Cell-DEVS Model for CO2 Diffusion in Closed Space with Mobility

Assignment2
SYSC 5104 - Methodologies for Discrete Event Modelling and Simulations
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Introduction

Sensors are used in closed spaces for occupancy detection and controlling the HVAC systems to reduce energy consumption while reducing the amount of CO_2 inside. However, these sensors are limited since it does not give a precise estimate of the number of people occupying the space because they are highly sensitive to the configuration parameters. As such, this model [1] is simulating the different configuration and sensors placed in a close space (Computer Lab as a use case) while the arrival/departure of occupants and shows the increase/decrease in the CO_2 levels. The model uses the Cell-DEVS formalism[2] to study the relationship between configuration parameters (e.g. room dimensions, window locations, and occupant's mobility) and the ability of CO 2 sensors to detect occupants and how this relationship can be used to determine the best placement of CO 2 sensors. Figure [1] shows the blueprint of a Computer Lab used as a use case to experiment with the model using Cell-DEVS.

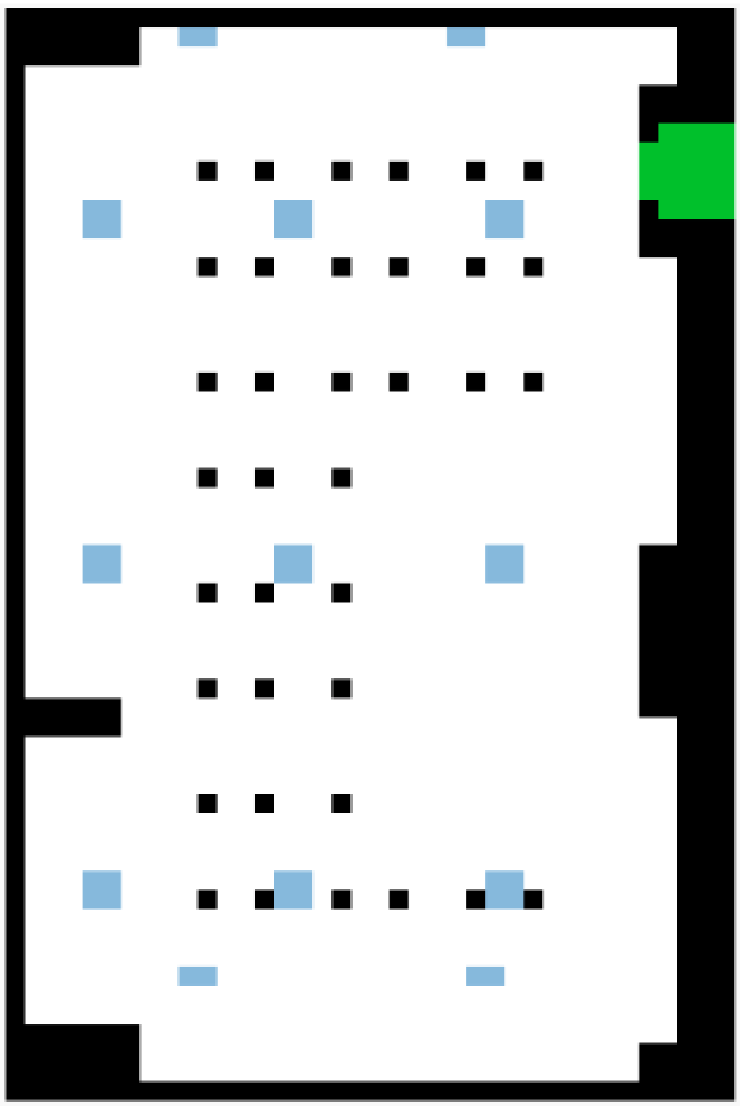


Figure 1 Computer Lab Blueprint

The Rules

Neigbors:

			(0,-3)			
		(-1,-2)	(0,-2)	(1,-2)		
	(-2,-1)	(-1,-1)	(0,-1)	(1,-1)	(2,-1)	
(-3,0)	(-2,0)	(-1,0)	(0,0)	(1,0)	(2,0)	(3,0)
	(-2,1)	(-1,1)	(0,1)	(1,1)	(2,1)	
		(-1,2)	(0,2)	(1,2)		
			(0,3)			

LeftUp Direction Zone

			(0,-3)
		(-1,-2)	**(0,-2)**
	(-2,-1)	**(-1,-1)**	**(0,-1)**
(-3,0)	**(-2,0)**	**(-1,0)**	**(0,0)**

