Agent-Based Social Simulation for the analysis of social, health and economic effects of the coronavirus pandemic – Conceptual Model

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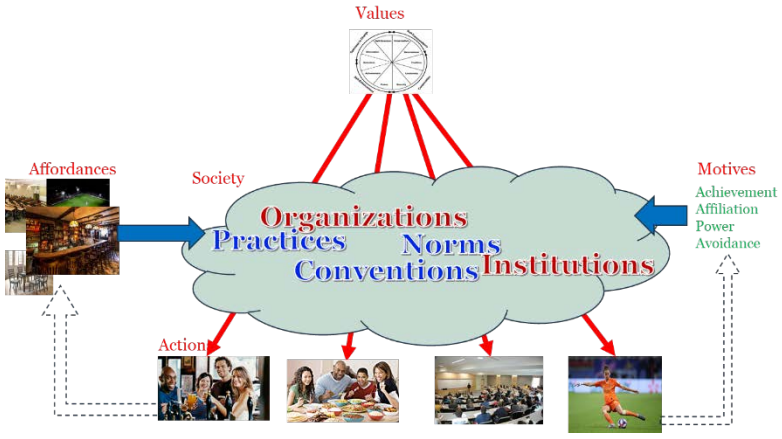
The design of the ASSOCC framework is based on the fact that individuals always have to balance their needs over many contexts. In the research that we have done in the past twenty years we have come to the following sketch that illustrates how people manage this balancing act in their daily life.



We assume that people have a value system that is reasonably consistent both over times, contexts and domains. The value system is based on the Schwartz value circumplex [Schwarz] that seems to be quite universal. It depicts a number of basic values that everyone possesses and their relations. People differ in which values they find more important rather on which values they have. We have extended this framework to make it more concrete and computational (see e.g. [Vanhee, Dignum, Heidari]). Thus values give a stable guideline of behavior and they will be kept satisfied to certain degree whenever possible. Thus, if "universalism" is important to a person, she will in general direct her behavior to things that will benefit the larger community.

The second type of drivers of behavior in the figure are the motives that all people have in common. This is based on the theory of McLelland [McLelland]. The motives indicate that people want to achieve some goals. The achievement motive means that we always want to progress from the current situation to something better (whatever "better" might mean). The affiliation motive means that we have a basic need to be together with other people and socialize. Thus we sometimes do things just to

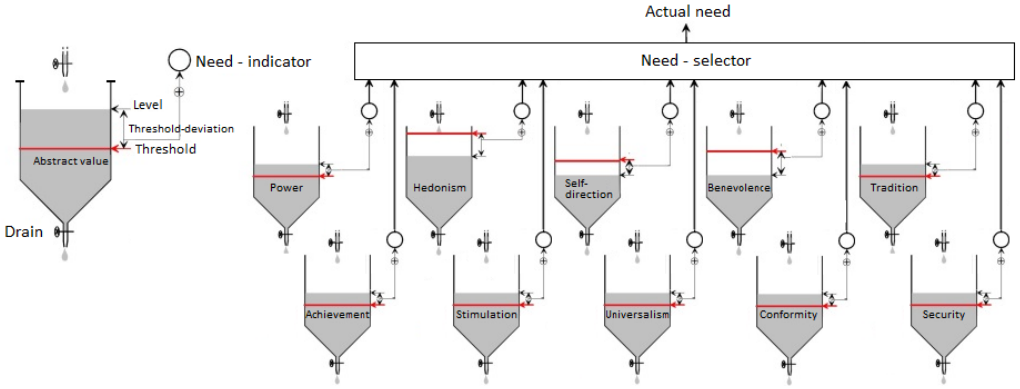
be doing it together with our friends and family. The power motive actually does not mean we want power over others, but rather that we want to be self-efficative. I.e. being able to do tasks without anyone's help. Finally, the avoidance motive lets us avoid situations in which we do not know how to behave or what to expect from others. Each of these motives is active all the time and whenever possible it will drive a concrete behavior. Thus, I might go to a colleagues office to ask a question rather than e-mail her, just because I want to have a chat.

