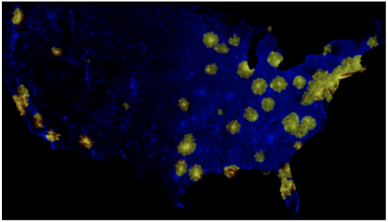
Case study: an epidemiological model

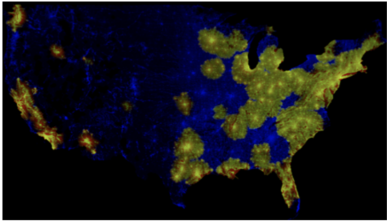
eX Modelo Summer School

August 31st, 2020

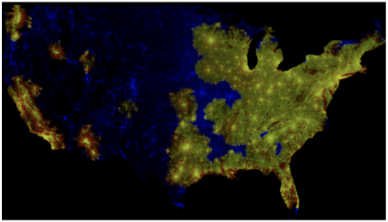
Decision making in a chaotic world



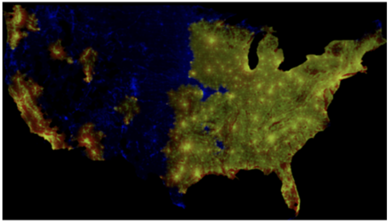
(c) 1 Week



(d) 2 Weeks



(e) 3 Weeks



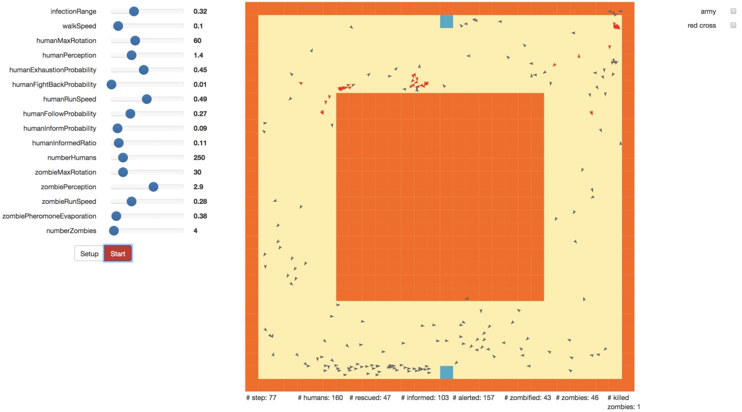
(f) 4 Weeks

Simulation of the 2010 Zombie outbreak in the US [Alemi et al., 2015]

History of Zombie epidemiology

- 2007: first outbreak in Iceland, relatively contained through ad-hoc measures
- 2010: it becomes pandemic
- 2010-2015: no clear records of events
- 2015-2018: reorganization of institutions, the MOLE (Medical Overview of Ludicrous Experiments) center in Chongqing gathers observational data from many local invasions across the world
- 2019: they released the first version of the model ZOMBIE (Zone of Optimal Management for Bacillus Infecting Everyone) and successfully applied

An operational model for local Zombie invasion



Local scale agent-based model

Let's get your hands on it

OpenMOLE

- A submodel is available at `https://om.exmodelo.org/coop`. Try the GUI and changing parameters
- Most of next courses will be based on that model (additional processes will be detailed when needed)

Overview of the model

OpenMOLE

- Simulate agent-level collective movements at the scale of a district
- Include behavioral processes for human (panic, search for rescues, . . .) and zombies (self-organization, spontaneous attacks, . . .), which can be adapted to local settings
- Include realistic pedestrian dynamics and realistic spatial configuration, which can be applied to local configuration

Objective of the model: better understand the Zombie invasion process; possible applications to optimal policies and behavioral prevention to minimize the impact of recurring invasions

Issue with model application: model has many parameters and processes, model behavior is unknown, application may be strongly case-dependent

→ *we need **YOU** to understand this model to save the world*

Basic processes and parameters

- Humans and Zombies walk/run randomly (smoothed random walk) in an open urban space (movement parameters: rotation angle, walk and run speed)
- Interactions: human flee from zombie, zombies run for food, fight when encounter
- Humans can be rescued and information on the existence of rescues propagates between humans
- Additional processes in a multi-modeling approach (army, vaccination, . . .)