RightUp Direction Zone

(0,-3)			
(0,-2)	**(1,-2)**		
(0,-1)	**(1,-1)**	**(2,-1)**	
(0,0)	**(1,0)**	**(2,0)**	**(3,0)**

LeftDown Direction Zone

(-3,0)	**(-2,0)**	**(-1,0)**	**(0,0)**
	(-2,1)	**(-1,1)**	**(0,1)**
		(-1,2)	**(0,2)**
			(0,3)

RightDown Direction Zone

(0,0)	**(1,0)**	**(2,0)**	**(3,0)**
(0,1)	**(1,1)**	**(2,1)**	
(0,2)	**(1,2)**		
(0,3)			

1) Entring the lab:

- Every ten seconds a new student will enter the lab.
- A cell in the middle of the door is counting the number of students entering the lab.
- If the number reach the maximum amount of students that can occupy the available workstations, the door will be closed and no more students are allowed to enter.

2) Orienting the students:

- The value of the central cell and the other nighn cells forms a orientation zone for the student to be oridented to the less crouded spaces and find an empty workstation.

- The movement direction of the student is calculated by finding the zone with less occupancy (e.g., any thing other than the walls, doors, windows and air).
- If the zones have equal occupancy, the student will find his direction on a clockwise direction or if the last nighbor node of each direction is an empty workstation.
- If the last node in each direction is a wall, the student will be directed to the opposit direction.

3) Movement:

- An empty cell will be occupied by the student if the cell is the next empty cell in the already set direction and/or located in the preferable orientation zone.
- The student keep walking utill one of immediate neighbor cells is a workstation.
- The student occupay the worksatation and keep sitting.

4) CO_2 Diffusion:

- Diffusion between normal air cells are calculated every one second.
- CO_2 sources have their concentration continually increased by 12.16 ppm every 5 seconds. Normal diffusion rule applies.
- Default rule: keep concentration the same if all other rules untrue.

Formal Specification of the coupled Cell-DEVS model

1) External Coupling Definition

M = < X, Y, D, {Mi}, {Ii}, {Zij}, select>

The model does not have any external coupling with the outside world.

2) Atomic Cell DEVS Model

M=<I,X,Y,Xlist,Ylist,η, N,{m,n}, C, B, Z, select>
Xlist=Φ
Ylist=Φ
η=24
I=<P^X,P^y>,with P^X={Φ},P^y={Φ};
N={ (0,-3), (-1,-2), (0,-2), (1,-2), (-2,-1), (-1,-1), (0,-1), (1,-1), (2,-1),(-3,0), (-2,0), (-1,0), (0, 0), (1,0), (2,0), (3,0), (-2,1), (-1,1), (0,1), (1,1), (2,1), (-1,2), (0,2), (1,2), (0,3) }
X = {c ty st cn dir};
Y = {c ty st cn dir};
c = {-10, 300, 500, 600} , ty = {-100, -200, -300, -400, -500, -600, -700}, st = {0, .. N},
cn = {-1, 0, .. .N}, dir = {0, 1, 2, 3, 4, 5, 6, 7, 8}
M = 23;
N = 23;
B={Φ};
C={Cij/iε[1,20], jε[1,20]}
Z:
$P_{ij}{}^{X}{}_{1} \neg P_{i,j+1}{}^{Y}{}_{1}$ $P_{ij}{}^{X}{}_{2} \neg P_{i,j+2}{}^{Y}{}_{2}$ $P_{ij}{}^{X}{}_{3} \neg P_{i,j-1}{}^{Y}{}_{3}$ $P_{ij}{}^{X}{}_{4} \neg P_{i,j-2}{}^{Y}{}_{4}$ $P_{ij}{}^{X}{}_{5} \neg P_{i+1,j}{}^{Y}{}_{5}$ $P_{ij}{}^{X}{}_{6} \neg P_{i+2,j}{}^{Y}{}_{6}$
$P_{ij}{}^{X}{}_{7} \neg P_{i-1,j}{}^{Y}{}_{7}$ $P_{ij}{}^{X}{}_{8} \neg P_{i-2,j}{}^{Y}{}_{8}$ $P_{ij}{}^{X}{}_{9} \neg P_{i-1,j-1}{}^{Y}{}_{9}$ $P_{ij}{}^{X}{}_{10} \neg P_{i-1,j-2}{}^{Y}{}_{10}$ $P_{ij}{}^{X}{}_{11} \neg P_{i-2,j-1}{}^{Y}{}_{11}$
$P_{ij}{}^{X}{}_{12} \neg P_{i-2,j-2}{}^{Y}{}_{12}$ $P_{ij}{}^{X}{}_{13} \neg P_{i+1,j-1}{}^{Y}{}_{13}$ $P_{ij}{}^{X}{}_{14} \neg P_{i+1,j-2}{}^{Y}{}_{14}$ $P_{ij}{}^{X}{}_{15} \neg P_{i+2,j-1}{}^{Y}{}_{15}$ $P_{ij}{}^{X}{}_{16} \neg P_{i+2,j-2}{}^{Y}{}_{16}$
$P_{ij}{}^{X}{}_{17} \neg P_{i-1,j+1}{}^{Y}{}_{17}$ $P_{ij}{}^{X}{}_{18} \neg P_{i-1,j+2}{}^{Y}{}_{18}$ $P_{ij}{}^{X}{}_{19} \neg P_{i-2,j+1}{}^{Y}{}_{19}$ $P_{ij}{}^{X}{}_{20} \neg P_{i-2,j+2}{}^{Y}{}_{20}$ $P_{ij}{}^{X}{}_{21} \neg P_{i+1,j+1}{}^{Y}{}_{21}$
$P_{ij}{}^{X}{}_{22} \neg P_{i+1,j+2}{}^{Y}{}_{22}$ $P_{ij}{}^{X}{}_{23} \neg P_{i+2,j+1}{}^{Y}{}_{23}$ $P_{ij}{}^{X}{}_{24} \neg P_{i+2,j+2}{}^{Y}{}_{24}$

