



HAL
open science

An Agent Architecture Embedding Spatial Reasoning for Actors Design in Land Use Modelling

Severin Vianey Kakeu Tuekam, Eric Fotsing, Marcellin Julius Nkenlifack

► **To cite this version:**

Severin Vianey Kakeu Tuekam, Eric Fotsing, Marcellin Julius Nkenlifack. An Agent Architecture Embedding Spatial Reasoning for Actors Design in Land Use Modelling. 2022. <hal-03706614v1>

HAL Id: hal-03706614

<https://inria.hal.science/hal-03706614v1>

Preprint submitted on 27 Jun 2022 (v1), last revised 4 Jul 2022 (v2)

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.



HAL Authorization

An Agent Architecture Embedding Spatial Reasoning for Actors Design in Land Use Modelling

Severin Vianey KAKEU TUEKAM^{*1}, Eric FOSTING², Marcellin Julius NKENLIFACK^{*1,2}

¹Department of Mathematics and Computer Science, University of Dschang

²Department of Computer Engineering, Fotso Victor University Institute of Technology of Bandjoun

*E-mail : {severinkakeu, efotsing}@gmail.com

Abstract

Cognitive abilities are studied in AI by observing real systems and developing entities called Agents that should interact with their virtual environments in an intelligent way to produce a multi-agent system. To model agents in land use simulations, modellers generally use BDI Architecture to endow easily agent with a behaviour corresponding to their observation. However, the spatial dimension led by cognitive representation and reasoning on the environment of agent are not explicitly captured in this architecture. In an attempt to mimic spatial attributes, several agent-based simulation platforms try to integrate some GIS functionalities. Our assumption is that the formalization and integration of this environment in the core component of agent can also be a good way to improve the efficiency of model. Spatial intelligence is a part of multiple intelligence of actors as human and allow them to keep their space in mind. From this fact, it is necessary to integrate the spatial reasoning abilities from agent architecture. This paper demonstrates how to formalise and integrate the spatial knowledge and reasoning in BDI architecture using Region Connection Calculus theory and predicates. The architecture obtained allows to maintain a mapping between the mental of agent and the real environment observed.

Keywords

Agent-based Modelling, Knowledge Representation, RCC Theory, Spatial Reasoning, Decision-Making, Land Use Modelling

I INTRODUCTION

Nowadays, Agent-Based Modelling(ABM) is increasingly used for explaining and understanding complex systems in several domains: social, ecological, environmental, robotic, etc. ABM represents an interesting alternative approach for representing and simulating real-world or virtual systems which could be decomposed in many entities for individual interactions in a Multi-Agent System(MAS) [1]. The design of each agent follows an appropriate architecture (Reactive, Deliberative or Hybrid). Particularly in land use modelling and simulations, BDI Architecture is generally used by modellers to endow agent with the actor behaviour that corresponding to their observation. One reason is that some simulation platforms propose the facility as BDI-template for modelling. Moreover, integration of spatial aspect (coming from GIS) in agent-based simulation platforms improves the quality and validity of models and increases the number of research works and non-computer scientist in land use modelling activities using ABM [2].

Land use represents the manner that biophysical attributes of our environment are manipulated and their changing process. It represents a process in which the actors (human beings especially) employ the resources of land (e.g. Forests, Agricultural Land, Mountains, Water, etc.). Human being represents one of main actors that causes the land use-cover changes and the disappearing of some biophysical entities at the land surface in which an abnormal discrepancy is observed on the using of resources [3].

If architecture is considered as a functional brain of agent in decision making and reasoning to solve complex problems and achieving goals, then it's the main skeleton of intelligent bases (cognitive, social, emotional, spatial, etc.). Thus, several BDI extensions have been proposed in the literature to resolve complex problems such as evacuation case [4], dynamic of land use [5], complex behaviour management [6], cropping plan decision-making [7]. However, the spatial dimension leads by cognitive representation and reasoning are not explicitly captured and described in this architecture. In an attempt to mimic spatial attributes, several agent-based simulation platforms try to integrate some GIS functionalities to facilitate the representation of spatial explicit environment using shape files. From this fact, our assumption is that the formalization and integration of this environment in the core component of agent can also be a good way to improve the validity of model constructed. It's not enough to integrate the geographic shape files in the simulator and give them certain capabilities. But it is also necessary to provide through an ability to reason from spatial representation of spatially explicit environment in order to improve the agent decision-making from Spatial Knowledge (SK).

The objective of this work is to describe an extension of BDI called SBDI (Spatial-Belief-Desire-Intention) architecture, based on Region Connection Calculus theory and logic predicates. Thus, we focus on SK representation and reasoning.

