondents in engineering, prototyping for resolution models seems to be the only aim, suggesting that social-scientific theories may not be considered useful, or even suggestive, in terms of inspiring their models. In business these two extremes are more evenly distributed.

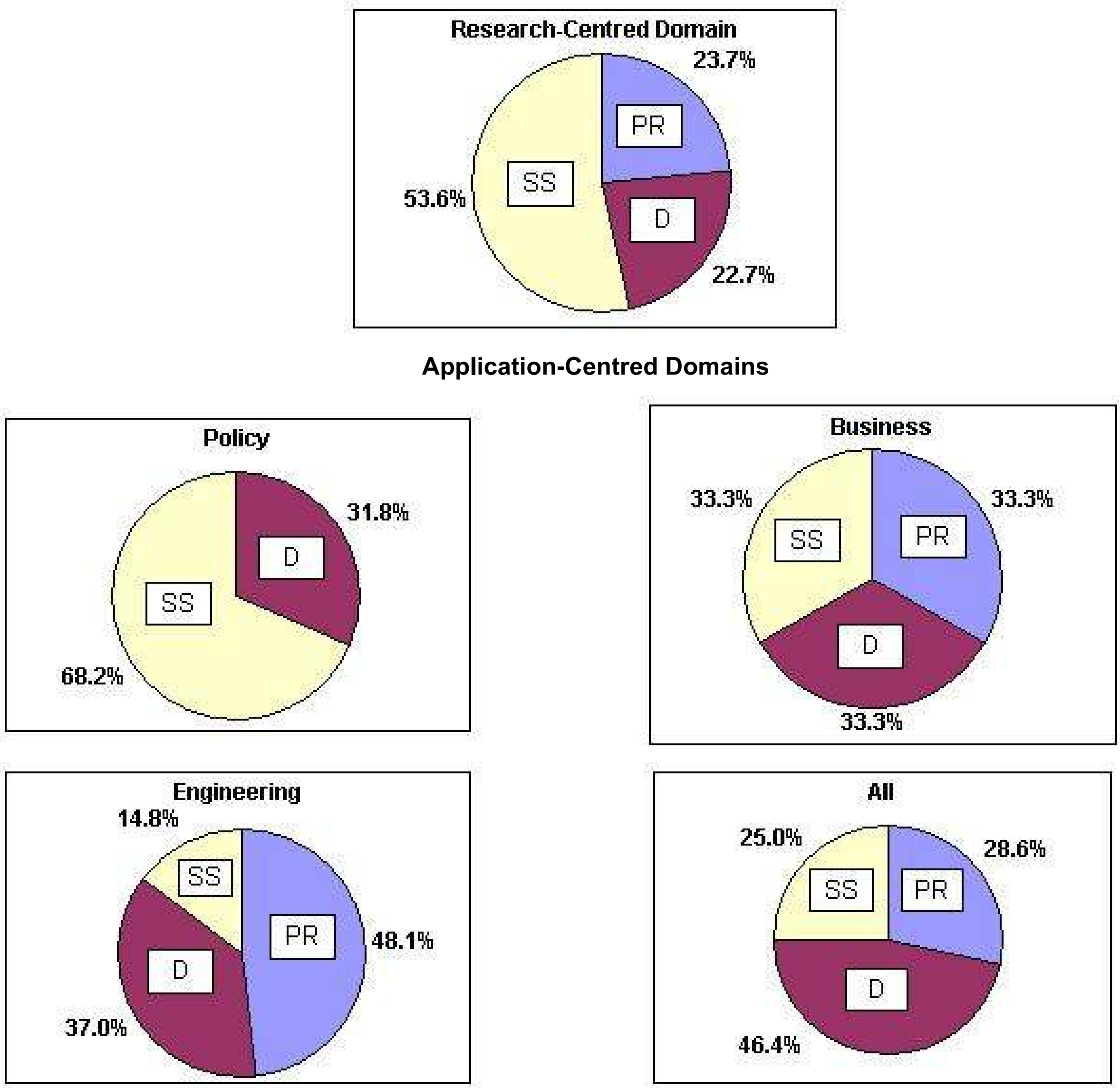


Figure 8: Distribution of branches SS, D and PR relative to each domain

5.3

Nevertheless, it is obvious that the dual approach is significantly desired in policy, engineering and business, achieving respectively 31.8%, 37.0% and 33.3% of respondents. These groups represent a potential interface for the exchange of social-scientific and prototyping for resolution models across the three domains. Moreover, the most representative approach among the eclectic type of respondents of leaf ALL is, precisely, dual modelling, with a response rate of 46.4%. Perhaps surprisingly, the fact that all these domains are application-centred indicates that the exchange of theories between different domains is likely to occur through practical problems and real applications, and less through theoretic levels of research.

5.4

Table 5 compares the percentages of research-centred domains with application-centred domains relative to each branch. The corresponding cross-tabulation has statistical support (Pearson Chi Square test, PCS=9.522 and p=0.009; see Table A.10 in Appendix A). The table suggests that research-centred domains are more common within social-scientific and prototyping for resolution branches, with respectively 63.4% and 46.0% of respondents. Conversely, application-centred domains are more common within the dual branch, with 62.1% of respondents. In any case, a concrete interface of interdisciplinary research is confirmed, within both research-centred and application-centred domains. Yet, this tendency seems to be more prominent within application-centred domains.

