The code used by G. Fioretti and A. Lomi in *Emergence of Organizations out of Garbage Can Dynamics*

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Abstract

This report describes the code used in *Emergence of Organizations out of Garbage Can Dynamics (Unpublished Working Paper). A previous publication on this same subject [5] made use of a preliminary, quite different version of this code. This description follows the ODD+D Protocol [14], an extension of the ODD Protocol [9] [10].*

1 Overview

Since its inception in 1972, the Garbage Can Model of Organizational Choice (GCM) by Cohen, March and Olsen [1] is one of the most-often cited models of organizational decision-making. It was presented by means of a combination of a verbal description and a computational model based on a FORTRAN code. In 2008 and 2010, Fioretti and Lomi offered a *NetLogo*-based re-interpretation [6] [7] [8].

In the GCM, hierarchical structures are eventually imposed upon the model. Since in agent-based contexts structures can emerge out of local interactions, we designed an agent-based GCM where organizations emerge out of a sort of "primordial soup" where decisions are made according to GCM principles. This implies focusing on an ecology of organizations instead of a single one.

1.1 Purpose

The GCM aims at highlighting organizational dynamics that do not derive from composition of individual decisions. In this sense, it is opposite to Game Theory or other frameworks where organizational action is a consequence of individual decisions. The GCM shows that, since individuals are embedded in organizations, the behaviour of organizations follows dynamics of its owm.

In doing so, it makes assumptions that are coherent with ecological modeling of organization, which is based on the idea that organizations are characterized by routines that are specified at birth and that are largely invariant with time. We created an ecology of GCMs out of this intuition.

Our organizational ecology of GCMs addresses scholars who are interesting in connecting previously unrelated theoretical streams of organization science. To scholars of organizational ecologies, the GCM brings a microfoundation of organization-level behaviour. To purporters of the GCM, our extension provides an answer to the criticism that, albeit the GCM is a model of organizational decision-making, organizational structure must be exogenously imposed upon it.

1.2 Entities, State Variables and Scales

The GCM understands decision-making as arising out of interactions between four classes of agents:

1. The participants to decision processes, also called decision-makers;

2. The opportunities to make a choice;

3. The solutions that make themselves available;

4. The problems that they eventually face.

In the GCM, participants are characterized by an "ability" as decision-makers, solutions are endowed with "efficiency" and problems have a "difficulty." These variables are used to express the idea that problems can be solved if decision-makers have sufficient ability and make use of a sufficiently efficient solution to solve a problem that is not too difficult for them.

In the original model by Cohen, March and Olsen, both the ability of participants and the difficulty of problems were called "energy." Their names derive from a concept of energy balance: think of an engine that takes as input some form of potential energy (stored, e.g., in the chemical bonds of fuel) to transform it into kinetic energy by means of a process characterized by a degree of efficiency.

Contrary to the original GCM, we think these agents to be embedded in a primordial soup that does not represent one single organization, but rather society at large. We posit that within this primordial soup, whenever isolated participants succeed in making a decision they found an organization, which other participants may join. In this way we generate second level entities that we name "organizations."

Organizations entail two sort of members:

- The *organization founders*, i.e., the participant who initiated the organization;

- The *organization associates*, i.e., those participants who joined the organization at a later stage.

Both founders and associates are organization members, but they are placed at different hierarchical levels. We stipulat that founders are at the top, whereas organization associates are at the bottom of organizational hierarchy. In our model, no possibility exists for organization members to move across hierarchical levels.

1.3 Process Overview and Scheduling

In our model, participants, opportunities, solutions and problems are placed on a torus. A lattice is superimposed on the torus. At each simulation step agents

eventually move by one square during one simulation step, either north, east, west or south of their current position.

Agents meet if they happen to be on the same square. If certain agents meet on the same square, decision eventually ensues. Following the standard GCM, meetings can generate three possible outcomes, two of which are decision styles:

- The first decision style is characterized by the fact that a problem is actually solved. This is called decicion-making *by resolution*. According to the GCM, decisions are made by resolution if: (*i*) At least one participant, one opportunity, one solution and one problem meet on the same square, and (*ii*) the participants to this decision process have sufficient ability, a sufficiently efficient solution is available to them, and the difficulty of the problems that they are called to solve is sufficiently low.

- The second decision style is defined by decisions that are made without any attention to existing problems. It is just sufficient that a participant, a choice opportunity and a solution are there: no problem is solved, because no problem is considered. Cohen, March and Olsen defined these decisions *by oversight* because of their disregard of problems.

The third outcome, *flight*, is no decision in itself. It is rather a means to escape from too difficult a problem if decision-making by resolution is blocked. The GCM (in its Fioretti-Lomi extension [8]) knows two sorts of flights:

- *Flights by Postponement* consist of avoiding difficult problems by postponing decision-making. In the GCM, this amounts to attach a particularly difficult problem to a different choice opportunity.

- *Flights by Buck-Passing* consist of avoiding difficult problems by passing them to colleagues, either maliciously or simply because someone else is better able at solving them. In the GCM, this amounts to attach a particularly difficult problem to a different participant.