Paper contribution: the major contribution of this paper is the proposal of an architectural framework that drives the design of cognitive agent endowed of spatial reasoning: At first, RCC theory allows to represent SK of the agent environment, and then we investigate several approaches of representations focusing on topological relationships. Then, we are therefore especially interested by the representation of knowledge using spatial predicates, the designing of Spatial BDI followed by his loop process.

Manuscript organization: This paper is structured as follows: Section 2 provides an overview of agent design driven by architecture, the agent and spatial data models coupling challenge for land use modelling followed by RCC theory where some formal derivatives are given. Different conceptualizations of mental system/map for spatial reasoning are presented in section 3. Section 4 presents the SBDI architecture with different components followed by his loop process, while section 5 is devoted to the conclusion.

II LAND USE MODELLING WITH AGENT-BASED AND SPATIAL APPROACHES

. In this section, we present some fundamental concepts dedicated to agent design driven by deliberative architecture as BDI, to the spatial process and data models. Then, the challenge of agent-based model and spatial data model coupling for land use modelling is presented. The complete presentation of this coupling can found in [8, 9].

2.1 Agent design, spatial process and data models coupling

Agent is just a self-contained problem solving entity implemented in software, hardware or a mixture of the two that should include the following properties: Autonomous, social ability,

reactivity and pro-activeness [1]. It can be represented as function named $Ag: Env \rightarrow Ac$, where Env is the set of three elements (E, e_0, τ) : where E is a set of environment states, e_0 the initial state, τ a state transformer function and Ac a set of possible actions that agents can performed ($Ac = a_0, a_1, a_0, \dots$). The design of agent is driven by an architecture decided by modellers such as software in computer engineering. BDI is an example of deliberative architecture because it is very useful, natural, simple to understand and his components match easily to the behaviour of modelled actor. It is good for land use modelling where the modeller should make the knowledge representation and actors reasoning. Several works are based on this architecture where some extension have been proposed for modelling ([5–7, 10, 11]). It consists of three logic components referred as mental states namely Beliefs (*the internal spatial thought that agent has about his world*), Desires (*the set of what agent wants to do*) and Intentions (*one among several options*). At each time t , these databases lead it to select the best choice of action to perform according to a plan. [12] presents some derivatives as EBDI (Emotional Belief-Desire-Intention) that expresses a precise specification of the Emotional State Manager, BEN (Behavior with Emotions and Norms) embeds a cognitive, effective and social dimensions [4], while BOID (Belief-Desire-Obligation-Intention) that provides a social ability in their environment. But none of those derivatives are interested in the integration of environment knowledge in the core component of agent nevertheless it is an important aspect for the live of agent.

In spatial process modelling, we distinguish some approaches that allows to represent dynamics in process-based models. Two theoretical views of spatial processes are borrowed from the Eulerian and Lagrangian views of fluid dynamics: The *Eulerian* view describes the processes that influences properties (e.g. temperature) at fixed locations, and thus is a description of change. The *Lagrangian* perspective, on the other hand, tracks the changing location of particles through space and, therefore, is a description of movement. Thus, many processes in the real world could reasonably described as either Eulerian or Lagrangian (e.g. *a cold air mass moves* described as Lagrangian motion) over a location it causes the temperature at that location to drop, affecting an Eulerian change [9]. However, the relationships affecting process-data coupling can be defined by: *identity* association, the *causal*, *temporal linkage*, and *topological*. We are interested in topological relationships between features. But, we focus on the possibility of description of those spatial relationships during the definition of an agent in order to pile up a set of SK in the mental of agent for reasoning and good decision-making (As illustrated in Figure 1.a,b, our simple question is that how does agent can keep his environment in mind).

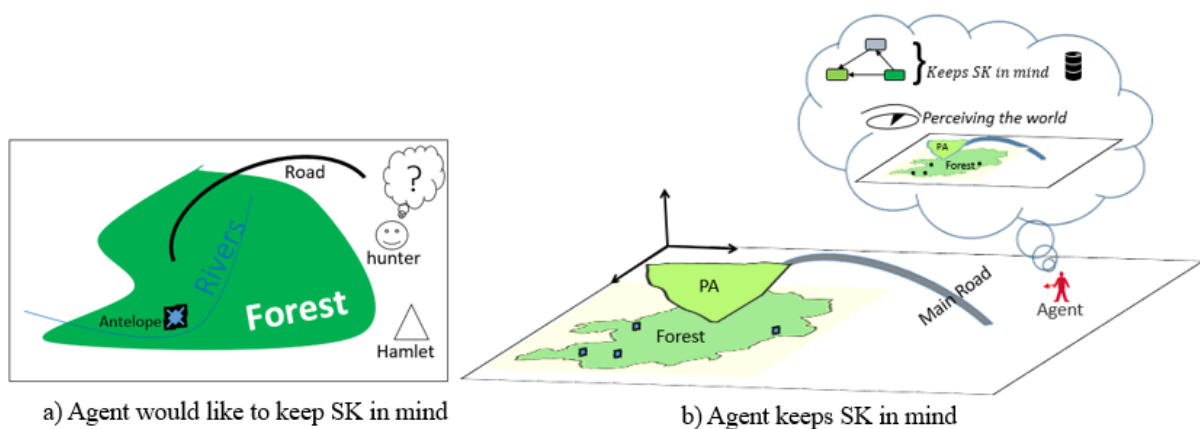


Figure 1: An illustration of predator-prey situation in spatially explicit environment(SEE)