The third type of elements that determine behavior are the affordance that a context provides. These affordances determine what kind of behavior is available and also what type of behavior is salient. E.g. in a bar one often drinks alcohol. Even though it is not obligatory it is salient and also afforded easily.

Individuals have to balance between their values, their motives and the affordances to determine what behavior would be more appropriate in each situation. As one can imagine this is quite tricky and will take too much time and energy if done in every situation from scratch. Therefore, in human society we have developed social structures to standardize situations and behaviors in order to package certain combinations that will be acceptable and usually good (even if not optimal). These social constructs are: norms, conventions, social practices, organizations, institutions, etc. Note that these constructs, such as e.g. norms, give general guidelines or defaults of behavior, but are no physical restrictions on what is possible!

From Theory to Practice: the needs model

We have investigated parts of the above framework in many papers, both theoretically as well as in practical systems. However, it will be clear that we cannot implement an agent architecture for an agent based simulation on this complete framework. It would be too complex to be computationally feasible. We have therefore take the main principle of the values and motives and used a model that can be easily implemented and extended to implement this based on the water tanks principle.



We implement the values and motives as needs that deplete over time if nothing is done about them. The model prevents that an agent will only look at the need with the highest priority and only at other ones when that need is completely satisfied. By calibrating the size and threshold and the depletion rate of each need we can calibrate and balance all the needs over a longer period, between different contexts and over several domains. E.g. using this model it becomes possible to decide for an individual whether it is more important to work a bit more or go home and be with the family. This simple model is the crux behind combining health, wealth and social wellbeing in a simulation model.

The Conceptual description of Needs in the implementation

The model has the following main needs, based on Maslow's hierarchy of needs:

- **Safety**
- **Belonging**
- **Self-Esteem**
- **Autonomy**
- **Survival**

These needs are implemented using the water tank model described above. They can be satisfied doing certain activities and decay over time. They also all have a certain importance to the agent. The agents will try to satisfy the need that is least satisfied at this point in time.

Safety is a composite need, so it is built up of several components, namely food-safety, financial-survival, risk-avoidance, compliance, and financial-safety. The first of these are most important for an agent's direct need to survive, so the safety need is defined as the minimum of the first two, and a weighted mean of the rest, where the weights are the importances assigned to each subneed.

Food-safety: this need is satisfied by having enough essential resources stocked up at home, such as food and medicine. This is measured over a two week period, so if they have two weeks of food it is satisfied, and goes down from there. The only way to increase this need, is by going shopping for essential resources.

Financial survival: This need is related to the ability to pay for expenditures that come up in the short term and are needed to survive, such as paying for groceries. This need gets decreased by spending capital, and gets increased by earning capital.

Risk avoidance: This need is satisfied by staying away from large groups of people, but is meant to represent avoidance of all risks of disease (update later).

Conforming to the rules (compliance): this need is satisfied by taking actions that conform to the rules, such as staying inside during lockdown, and going to school if it is possible. This need also has negative increases if the agent decides to break a rule.

Financial safety: This need represents an agent's need to have a balanced income and outcome. This is modelled by looking at the change of capital between ticks. Like the Financial survival need, this need depletes from spending money, and increases from getting money.

The need of Self-Esteem is split up into Relaxing and Luxury, which are combined by taking the weighted mean, where the weights are the importances for relaxing and luxury.

Relaxing: People need to rest, especially during the night. Therefore, people can relax and leisure places, while the strongest increase in this needs satisfaction will be in the night when they are home to sleep.

Luxury: Luxury is part of self-esteem, because agents can spend money in non-essential shops on goods which are not mandatory to survive but rather for one's own personal pleasure

The belonging need is mostly satisfied by being expected to be around other people. Bonuses will be multiplied when people of your social networks, such as family, friends, or colleagues are present. It is important to note here that belonging needs deplete faster if the agent didn't see people from their social networks for a longer time.

