ACTISS
ACTION FOR COMPUTATIONAL THINKING IN SOCIAL SCIENCES

THEMATIC COURSE

Why do ghettos form in a tolerant society? Schelling's model and the introduction of cellular automata

MATERIALS FOR WEEK 2

Cellular automata

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Why do ghettos form in a tolerant society? Schelling's model and the introduction of cellular automata

MATERIALS FOR WEEK 2

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ACTION FOR COMPUTATIONAL THINKING
IN SOCIAL SCIENCES
Project number: 2018-1-PL01-KA203-050951

Co-funded by the
Erasmus+ Programme
of the European Union

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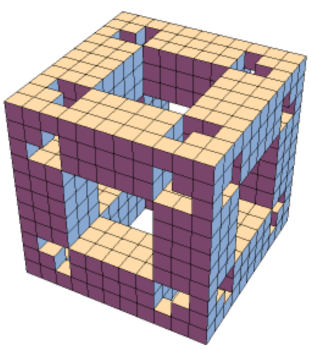
OVERVIEW OF THIS WEEK'S MATERIALS

This week we will concentrate on the world of cellular automata models and most important terms. You will also learn what segregation might have to do with the game of life (and what it exactly is), forest fires and gossip.

Keywords:
Cellular Automata, cells, iteration, grid, borders of grid, attributes of an agent, Game of life, forest fire, neighbourhood

STRUCTURE OF THIS WEEK'S MATERIALS



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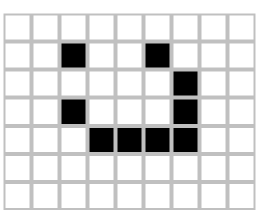

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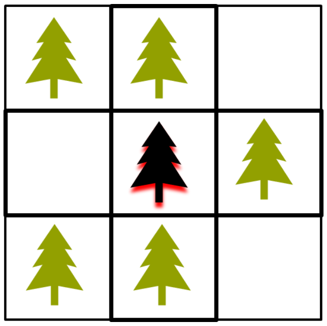

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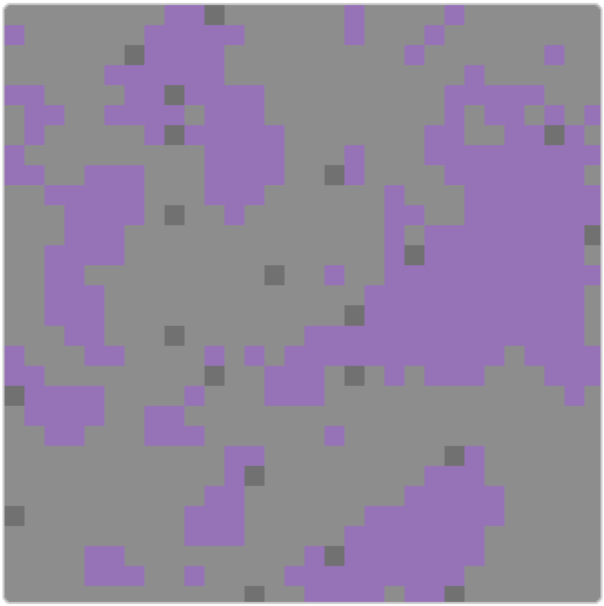
EDUCATIONAL MATERIALS

1. Cellular automata - ARTICLE



Source: ACTISS

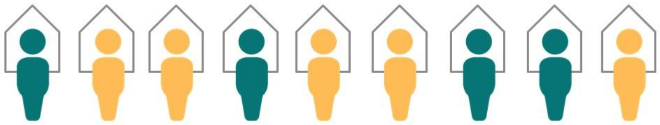
Schelling's model - apart from the fact that it is interesting as itself and refers to important social problems - is an example of a wider group of models called Cellular Automata. They are a type of Agent Based Models. John von Neuman is considered to be the creator of cellular automata, a significant contribution to his work came from his collaboration with the mathematician Stanislaw Ulam, who came from the famous Lvov school of mathematics. In the life sciences it is used to simulate many phenomena such as crystal formation, erosion, diffusion and fluid dynamics (Hagselmann, Flache 1998 p. 29).

Typical for them is simplicity and concentration on relations between agents in space. In this part of the course we will focus on them. What is interesting, when Schelling was working on his models, nobody called it cellular automata and for linear one he didn't even use a computer!

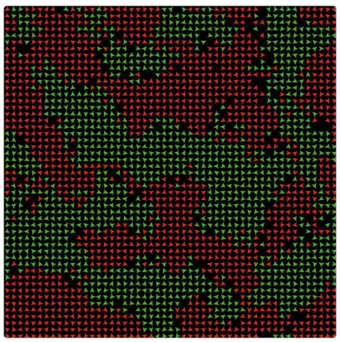
A cellular automaton must consist of three elements:

- a grid of cells
- a set of single cell states
- a rule defining the state of a cell at one time moment depending on the state at time previous moment of the cell and the cells surrounding it (neighbours).

In the second Schelling's model this grid was similar to chessboard - a two-dimensional grid with square shaped cells. In the first one (with houses along the street) we had a one-dimensional square shaped grid.

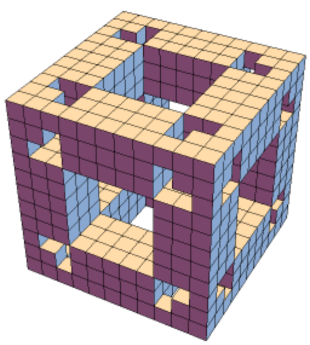


1-D Schellings Model; Source: ACTISS



Source:Schelling Model

However it can be also three-dimensional and cells can have different shapes.



3-D cellular atomata; Source: https://demonstrations.wolfram.com/3DTotalisticCellularAutomata/

Cells were constructed in a very simple way. Inhabitants of our villages could had colour, could be happy from location or not and has some tolerance level (common for a colour). Neighbourhood is defined as 8 nearest cells. The rules say: look around, if the proportion of cells in your colour is lower than your tolerance level, you should move to a better location. What is common for cellular automata, is the fact that rules (simler, or more complicated) base on the state of a cell and its neighbours in some time moment and transfer them to the next time moment. As a time moment we can imagine any repeatable measure of passing time - minutes, days, years but also (as in Schelling model) rounds or iteration.

2. Block of cells - DISCUSSION

Block of flats Source: https://commons.wikimedia.org/

Imagine that we are modeling segregation in a residential block... What kind of grid would be appropriate?

3. Neighbourhood - ARTICLE

One of the decisions that researchers have to make is the shape and size of the neighbourhood. It's important because generally in the base of the neighbourhood the whole model dynamic is built.
In the case of Schelling 2-dimensional model every house had 8 neighbours. In the literature it's called "Moore's neighbourhood".