Select={ (0,-3), (-1,-2), (0,-2), (1,-2), (-2,-1), (-1,-1), (0,-1), (1,-1), (2,-1),(-3,0), (-2,0), (-1,0), (0, 0), (1,0), (2,0), (3,0), (-2,1), (-1,1), (0,1), (1,1), (2,1), (-1,2), (0,2), (1,2), (0,3) }

Model Structure

[top]
components : computer_lab

[computer_lab]
type : cell

% Each cell is 25cm x 25cm x 25cm = 15.626 Liters of air each
dim : (38,57)
delay : transport
defaultDelayTime : 1000
border : nonwrapped

neighbors : computer_lab(0,-3)
neighbors : computer_lab(-1,-2) computer_lab(0,-2) computer_lab(1,-2)
neighbors : computer_lab(-2,-1) computer_lab(-1,-1) computer_lab(0,-1) computer_lab(1,-1) computer_lab(2,-1)
neighbors : computer_lab(-3,0) computer_lab(-2,0) computer_lab(-1,0) computer_lab(0,0) computer_lab(1,0) computer_lab(2,0) computer_lab(3,0)
neighbors : computer_lab(-2,1) computer_lab(-1,1) computer_lab(0,1) computer_lab(1,1) computer_lab(2,1)
neighbors : computer_lab(-1,2) computer_lab(0,2) computer_lab(1,2)
neighbors : computer_lab(0,3)

% Background indoor CO2 levels assumed to be 500 ppm
initialvalue : 500
localtransition : rules

% 2 State Variables corresponding to CO2 concentraion in ppm (conc) and the kind of cell (type)
% Default CO2 concentration inside a building (conc) is 0.05% or 500ppm in normal air
StateVariables: conc type step counter direction
NeighborPorts: c ty st cn dir
StateValues: 500 -100 0 0 0
InitialVariablesValue: computer_lab.val
% STATE VARIABLE LEGEND :
% conc = double : represents the CO2 concentration (units of ppm) in a given cell, can be any positive numbe, default value is 500ppm
%
% type = -100 : normal cell representing air with some CO2 concentration
% type = -200 : CO2 source, constantly emits a specific CO2 output
% type = -300 : impermeable structure (ie: walls, chairs, tables, solid objects)