2.2 RCC theory for spatial knowledge representation and reasoning: an overview

RCC theory allows to formalize the topological relationships between Regions (an extended portion of space). Then, it abstractly and qualitatively describes regions (in a Euclidean or topological space) by the possible relations between them [13]. It is analogous to the thirteen relations of Allen's Interval Calculus to describe the temporal representation (where the temporal interval is taken as primitive).

The Environment in spatially explicit simulation platforms can be described by two concepts: Space (σ) is used to model the world in which agents are moving. σ can often split in several regions (*sub-space named* ρ_i). ρ_i can be a road, country, city, farm, forest, building, hamlet, etc. In SEE, those regions are overlapped with them exactly as in GIS tools. Thus, σ forms a world where agents are deployed for simulation. In this work, the notion of connection is a relation between regions (*shapes or sub-shapes depending to the modeller*) in SEE. Thus, two regions (ρ_1 and ρ_2) are to be regarded as connected so long as they are not separated because they have one or many contact points. According to [14], the relation between two spatial objects O_1 , O_2 (point, line or polygon) is defined by comparing boundary and interior of O_1 with corresponding and opposite parts of O_2 .

Definition 1:

Region Connection Calculus. Given a set of regions $\sigma = \{\rho_1, \rho_2\}$ that forms an SEE, the theory is governed by two axioms:

- $\forall \rho_i \in \sigma$, ρ_i is connected with itself
- $\forall \rho_1, \rho_2$, if ρ_1 is connected with ρ_2 , then ρ_2 is connected with ρ_1

Definition 2:

Region. In the scope of this work, the concept of region noted ρ_i used in this paper is general and represents any geographic object like *point, line, polygon*.

We note that in the scope of this paper, region is a layer or an entity design in GIS tools and used in SEE. So, a line (road, river, etc.) is considered as a type of region.

RCC8 is a variant of RCC that consists of eight basic possible relations between two regions and is intended for reasoning about their spatial configurations (a formal qualitative reasoning) as P (*part of*), C (*Connect*), DC (*Disconnect*), O (*Overlap*), PO (*Partial Overlap*) EC (*Externally Connected*), TPP (*Tangential Proper Part of*) [15]:

- $C(x, y) \equiv \forall z, C(z, x) \rightarrow C(z, y)$, for all z if z is connected to x and y then $C(x, y)$
- $DC(x, y) \equiv \neg C(x, y)$, X and Y are not connected
- $P(x, y) \equiv \forall z, C(z, x) \rightarrow C(z, y)$, x is a part of y
- $O(x, y) \equiv \exists z, P(z, x) \wedge P(z, y)$, x overlaps y
- $PO(z, x) \equiv X$ overlaps Y but neither is part of the other.

If we consider the Figure 2 in a real modelling situation, *protected_area1* and *protected_area2* are connected through a main road. Each protected area is located in one government property (*district1* or *district2*): Taking that example, the question asked is that what can we infer relation of the second district (*district2*) to the main road using that theory. Then, some spatial configurations can formalized using RCC8 as the following constraint network:

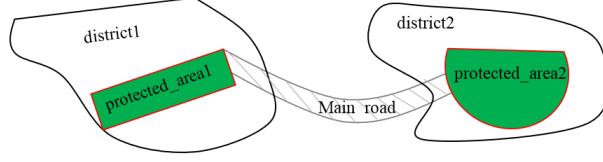


Figure 2: Representation of two protected areas in two different districts linked by a main road

```

protected_area1 DC protected_area2
protected_area1 {TPP, NTPP} district1
protected_area1 {DC, EC} district2
protected_area1 EC main_road
protected_area2 { DC, EC } district1
protected_area2 NTPP district2
protected_area2 EC main_road
district1 { DC, EC } district2
main_road { DC, EC, TPP, TPPi, PO, EQ, NTPP, NTPP^-1 } district1
main_road { DC, EC, TPP, TPPi, PO, EQ, NTPP, NTPP^-1 } district2

```

The topological relations between regions can be defined by mathematical representation as follows(see [14] for more details):

- Each region is characterized by its interior and boundary.
- The description of the topological relationship between two regions is a 2×2 matrix (\mathcal{M}) that represents the 4-intersections. \mathcal{M} indicates intersection between the interior (*called int*) and boundary (*called bdy*) of one with both the interior and boundary of other or indicates an emptiness.