Figure (1) depicts a flowchart of postponing decision-making, buckpassing, making decisions by resolution and making decisions by oversight. Flights are eventually enacted in order to unlock blocked decision processes.

Whenever isolated agents succeed to make a decision, they found an organization. In particular, we envisage the following mechanisms for organizational evolutionary dynamics:

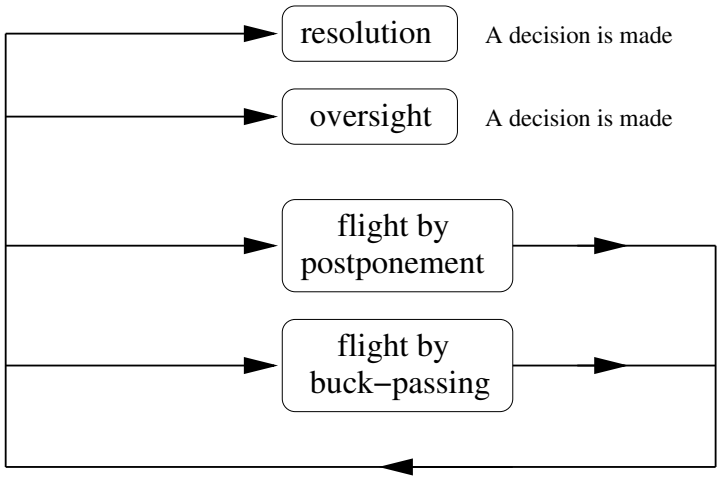

Figure 1: The flow chart of the GCM with two kinds of flight: flight by postponement and flight by buck-passing. Resolutions and oversights mark the end of a decision process, whereas flights make it start again.

Birth If no organization exists, a new organization is born whenever an independent participant makes a decision, either by resolution or by oversight. The participant retains the solution that (s)he employed and this pair 'participant + solution' constitutes the core of the new organization, which stops moving while independent participants continue their random walk. The solution owned by an organization stays in the same location as the organization founder. If at least one organization already exists in the primordial soup, a diffusion mechanism operates as well (see below).

Diffusion Not all independent participants come to the idea of founding organizations. Only those who have met at least one organization try to imitate its founder. Thus, if at least one organization exists in the primordial soup, only those independent participants who have seen organizations in their neighbouring positions create in their turn a new one as soon as they make a decision.

Growth Randomly walking independent participants who happen to jump where a member of an organization is, they join that organization in the role of organization associates. Organization associates place themselves around the organization founder.

Death Organizations are born with an endowment of resources which is equal to their founder's ability. Throughout their existence, every time organizations make a decision by resolution they increase their endowment by the difficulty of the problems that they solved. However, at each time step their endowment decreases by a fixed decay rate multiplied by organization size. If this endowment shrinks down to zero, the organization is dismantled. The members of a dismantled organization become independent participants, their memory is erased so they act as if they never met any organization throughout their life. The solution owned by a dismantled organization becomes publicly available and start its random walk.

Birth, Diffusion, Growth and Death make for a bubbling ecology where organizations continuously appear, grow and suddenly dissolve. In spite of its apparently chaotic, a few reccurring patterns can be observed.

2 Design Concepts

In the GCM, all agents exist independently of one another. Note that the assumption that solutions exist independently of problems is a clear departure from the received wisdom assuming that decision-makers conceive solutions in their minds as soon as they meet specific problems. According to the GCM, solutions are schemes that decision-makers apply to any problem they meet. Organizations make these schemes available to their members. Thus, organizations are not conceived as arising out of some arrangement of individuals endowed with their own preferences but rather socialize their members into an organizational culture epitomized by the solutions that they make available.

In its turn, the ecological approach to organizations starts from the observation that organizations are characterized by a broadly defined "culture", eventually epitomized by its behavioural routines, which is rather invariant throughout organizational life. In other words, at the point when organizations are founded and during a short time thereafter crucial decisions are made, that will stay invariant until the organization, for one or another reason, dies. Organization members, even those at the top of the hierarchy, can only make minor changes to those dogmas and routines that define the very essence of an organization. Recognizing that major changes are impossible, they have no choice apart from leaving that organization to spin-off a new one, characterized by a new culture that in its turn will be invariable with time.

This observation allows to draw a similarity with the ecologies of living organisms, who cannot change their own genome. However, by means of random mutation and recombination of genomes, organisms with novel traits appear and eventually whole new species establish themselves.

By recognizing that the GCM's "solutions" are nothing but a crude representation of organizational routines and cultures, we are able to establish a link between two previously unrelated streams of organizational theory. Notably, this had been impossible to do when the GCM was first published in 1972, because the ecological approach to organizations took off a few years later.

2.1 Theoretical and Empirical Background

With respect to Cohen, March and Olsen's GCM [1], we made efforts at embedding the GCM within organizational literature that appeared after its inception. In particular, in previous publications [6] [7] we interpreted decisions by oversight as due rituals that confirm the legitimacy of an organization as highlighted by the neo-institutional literature [13] [4]. These decisions make sense because any organization is embedded in a wider society, that requires them. As a typical example one may think of a firm that complies with screening procedures in order to obtain a favorable classification by a rating agency, though these procedures do not provide any immediate benefit. More in general, compliance to safety, environmental, fiscal and many other institutional rules helps gaining acceptance, recognition and trust by stockholders, banks, the Government and the general public. Furthermore, in a previous publication [8] we added buck-passing to postponement as a second means to avoid decision-making [12].