Morre’s neighbourhood, ACTISS

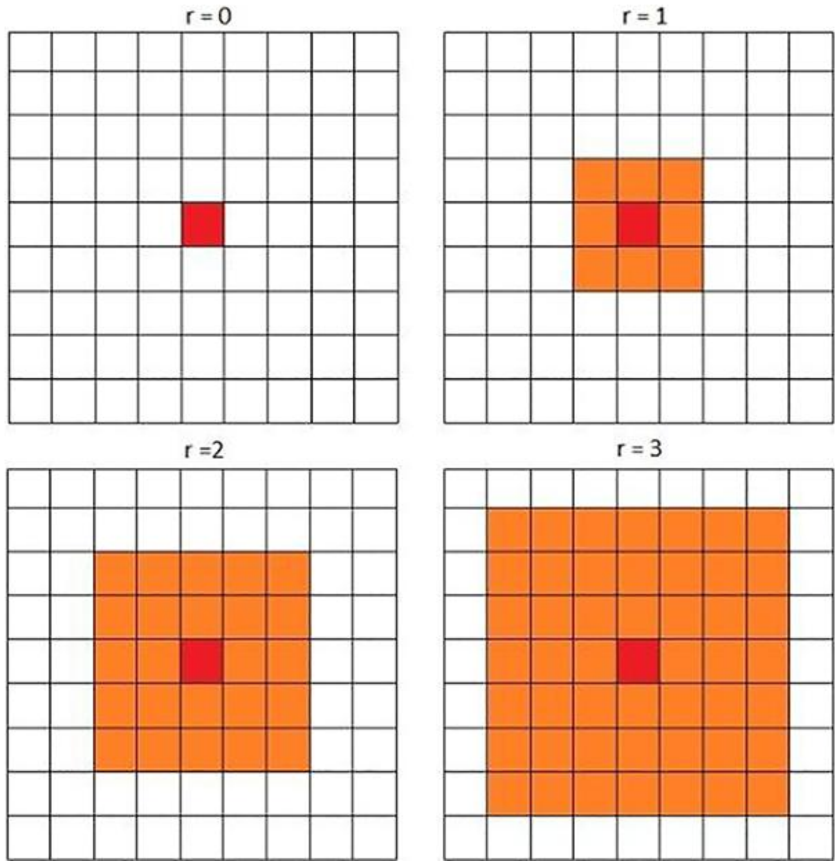
But, we can imagine a decision, that only 4 neighbours better fit the idea of segregation. Imagine the model of relations in houses with gardens. Maybe we have a relationship with our neighbours, who are only bordered by the corner of the garden? If so, the model could assume that there are only four neighbours. Such a neighbourhood also has its name "von Neumann's neighbourhood".

Von Neumann’s neighbourhood, ACTISS

Of course, neighbourhood can be also wider. Let’s imagine, that we will extend the number of neighbors by another row. In the case of grid used for Schelling’s model it can look as follow: Formally we will call it: extended von Neumann’s neighbourhood for houses on square-shape grid.

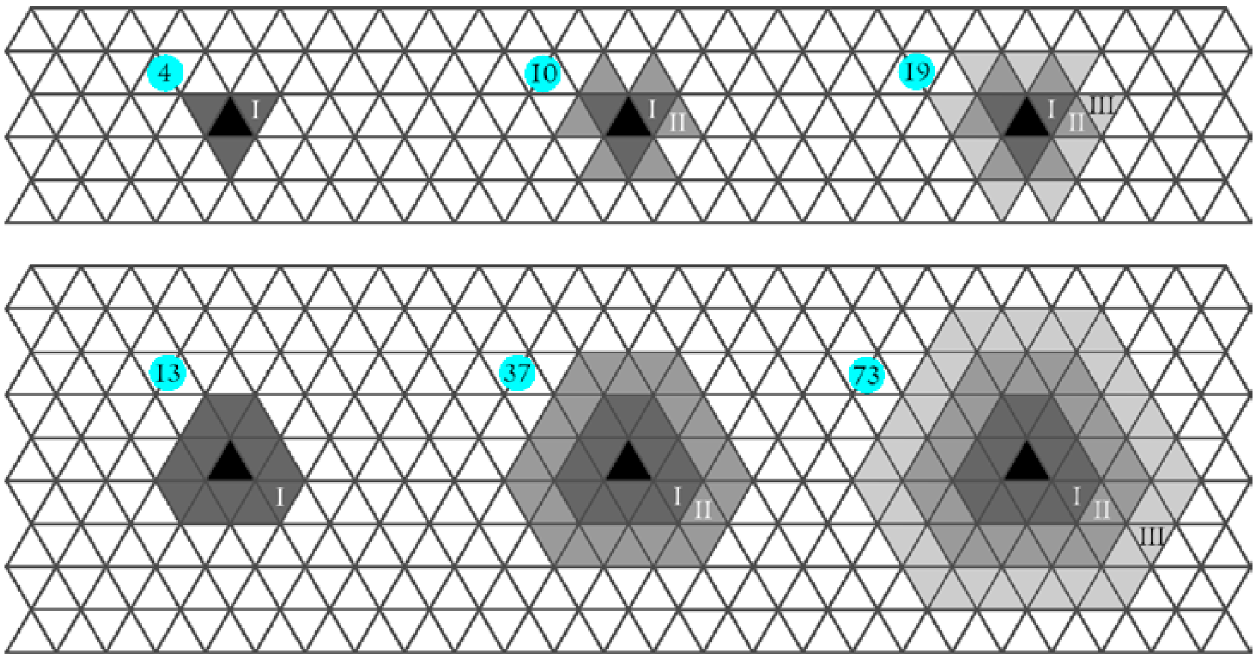
Source: ACTISS

Of course not all grids are full of houses. In more general cases neighborhoods for squared grid can look like this. And yes, here we have Morre's neighbourhoods - basic and extended; "r" on the pictures (r=1; r=2, etc.) is an abbreviation of the word radius, which here says how many additional consecutive rows of neighbors we take into account.



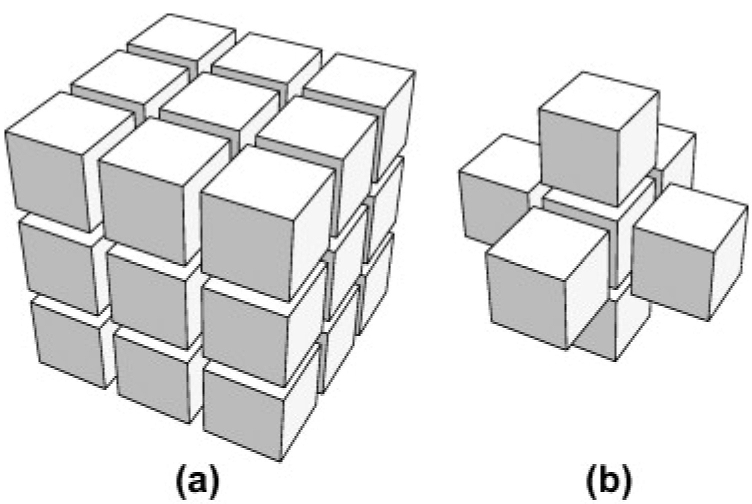
Source: Yousefi, Milad et al. Simulating the behavior of patients who leave a public hospital emergency department without being seen by a physician: a cellular automaton and agent-based framework. Brazilian Journal of Medical and Biological Research [online]. 2018, v. 51, n. 3 [Accessed 11 February 2022] , e6961. Available from: <https://doi.org/10.1590/1414-431X20176961>. Epub 11 Jan 2018. ISSN 1414-431X. https://doi.org/10.1590/1414-431X20176961.

However, deependly on the shape of grid neighborhoods can look in many different ways. Here you have an example how different neighbpourhoods (less and more extended) can look for trangular grid. In the first line are von Neumann's neighbourhoods, in the seckond Morre's, and I, II, II means subsequent circles of neighbors. Blue numbers are a summarized numbers of whole neighborhood with surrounded cell (for example: cell and her 3 neighbours gives 4, cell and her 3 nearest and 5 more distant neighbours gives 10 etc.)



Source: Zawidzki, Machi. (2011). Application of Semitotalistic 2D Cellular Automata on a Triangulated 3D Surface. International Journal of Design & Nature and Ecodynamics. 6. 34-51. 10.2495/DNE-V6-N1-34-51.

And .. for dessert, some spectacular examples of Morre's (a) and von Neumann (b) neighborhoods for three-dimensional grids.



Source: Pérez-Brokate, C. F., Di Caprio, D., Féron, D., de Lamare, J., & Chaussé, A. (2017). Pitting corrosion modelling by means of a stochastic cellular automata-based model. *Corrosion Engineering, Science and Technology*, *52*(8), 605-610.