Let $\rho_1, \rho_2 \in \sigma$, the intersections between region ρ_1 and ρ_2 is represented as follows:

$$\mathcal{M}(\rho_1, \rho_2) = \begin{bmatrix} I_{bdy-bdy}(\rho_1, \rho_2) & I_{bdy-int}(\rho_1, \rho_2) \\ I_{int-bdy}(\rho_1, \rho_2) & I_{int-int}(\rho_1, \rho_2) \end{bmatrix}$$

where I is intersection and σ the world(set of shapes)

In this matrix these variables can take 0 or 1 depending on the intersection (empty or not). Thus, we count eight possible matrix that correspond to the RCC8 relations.

Table 1: 4-intersection formalism with RCC8

RCC8	DC	EC	PO	EQ	TPP	NTPP	TPP ⁻¹	NTPP ⁻¹
\mathcal{M}	$\begin{bmatrix} 0 & 0 \\ 0 & 0 \end{bmatrix}$	$\begin{bmatrix} 1 & 0 \\ 0 & 0 \end{bmatrix}$	$\begin{bmatrix} 1 & 1 \\ 1 & 1 \end{bmatrix}$	$\begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix}$	$\begin{bmatrix} 1 & 1 \\ 0 & 1 \end{bmatrix}$	$\begin{bmatrix} 0 & 1 \\ 0 & 1 \end{bmatrix}$	$\begin{bmatrix} 1 & 0 \\ 1 & 1 \end{bmatrix}$	$\begin{bmatrix} 0 & 0 \\ 1 & 1 \end{bmatrix}$

In the same way, the general 3×3 -matrix in 9-Intersections for topological relationships between two regions noted ρ_1 and ρ_2 is represented as follows (in this case, the exterior of the region is taken into account) :

$$\mathcal{M}(\rho_1, \rho_2) = \begin{bmatrix} \partial\rho_1 \cap \partial\rho_2 & \partial\rho_1 \cap \rho_2^\circ & \partial\rho_1 \cap \rho_2^- \\ \rho_1^\circ \cap \partial\rho_2 & \rho_1^\circ \cap \rho_2^\circ & \rho_1^\circ \cap \rho_2^- \\ \rho_1^- \cap \partial\rho_2 & \rho_1^- \cap \rho_2^\circ & \rho_1^- \cap \rho_2^- \end{bmatrix}$$

Where: the *interior* of a region noted ρ_i is the union of all open sets in ρ_i and denoted by ρ_i° , the *exterior* of ρ_i is the set of all points available in ρ_i^2 and denoted by ρ_i^- . *boundary* of ρ_i is the intersection of her closure and closure of her exterior of ρ_i and denoted $\partial\rho_i$.

The previous configurations will allow to propose a conceptualisation of the mental map and SK in the core component of agent using the logic predicates.

III CONCEPTUALISATION OF AGENT SPATIAL MENTAL MAP

This section presents a formal representation of spatial mental map as a graph and then the spatial knowledge is also conceptualised using the logic predicates.

3.1 Representation of mental map with a topological knowledge graph

In the real life, Actor/Human observes his environment, saves an important set of spatial information, analyses and reasons with them in his mind system in order to make the good decisions. One way to conceptualise that mind is to use a knowledge graph where nodes are represented by Regions (different layers used) and edges by topological relationships between nodes. A node can be an entity using the following concepts: *point, line or/and polygon*. The edge joining two nodes is characterized by a Matrix label ($\langle M \rangle$, 2×2 or 3×3 -Matrix). Conceptually, given a set of nodes N , and a set of labels for edges E ($\langle M \rangle$), a knowledge graph is a subset of the cross product $N \times E \times N$. To design a Topological Knowledge Graph (TKG), we propose a meta-Graph (Figure 3) :