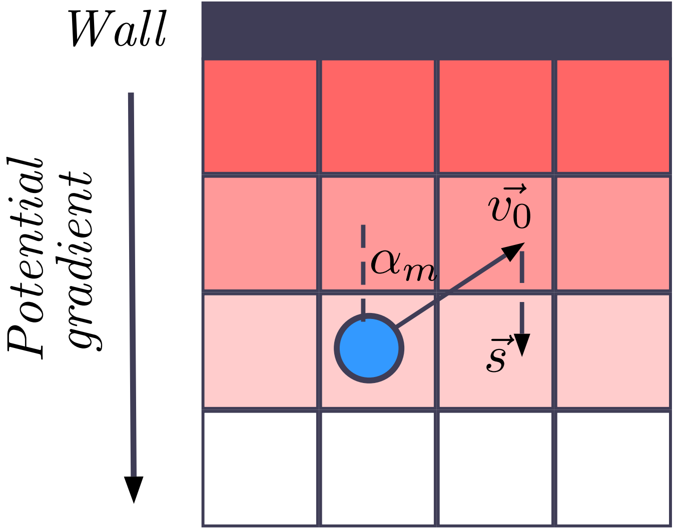
Pedestrian simulation

OpenMOLE

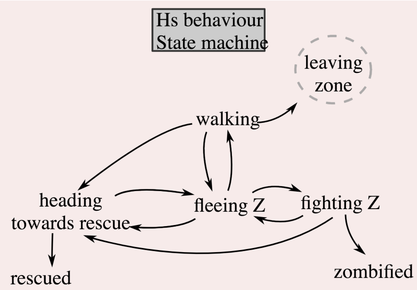
Multiple approaches to pedestrian simulations:

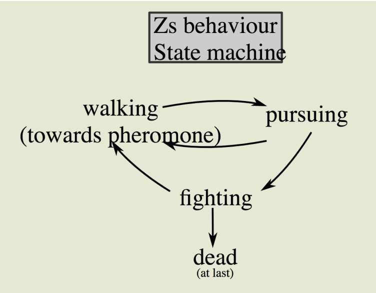
- Social force models [Helbing and Molnar, 1995]
- Granular flows [Cristiani et al., 2011]
- Behavioral models [Antonini et al., 2006]
- Cellular automatons [Burstedde et al., 2001]
- Potential field [Jian et al., 2014]

The ZOMBIE model takes the last approach, relatively realistic in a panic setting


$Wall$
$Potential\ gradient$
$\vec{v_0}$
α_m
$\vec{s}$

Agents state machines



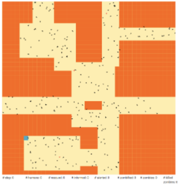


Information and rescues

- Some spots allows informed humans to be rescued and get out of the world
- An initial ratio of humans `humanInformRatio` is informed of the existence of rescues
- Informed humans which are not in a panicking state follow a specific potential field leading to rescues
- A human can inform an other one at the same location with a probability `humanInformProbability`

With the additional parameter `humanFollowProbability` (probability for a human to begin running and follow when they encounter an other running human), the submodel with three parameters is aimed at studying cooperation between humans.

quarantine:
no rescue zones.
You'd better run.



jaude:
one rescue zone
of width 1

Alternative worlds . . . and many more automatically generated (spatial sensitivity module on Wednesday)

A flexible and more general model

- The general model, of which the three-parameter model is a particular case has more processes (deactivated or fixed)
- No need to know them for now, with the aim to understand the submodel on which we have the less knowledge
- Multi-modeling and model embedding (model as black box)

The model in practice

- Model implemented in scala (highly performant language mixing the best from functional programming and object programming)
- Simple GUI for interactive exploration
- Integrated into OpenMOLE as a `jar` plugin in the GUI

Scala syntax to run an execution of the model

```
import zombies._

val rng = new scala.util.Random(replication)

val result = zombieInvasion(
   humanFollowProbability = humanFollowProbability,
   humanInformedRatio =humanInformedRatio,
   humanInformProbability = humanInformProbability,
   zombies = 4,
   humans = 250,
   steps = 500,
   random = rng
)

val humansDynamic = result.humansDynamic(20)
val zombiesDynamic = result.zombiesDynamic(20)
```

References I

Alemi, A. A., Bierbaum, M., Myers, C. R., and Sethna, J. P. (2015).
You can run, you can hide: The epidemiology and statistical mechanics of zombies.
Physical Review E, 92(5):052801.

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Discrete choice models of pedestrian walking behavior.
Transportation Research Part B: Methodological, 40(8):667–687.

Burstedde, C., Klauck, K., Schadschneider, A., and Zittartz, J. (2001).
Simulation of pedestrian dynamics using a two-dimensional cellular automaton.
Physica A: Statistical Mechanics and its Applications, 295(3-4):507–525.

References II

- Cristiani, E., Piccoli, B., and Tosin, A. (2011).
  Multiscale modeling of granular flows with application to crowd dynamics.
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- Helbing, D. and Molnar, P. (1995).
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- Jian, X.-X., Wong, S., Zhang, P., Choi, K., Li, H., and Zhang, X. (2014).
  Perceived cost potential field cellular automata model with an aggregated force field for pedestrian dynamics.
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