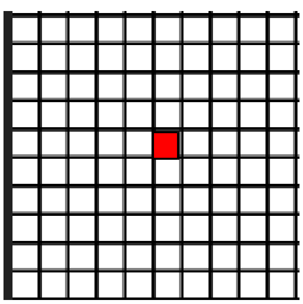
4. Your neighbourhood - DISCUSSION

Source: https://kinomuranow.pl/film/pat-i-mat

Think about your neighbours. Who are the most important for you? Who do you meet most often? How would you translate this relations into the neighbourhood construction?

5. Neighbourhood - QUIZ

We have cellular automata with square grid 10x10.



1. How many neighbours will have a red cell (we don't count her), when we will draw von Neuman's neighbourhood with radius = 4?

a) 4
b) 8
c) 16
d) 80

2. How many neighbours will have a red cell (we don't count her), when we will draw Morre's neighbourhood with radius = 3?

e) 48
f) 12
g) 8
h) 10

5. Game of life - ARTICLE

Lets look at another cellular automaton called "**Game of life**".

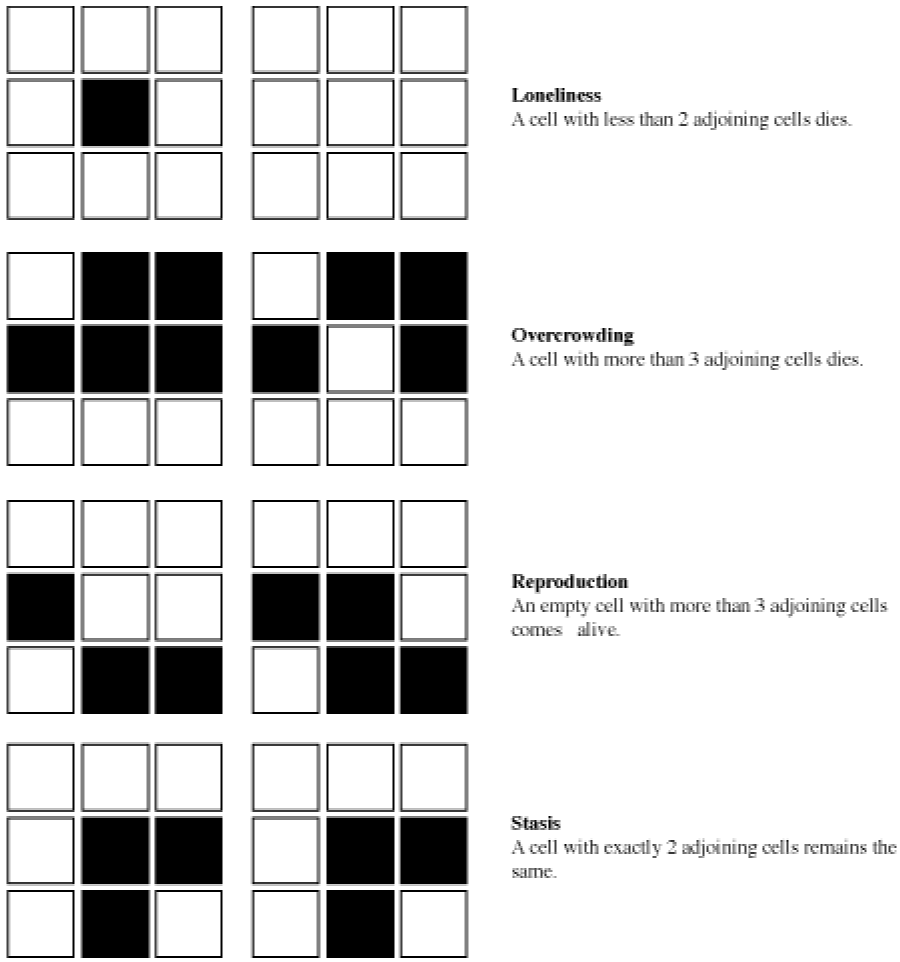
First please imagine some organisms that live in a resource-limited environment, such as for example savannah antelopes. If there are not enough of them in the drove, predators will eat them. If their density in some areas is too high, there will be too little grass for them. If the density and size of drive is just right, they will be fed and safe, so they will reproduce.

Let's represent it as a CA model.

Start from the grid - the same as in two-dimensional Schelllings model - two-dimensional with square grids. Here cells will have two possible states - be alive or dead (as it generally happen in real life ;)). Each cell has eight neighbours.
Cell is going to be alive if she has the proper number of neighbours. Neighbourhood is also familiar to you - every cell has eight neighbours.
Now it's time for rules. At each step in time, the following transitions occur:

1. If cell has fewer than two or more than three live neighbours, she will die in the next round (loneliness or overcrowding)
2. If cell has two or three live neighbours, she will be alive in the next round (stasis)
3. Dead cell with three exactly three live neighbours will come alive in the next round (reproduction)

Rule 1 corresponds to the situation of an appropriate drive size, the second one is a case of too small or too big drive size. Rule three can be interpreted as the possibility of reproduction, where deceased individuals are replaced by a new generation. On the picture all rules are drawn - please follow them carefully.



Source: https://github.com/alella/GOL

6. Play with the game of life - EXERCISE/INVESTIGATE

Open "LIFE" and test it.

Instruction
Clicking on a cell will "animate" it. Clicking again will do the opposite. Draw a layout this way, then start the automaton. One move - change by one step; 5, 10 - similarly. You can also select "start the presentation" - more steps, until the layout stops.

https://www.mimuw.edu.pl/~ajank/zycie/

Now you can see the movement and “life”of cells.

Check several combinations, play a bit.

Please start with empty screen and check some of those combinations. What is happen when you start the simulation? Maybe you will find combinations which have similar characteristics?

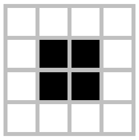
7. Conway and game of Life - VIDEO

Watch the video, where John Conway is talking about his game.

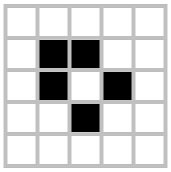
Another one :

8. Play with the game of life part 2 - John Convay and his typologies - INVESTIGATE

In the video Conway was talking about some typologies od possible cells combinations. Do you know that they have even some names? Please try several those combinations and look what is happen:
a)

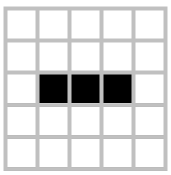


Block

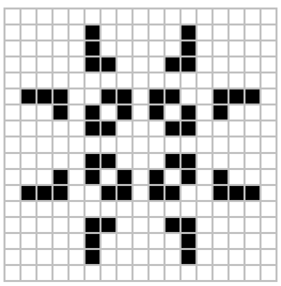


Boat

b)

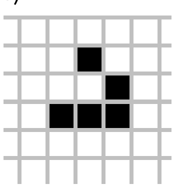


Blinker

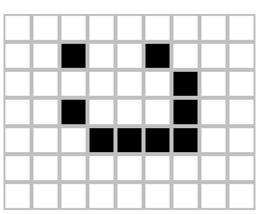


Pulsar

c)



Glider



Light-weight spaceship

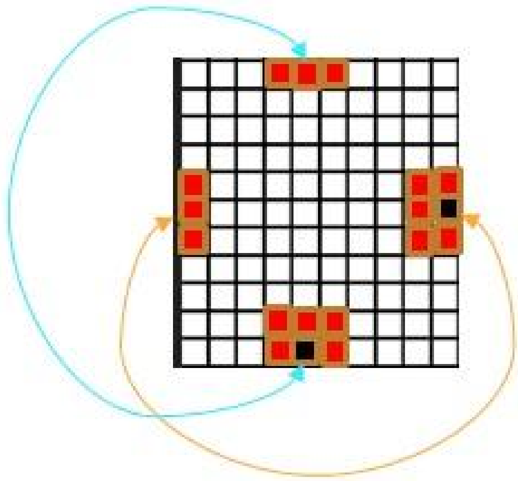
Type a) are called “stable”, type b) - Oscillators and c) - Spaceships.