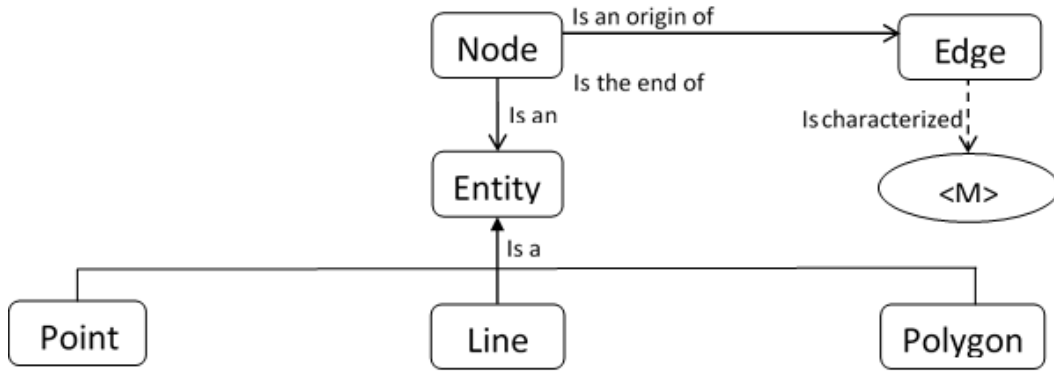


Figure 3: Meta-Graph for building of TKG

As illustration of construction, we consider the figure 1 where we suppose that the space (σ) contains a river (R) and a forest(F) layers came from shape files. We see for example that R is in a part of F (Figure 4a, Partial Overlap). So, we can deduce an instance of TKG with PO relation in Figure 4.

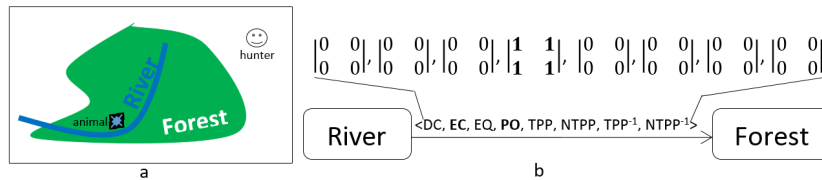


Figure 4: Illustration of SEE(a) and instance of TKG deduced (b)

3.2 Conceptualisation of a particular predicate for spatial mental map

Previously, we have represented the topological relationships using a qualitative approach led by RCC theory. Agent can use these Matrix to get the spatial information on his environment in order to perform a plan after the deliberation process. From this fact, we define a Spatial Predicate (SP) as : $\mathcal{P}_{i(r,w)}(\mathcal{F}(r_j, w_k))$

Where,

- \mathcal{P} is a name that identifies the predicate,
- i represents agent getting the spatial information,
- r_j and w_k represent the geographical entity (Regions) concerned by computation,
- \mathcal{F} is a function (e.g. DC, EQ, PO, TPP, NTPP etc.) that returns several values (4 in RCC8 or 9 if the 9-Intersection approach is used) stored in predicate P.

SP may change depending on the simulation context. In a scenario, we can have one instance of road, river, forest, protected area or another spatial entity. Consequently, the general predicate becomes $\mathcal{P}_{i(r,w)}(\mathcal{F}(r, w))$ in the case that we only have one instance for each entity (e.g. a road, railway or river comes from GIS file). For illustration (Figure 4a), if we want to represent the fact that an agent called *toto* knows that a river(\mathcal{R}) crosses village (\mathcal{V}), *sp_riverExistsInVillage* represents the associated predicate: *sp_riverExistsInVillage_{toto}(\mathcal{R}, \mathcal{V})($PO(\mathcal{R}, \mathcal{V})$)*.

In this expression, agent knows that \mathcal{R} is partially overlap to \mathcal{V} . An important information for agent (*For illustration, if toto is a hunter, then he knows that it is possible to catch a prey as blue-duiker (small antelope) in this village along the river*)

3.3 Conceptualisation of spatial knowledge and mental map as variables

We suppose that each agent has a Spatial Mental Map (SMM) that represents its thoughts on the world and contains several SK. In the previous section we have given an idea on the representation of spatial agent mental map followed by a presentation of information using a spatial predicate that can be used in deliberation process. Another way to conceptualize the mental system of agent is to use either a particular database or a data structure of SP in memory. The mental state of BDI agent is driven by belief, desire and intention databases. Moreover, a SK Base can store SK that should directly help in the agent decision-making process. Conceptually, a SK is defined as follows:

$SK_i = (Pr, Val, Po, LT)$ where:

- SK_i : the name of spatial knowledge getting by agent i,
- Pr : the name or identifier of a predicate,
- Val : the value of Pr,
- Po : the importance of knowledge for agent (between 0 and 1),
- LT a Life Time value that indicates how long this knowledge can stay in the agent memory (Defined by modeller like Po).

From this predicate, we propose another formal representation of Spatial Mental Map (SMM). An idea is that we see that map as a set of spatial predicates. So, we called \mathcal{S}_m a SMM of agent called α at a time t . Thus, the agent can simply update her local configuration with the following value:

$$\mathcal{S}_{m(\alpha,t)} = \sum_0^{n-1} SK_i = SK_0, SK_1, SK_2, SK_3, SK_4, \dots SK_{n-1}$$

IV SBDI ARCHITECTURE AND DELIBERATION PROCESS

. This section presents the databases of spatial BDI architecture and describes the conceptualisation of deliberation process.