5.5

The desire to apply social simulations to practical problems is an encouraging consolidation of the field. The prospects for using computer simulations in application-centred domains should nevertheless be regarded with care. The extent to which a model may be implemented in computers in order to test tentative computer applications is easy to acknowledge, since the interpretative references for verifying and validating simulations overlap almost exactly: the program executions behaviours themselves. Basically, the computer simulation serves as a prototype for a future computer application.

5.6

Conversely, the extent to which a model may be implemented in computers in order to assess policies and try to apply the results to socio-economic or political arenas is more difficult to acknowledge. The interpretative references for verifying and validating simulations do not overlap. But this should not be a problem at theoretic and interpretative levels of research.

Table 5: Percentages of research-centred and application-centred domains relative to social-scientific, dual and prototyping for resolution branches

	Research-centred	Application-centred
Branch SS (%)	63.4	36.6
Branch D (%)	37.9	62.1
Branch PR (%)	46.0	54.0

5.7

It may be informative to analyse the relative use of socio-cognitive and socio-concrete models within different domains. We will restrict our report to the case of dual modelling, with respect to policy, engineering and research-centred domains. As we mentioned before, the use of socio-cognitive metaphors to inspire the design of computer applications based on multiagent systems is common in Artificial Intelligence. On the other hand, both socio-cognitive and socio-concrete models have been widely used in social simulation. Nonetheless, socio-concrete approaches tend to use very simple agents, mostly due to limitations on scalability and the desire to base the agents' behaviours on empirical evidence.

5.8

Table 6 illustrates the use of socio-concrete and socio-concrete models within the dual branch, relative to the total number of respondents in the policy, engineering and research-centred domains (the table is a subset of Table A.11 in Appendix A). The use of socio-cognitive and socio-concrete models in research-centred domains seems to be quite balanced. Moreover, it is not a surprise that in policy the use of socio-concrete models is more common than socio-cognitive models. In fact, socio-cognitive models are only used in conjunction with socio-concrete models. What we did not anticipate is the good standing of socio-concrete models in engineering, with D.socio-concrete modelling reaching 14.8% whereas D.cognitive/concrete reaches 11.1%. This seems to express the potential contribution of socio-concrete models to the design of computer applications based on multiagent systems. To the best of our knowledge, however, socio-concrete models have not had a visible influence on computer engineering. The question remains if this reflects more of a tendency or more of a desire to design multiagent-based computer applications inspired by direct representational approaches.

Table 6: The use of socio-cognitive and socio-concrete models within the dual branch, relative to the total number of respondents in domains policy, engineering and research-centred

	D.socio-cognitive	D.socio-concrete	D.cognitive/concrete
Research-centred (%)	7.2	6.2	9.3
Policy (%)	0.0	22.7	9.1
Engineering (%)	11.1	14.8	11.1

Third Hypothesis: Type of Model *vs.* Software Requirements

5.9

In this section we wish to assess the hypothesis that respondents are more or less likely to prefer different software requirements depending on the type of model. In doing so we pursue its non-confirmation to some extent, seeking for a common core of requirements that may be independent of the use of different models.

5.10

In Table 7 we indicate the percentage of respondents who selected each requirement in social-scientific (SS), dual (D) and prototyping for resolution (PR) branches with the option of "Imperative" or "Important". A detached line separates the group of sixteen requirements that reached percentages greater than fourty eight (see Tables A.14 to A.45 in Appendix A). At this point, it is possible to outline a common set of requirements for ABSS platforms. By comparing Table 3 with the first sixteen requirements of each column in Table 7, we identify the requirements in each column of Table 7 that also pertain to Table 3. The resulting twelve requirements are written in bold and with grey shadowing in Table 7, and can be interpreted as a core of common requirements for any platform, regardless of the intended type of modelling. For instance, the requirement "Provide Sensitivity Analysis" does not pertain to this group. Even though it is a top requirement for researchers in the SS branch, it is not for researchers in the PR branch.

Table 7: Requirements selected as Imperative or Important in branches social-scientific, dual and prototyping for resolution