Source of pictures: https://en.wikipedia.org/wiki/Conway%27s_Game_of_Life

9. Borders of a grid - ARTICLE

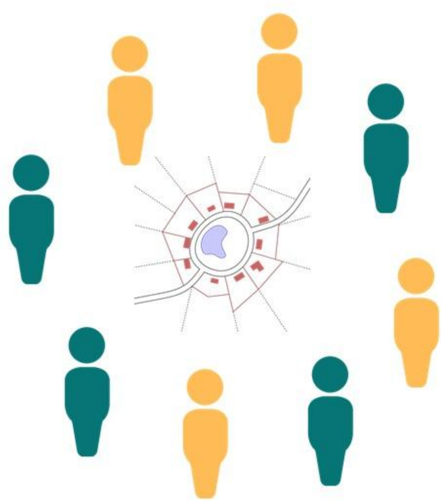
Source:
https://upload.wikimedia.org/wikipedia/commons/thumb/8/85/Granica_pa%C5%84stwa_w_okolicy_Lipszczan_grudzie%C5%84_2007.jpg/450px-Granica_pa%C5%84stwa_w_okolicy_Lipszczan_grudzie%C5%84_2007.jpg?20071007120940

Now please check what is happen in Game of Life when you put some figures near the border or corner of a grid. How is the game working here? Yes, generally you will feel that there is a border here. In this game there are no special rules for corners. But imagine, how “glider” would move if the game would be programmed in such a way that cells next to he borders would have really 8 neighbours like on the picture



Source: ACTISS

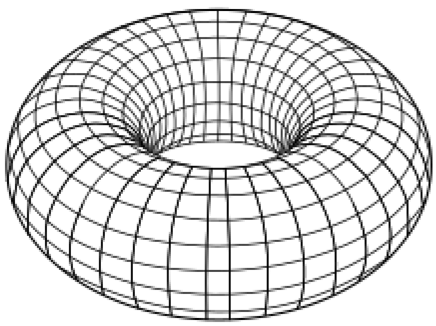
Yes, you are right. The “glider” could move around and around.
Generally deciding what to do with the borders of a grid is one of decisions that the author of a model has to make. It generally depends on the problem which we want to simulate. If we model a city (like in Schelling) there is no sense to construct special rules for those next to the border. It’s also no sense in “artificial” additional Neighbours. However, let's come back to one-dimensional Schelling. If we connect the ends of our street we will got a circle, which can be a good model of houses located around the square.



Source: ACTISS

Try to imagine which shape we will get if we perform a similar procedure with the square touching its edges.

Source: https://commons.wikimedia.org/wiki/File:Christmas_doughnut_(15456531431).jpg



Source: https://pl.wikipedia.org/wiki/Torus

Yes, you are right. It looks like a bagel or donut. Matematician will call his shape a torus. In 1-dimentional model (like linear model) it just takes the shape of a circle.

9. Borders of a grid - QUIZ

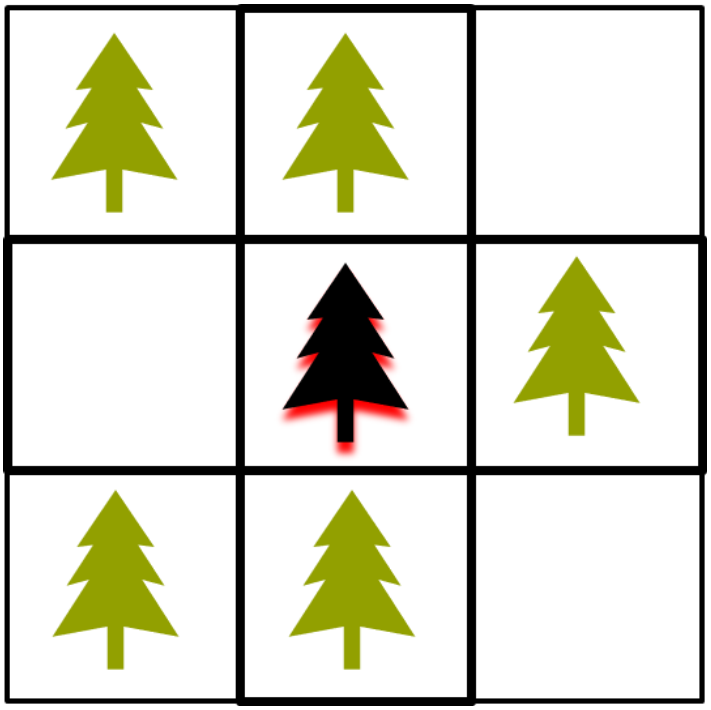
Please take a peace of gridded paper and a pen. Draw a grid 10x10. Than try to draw neighbours of a cell located at the corner for:

a) Von Neumann's neighbourhood
b) Moor's neighbourhood
c) Extended von Neumann's neighbourhood with r=2

10. Forest fire - ARTICLE

Models with features of cellular automata are numerous. Explore another classic: **the forest fire model**.

The fire starts on the left edge of the forest, and spreads to neighbouring trees. The fire spreads in four directions: north, east, south, and west.



The fire must have trees along its path in order to advance. That is, the fire cannot skip over an unwooded area (patch), so such a patch blocks the fire's motion in that direction.

11. Forest fire - neighbourhood - QUIZ

Do you remember how this type of neighbourhood was called?

a) Moor's neighbourhood
b) Von Neumann's neighbourhood
c) Schelling's neighbourhood
d) Conway's neighbourhood

12. Forest fire - basic model - EXERCISE

NETLOGO - BASIC MODEL

http://www.netlogoweb.org/launch#http://www.netlogoweb.org/assets/modelslib/IABM%20Textbook/chapter%203/Fire%20Extensions/Fire%20Simple.nlogo

First choose "setup" - you will get the basic setup. You will see a lot of green and black dots. Here the green cell is a tree, and black is a space between trees.
You also have a slider with "density". Default is 78% - less start from that.
Select "go" and start a fire.

What is happen?

Now start a real play - change a density; check how it will work around 5%, 25%, 50%, 90%.