The need of autonomy is satisfied when people are able to follow their plans. Another aspect which is taken into account is that agents can increase their autonomy satisfaction when they are breaking lockdown and doing their own activities and thus make an "autonomous" decision. However, to regulate this effect and not provide agents with too strong incentives to break the lockdown, "conforming to rules" will be utilized as a regulating factor.

The need for survival represents an agent's need to rest if it is sick. This need can be satisfied by resting at home if the agent believes it is sick, and depletes if it does anything else while it believes to be sick.

Relation between Needs and Actions/States

In the appendix we have included a table which shows the broad relation between the needs and how actions, combined with motives, increase and decrease the respective needs.

During lockdown, compliance also depletes every time an agent leaves the house, while it is satisfied while staying at home, and autonomy decreases every time an agent has to stay at home but want to do something else.

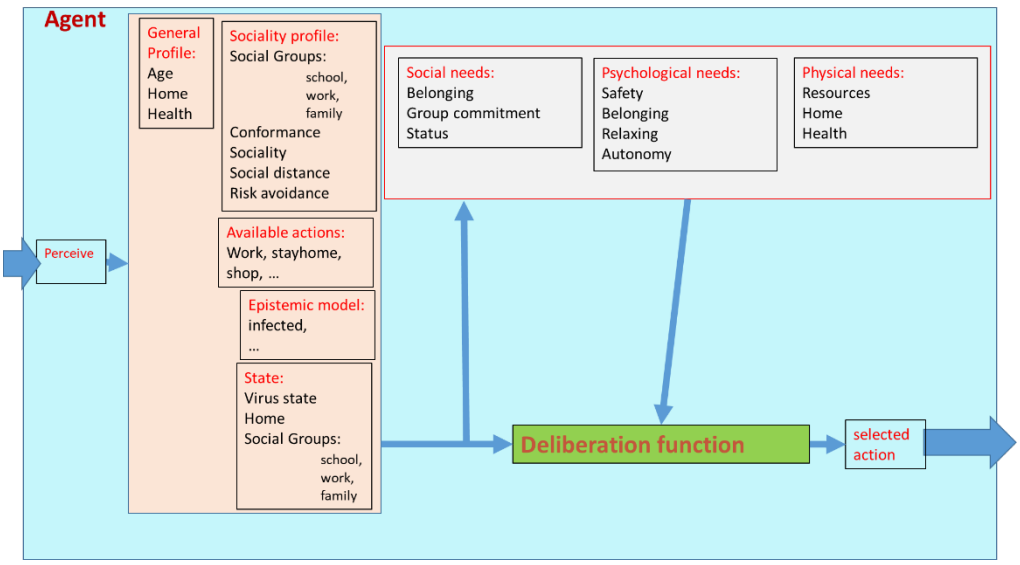
Overview of the agent architecture of the ASSOCC agents

So, the values and motives have been translated to the above needs model. How about affordances? Actually, they play a minor role in this simulation and are very easily implemented by creating available actions at each place where an agent can move to. E.g. working is done at work places, which can be offices, shops, schools, hospital or university. Thus, homes are not normally used to work. This changes when the "work at home" policy is adopted. Then homes also afford working behavior. However, the productivity at home is lower than at the workplace. Moreover, not all work can be done at home. Shop workers can only do their work at the shop, because that is the place where the products is they have to sell.

The norms, organizations etc. are implemented only in as far as they are general policies. E.g. with a lock down everyone should stay at home and only go to essential shops if needed. This is a rule that can be violated when the social needs of an agent get too high and it wants to go out. A similar thing holds for the "social distance" rule. In general the norms, conventions and practices are implemented through rules that can be violated by an agent if one of its needs cannot be satisfied.

We have started the implementation of social groups as well. The social groups consist of people whose behavior is observed and also influences the agent behavior. E.g. if all your friends go to the supermarket today, maybe you should also go, even though you do not really need to buy food. This will lead to the hoarding behavior as observed.