branch SS	%	branch D	%	branch PR	%
Manage Communication	81.7	**Manage Communication**	81.0	**Observe Behavioral Events**	86.0
Manage Scheduling Techniques	81.7	**Observe Behavioral Events**	81.0	**Manage Communication**	82.0
Observe Behavioral Events	81.7	**Manage Agents Life Cycle**	74.1	**Control Tracking**	78.0
Control Tracking	80.5	**Define Scenarios**	74.1	**Manage Agents Life Cycle**	68.0
Provide Graphical Interface	78.0	**Manage Scheduling Techniques**	72.4	**Define Scenarios**	66.0
Manage Agents Life Cycle	73.2	Use Groups	67.2	Guarantee Independency from the Simulator	64.0
Define Scenarios	73.2	**Control Tracking**	63.8	**Observe Cognitive Events**	64.0
Model Scalability	72.0	**Provide Graphical Interface**	63.8	**Model Scalability**	62.0
Provide Graphical Representation of Domain(s)	68.3	**Model Scalability**	60.3	Launch Agents	62.0
Observe Cognitive Events	68.3	Provide Sensitivity Analysis	60.3	**Provide Graphical Interface**	62.0
Provide Sensitivity Analysis	68.3	**Provide Graphical Representation of Domain(s)**	58.6	**Use Roles**	54.0
Develop Agent Architecture	61.0	**Develop Agent Architecture**	58.6	**Manage Scheduling Techniques**	52.0
Provide Data Analysis	58.5	**Use Roles**	58.6	Model the Platform Execution Model	52.0
Use Groups	53.7	**Observe Cognitive Events**	56.9	**Develop Agent Architecture**	52.0
Use Organisational Abstractions	50.0	Launch Agents	53.4	**Provide Graphical Representation of Domain(s)**	50.0
Use Roles	50.0	Intervene in Behavioural Events	48.3	Integrate Controlled and Non-Controlled Environments	48.0

Use Organisational Rules	50.0	Use Organisational Abstractions	46.6	Use Groups	48.0
Launch Agents	41.5	Use Organisational Rules	46.6	Use Ontologies	48.0
Intervene in Behavioural Events	41.5	Provide Data Analysis	46.6	Provide Sensitivity Analysis	46.0
Intervene in Cognitive Events	41.5	Intervene in Cognitive Events	44.8	Adopt Ontological Commitment	44.0
Integrate Controlled and Non-Controlled Environments	39.0	Guarantee Independence from the Simulator	43.1	Use Organisational Abstractions	42.0
Manage Intentional Failures	35.4	Integrate Controlled and Non-Controlled Environments	41.4	Provide Data Analysis	42.0

5.11

Of course, since each type of model is associated with a descending order of preference of requirements, there may be other arrangements. For example, by using the column of the SS branch in Table 7 and the columns of the SS.socio-cognitive, SS.socio-concrete and SS.socio-cognitive/concrete leaves in Table A.13 of Appendix A, we could identify a set of imperative/important requirements to simulate social-scientific models. For the time being, we will describe the set of requirements that are more or less imperative/important depending on the intended type of model.

5.12

Table 8 indicates the requirements that reveal differences of approximately fifteen percent between any two of the branches SS, D or PR. Only ten requirements out of thirty-two seem to reveal significant differences, and only seven revealed statistical significance to support this hypothesis.

5.13

The fact is that the sample does not show that the intended type of model crucially influences the respondents' opinions, at least when considering the scope of requirements that we analysed. Differences seem to hold an emphatic rather than a substantive character. For instance, while the requirement "Manage Scheduling Techniques" seems to be more imperative/important to social-scientific models than prototyping-resolution models, it still remains relevant to the latter, with more than fifty percent of respondents.

5.14

In short, the third hypothesis put forward in section 3 is confirmed, but to a limited extent. Despite the intense interdisciplinary character of simulation there is a considerable agreement over a large set of basic software requirements, even if, as we observed in the previous section, different research goals are sometimes at stake.

Table 8: Requirements that reveal differences of approximately fifteen percent between any two branches

	branch SS (%)	branch D (%)	branch PR (%)	P-value
SS Inclined				
Manage Scheduling Techniques	81.7	72.4	52.0	P=0.001
Provide Graphical Representation of Domains	65.9	58.6	50.0	-
Provide Sensitivity Analysis	68.3	60.3	46.0	P=0.040
Control Tracking	46.5	26.1	27.5	-
PR Inclined				
Guarantee the Independency from the Simulator	32.9	43.1	64.0	P=0.002
Launch Agents	40.0	53.4	62.0	-
Model the Platform Execution Mode	26.8	29.3	52.0	P=0.008
Use Ontologies	26.8	34.5	48.0	P=0.046
Adopt Ontological Commitment	23.2	27.6	44.0	P=0.036
Manage Security	12.2	25.9	32.0	P=0.017

Classification of Agent-Based Social Simulations

6.1

The above results offer evidence for an overview of paradigmatic agent-based models in agent-based social simulation. The analysis of paradigmatic models offers two related advantages. On the one hand, gives the possibility of classifying models according to standard sets of common and explicit assumptions. This may improve the methodological viability of submitting, explaining and comparing agent-based simulations in articles, which is an important requirement to consolidate the field. On the other hand, it gives the possibility of investigating certain methodological contexts or philosophical foundations associated with different classes of models. It can be useful as well for analysing more practical considerations, such as extending or detailing the previous set of software requirements depending on the intended class of models. We also expect that it will motivate other proposals that could further validate, extend or change ours, in order to refine the classification with more specific types of models.

6.2

The classification in Figure 9 is based on the hierarchical organisation of responses that was illustrated previously in Figure 2. Table 9 associates the response patterns in Figure 2 with the classification in Figure 9. The classification is organised under a multi-level approach. By choosing different abstraction levels we can switch between levels and analyse the appropriateness of the abstraction for a specific situation.