4.1 Main databases

This architecture proposes five databases that participated to the deliberation process. Thus, each of databases communicate together to compute an action that agent can perform at a moment during the simulation process.

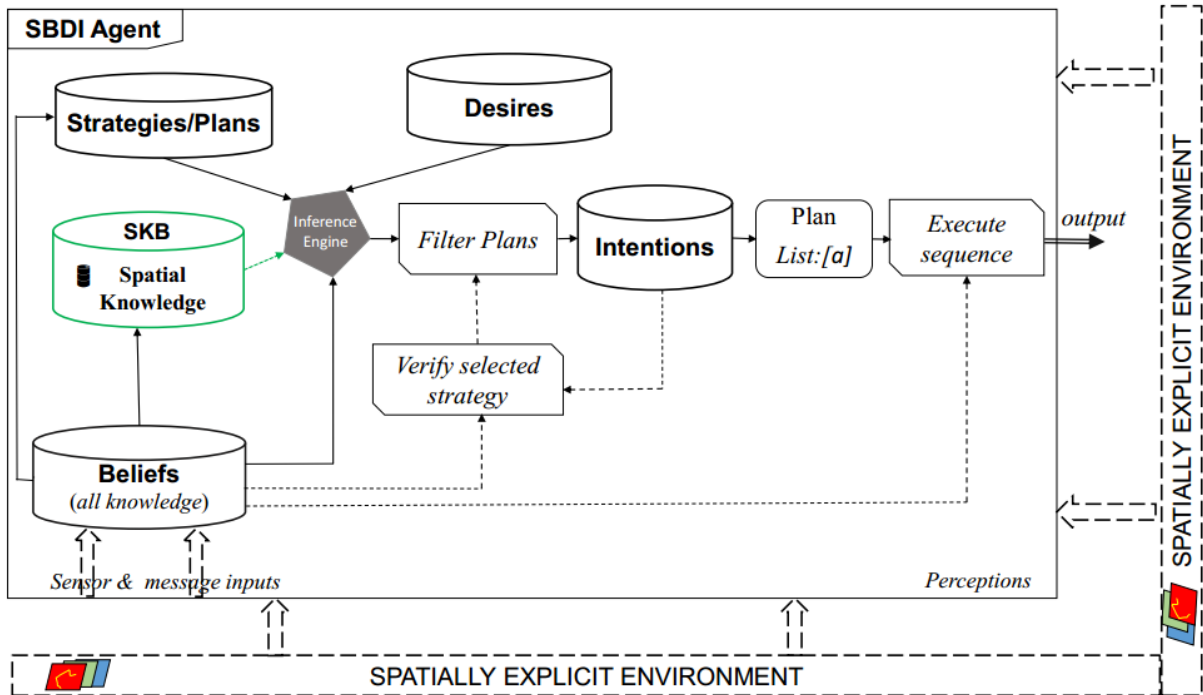


Figure 5: SBDI Architecture (Adapted from BDI scheme proposed in [7])

The four main databases of SBDI (Figure 5) are presented as follows:

- **Beliefs** represents the knowledge that agent has about the environment and his own internal state. For example, all geographic layers that constituted his world or particular information (e.g., $trap(false, position :: (14.46, 3.06))$, $hamlet(position :: (14.03, 3.10))$). The perm perception allows to update and enriches this database all the time.
- **SKB** (Spatial Knowledge Base) is deduced from Belief database to store the SK about environment. SP can be evaluated and stored in this sub-databases. For implementation, the data structure can be used to manipulate SP such as defined in section 3.2.
- **Desires** is the set of what an agent would like to accomplish during the simulation process. For example, SBDI agent wants to catch a prey.
- **Intentions** represents what agent has chosen to do at a moment. So, agent determines his intentions basing on beliefs, SKB and desires database. The intention selected from the current desire easily determines a strategy to perform.
- **Strategies**: A selected plan constituted by a list of actions is performed by agent.

4.2 Reasoning process

The deliberation process is conducted by a cyclic three phases as in traditional BDI with spatial reasoning included. The practical reasoning involves several important processes. It decides what state of affairs agent want to accomplish, deliberate, and decide how agent want can achieve ([1, 12]). We assume that SEE is constitutes of the set of shape files called \mathcal{S} . SKB that contains all SK deduced from \mathcal{S} . SK are associated to the Attribute Knowledge(AK) that indicates some meta-data on environment (ENV). Thus, Knowledge Base or beliefs are constituted by AK and SK: ($\mathcal{S} \rightsquigarrow SK$ and $KB = AK \cup SK$).