The above considerations lead to the following agent architecture:



It can be seen that the needs are divided in three parts: the psychological needs, the social needs and the physical needs. Creating these parts is purely done to keep the design clear and to facilitate further needs in a part when more elaborate scenarios in that direction are developed. It is clear that we did not include all the Schwartz values and McClellands motives. We picked the most relevant values for the base situation. Other values can be added when particular aspects are focused on. E.g. what is the impact of the COVID-19 crisis on environmental issues? For this kind of question one would incorporate an environment or sustainability need that influences green behavior. That might lead to still invest in solar panels even in these times or abandon any investment in the future. The needs drive the deliberation function that determines the behavior at each moment. The other input comes from the agent profile and state. The most notable is the epistemic state that indicates whether an agent knows whether he is infected, immune or not. Getting tested will update its epistemic state and determines whether the agent will isolate itself, go to hospital or continue as before.

Action Selection and Execution

To select an action, an agent first creates a list of all possible places (gathering-points) it can go with different motivations, which together we will call an action. This list is based on their current age, time of day, day in the week, and parameters set in the model. Then for all of these actions, the global expected effect on the needs is calculated, by summing over the expected effects times the desire for each main need. The action that satisfies the highest number of needs is then selected to be acted upon.

The subneeds are then taken into account indirectly, because they are incorporated into their main need.

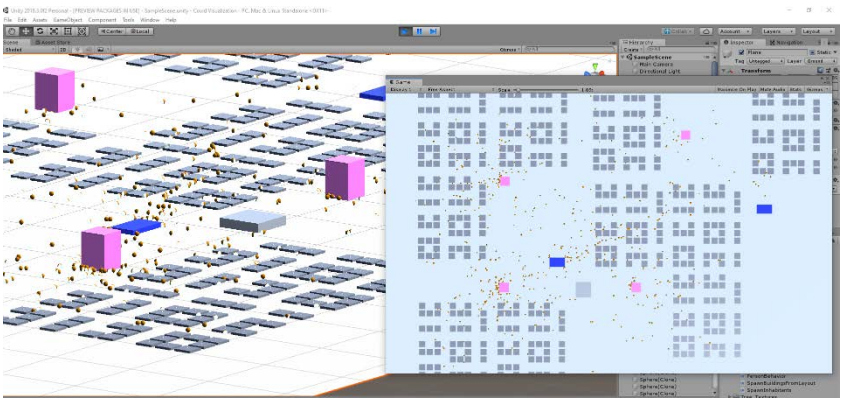
Note that, in order to make unsatisfied needs more important, this calculation is not done on the absolute expected increase, but the increase is discounted by (1 - need-satisfaction). This means that needs that are least satisfied are prioritized over needs that are nearly (or fully) satisfied. For combined needs, this discounting also happens when combining them. After an agent has selected an action, it moves to a selected location for that action.

After all agents have moved to the location where they want to execute their action, the actions get executed, and the needs get updated. It is important to do this after all the agents have moved, so that the needs can be updated after the actual state of the model (important for the belonging need for example, which depends on where other agents are).

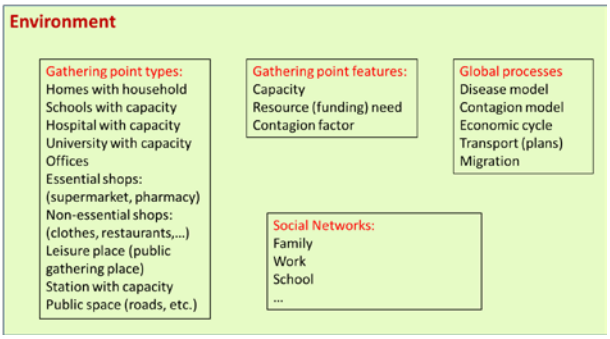
Environment

The agents in ASSOCC exist in more than just a grid. We created a physical environment with homes, hospitals, schools, shops and other buildings. For the current scenarios we tried to balance between having enough agents and homes to display a diversity of people and places in a town and speed and ease of developing the scenarios. That led to having

300 agents
100 Homes
4 Schools spread over the area
1 Hospital
1 University
3 Office or production facilities
5 Essential shops: (supermarket, pharmacy)
10 Non-essential shops: (clothes, restaurants,…)
1 Leisure place (public park)
1 airport to enter and leave the town