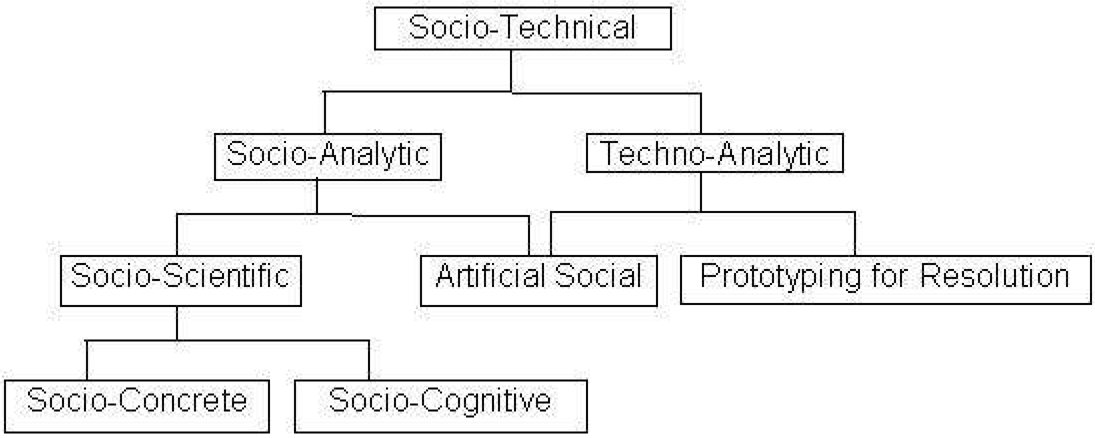


Figure 9: A classification of paradigmatic models in Agent-Based Social Simulation

6.3

The classification converges in the union of two general classes: socio-analytic and techno-analytic. The meeting of social-scientific models with the exploratory character of artificial social models converges in the class of socio-analytic models. The meeting of prototyping for resolution with artificial social models gives rise to techno-analytic models. At the top level, the meeting of socio-analytical with techno-analytic models converges in the class of socio-technical models.

Table 9: Classification of models *versus* the patterns of responses in Figure 3

Classification of models	Pattern of Responses
socio-technical	D branch
socio-analytic	SS branch, including or not artificial social models
techno-analytic	PR branch, including or not artificial social models
prototyping for resolution	PR branch without artificial social models
social-scientific	SS branch without artificial social models
socio-cognitive	SS.socio-cognitive leaf without artificial social models
socio-concrete	SS.socio-concrete, leaf without artificial social models

Characteristic dimensions

6.4

In the rest of this paper, we will give an example of how the classification facilitates the analysis of different methodological contexts. Since each researcher may have different assumptions about the world, different models can be designed for a single target. We will use the term dimension to indicate any perspective that may be adopted in the process of modelling. The simulations will be characterised with three dimensions, as follows.

6.5

The dimension *Abstraction Level to model the Target System* (ALTS) considers that the researcher may assign different levels of hypothetical existence to the target. Three levels will be considered: *low*, *intermediate* and *high*. If the level is high, then the target is a pure "would-be world"[4] where the intention is not to establish an actual relationship between the simulation and a real world target. Conversely, if the level is low, then there is a real intention in representing an actual target.

6.6

Type of Evidence in the Validation Process (TEVP) considers that the validation process tries to ensure that the specification, the program executions and the outcomes represent the target with an acceptable degree of adherence. We will consider two broad kinds of validation. Validation through structural similarity, which seeks for qualitative elements of realism, striving for structural similarity between theories and the target as we know it, making it "plausible" or "credible" (Gross and Strand 2000). In addition, empirical validation considers that the main source of knowledge comes from experimentation, giving importance to perception, trial-and-error and control. The following levels will be used:

- *structural-weak*, when the structural similarity with the target is pictorial and evocative, such as the suggestive effect of colour clusters in a grid interpreted according to the real social world (*e.g.* like the suggestive effect of Shelling's model);
- *structural-strong*, when the structural similarity is suggested through a richer domain of descriptive representations such as mathematical-based expressions of social networks or high-order logics for mental states;
- *empirical-weak*, when the adequacy of the specification and the outcomes are actively negotiated by stakeholders and domain experts such as in participatory-based simulations;
- *empirical-strong*, relying on empirical overt procedures and real world quantitative data.

6.7

The dimension *Application Context* (AC) considers two contexts where the simulations are applied. The *social-scientific context*, which uses computers to simulate social phenomena and theories; and the *technological context*, where simulations are used for prototyping software applications based on multiagent systems.

Investigating the Scope of ABSS

6.8

Each class of models will be characterised according to the three dimensions described above. Furthermore, we will duly characterise the scope of the area by integrating all classes. A subset of these classes will be our assumptions or given axioms. For the purpose of illustration we will depict each class in a Cartesian chart according to the aforesaid dimensions[5].

6.9

Artificial social models. This class involves simulations where its relation to a real world target is deliberately non-existent or very weak, where:

- the application context, given by the dimension AC, can assume a technological or a social-scientific context;
- the abstraction level, given by the dimension ALTS, can assume the high value;
- the validation process, defined in the dimension TEVP, is structural-weak.