- **Belief functions:** the perception functions (-Per) generates the belief.
 - Agent perceives environment with : $BE-Per: ENV \rightarrow BE_p$,
where BE_p denotes the potential belief elements and ENV the environment.
 - SK is generated with : $SKPred: ENV \rightarrow SK$,
where $SKPred$ denotes the predicate used to create SK. $BE-Per$ becomes :
 $BE-Per: (AK \cup SK) \rightarrow BE_p$ or $BE-Per: (KB) \rightarrow BE_p$
 - The SK update function can be defined such as: $updatesk: (BE_p \cup BE_m) \rightarrow SK$
 - However agent can get a belief trough another agent (e.g. *broadcast messages(Msg)*),
Thus the contain of message can generate the new belief :
 $BE-Msg: CoM \rightarrow BE_m$ where CoM denotes the content of messages.
 - Agent can get the set of belief elements from Environment and communication messages. Thus, both are takes in consideration to generate the BE though BE_{in} function:
 $BE-in: (BE_p \cup BE_m) \rightarrow BE$ or $BE-in: (KB \cup CoM) \rightarrow BE$
- **Option generate function :** As in traditional BDI model, the option generates function (*ops*) produces the desires (DE) based on belief and intentions if it exists. The *ops* function is defined as: $ops: (BE \times IN) \rightarrow DE$
- **Filter Function (Filter Plans in figure 5) :** This function adds, combines, or uses SK to find the best plan(s) or option(s). The filter function (*filter*) that produces an intention (IN) is defined as : $filter: (SK \times BE \times DE \times IN) \rightarrow IN$
- **Plan function:** The previous functions completes the deliberation process and generates the best option(s) linked to intention(s), with some actions according to the states of mind. The function plan is represented :
 - $plan: IN \times RU \rightarrow AC$,
where RU is the set of possible rules of agent's reasoning engine, and AC denotes a plan (sequence of actions) :
 $AC = (a_1, \dots, a_n)$ where a_i is a single action.
- At the end, an **execution function** is used to execute the sequence of actions (AC) produced by *plan* function. It is represented as follows: $execute: AC \rightarrow ENV$

The following pseudo-code based description (adapted from the one proposed in [16]) presents its processing loop:

Algorithm: SBDI-Processing-Loop

-
- | | |
|---------------------------|--|
| 1: $BE \leftarrow BE_0$; | ▷ <i>Initialises a base of Beliefs</i> |
| 2: $SK \leftarrow SK_0$; | ▷ <i>Initialises the base of spatial knowledge</i> |
| 3: $DE \leftarrow DE_0$; | ▷ <i>initialises the base of desires</i> |
| 4: $IN \leftarrow IN_0$; | ▷ <i>initialises the base of Intentions</i> |
| 5: $PL \leftarrow PL_0$; | ▷ <i>initialises the base of plans</i> |
| 6: Begin | |
| 7: while true do | |

```

8:  BE-per  $\leftarrow$  BEp(ENV); ▷ updates BE from potential percepts
9:  BE-m  $\leftarrow$  BE-Msg(CO); ▷ updates BE with messages if it exists
10: BE  $\leftarrow$  BE-in(BE  $\cup$  BEp  $\cup$  BEm, IN); ▷ updates beliefs base from others sources
11: SK  $\leftarrow$  updatesk(SK  $\cup$  BE); ▷ updates spatial knowledge base
12: DE  $\leftarrow$  ops(BE, IN);
13: IN  $\leftarrow$  filter(IN, SK, BE, DE); ▷ Computes the most recent intentions to perform
14: PL  $\leftarrow$  IN; ▷ updates the base of plans
15: AC  $\leftarrow$  plan(IN, RU); ▷ computes the new plan according to intention and rulers
16: if (IsNotOver(time)) then
17:     while (!empty(AC)) do ▷ the list of action is not empty
18:         a  $\leftarrow$  head(AC); ▷ the first action is extract in order to be executed
19:         execute(a); ▷ the execution can use an item of BE as input
20:     elseif
21:         break;
22:     endif
23: endwhile
24: End.

```

SBDI processing loop above is described as follows:

- After initialisation (line 8), when the sensor detects a new stimulus from the environment, it generates new perceptions (BE-per) which are stored immediately in Belief database. Beliefs came from content (CoM) of message passing are also added in BE-m (line 9). In line 10, the belief base is revised with pre-existing current beliefs and all available knowledge (BE, BE_p, BE_m) associated to the current intention (IN). The spatial knowledge base is revised according to pre-existing current SK and another spatial information of ENV (line 11). Thus, the deliberation process starts by analysing its desires, its current intentions and generated the options (*ops function*) items as in following points.
- Desires base is revised with the previous belief (BE) computed and the current intention (line 12). Intentions base is revised according to the current intention (IN), the set of spatial knowledge, belief and previous desires computed (line 13). From Options, under the influence of spatial knowledge stored in SK and intentions, agent is committed to the selected plan which presents its new intentions (line 14 and 15). Thus, the deliberation process is over. In the second while loop agent performs the sequence of actions available in AC (line 18 and 19) until that this one becomes empty.