With this model we have been able to let GCM-like organizations emerge spontaneously out of a sort of primordial soup. This is quite an important achievement, because the standard GCM depicts decision-making in organizations that have no structure whatsoever unless exogenous hierarchies are imposed on it. For a model of organizations, this was quite a serious shortcoming.

2.2 Individual Decision-Making

Let A_i denote the ability of the ith participant. Let e_j denote the efficiency of the jth solution. Let D_k denote the difficulty of the kth problem. Let us consider a generic opportunity for decision-making and let us denote it by an index l.

A decision is made by oversight if at least one participant and at least one solution are attached to opportunity l, but no problem is attached to l. If several

solutions are available, one of them is selected at random. Neither the ability of participants nor the efficiency of solutions matter in this case. By contrast, the ability of participants, the efficiency of solutions and the difficulty of problems matter when it comes to decisions by resolution.

A decision is made by resolution if at least one participant, at least one solution and at least one problem meet opportunity l on the same square, and if the sum of the abilities of the participants on that square, multiplied by the efficiency of the most efficient solution on that square, is greater than or equal to the sum of the difficulties of the problems on that square:

$$\left(\sum_{I \in I_l} A_i\right) \max_{j \in \mathcal{J}_l} e_j \;\geq\; \sum_{k \in \mathcal{K}_l} D_k \tag{1}$$

where I_l is the set of participants on opportunity l, $\mathcal{J}_l$ is the set of solutions on opportunity l and $\mathcal{K}_l$ is the set of problems on opportunity l.

If condition 1 is not satisfied, decision-making is blocked because of one or several too difficult problem(s). Participants who are stuck in blocked decision processes attempt to get rid of difficult problems by means of a flight. They first of all attempt to get rid of their most difficult problem with a flight by postponement if a freely-moving opportunity jumps on their square. If the remaining problems are sufficiently simple, then a decision is made by resolution. If no problem is left after the flight, a decision is made by oversight. If the remaining problems are still sufficiently difficult to block decision-making, they attempt to get rid of their most difficult problem with a flight by buck passing if a freely-moving participant jumps on their square. If no freely moving opportunities and no freely moving participants jumped where they are, or if they did free themselves of their most difficult problem but the remaining problems are still too difficult to be solved, the cycle repeats.

Figure (2) illustrate this sequence of choices in greater detail. For each square, the program checks first of all if an opportynity is there, then if a participant is there, then if a solution is there and, finally, if a problem is there. This last condition determines whether a decision by oversight is made, or a decision by resolution is attempted. If a decision by resolution is attempted but it proves unfeasible, a flight by postponement is first attempted, then a flight by buck-passing.

This is what happens in the basic one-organization GCM, as well as what independent participants do in our ecology of GCMs. However, for organization members a few qualitications are in order:

- Organization members who make a decision *must* use their organization's

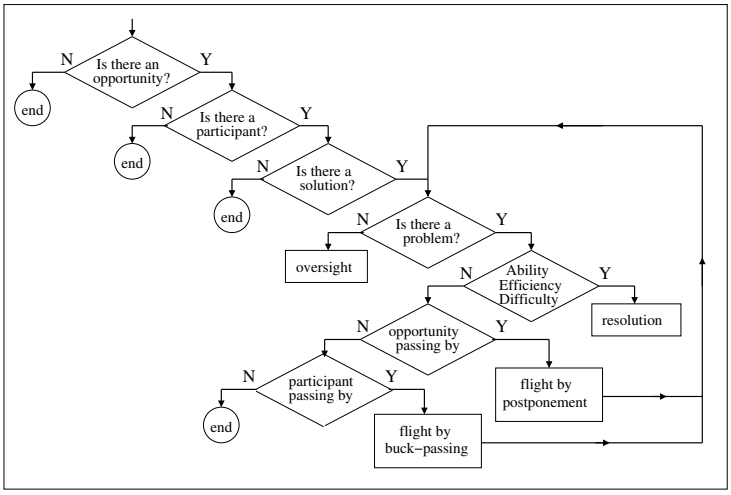

Figure 2: The flow of choices leading to either a decision (by either resolution or oversight) or a flight (by either postponement or buck-passing).

solution even in the rare, but conceptually interesting case that a more efficient solution has become available on their location.

- Randomly walking problems approach organizations along their fringe. Unless organizations are very small, founders are at the centre whereas organization associates are on the fringe. Thus, oranizations associates typically receive more problems to solve than organization founders do. In order to provide a symmetrical bias for decisions by oversight we imposed that opportunities approaching organizations meet the founder first, and later on proceed with thair random walk either meeting organization associates or exiting the organization.

- Opportunities entering an organization's area are allowed to make one single decision before they exit (since organizations own a solution, they would make a disproportionately high number of decisions by oversight once an opportunity entered their area). The one exception is for opportunities that get involved in blocked decision processes.