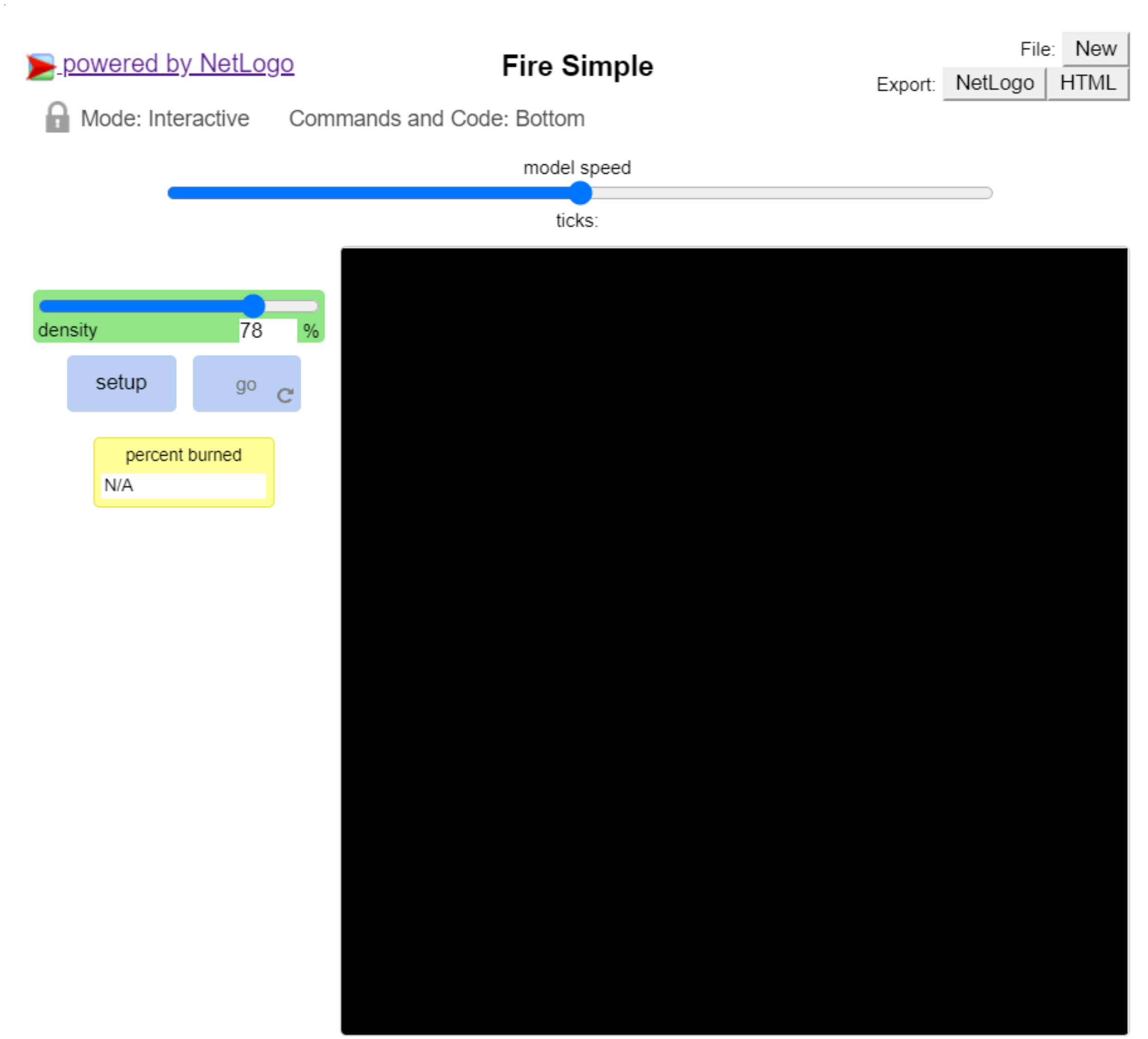
Ok. You probably observed that higher density gives faster spread of fire. Very low density very low density blocks the fire.

In this exercise, you will experiment with the forest and the fire, and observe the impact of the density of the forest.

This basic model allows users to play around with one parameter: The DENSITY slider controls the density of trees in the forest. At each timestep or tick, you can experiment with the density and see how the density affects the fire.

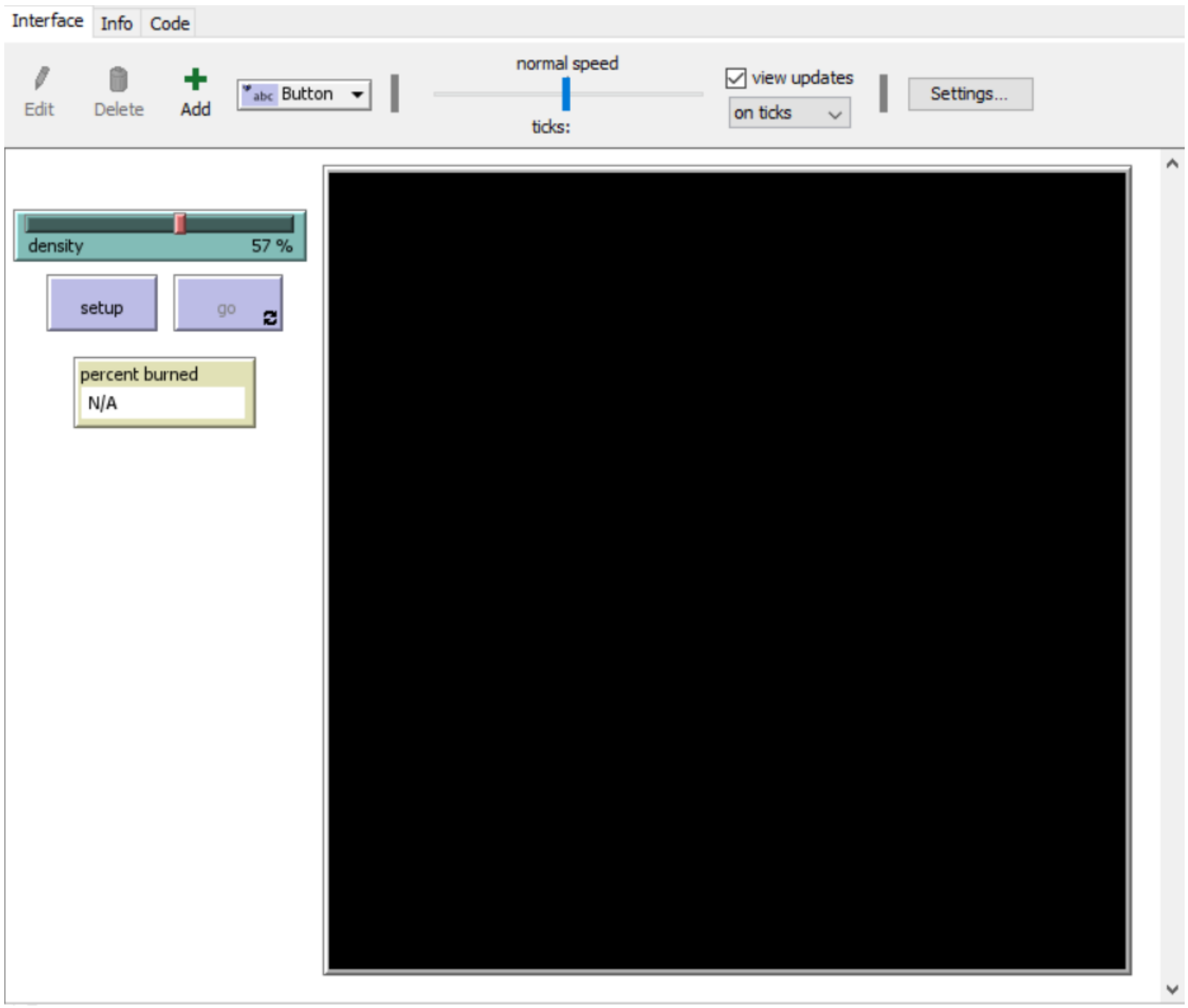
Setting up

To start the experiment click on LINK.



The layout of the online version of the Fire Simple model

Alternatively, you can also download the [Fire Simple model]. For this, go to the online model, click on **export netlogo**, and store the file **Fire Simple.nlogo**. If you have not done so, you can download [Netlogo]. Next, open your netlogo, go to “file”, “open” and find the “Fire Simple.nlogo” in the folder where you saved it.



The layout of the download version of the Fire Simple model

What do you see?

Launching the model shows you an empty model that needs filling first. Press ‘Setup’ to do that.

This model simulates the spread of a fire through a forest. The fire starts on the left edge of the forest, and spreads to neighboring trees. The fire spreads in four directions: north, east, south, and west.

Clicking on **go** will show a one-time step, clicking on **go**↻ will run the model continuously. (to stop the run, click this button twice). You can observe how the spread of fire changes throughout time. The simulation stops once the fire cannot spread anymore.

Things to explore

Starting with the basic setup, the model shows you how the fire moves and stabilizes under the default condition. Run this default setting of the simulation model multiple times by clicking on **go**↻ repeatedly, and observe the stability of the outcomes. **What do you see happening with the fire?**

We encourage you to experiment with different settings of density (ex. 5%, 25%, 50%, 90%). What do you observe when you increase or decrease the density? When is the breaking point?