On a more abstract level the environment contains the following social and physical elements:

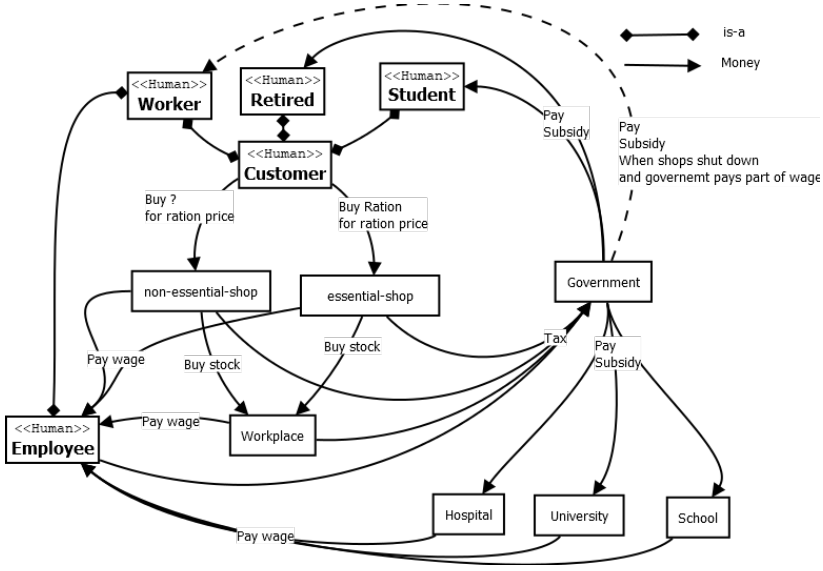


Global cycles

There are basically three cycles that influence the daily activities and interactions between the agents.

1. The daily pattern of life that forms the basis of all actions of an agent. Typically an adult agent will go to work and back every day. Based on its needs it will do some shopping and/or do some leisure activity. Children do not do the shopping but only go to school and leisure activities. Children cannot go to school without at least one adult bringing and getting them from school. So, adults that have children do that before and after work.
   Essential shops have to be frequented a few times each week to have enough food. The non-essential shops contribute with products that increase the physical resource needs of an agent.
2. The second cycle is that of the COVID-19 status. Agents generally do not know whether they are infected or not until they are tested or have symptoms. If they have symptoms they go to hospital otherwise they isolate at home. (Note: we simplify the distinctions here in order to have a first model running. This can easily be extended later on with distinguishing between severe cases, critical case, light cases, etc.). Once an agent is infected it will take two weeks before symptoms show. Thus other agents will not see this during that time. Infected agents with symptoms will be treated in hospital and either die or get immune.
3. The third cycle is a simple closed economy cycle. This is implemented in order to handle the fact that schools, hospitals, shops, and offices/production needs labour in order to produce their services or products. So, e.g. when agents cannot work in the shops the shops have to

close. All agents that work have an income. The agents that represent retired people, children, students or unemployed get some subsidy from the government in order to keep them surviving. The government also pays the school, university and hospital workers. The government gets money from the taxes paid by workers and companies. The government has a reserve it can use when the taxes drop to far, but if the reserve is depleted it cannot subsidize anything anymore and the economy collapses. The main cycle is depicted in the following figure:



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Appendix

This tables shows which actions, in combination with motives, increase (+) and decrease (-) the needs of agents implemented in this model

Work days Monday - Friday, color: red **Non-Work days** Same as the evenings **Agent types:** Worker Young Student Retired

Black means it holds for both work days and non-work days **nl means that does not hold during lockdown**

The plusses on their own do not have a strict meaning, but give the relative satisfaction given for all the different needs for a group of agents. So if working from the workplace is ++, and working from home is +, this does not mean that working from home satisfies half as much as working from the workplace, but just that it satisfies it less