6.10

Figure 10 characterises this class. For instance, in the Daisyworld model (Lovelock 1992) we have: (i) the application context is social-scientific, since it simulates the self-regulating behaviour of a population of flowers called 'daisies'; (ii) the abstraction level is high, since the Daisyworld is an imaginary planet; (iii) the validation is structural-weak, since the outcomes of the simulation are confronted with an idealised structure of an imaginary world.

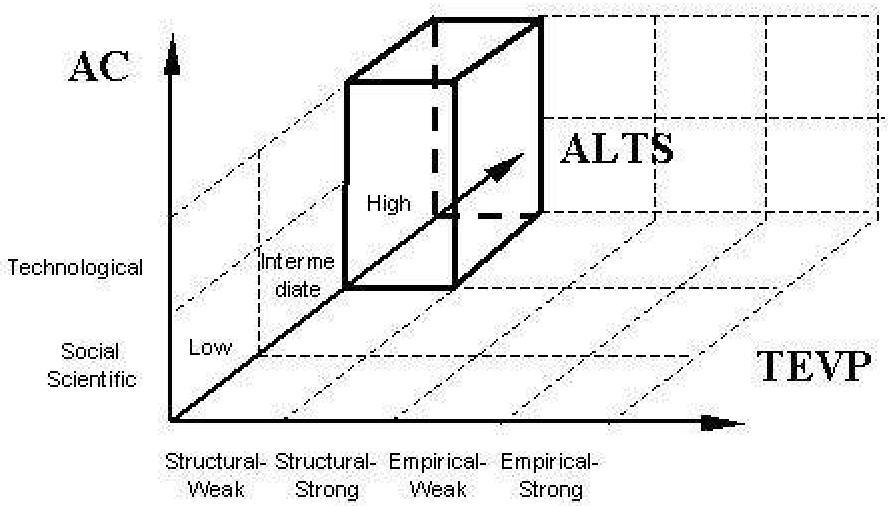


Figure 10: Characterisation of artificial social models

6.11

Socio-cognitive models. Simulations in this class serve the purpose of checking the consistency of or refining socio-cognitive theories. Figure 11 characterises these models. Most of the (hypothetical) objects to which the theories refer are non-directly observable. The validation process is eminently qualitative and does not rely on empirical overt procedures:

- the application context, given by the AC dimension, can assume the social-scientific context;
- the abstraction level, given by the ALTS dimension, can assume the intermediate value;
- the validation process, defined in the TEVP dimension, is structural-weak or structural-strong.

6.12

For instance, in the DEPNET model (Conte and Sichman 1995): (i) the application context is social-scientific, since the purpose of the model is to test and refine the theory of dependence and social power; (ii) the abstraction level is intermediate, since the intention is to model socio-cognitive phenomena with a theory that is largely abstract and metaphorical; (iii) the validation process is structural-strong since the specification and the outcomes of the simulation are based on a well-defined formal-logic framework, but does not rely on strong empirical overt procedures.

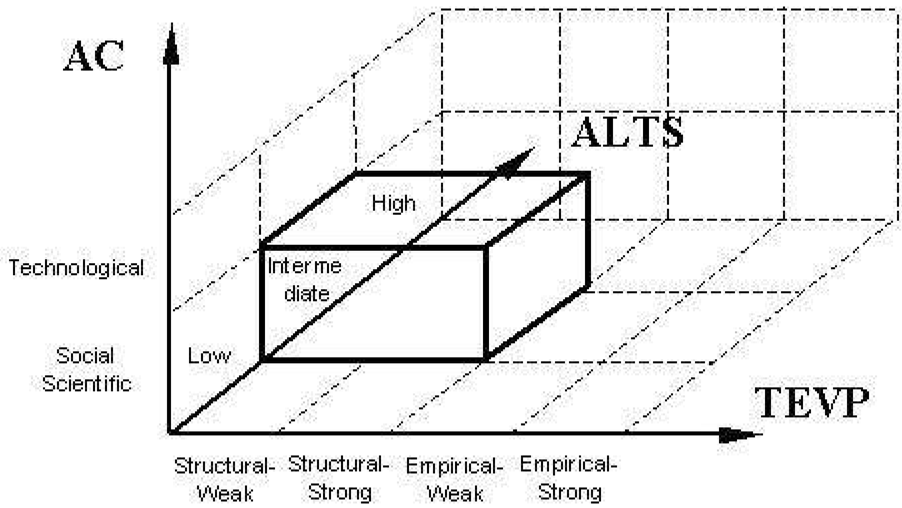


Figure 11: Characterisation of socio-cognitive models

6.13

Socio-concrete models. These models should establish substantial relationships between the simulation and the target, which typically calls for participatory based modelling and data-driven empirical research in the target. The class in Figure 12 involves simulations where:

- the application context can assume the social-scientific context;
- the abstraction level can assume the low value;
- the validation process is structural-strong, empirical-weak or empirical-strong.

6.14

As an example, (i) the application context of the simulation of the Kayenta Anasakii population (Dean et al. 1999) is social-scientific, since the target is a pre-historic civilisation; (ii) the abstraction level is low, since the intention is to confront the simulation outcomes with archaeological aggregated data; (ii) the validation is structural-strong, empirical-weak and empirical-strong. While the simulation outcomes are confronted with empirical data and knowledge of experts, the specification of the model is highly hypothetical. In effect, this means that the simulation could as well be classified as socio-analytical.