13. Forest fire - advanced model nr 1 - EXERCISE

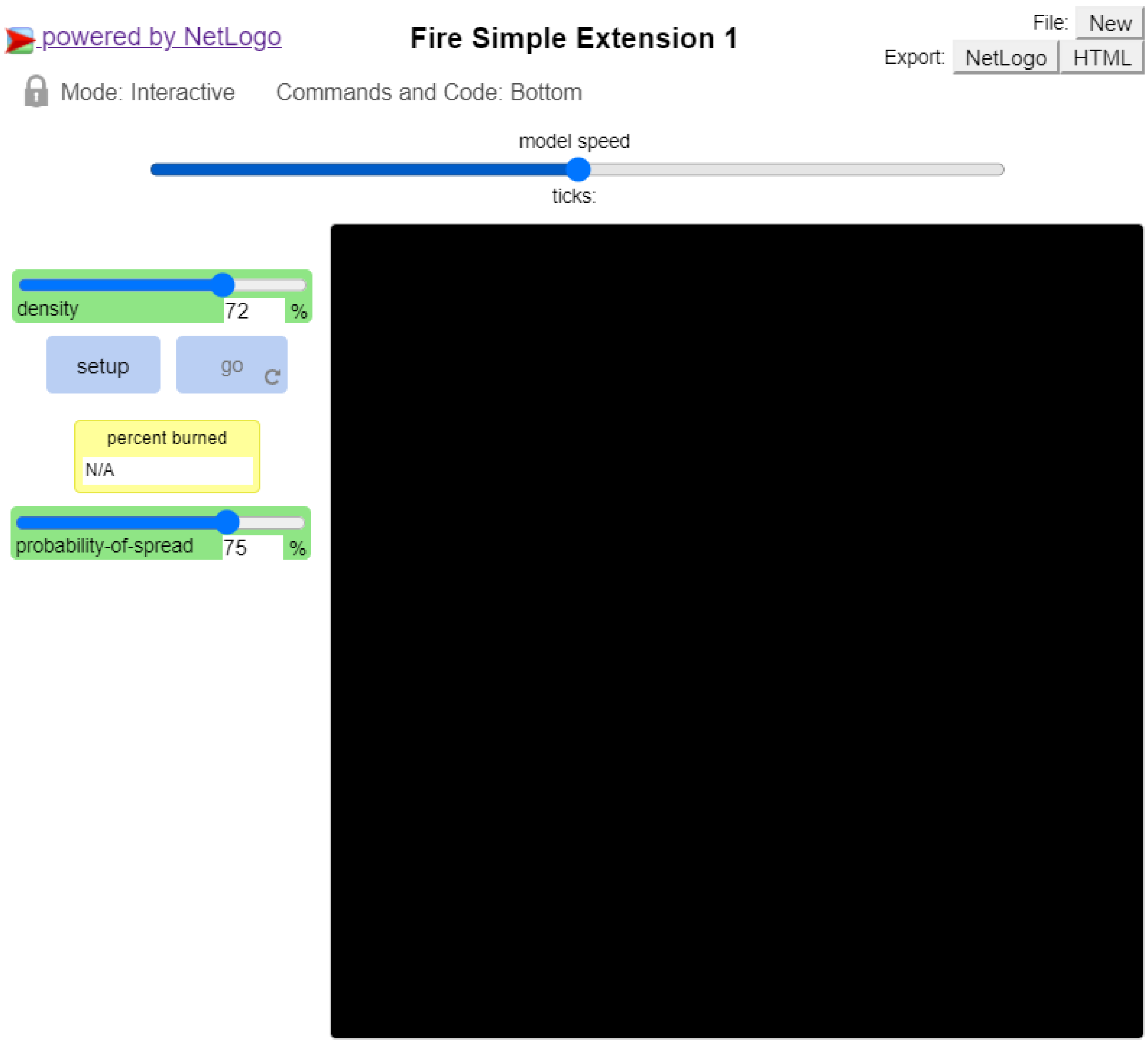
As you could probably see the first model was very, very simple. Now lets try something a bit more advanced. Here we will add a probability of spread.
http://www.netlogoweb.org/launch#http://www.netlogoweb.org/assets/modelslib/IABM%20Textbook/chapter%203/Fire%20Extensions/Fire%20Simple%20Extension%201.nlogo

In this exercise, you will experiment with the forest and the fire, and observe the impact of the density of the forest and the probability of spread.

This model allows users to play around with two parameters: The DENSITY slider controls the density of trees in the forest and the PROBABILITY OF SPREAD slider affects how the fire spreads from patch to patch. At each timestep or tick, you can experiment with the density or probability of spread and see how those parameters affect the situation.

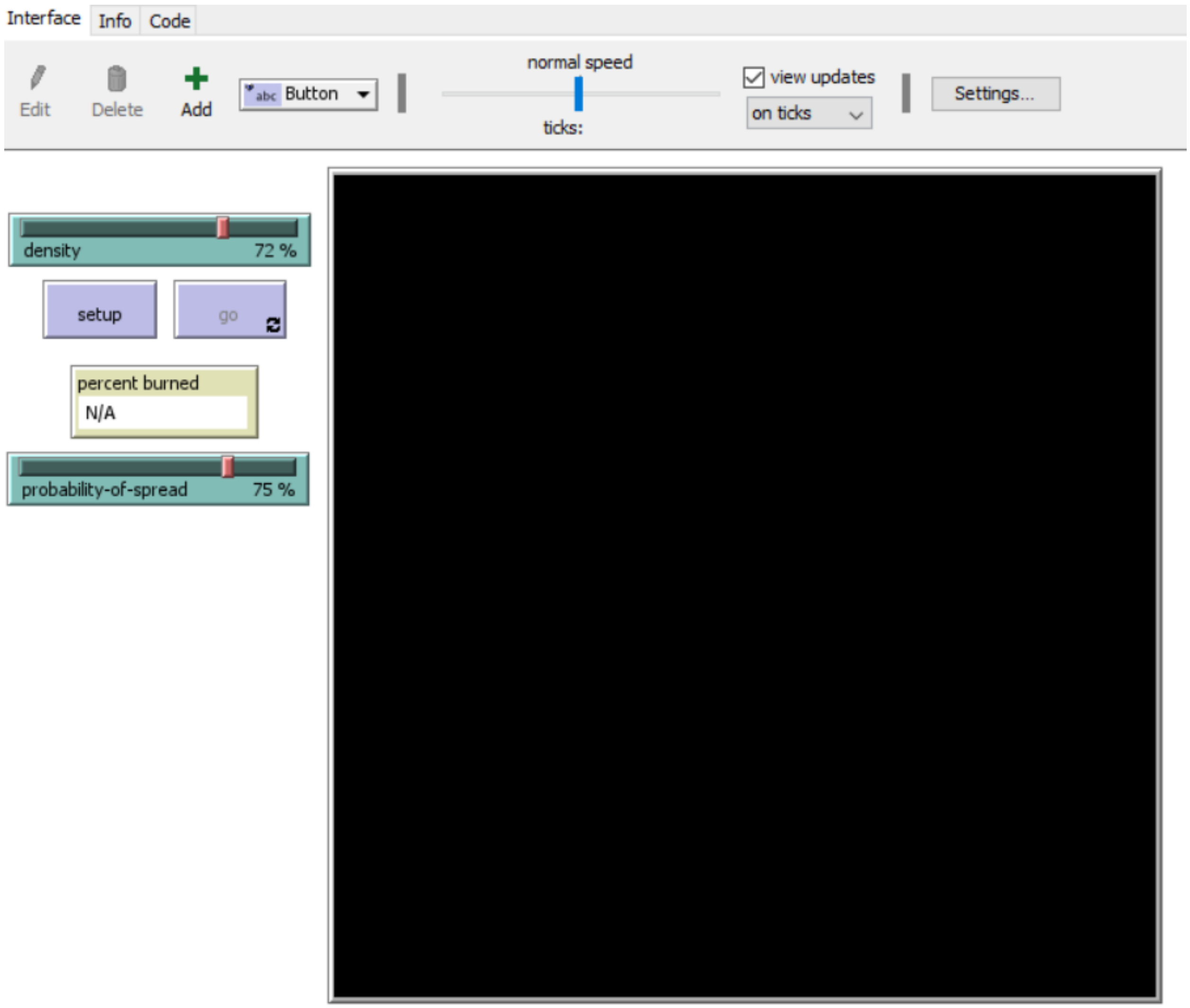
Setting up

To start the experiment click on LINK.