Morning

Need	Subneed \ Actions & Motives	Buy at essential shops				Buy at non-essential shops				be at your workplace				working from home				be at school				be at university				be at public leisure place				be at private leisure place				be at home			
Safety	Food safety	+		+	+																																
	Financial survival	-		-	-	-		-	-	+				+																							
	Risk avoidance	-		-	-	-		-	-	-				-					-					-		-	-	-	-	-	-	-	-	+	+	+	+
	Conforming to rules					+ (nl)		+ (nl)	+ (nl)	++				+					+					+					++ (nl)				++ (nl)				
	Financial safety	-		-	-	-		-	-	+				+																							
Belonging	No subneed									+									+					+		+	+	+	+	+	+	+	+	+	+	+	+
Self-Esteem	Relaxing					+		+	+																	+	+	+	+	+	+	+	+	+	+	+	+
	Luxury					+		+	+																												
Autonomy	No subneed									++				+					+					+													
Survival	No subneed																																	+ (if sick)	+ (if sick)	+ (if sick)	+ (if sick)

Afternoon

Need	Subneed \ Actions & Motives	Buy at essential shops				Buy at non-essential shops				be at work				working from home				be at school				be at university				be at public leisure place				be at private leisure place				be at home			
Safety	Food safety	+		+	+																																
	Financial survival	-		-	-	-		-	-	+				+																							
	Risk avoidance	-		-	-	-		-	-	-				-					-					-		-	-	-	-	-	-	-	-	+	+	+	+
	Conforming to rules					+ (nl)		+ (nl)	+ (nl)	++				+					+					+					+ (nl)				++ (nl)				
	Financial safety	-		-	-	-		-	-	+				+																							
Belonging	No subneed									+									+					+		+	+	+	+	+	+	+	+	+	+	+	+
Self-Esteem	Relaxing					+		+	+																	+	+	+	+	+	+	+	+	+	+	+	+
	Luxury					+		+	+																												
Autonomy	No subneed									++				+					+					+													
Survival	No subneed																																	+ (if sick)	+ (if sick)	+ (if sick)	+ (if sick)

Evening

Need	Subneed \ Actions & Motives	Buy at essential shops				Buy at non-essential shops																				be at public leisure place				be at private leisure place				be at home			
Safety	Food safety	+		+	+					Action not available				Action not available				Action not available				Action not available															
	Financial survival	-		-	-	-		-	-																												
	Risk avoidance	-		-	-	-		-	-																	-	-	-	-	-	-	-	-	+	+	+	+
	Conforming to rules					+ (nl)		+ (nl)	+ (nl)																	+ (nl)	+ (nl)	+ (nl)	+ (nl)	+ (nl)	+ (nl)	+ (nl)	+ (nl)				
	Financial safety	-		-	-	-		-	-																												
Belonging	No subneed																									+	+	+	+	+	+	+	+	+	+	+	+
Self-Esteem	Relaxing					+		+	+																	+	+	+	+	+	+	+	+	+	+	+	+
	Luxury					+		+	+																												
Autonomy	No subneed																																				
Survival	No subneed																																	+ (if sick)	+ (if sick)	+ (if sick)	+ (if sick)

Night

Need	Subneed \ Actions & Motives	Buy at essential shops				Buy at non-essential shops																				be at public leisure place				be at private leisure place				be at home			
Safety	Food safety	+		+	+					Action not available				Action not available				Action not available				Action not available															
	Financial survival	-		-	-	-		-	-																												
	Risk avoidance	-		-	-	-		-	-																	-	-	-	-	-	-	-	-	+	+	+	+
	Conforming to rules					+ (nl)		+ (nl)	+ (nl)																	+ (nl)	+ (nl)	+ (nl)	+ (nl)	+ (nl)	+ (nl)	+ (nl)	+ (nl)				
	Financial safety	-		-	-	-		-	-																												
Belonging	No subneed																									+	+	+	+	+	+	+	+	+	+	+	+
Self-Esteem	Relaxing					+		+	+																	+	+	+	+	+	+	+	+	+++	+++	+++	+++
	Luxury					+		+	+																												
Autonomy	No subneed																																				
Survival	No subneed																																	+ (if sick)	+ (if sick)	+ (if sick)	+ (if sick)