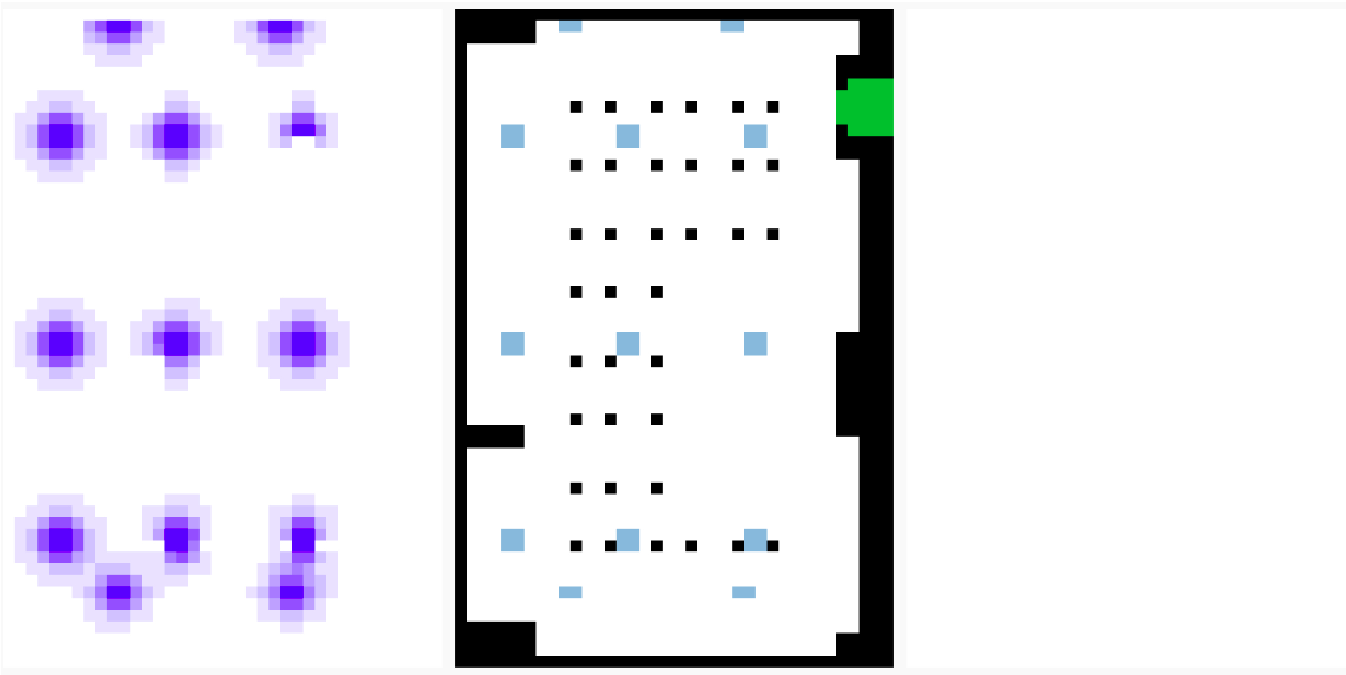
% type = -400 : doors, fixed at normal indoor background co2 level (500 ppm)
% type = -500 : window, fixed at lower co2 levels found outside (400 ppm)
% type = -600 : ventillation, actively removing CO2 (300 ppm)
% type = -700 : workstations (500 ppm)

% direction = -1 : sit
% direction = 0 : stand
% direction = 1 : Left
% direction = 2 : top
% direction = 3 : right
% direction = 4 : down
% direction = 5 : LeftUp
% direction = 6 : LeftDown
% direction = 7 : RightUp
% direction = 8 : RightDown