The layout of the online version of the Fire Simple Extension 1 model

Alternatively, you can also download the [Fire Simple Extension 1 model](). For this, go to the online model, click on **export netlogo**, and store the file **Fire Simple Extension 1.nlogo**. If you have not done so, you can download [Netlogo](). Next, open your netlogo, go to "file", "open" and find the "Fire Simple Extension 1.nlogo" in the folder where you saved it.



The layout of the download version of the Fire Simple Extension 1 model

What do you see?

Launching the model shows you an empty model that needs filling first. Press 'Setup' to do that.

This model simulates the spread of a fire through a forest. The fire starts on the left edge of the forest, and spreads to neighboring trees. The fire spreads in four directions: north, east, south, and west.

Clicking on **go** will show a one-time step, clicking on **go**↻ will run the model continuously. (to stop the run, click this button twice). You can observe how the spread of fire changes throughout time. The simulation stops once the fire cannot spread anymore.

Things to explore

Starting with the basic setup, the model shows you how the fire moves and stabilizes under the default condition. Run this default setting of the simulation model multiple times by clicking on **go**↻ repeatedly, and observe the stability of the outcomes. **What do you see happening with the fire?**

We encourage you to experiment with different settings of density and probability of spread. What do you observe when you increase or decrease the probability of spread? What happens when density is low, but probability of spread is high? What happens in the opposite situation?

14. Forest fire - advanced model nr 1 - EXERCISE

At last, lets add two more sliders. You probably thought, that fire without a wind is not a real fire. Here by moving sliders we can control how strong south-north and west-east a wind will be.

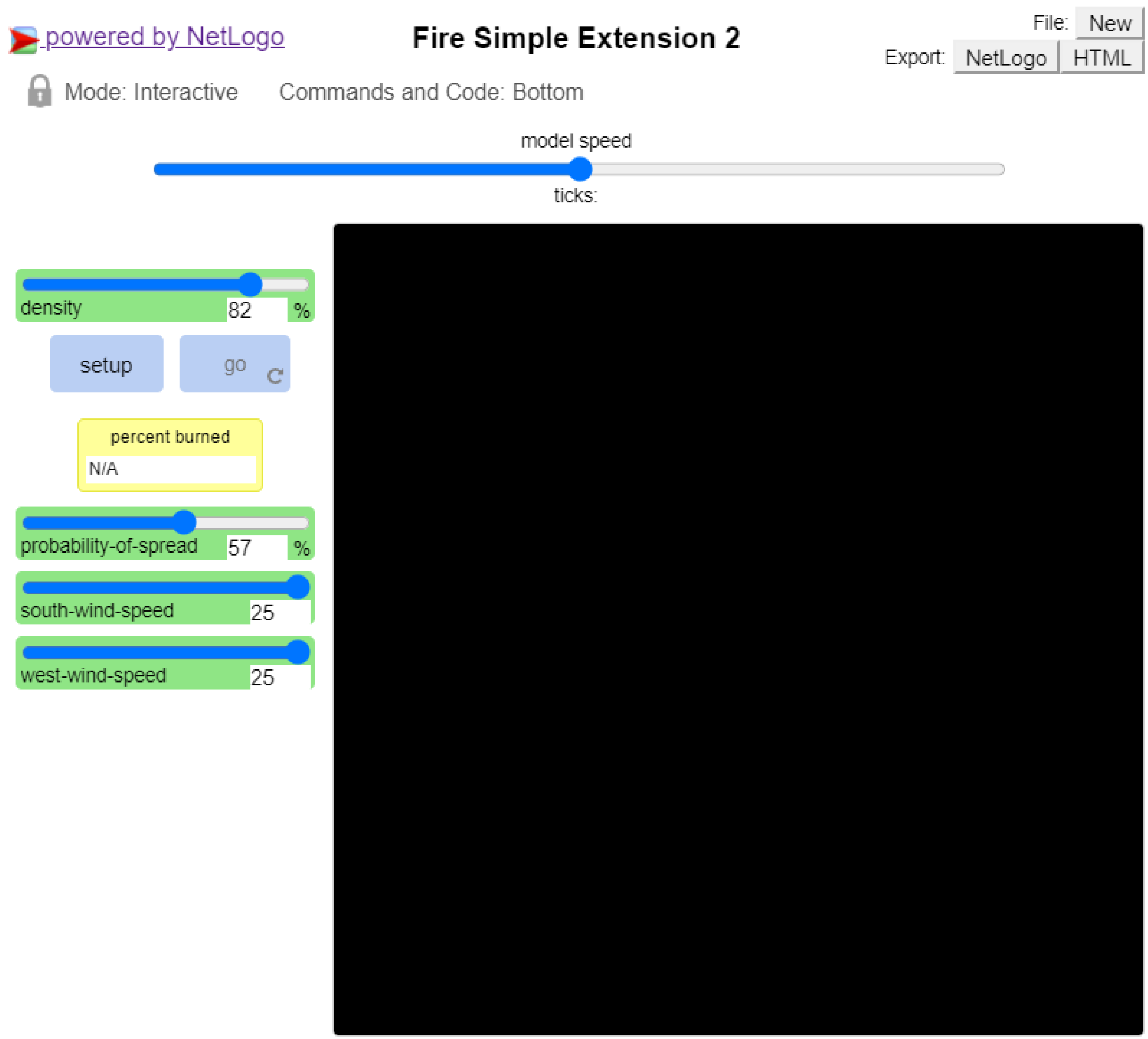
http://www.netlogoweb.org/launch#http://www.netlogoweb.org/assets/modelslib/IABM%20Textbook/chapter%203/Fire%20Extensions/Fire%20Simple%20Extension%202.nlogo

In this exercise, you will experiment with the forest and the fire, and observe the impact of the density of the forest, the probability of spreads and additionally the wind.

This model allows users to play around with four parameters: The DENSITY slider controls the density of trees in the forest, the PROBABILITY OF SPREAD slider affects how the fire spreads from patch to patch, The SOUTH-WIND-SPEED slider affects how strong the wind is from the south (you can set it negative to create a north wind) and the WEST-WIND-SPEED slider affects how strong the wind is from the south (you can set it negative to create an east wind). At each timestep or tick, you can experiment with the density and see how the density affects the fire.