- Organization members whose decision process is blocked on a very difficult problem can postpone it to any opportunity available in the organization that has not already been charged with a problem and is not involved in a

blocked decision process. Unlike independent participants, they may not need to wait for a randomly moving opportunity to come where they are.

- Organization members whose decision process is blocked on a very difficult problem can pass it on to any other organization member who has not already been charged with a problem (they can pass it to organization members who are stuck in a blocked decision process, anyway). Unlike independent participants, organization members do not need to wait for a randomly moving participant to come where they are in order to pass the buck.

A consequence of the above points is that independent participants have clear advantages in joining organization:

1. Since the founder's solution is always available, organization members are more likely to make decisions than independent participants;

2. Since organization members can postpone difficult problems to any opportunity that is in the organization, flights by postponement are easier for organization members than it is the case for independent participants;

3. Since organization members can pass difficult problems to any other organization members, flights by buck-passing are easier for organization members than it is the case for independent participants;

Thus, independent participants immediately join an organization if they happen to jump on it. However, organizations must make decisions in order to accumulate resources, which they also give away at each simulation step proportionately to their size. Inpependent participants have an incentive to join, organizations grow, but sooner or later they dissolve. Organization members return independent participants and the cycle starts again.

2.3 Learning

No learning takes place in the original GCM by Cohen, March and Olsen [1] as well as in its remake by Fioretti and Lomi [6] [7]. Notably, inability to learn how to make decisions by oversight for those who are good at solving problems is key to the result that efficient organizations are those where those who are not good at solving problems — but possibly able at obtaining legitimacy by means

of decisions by oversight — sit on top of hierarchies. In the real world, upward movement across hierarchical levels occurs through learning of social skills by people who originally had been hired in middle-range positions in order to solve problems.

However, the management literature recognizes that this sort of learning can be extremely difficult, particularly when organization members are called to switch from technical to managerial positions [11]. In the limit, inability to learn the abilities required by new roles leads to the so-called "Peter's Principle" stating that organizations typically promote their members up to the level where they display utmost incompetence [15] [16].

However, our ecology of GCMs exhibits a weaker form of learning. In our model, independent participants come to the idea of founding an organization only after they have met one (unless none is there, in which case the first decision that is ever made gives birth to an organization). Thus, independent participants must learn that it is possible to found organizations before actually founding one.

2.4 Individual Sensing

For the sake of simplicity and without any loss of generality we assumed that for independent participants flights become possible once a freely moving opportunity or a freely moving participant happened to jump on a square where a blocked decision process resides. Thus, blocked independent participants have been assumed to sense freely moving opportunities and participants that are on their square only. However, organization members can postpone difficult problems to any opportunity in the organization, or pass them to any other organization member. Thus, organization members demonstrate organization-wide sensing when it comes to arranging a flight.

Freely moving independependent participants join organizations if they happen to jump on one of their members. Thus, they only sense their own square in this respect.

However, freely moving independent participants sense organizations in their 8 neighbouring squares when it comes to learning that organizations can be founded. Thus, diffusion of the idea of founding organizations occurs through much larger neighbourhoods.

2.5 Individual Prediction

In the GCM, decision-makers make no prediction whatsoever. Generally speaking, the GCM instantiates the KISS approach to agent-based modelling.

2.6 Interaction

Independent participants move randomly in the primordial soup, eventually making a decision if they meet other agents. However, for organization members decision-making is quite more a complicated affair.

We illustrate the algorithms for organization members' behaviour by means of three flow charts. First, Figure (3) illustrates the circumstances that make independent participants join an organization, or eventually found a new one. Subsequently, Figure (4) recapitulates the rationales for making decisions by either resolution or oversight and the consequences for organizations that either accumulate resources or go bankrupt. Finally, Figure (5) illustrates how flights are sought, first by postponement, then by buck-passing, first outside the organization, then outside it. Figure (3) links to a block that pertains to Figure (4), so this block is shown in dashed lines in Figure (3). Likewise, Figure (4) links to a block that pertains to Figure (5) so this block is shown in dashed lines in Figure (4).

Figure (3) starts with independent participants quietly busy with their random walk. Independent participants can possibly meet an organization if they happen to jump on a position where one of its members is, or they can see an organization if they happen to jump on a position that has an organization member in one of its eight surrounding positions. Their random walk continues unless they meet an organization or, if they saw one, their random walk continues until they make a decision and found a new organization.

Figure (4) illustrates the consequences of decisions made by organization members. Since we assumed that problem-solving yields resources whereas obtaining social legitimacy does not, organizational resources may either increase or decrease depending on what decisions are made. If resources shrink down to zero organizations are dismantled, yielding independent participants that feed back into Figure (4).