V CONCLUSION

In this paper, we have presented an approach defining spatial ability agent driven by architecture in which spatial reasoning is embed. We have formalized the spatial knowledge representation with predicates basing on RCC theory and include spatial reasoning in the SBDI processing loop. The main advantage of this architecture is that it offers the possibility to manipulate knowledge of the world observed into agent and allows him to deduce another knowledge for good decision-making. This contribution participates to the formal and effective agent-based modelling for land use changes analysis domain. A direct perspective of this work could be to provide an implementation of this architecture in a simulation platform such as GAMA or Netlogo. Practically, an idea would be to design and implement a simple-to-use template and integrate to a spatially explicit agent-based platform for land use modelling activities.

REFERENCES

- [1] M. Wooldridge and N. Jennings. “Agent Theories, Architectures, and Languages: A Survey”. In: volume 890. Jan. 2000. ISBN: 978-3-540-58855-9.
- [2] A. Dorri, S. S. Kanhere, and R. Jurdak. “Multi-Agent Systems: A Survey”. In: *IEEE Access* 6 (2018). <https://doi.org/10.1109/ACCESS.2018.2831228>, pages 28573–28593.
- [3] H. Briassoulis. *Analysis of Land Use Change: Theoretical and Modelling Approaches*. Advanced Information and Knowledge Processing. Regional Research Institute, West Virginia University, 2000.
- [4] M. Bourgais, P. Taillandier, and L. Vercouter. “BEN: An Agent Architecture for Explainable and Expressive Behavior in Social Simulation”. In: edited by D. Calvaresi, A. Najjar, M. Schumacher, and K. Främling. Volume 11763. Springer, 2019, pages 147–163.
- [5] P. Caillou, B. Gaudou, A. Grignard, C. Q. Truong, and P. Taillandier. “A Simple-to-Use BDI Architecture for Agent-Based Modeling and Simulation”. In: (2017). ISBN: 978-3-319-47253-9, pages 15–28.
- [6] P. Taillandier, M. Bourgais, P. Caillou, C. Adam, and B. Gaudou. “A BDI Agent Architecture for the GAMA Modeling and Simulation Platform”. In: 10399 (2016). Edited by L. G. Nardin and L. Antunes, pages 3–23.
- [7] P. Taillandier, O. Therond, and B. Gaudou. “Une architecture d’agent BDI basée sur la théorie des fonctions de croyance: application à la simulation du comportement des agriculteurs”. In: *Journées Francophones sur les Systèmes Multi-Agents 2012* (Jan. 2012), pages 107–116.
- [8] S. Manson, L. An, K. C. Clarke, A. Heppenstall, J. Koch, B. Krzyzanowski, F. Morgan, D. O’Sullivan, B. C. Runck, E. Shook, and L. Tesfatsion. “Methodological Issues of Spatial Agent-Based Models”. In: *Journal of Artificial Societies and Social Simulation* 23.1 (2020), page 3. ISSN: 1460-7425.
- [9] D. Brown, R. Riolo, D. Robinson, M. North, and W. Rand. “Spatial process and data models: Toward integration of agent-based models and GIS”. In: *Journal of Geographical Systems* 7 (May 2005), pages 25–47.
- [10] C. Adam and B. Gaudou. “BDI agents in social simulations: a survey”. In: *Knowl. Eng. Rev.* 31.3 (2016), pages 207–238.
- [11] E. D. Kameni, T. P. van der Weide, and W. T. de Groot. “From conceptual model to implementation model - Piloting a multi-level case study in Cameroon”. In: *ARIMA J.* 32 (2019).
- [12] T. Balke and N. Gilbert. “How Do Agents Make Decisions? A Survey”. In: *JASSS* 17 (Oct. 2014). doi:10.18564/jasss.2687.
- [13] B. Nebel and C. Freksa. “AI Approaches to Cognitive Systems - The Example of Spatial Cognition”. In: *Inform. Spektrum* 34.5 (2011), pages 462–468.
- [14] M. Egenhofer and K. Al-Taha. “Reasoning about Gradual Changes of Topological Relationships.” In: Jan. 1992, pages 196–219.
- [15] A. Galton. ““Spatial and temporal knowledge representation ””. In: *Earth Sci Inform* 2 (Dec. 2009).
- [16] H. Jiang, J. Vidal, and M. Huhns. “EBDI: an architecture for emotional agents”. In: doi 10.1145/1329125.1329139. Jan. 2007, page 11.