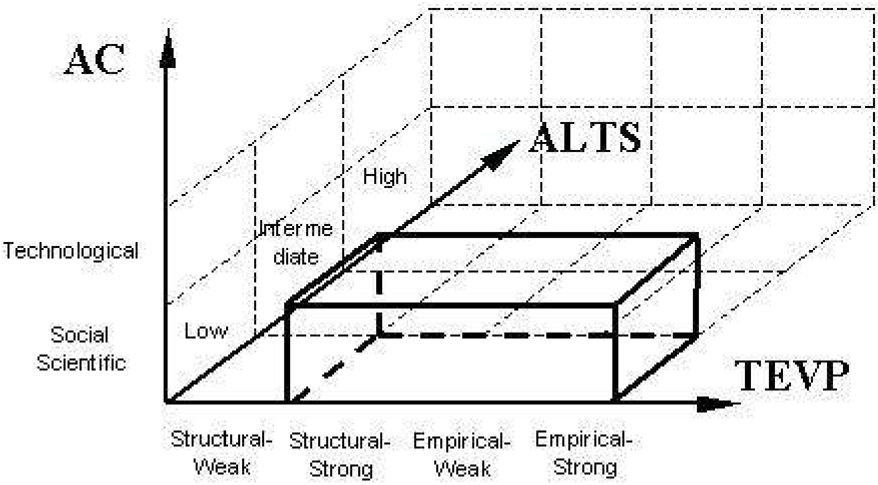


Figure 12: Characterisation of socio-concrete models

6.15

Social-scientific models. Social-scientific models are characterised in Figure 13. It is a linear integration of socio-cognitive and socio-concrete models.

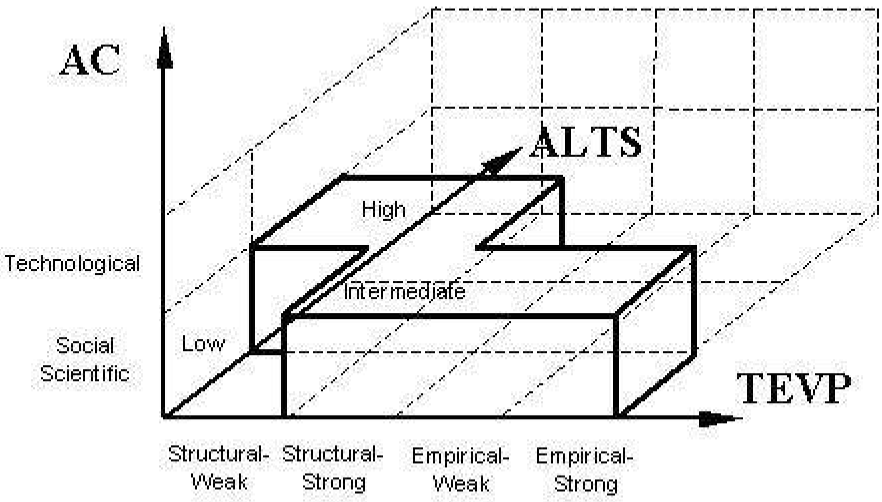


Figure 13: Characterisation of social-scientific models

6.16

Socio-analytic models. This class, characterised in Figure 14, combines social-scientific models with the exploratory character of artificial social models.

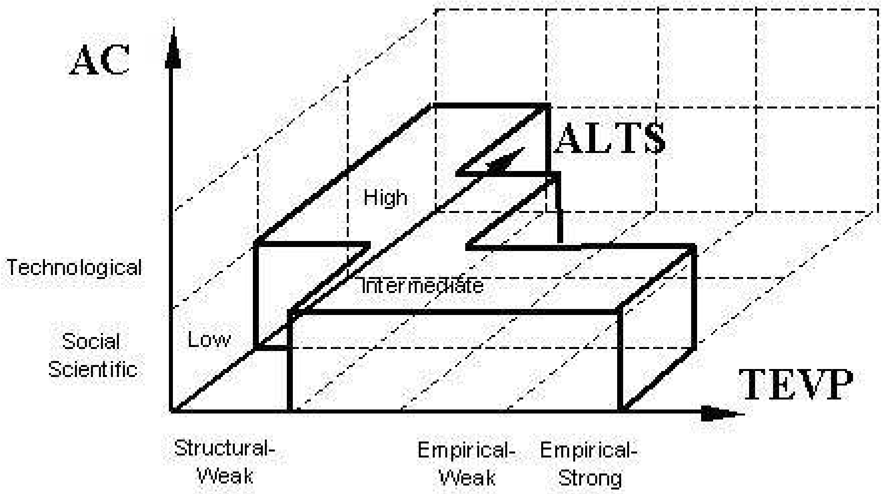


Figure 14: Characterisation of socio-analytic models

6.17

Prototyping for resolution. Typically, the goal is to prototype intended computer applications based on multiagent systems. The goal of the prototype is to test technical figures (*e.g.* efficiency, response delay) and, quite like participatory-based modelling, the end-users' evaluation of the simulation behaviour. In Figure 15 this class involves simulations where:

- the application context can assume a technological context;
- the abstraction level can assume the low value;
- the validation process is structural-strong, empirical-weak and empirical-strong.