Figure (5) illustrates flights by organization members. First flights by postponement are attempted, then flights by buck-passing. In each category, organization members first check with independent participants or opportunities that happen to be on the spot where a decision process is blocked. If there are none, then they either pass the buck to other organization members or look for opportu-

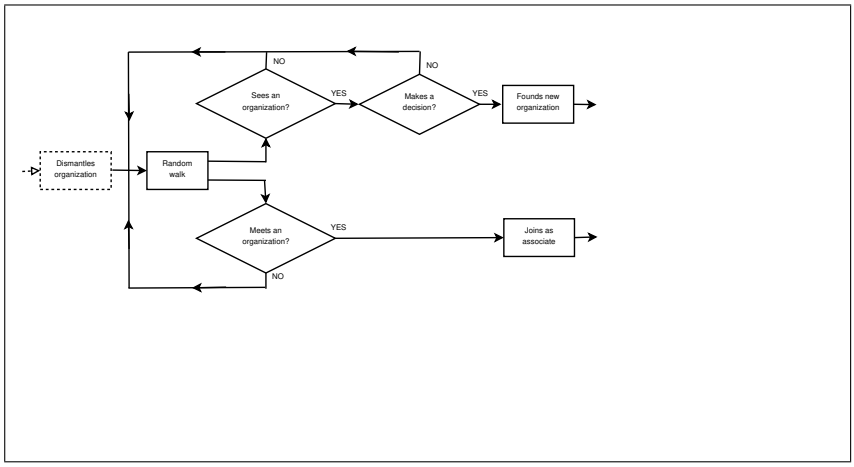

Figure 3: Independent participants join an organization if they happen to jump where an organization is. If they did not jump where an organization member is, but there is one in one of its neighbouring position, then those independent participants have "seen" an organization. Hence, the first time they make a decision they capture the solution that they used and found a new organization.

nities that are at other sites occupied by the organization.

Independent participants who stay independent make decisions by resolutions, decisions by oversight and flights as in Figure (2). Likewise, opportunities, solutions and problems that have no contacts with organizations behave according to the basic GCM.

Figure (6) illustrates the algorithm of opportunities. Opportunities walk randomly anywhere, but special care must be taken as soon as they enter an area where an organization is. Opportunities randomly walking within the area occupied by an organization would make it make a decision by oversight at each step, which clearly makes little sense. In order to avoid this, we imposed that opportunities can only be involved once in a decision process once they entered an organization's area and until they exit it, with the one exception of opportunities to whom a difficult problem is passed. This detail is not shown in Figure (7).

Furthermore, we want decisions by oversight to be preferably made at high hierarchical levels. Thus, if a freely moving opportunity reaches the borders of an organization and no problem is there (thus, no decision by resolution can be made), it immediately jumps to the founder or one of its closest organization members, provided that no problem is with them.

Figure (7) illustrate the algorithm of solutions. Solutions generally walk ran-

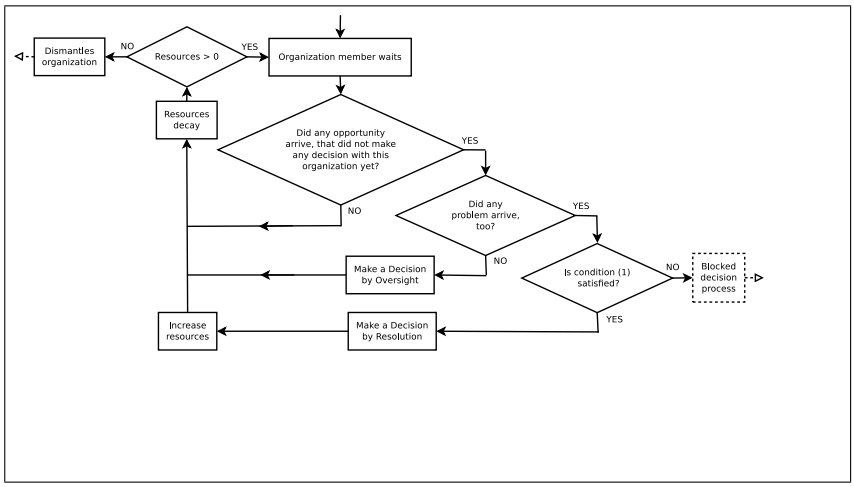

Figure 4: Organization members can only make decisions with opportunities that did not yet make any decision since they entered the organization's area in their random walk. If they find one, they check whether a problem is there, too. If there is, they check whether condition (1) holds. Once all these hurdles have been overcome they can make a decision by resolution, which eventually increases the organization's resources. If they do not, organizational resources decay until the organization is eventually dismantled.