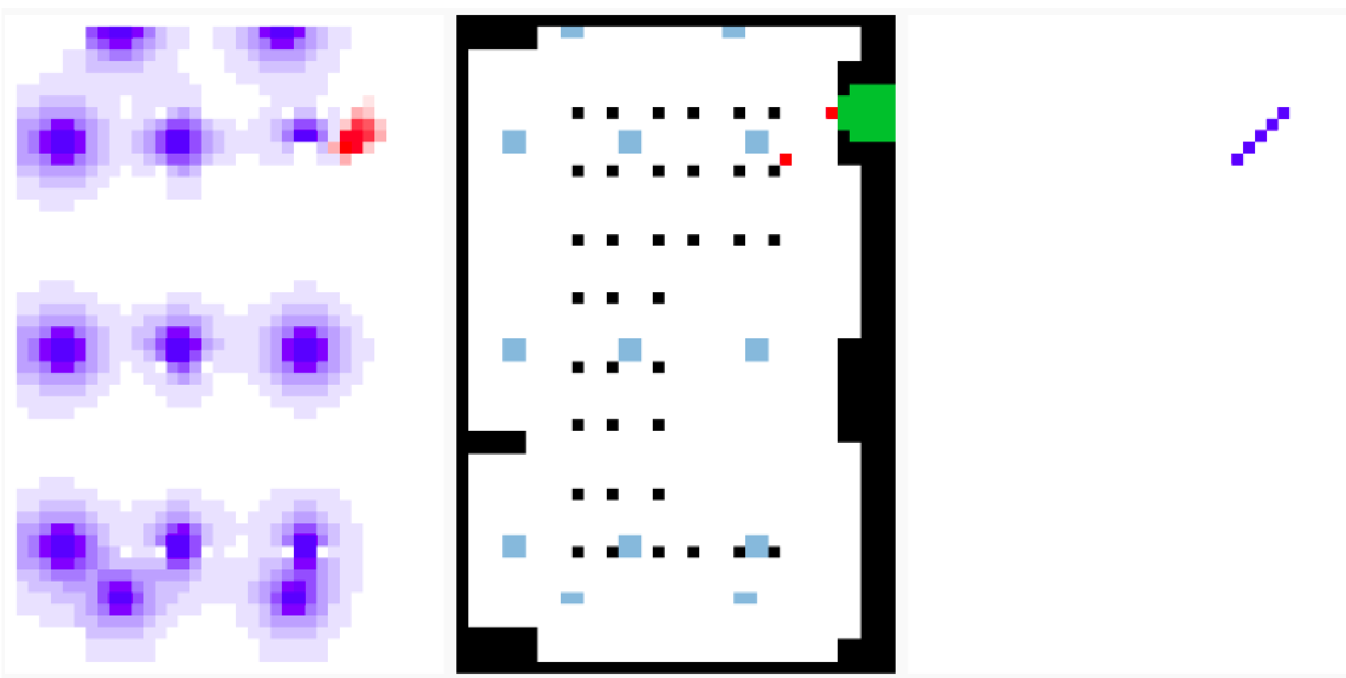
% counter = 1 : move
% counter = 0 : stop
% counter = -1 : occupied

Simulation and Testing

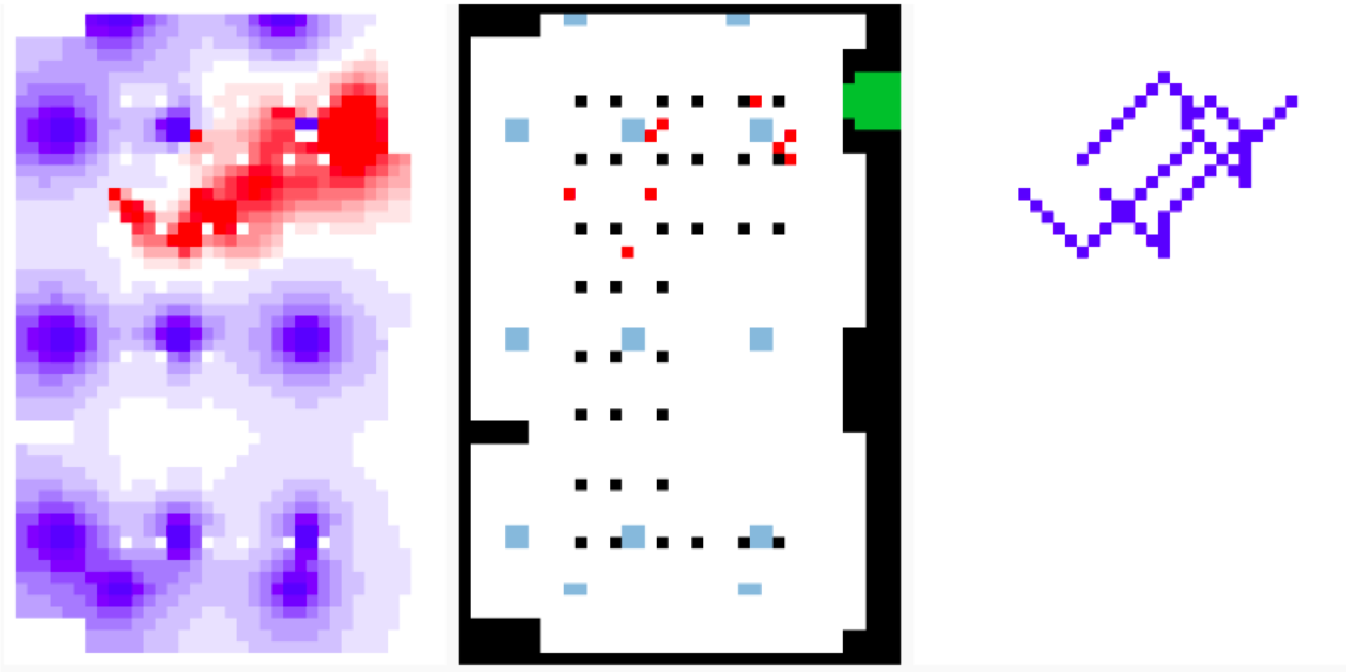
At 00:00:10:000:0 time unit:



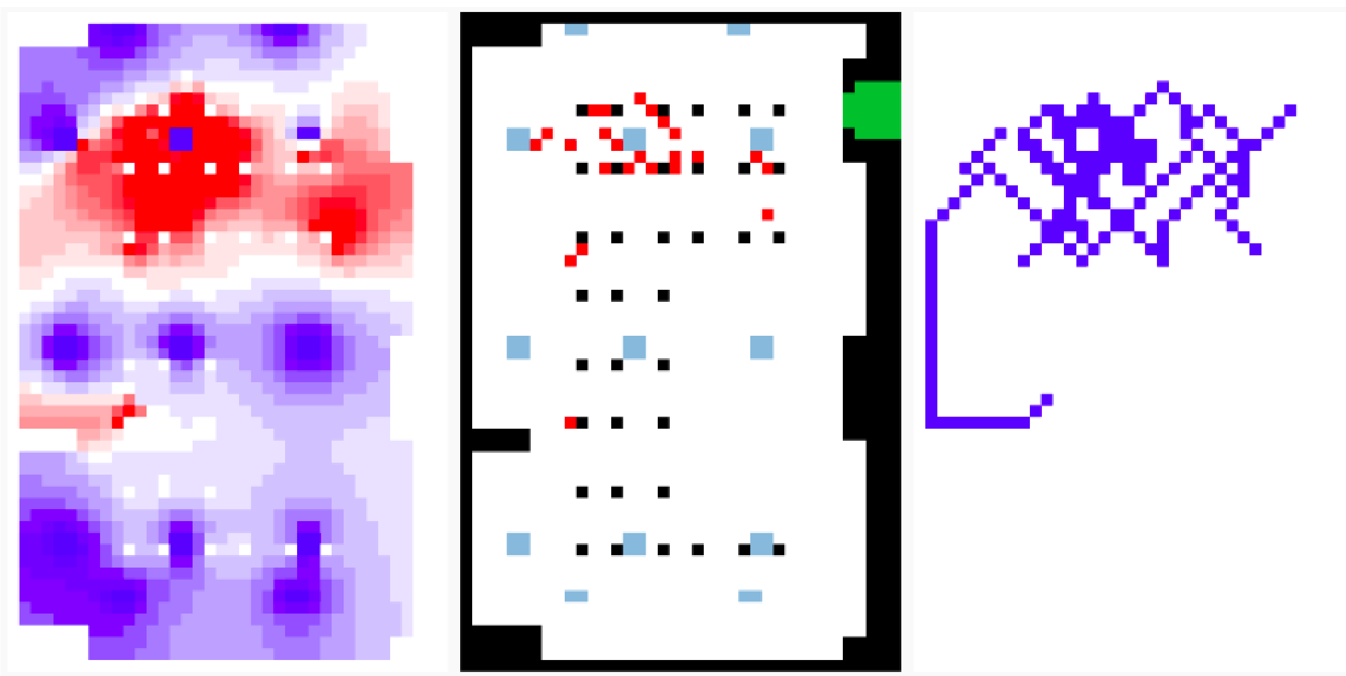
At 00:00:25:000:0 time unit:



At 00:01:01:000:0 time unit:



At 00:01:46:000:0 time unit:



A Suggested future enhancement to the model:

- ventillation system in a specific zoon can be switched on/off based on the surrounded CO_2 level.
- Numbers of person's steps have be taken into account as this will increase the amount of emitted CO_2.
- Direction of person's move should be defined more logically using some complex algorithms.

References:

[1] Wainer G., 2009. Discrete-Event Modeling and Simulation: A Practitioner's Approach. 1st ed. CRC Press.

[2] Hoda khalil, Gabriel A. Wainer, Z Dunnigan "Cell-Devs Models for CO2 Sensors Locations In Closed Spaces", Proceedings of the Winter Simulation Conference 2020, Orlando, Florida, USA - 2020