6.18

The ARCHISIM project (El Hadouaj, Drogoul and Espié 2000), which models a realistic road traffic evolution, seems to exemplify this class, although it could arguably be considered a socio-technical simulation: (i) the application context is a technical one, since the ultimate goal of the simulation is to make the computer behaviour credible for a human driver; (ii) the abstraction level is low, since there is a commitment to reproducing a realistic traffic system; (iii) the validation is empirical-weak and strong, since the outcomes are validated with both the end-users's opinions and other technical figures.

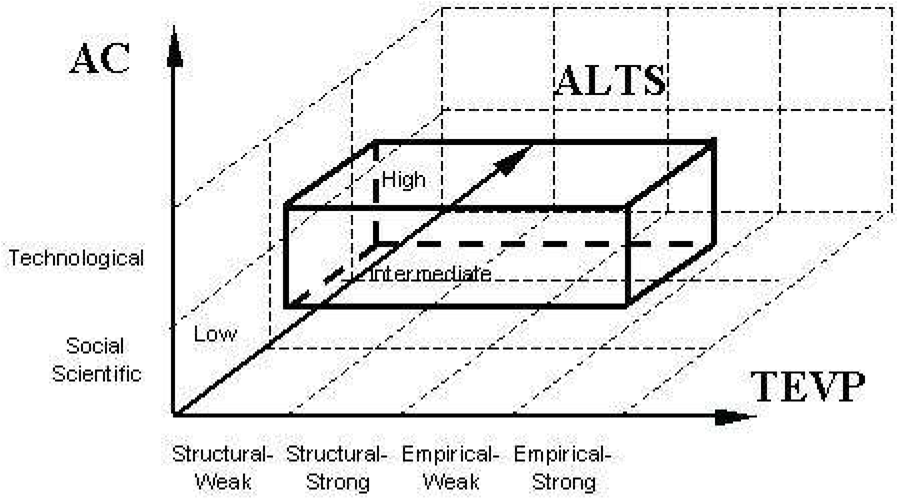


Figure 15: Characterisation of prototyping for resolution models

6.19

Techno-analytic. In Figure 16, this class enlarges the scope of prototyping for resolution with the exploratory influence of artificial social models. The high abstract character and structural-weak validation of artificial societies introduce intermediate levels of abstraction and structural-strong forms of validation into the models.

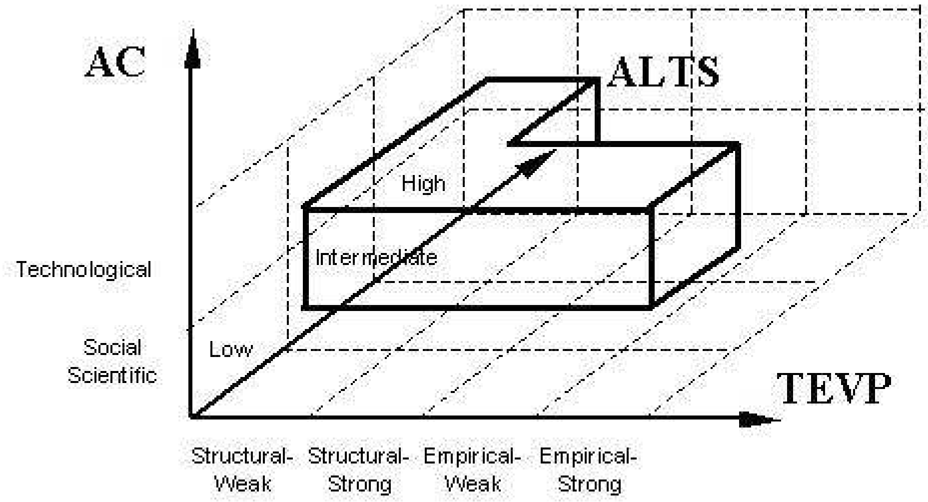


Figure 16: Characterisation of techno-analytic models

6.20

Socio-technical. In Figure 17 we characterise socio-technical simulations. This class should add the exploratory character of techno-analytic simulations with the stronger exploratory and metaphorical character of socio-analytic simulations. An example of ongoing projects that seems to be in this class is the Socionics project (Müller, Malsch and Schulz-Schaeffer 1998).

6.21

Socio-technical models are probably where the interdisciplinary effort between the computational sciences and the social sciences is more intense, and where agent-based theories are more often transferred between different domains. The goal seems to be twofold: (i) to apply theories of complex social systems to computer technologies, which should become more adaptive in response to the intractability of large and decentralised software environments; (ii) to infer and explore the consequences of those theories, and interpret those consequences back in the social-scientific domain.

6.22

The class seems to be the one with the largest scope, giving us the conditions to characterise the scope of ABSS according to the three dimensions. Apparently, the area does not involve the co-ordinates:

- (structural-weak, abstraction low, {social-scientific and technological contexts})
- (structural-strong, abstraction high, {social-scientific and technological contexts})
- ({empirical-weak,empirical-strong}, {abstraction intermediate and high}, {social-scientific and technological contexts})

6.23

Unsurprisingly, there is an incompatibility between high levels of model abstraction and strong levels of model validation. Of course, depending on the set of axioms considered one can draw different characterisations of models, maybe by using other dimensions. But although there are certainly different kinds of epistemic conceptions to validate models, all seem to be useful in their own right, provided their assumptions and goals are clearly stated.