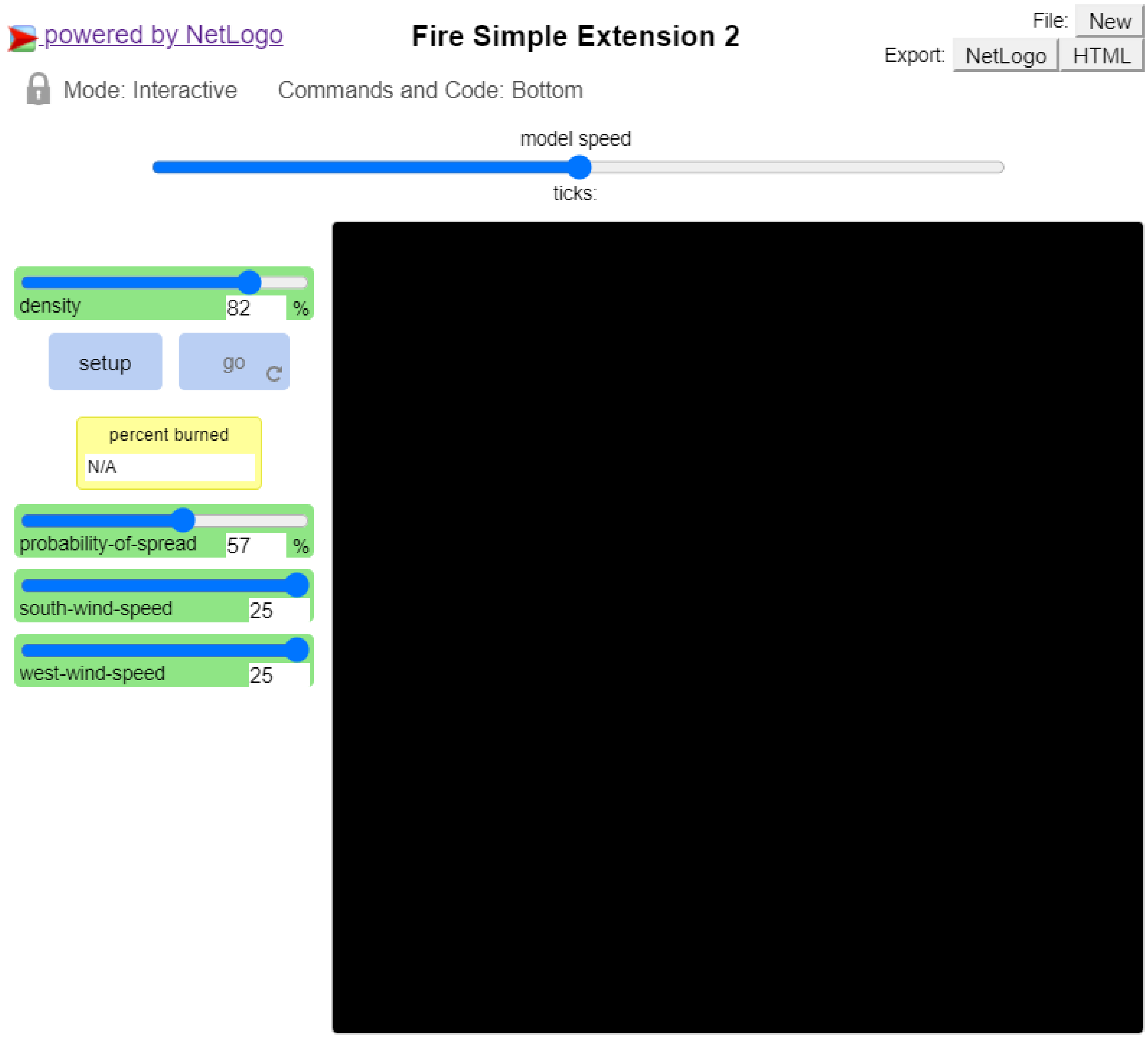
Setting up

To start the experiment click on LINK.



The layout of the online version of the Fire Simple Extension 2 model

Alternatively, you can also download the Fire Simple Extension 2 model. For this, go to the online model, click on **export netlogo**, and store the file **Fire Simple Extension 2.nlogo**. If you have not done so, you can download Netlogo. Next, open your netlogo, go to "file", "open" and find the "Fire Simple Extension 2.nlogo" in the folder where you saved it.



The layout of the download version of the Fire Simple Extension 2 model

What do you see?

Launching the model shows you an empty model that needs filling first. Press ‘Setup’ to do that.

This model simulates the spread of a fire through a forest. The fire starts on the left edge of the forest, and spreads to neighboring trees. The fire spreads in four directions: north, east, south, and west.

Clicking on **go** will show a one-time step, clicking on **go**↻ will run the model continuously. (to stop the run, click this button twice). You can observe how the spread of fire changes throughout time. The simulation stops once the fire cannot spread anymore.

Things to explore

Starting with the basic setup, the model shows you how the fire moves and stabilizes under the default condition. Run this default setting of the simulation model multiple times by clicking on **go**↻ repeatedly, and observe the stability of the outcomes. **What do you see happening with the fire?**

We encourage you to experiment with different settings of density, probability of fire, south wind speed and west wind speed. What do you observe when you increase or decrease the wind speed? How all four parameters change the situation? What are the implications in terms of fire managing, do you think? What would you advise the officials to stop a fire? Please share with other learners.

Forest Fire models are one of the models prepared for a book “Introduction to Agent-based Modeling” by Uri Wilensky and William Rand. On the book webpage a lot of Agent Based Models are introduced. If you are interested in cellular automata, this is a great place to continue your development in this direction.

15. Help for firefighters - EXERCISE

Source: https://cdn.pixabay.com/photo/2013/02/18/03/59/forest-82701_960_720.jpg

Imagine that you work for Forestville Fire Brigade. They are interested in forest fire those models and they asked you to prepare for them a more realistic model that can be really useful in their work. They even gave you a map of the real forest in which they are working. You have IT-specialist, so you don’t have to care about programming. What would you add to the model to make it more realistic? Think about a grid, possible states of cells, definition of neighbourhood and rules of transformation.

16. From forest fire to gossiping - DISCUSSION

Forest fires are a serious problem, and it really influences people's lives. However it is not a typical example of social phenomena. However, many social phenomena have a very similar dynamic to fire in the forest. Think about gossiping, spread of innovations, spread of information. What is extremely interesting about models is their universality - we can use models which have similar basis and mechanisms to different phenomena, from different disciplines.

Source: https://pl.freepik.com/darmowe-zdjecie/zblizenie-biznesmenow-plotkowac-razem_1006155.htm
Imagine that you want to transform the model of forest fire into a model of gossip (you also have a programmer;)). What would you do? Suggest changes. Think about a grid, possible states of cells, definition of neighbourhood and rules of transformation.

17. Go back to segregation - ARTICLE

Let's go back to the topic of segregation. What does the model approach bring to the topic of segregation?

In addition to taking into account factors that influence a large group of social processes such as location, changing neighborhoods and repeated interactions, they have several additional advantages:

1. They allow us to understand non-intuitive causes of macro-level effects
2. Models of "artificial" societies provide the opportunity for simultaneous exploration and prediction. Additionally, they allow us to learn something about the real world, to get to know the mechanisms that control it, often replacing intuition
3. Despite appearances, the use of cellular automata does not exclude the inclusion of external forces in the model, they are very flexible when it comes to such extensions.
4. They allow the researcher to discover previously unforeseen and often surprising consequences of their theoretical assumptions. Thus, they will be a good tool for deduction.

5. They are a good basis for investigating various substrates of decision making such as selfish or altruistic preferences.
6. Their great advantage is simplicity, especially useful in studying elementary interactions and social mechanisms

18. Wrap up

Well done, you have completed the whole course!

We started from the problem of spatial segregation with its specific mechanisms is a fascinating example of a macroscale social phenomena which is not only a simple sum of individual actions - if we compare it with answers for survey questions about level of tolerance (which base on individual declarations), they cannot be translated in an easy way into results on maps. It shows that there is a need for a tool which could help us understand the underlying mechanisms of spatial segregation. In this module we would like to introduce agent based models that focus on dynamics of agents in a certain physical space - called spatial models, namely cellular automata. You met several models - starting from Thomas Schelling's segregation model, then - in week two - more examples of cellular automata - game of life, forest fire and you tried to translate it into a model of gossip spread. You also have wondered several times how to bring models closer to reality. At the end we came back to Schelling's model, and advantages associated with dynamic approach to spatial segregation topic.

We hope you enjoyed learning with us!