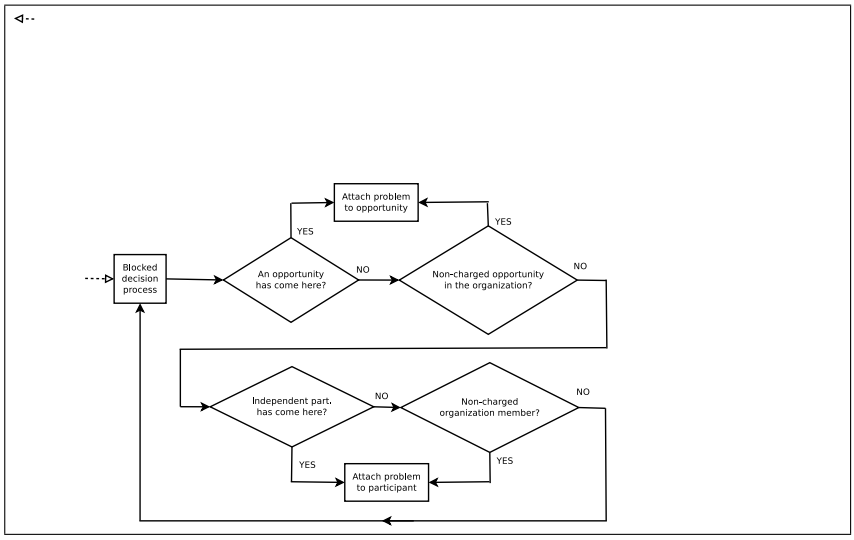

Figure 5: Organization members stuck in a blocked decision process first check whether a second opportunity has come where they are, then whether an opportunity that is not already charged with a problem is anywhere else in the organization. In either case, they attach their most difficult problem to that opportunity. If no opportunity is available, they first check whether by chance an independent participant has come where they are. If none did, they look for an organization member that is not already charged with a problem. In either case, they attach their most difficult problem to another participant.

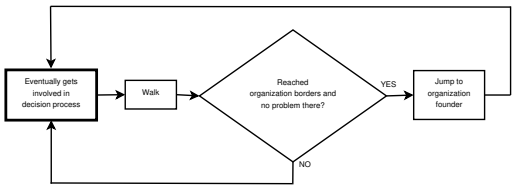

Figure 6: Opportunities walk around and, if they reach the borders of an organization and no problem is there, they jump to the place where the founder is where they either make a decision by oversight, or they continue with their random walk. The square representing decision-making has been depicted with thick borders because it subsumes many details of the decision process.

domly, but they stay put when they are involved in blocked decision processes as well as when they serve as an organization's solutions.

Figure (8) illustrates the algorithm of problems. Since our organizations are made of associates that surround the founder at the centre, randomly walking problems naturally meet organization associates before founders, thereby generating the property that low hierarchical levels typically solve more problems than high hierarchical levels. In other words, organizations filter problems through hierarchical levels in order to let as few as possible reach the top. Thus, it is not necessary to add further mechanisms to problems simply walking around.

2.7 Collectives

In our ecology of GCMs, organizations emerge to be eventually dissolved after some time. Organizations are collective entities generated by the agent-based model.

Emerging organizations have properties that none of their members, taken in isolation, would exhibit. One such property is their greater ability at making decisions due to the fact that a solution is always available, as well as to easier flights onto other organization members and opportunities. This greater ability

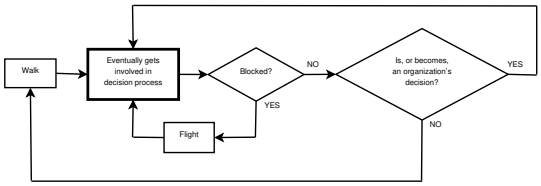

Figure 7: Solutions walk randomly unless they are involved in a blocked decision process or they are an organization's solution. With some simplification, this figure does not distinguish the point in time when a solution is captured by a founder from all the time it remains an organization's solution. The square representing decision-making has been depicted with thick borders because it subsumes many details of the decision process.

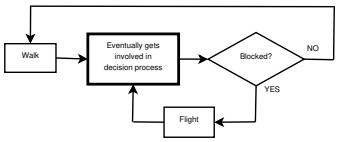

Figure 8: Unless involved in a blocked decision process, problems just walk around. The square representing decision-making has been depicted with thick borders because it subsumes many details of the decision process.

stems from the fact that organization members collaborate on usage of common resources whereas it would not be available to them in isolation from one another.

2.8 Heterogeneity

The GCM has four classes of agents: participants, opportunities, solutions and problems. Opportunities are indistinguishable from one another, whereas participants, solutions and problems differentiate from one another with differential ability, efficiency and difficulty, respectively.

The GCM does not differentiate between abilities in different domains. Similar considerations apply to the efficiency of solutions and the difficulty of problems, respectively.

Organizations are heterogeneous depending on whether they have been founded with a decision by resolution or oversight. Notably, this heterogeneity does not reside within their members.

2.9 Stochasticity

At initialization, stochasticity influences the placement of agents on simulation space. Agents are placed according to a uniform distribution. By selecting an appropriate option, at initialization ability, efficiency and difficulty values can be randomly assigned to participants, solutions and problems, respectively.

Subsequently, stochasticity enters the picture through agents' movements. Specifically, one out of 4 directions (North, South, East, West) is selected by means of a uniform random distribution. Subsequently, agents move forward by 1 square. Furthermore, organization members randomly pick up a colleague or an opportunity within the organization when they want to pass or postpone a difficult problem.

2.10 Observation

The GCM reaches a stable state that is influenced by the parameters that are selected at initialization. Beyond minor stochastical variations, the outcomes of this model are observed in its asymptotic behaviour depending on parameter choice.

Cohen, March and Olsen [1] identified several regularities, some of which were confirmed by Fioretti and Lomi, others discomfirmed [6] [7]. Sobsequently, Fioretti and Lomi pointed to other, additional regularities [8]. Our ecology of GCMs reproduces a substantial fraction of these properties:

1. Decisions by oversight are much more common than decisions by resolution. This outcome applies to any parameter configuration.