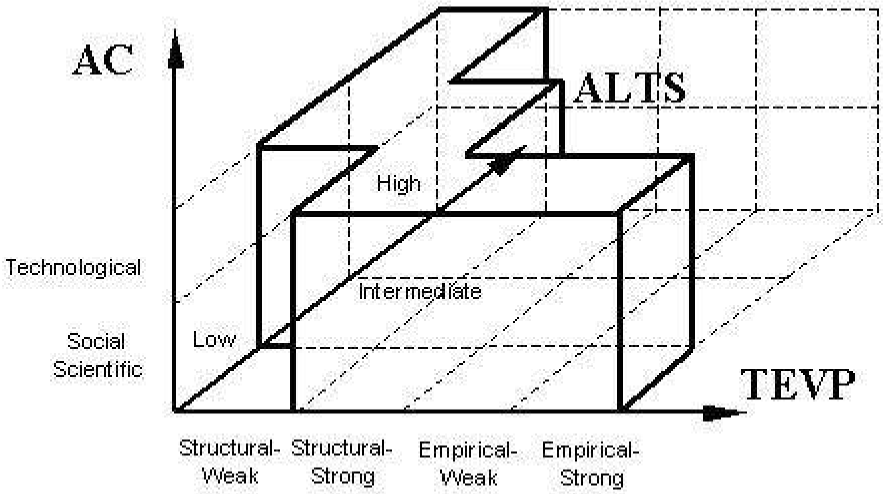


Figure 17: Characterisation of socio-technical models

6.24

In principle, two different simulations should only be compared if their underlying paradigmatic models have been stated explicitly. It is normal practice in many well-established scientific areas to have a specific section at the beginning of the articles describing the methodological assumptions and tools. Given the strong interdisciplinary character of agent-based social simulation, there is an increasing need to make the modelling paradigm that underlies each article or project more explicit. The present proposal is interesting, since the taxonomy was well validated by researchers in the field.

Conclusions

7.1

Our objective in this article has been to clarify the interdisciplinary structure of agent-based social simulation, and its relationships to its foundations and technical frontiers. There have been some few attempts to analyse the research process of simulation (*e.g.* Troitzsch 1997; Edmonds 2000; Marietto et al. 2003). However, our proposal identifies a broader set of models, is more detailed, and identifies the interdisciplinary context of each model. Moreover, it is based on the opinions of a significant portion of the research community.

7.2

Some interesting questions arise from the results. Among them, we would single out the question related to the motivation and direction of the current platforms. It is noticeable that most of them have a domain-independent approach, with a technical-operational infrastructure to assist different types of simulation models (artificial social, socio-cognitive, socio-concrete and prototyping for resolution). This general approach seems to be due to an engineering vision, which considers that, if it is possible to implement a specific functionality, then that functionality deserves to be implemented.

7.3

At the same time, there seems to be an increasing debate about whether the simulations should or should not be seen as something more than a tool in the social sciences. But in fact, the understanding of a particular simulation depends on various factors, such as (i) the intention in building a particular implementation (i.e. the intention in building a particular technology); (ii) the experimentation processes (e.g. how to test the correctness of that particular implementation); (iii) and the analysis of its results (e.g. of the program executions, the simulation outcomes). It then becomes apparent that a simulation requires a dialectical approach between the technology (the simulation platform, the implementation) and the particular theoretical-methodological context of the social scientist. It could be asserted, however, that the role of the technology is just to help to ascertain if any model as implemented is, or represents, the intended theory (verification); and that the only role of the social sciences would be to use the implementation as a tool of theory building (discovery and validation). It seems difficult, however, if not inadvisable, to make a sharp division between these two dispositions. Nonetheless, if it is clear that the debate on simulation arises from the encountering of these two tendencies, it seems inevitable that methodological solutions are found precisely in that encounter. And as it is all too well known, the theoretical-methodological context of the social sciences is very diverse.

7.4

We therefore consider that the development of domain-dependent platforms, working with specific simulation models, is important at the current stage of the area. In the context of the SimCog project, such a bottom-up approach has now been adopted. Initially, this project proposed the description of an ideal reference model for a general agent-based simulation platform. Nowadays, the project is focused on socio-cognitive models.

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Notes

[1] Further reasons for using this kind of sample can be found in Appendix A.

[2] simsoc(simsoc@jiscmail.ac.uk), cormas(cormas@cines.fr), swarm-modelling(swarm-modelling@santafe.edu), distributed-AI (distributed-ai@jiscmail.ac.uk) and agents (agents@cs.umbc.edu).

[3] The domain "Industry" is omitted since its number of respondents is negligible.

[4] The term would-be world is borrowed from Casti 2001, but the meaning that he ascribes to the term is slightly different form ours.

[5] This does not mean that the dimensions are (orthogonally) independent of each other, as we will demonstrate later.

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