2. On top hierarchical levels (organization founders) the ratio of decisions by oversight to decisions by resolution is higher than at low hierarchical levels (organization associates).

3. If flights are enabled, many more decisions are made.

Furthermore, our ecology of GCMs desplayed new properties that pertain to the ecology as a whole. These properties originate from the fact that organizations that are founded with a decision by resolution have a higher probability to overcome the very initial phase of their existence than those that are founded with a decision by oversight. This makes sense, because decisions by resolution are most likely made by participants with a high ability who are making use of a solution with a high efficiency. Later on, one such pair is likely to make many more decisions than low-ability participants coupled with low-efficiency solutions, which is more likely to be the case if the founding decision was made by oversight.

We draw a parallel with a stream empirical research on organizational ecologies that identified two regularities known as *liability of newness* and *liability of adolescence*, respectively. Liability of newness stands for the empirical observation that, in general, organizational mortality decreases with age. Liability of adolescence stands for the empirical observation that for certain organizations, notably high-tech firms and firms with a balanced managerial team, mortality first increases, then decreases with age. It is generally believed that this difference arises from the fact that high-tech firms with balanced managerial teams more often than not have resources that enable them to overcome initial difficulties. Just like in our ecology of garbage cans, those organizations that are founded with a decision by resolution can generally mobilize greater ability and efficiency.

The correspondence between forms of liability and having been founded with a decision by resolution or oversight generates the following properties:

5. The average mortality of organizations that have been founded with a decision by resolution is greater than the corresponding average for organizations that have been founded with a decision by oversight (*liability of adolescence* vs. *liability of newness*).

6. The average size of organizations that have been founded with a decision by resolution is greater than the corresponding average for organizations that

have been founded with a decision by oversight (*liability of adolescence* vs. *liability of newness*).

All these properties can be probed on the output generated by the model. Figure (9) illustrates the monitors of the model:

Decisions by Oversight: The Cumulative Number of Decisions by Oversight;

Decisions by Resolution: The Cumulative Number of Decisions by Resolution;

Postponements Inside: The Cumulative Number of Flights by Postponement towards Opportunities Inside the Organization;

Postponements Outside: The Cumulative Number of Flights by Buck-Passing towards Independent Participants;

Buck-Passings Inside: The Cumulative Number of Flights by Buck-Passing towards Organization Members;

Buck-Passings Outside: The Cumulative Number of Flights by Buck-Passing towards Independent Participants;

Blocked Decisions: The Current Number of Blocked Decision Processes;

Postponed Problems: The Current Number of Problems Postponed to Other Opportunities;

Passed Problems: The Current Number of Problems Buck-Passed to Other Participants;

Ove/Res Founders: The Number of Oversights to Number of Resolutions Ratio for Organization Founders;

Ove/Res Associates: The Number of Oversights to Number of Resolutions Ratio for Organization Associates;

Ove/Res Independents: The Number of Oversights to Number of Resolutions Ratio for Independent Participants;

Furthermore, three graphs depict:

- Current values of decisions and flights;

Decisions by Oversight	Postponements Inside	Buck-Passings Inside
1432	29	123
Decisions by Resolution	Postponements Outside	Buck-Passings Outside
109	185	82
Blocked Decisions	Postponed Problems	Passed Problems
9	25	17
% Founders Deciding	% Associates Deciding	% Independents Deciding
12.147683885937134	1.3061013314213126	0.38340829823229766
Ove / Res Founders	Ove / Res Associates	Ove / Res Independents
55.833333333333336	6.5	9.771428571428572

Figure 9: Top to bottom, left to right: The Cumulative Number of Decisions by Oversight (Decisions by Oversight), The Cumulative Number of Flights by Postponement towards Opportunities Inside the Organization (Postponements Inside), The Cumulative Number of Flights by Buck-Passing towards Organization Members (Buck-Passings Inside), The Cumulative Number of Decisions by Resolution (Decisions by Resolution), The Cumulative Number of Flights by Postponement towards Opportunities Outside the Organization (Postponements Otside), The Cumulative Number of Flights by Buck-Passing towards Independent Participants (Buck-Passings Outside), The Current Number of Blocked Decision Processes (Blocked Decisions), The Current Number of Problems Postponed to Other Opportunities (Postponed Problems), The Current Number of Problems Buck-Passed to Other Participants (Passed Problems), Average Percentage of Organization Founders Making a Decision (% Founders Deciding), Average Percentage of Organization Associates Making a Decision (% Associates Deciding), Average Percentage of Independent Participants Making a Decision (% Independents Deciding), The Number of Oversights to Number of Resolutions Ratio for Organization Founders (Ove/Res Founders), The Number of Oversights to Number of Resolutions Ratio for Organization Associates (Ove/Res Associates), The Number of Oversights to Number of Resolutions Ratio for Independent Participants (Ove/Res Independents).

- Current aggregated ability, efficiency and difficulty, respectively;
- Current number of organizations founded with a decision by resolution and oversight, respectively;
- The size distribution of organizations;
- The mortality distribution of organizations.

Outputs can be printed on file by selecting the switch *print?*. Outputs are printed on the following files:

- oversights.txt
- resolutions.txt
- decision-efficiency.txt
- decisions.txt
- postponements-outside-organization.txt
- postponements-inside-organization.txt
- buck-passings-outside-organization.txt
- buck-passings-inside-organization.txt
- time-series-random-independents.txt
- time-series-headed-independents.txt
- time-series-O-organizations-members.txt
- time-series-R-organizations-members.txt
- time-series-O-organizations.txt
- time-series-R-organizations.txt
- average-number-organizations.txt
- founders-making-decisions.txt

- associates-making-decisions.txt
- independents-making-decisions.txt
- ove-res-founders.txt
- ove-res-associates.txt
- ove-res-independents.txt
- O-size-distribution.txt
- O-size-distribution-mean.txt
- R-size-distribution.txt
- R-size-distribution-mean.txt
- O-mortality-distribution.txt
- O-mortality-distribution-mean.txt
- R-mortality-distribution.txt
- R-mortality-distribution-mean.txt
- blocked-life-lengths.txt
- blocked-mean-life-lengths.txt

3 Details

Our GCM is based on *NetLogo* 6.1.1. *NetLogo* is available at: <http:// ccl.northwestern.edu/ netlogo>. Details on our model can also be found in the "Info" section of my *NetLogo* model.

This code is also available on the *NetLogo* web site under the rubric *NetLogo User Community Models*, April 2020 (forthcoming).

3.1 Implementation Details

Agents are placed on a torus upon which a 50×50 grid is superimposed. This space appears as a black square. Agents are represented as follows:

Independent Participants are represented by yellow stylized persons. Insofar they have never seen an organization, their orientation is assigned randomly. As soon as they see an organization (and get prepared to found a new one) they place themselves vertically. Independent participants move randomly, except for those who are involved in a blocked decision process.

Organization Members are represented by grey, vertically placed stylized persons. Organization members do not move. Organization founders distinguish themselves from organization associates because a solution stays with them.

Opportunities are represented by orange squares. Opportunities move randomly, except for those that are involved in a blocked decision process.

Solutions are represented by red circles. Solutions move randomly except for those that are owned by organization founders and those that are involved in a blocked decision process.

Problems are represented by violet triangles. Problems move randomly, except for those that are involved in a blocked decision process.

The square where a decision by resolution is made becomes lime green for one time step. The square where a decision by oversight is made becomes sky blue for one time step. The square where agents are stuck in a blocked decision process is white for all the time the decision process remains blocked.

While postponed problems and the opportunities to which they are coupled are moving around, the square on which they are takes the colour brown. The same happens to buck-passed problems and the participants to which they are bound.

Organization associates are placed around organization founders. Thus, large organizations display a roughly circular shape around the founder and the solution that all organization members must employ.

Figure 10: Top to bottom, left to right: Agents are placed on the torus (Set Up), The simulation proceeds by 1 step (Go Until), The simulation proceeds until the end step (Go Until), The end step (stop-at), The number of agents per each breed (agents-per-breed), Enables organizations to emerge from interactions (organizations?), The decay coefficient of organizations' resources (decay), The minimum value of ability (min-ability), The minimum value of efficiency (min-efficiency), The minimum value of difficulty (min-difficulty), The maximum value of ability (max-ability), The maximum value of efficiency (max-efficiency), The maximum value of difficulty (max difficulty), Enables flights by postponement (postpone?), Enables flights by buck-passing (buck-pass?), Prints data on output files (print?).

3.2 Initialisation

Like all *NetLogo* models, also the GCM is initialized with a **Set Up** button. Subsequently, one can either run it stepwise by pressing the **Go Step** button to advance it by 1 step only, or let it run until the number of steps specified by the slider **stop-at** by pressing the **Go Until** button. Several other sliders and switches follow. Figure (10), top to bottom, left to right, shows the buttons and parameters of the model:

Set Up: Agents are placed on the torus;

Go Step: The simulation proceeds by 1 step;

Go Until: The simulation proceeds until the step specified by **stop-at**;

stop-at: The end step if the **Go Until** button is pressed;

agents-per breed: The number of agents per breed (which implies that the number of participants is equal to the number of opportunities to the number of solutions to the number of problems);

organizations?: Enables organizations to emerge from interactions;

decay: The decay coefficient of organizations' resources, which multiplies organization size;

min-ability: The minimum value of ability;

min-efficiency: The minimum value of efficiency;

min-difficulty: The minimum value of difficulty;

max-ability: The maximum value of ability;

max-efficiency: The maximum value of efficiency;

max-difficulty: The maximum value of difficulty;

postpone?: Enables flights by postponement;

buck-pass?: Enables flights by buck-passing;

print?: Prints data on output files.

Typically, this model is run with 200 agents per breed, the decay coefficient at 0.07, ability and difficulty in a range $[0.0, 10.0]$, efficiency in a range $[0.0, 1.0]$. In general, $5,000$ time steps ensure that steady-state dynamics is sustained for a long time.

3.3 Input Data

The ecology of GCMs requires no input data.

3.4 Submodels

There are no submodels.

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