DON'T PANIC!!! EMERGENCY EGRESS.

New Mexico
Supercomputing Challenge
Final Report
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Artesia High School

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Executive Summary

This project's aim is to reduce the number of deaths that may result from the large scale emergency evacuation that would take place in response to a chemical leak. While an egress, or evacuation, seems simple, the variables that affect an egress are numerous. This paper, like the subject matter that it attempts to describe, is a work in progress. Artesia, NM was decided upon as the sample population for this project because it contains many properties that make a chemical leak possible. These properties include but are not limited to a working refinery, relation to the oil and gas industry, and numerous chemical substances at the refinery for refining purposes. This project relies upon sources found on Internet databases, books, and articles about chemicals and egress, information gleaned from various professional residing in the town of Artesia, and the Scientific Method for evaluating the emergency guidelines. Results have indicated that evacuation under the current emergency egress guidelines, General Operating Order #OPR36 Unusual Occurrences is possible. This project might be used to improve plans pertaining to the evacuation of other towns that contain few exits like Artesia, NM.

Introduction

Artesia is a small town heavily reliant upon the oil and gas industry. It contains a population near 11,000, of which 3,600 are under the age of 18, 8.. Located at the junction of the Roswell Highway, otherwise known as the US 285 and US 62, Artesia's main economic employment is in the oil and gas industry, 8.. The town boasts various companies with the purpose of retrieving and refining the abundant supply of oil and natural gas found in the area. One company, Holly Corporation owns Navajo Refinery, the refinery is located within the town limits. As Holly Corporation has refused to meet with us due to Homeland Security purposes, the views and subject material of this work are neither complete or reflect anyway on Navajo Refinery or its parent company.

The inclusion of a refinery in a city is not without risks. Refineries are required to conform to the safety standards put forth by OSHA[1],10., but this does not mean that they are safe. As illustrated by a tank explosion that left two workers dead and another two severely injured in 2010, 8., accidents that occur at refineries can often have dire consequences. The incidents are not necessarily retained to the premises of the refinery either.

Refineries require various chemicals to refine oil. Navajo Refinery maintains a stock of highly dangerous chemicals for this purpose. Navajo Refinery is located inside of the city limits, it is quite plausible that a leak of hazardous gas might occur that could result in the subsequent evacuation of the town. This reality caused us to review the extensive list of potential hazardous materials located at refineries. For a variety of reasons, including the fact that Hydrogen fluoride is gaseous above 19.4°C (67°F),Error: Reference source not found, is easily spread via wind or breeze, we selected it as the type of gas leaked. We have attempted to surmise, through agent based modeling on NetLogo[2], the effectiveness of the local emergency egress guidelines presented in General Operations Order #OPR36 Unusual Occurrences,3., for the safe evacuation

1 For information about the standards of safety put forth by OSHA please check the web address, <https://www.osha.gov/pls/oshaweb/owadisp.show_document?p_table=STANDARDS&p_id=10114> or <https://www.osha.gov/pls/oshaweb/owasrch.search_form?p_doc_type=STANDARDS&p_toc_level=0&p_keyvalue=>.

2 NetLogo is a computer program with that uses moving and non-moving agents to help in the modeling or simulation of real world events.

of the citizens of Artesia. Current beliefs hold that an evacuation of Artesia, NM under the current guidelines would prove successful. In part, this model was designed to answer whether this assumption is valid.

The consequences of this experiment are far reaching. Although it is a work in progress, a successful model of an accurate evacuation could help in the planning and execution of emergency evacuation plans for other cities, nationwide similar to Artesia in that they have few exits. Another example of a town with few exits in New Mexico would be Los Alamos which contains a government research facility with a wide variety of potential hazards. As residents of Artesia though, our main purpose with this project is to ascertain the viability of the current guidelines in saving the population of Artesia in the aforementioned emergency situation.

Description

Since late August, we consulted with professionals in the fields of safety, emergency egress, and refining and reviewed Internet databases, articles, and books upon the subjects to devise a few limitation for our project. Due to the numerous gases used in refineries, the first limitation decided upon was the gas to be used. Hydrogen fluoride was chosen because of its properties which include a gaseous state, high toxicity, and various forms of exposure[3],Error: Reference source not found,4.. The next step was to decide what limitations a person has in an evacuation. How would an ordinary person react? What would affect the gas or evacuation? A few of the real world problems that could affect the emergency egress are listed below:

- Normal weather conditions[4],11..
- Normal traffic patterns[5].
- Possibility of imperfect information[6].

3 Skin or direct contact, inhalation, and ingestion.
4 Normal weather conditions for the town of Artesia, NM. This means sunny or windy. Wind direction usually comes from South East and heads towards North West. Wind speed is an average of 8 – 12 mph.
5 Normal traffic patterns for this article will be defined as agents staying on areas designated as the road and keeping a safe distance between themselves and others.
6 e.g. Brownian motion (agent picks random direction checks to see if it is okay to move there, and then moves if it is. If not starts process over again.)

- Spread of gas.

Extreme weather[7] conditions are excluded. As Hydrogen Fluoride is very hazardous,Error: Reference source not found,3., we are working on including the possibility of agent death. We also plan to include parent-child relationships, movement of the gas, visualization of the gas cloud, and variation of transportation methods (walking and motorized vehicles).

In accord with the scientific method, we began by researching a topic, that of the emergency egress of Artesia, NM. In doing so we met with many professionals at the local fire and police departments and a former safety manager of Navajo Refinery. The police and fire departments informed us of their role in an evacuation, that of assistance and guidance,7.,Error: Reference source not found. We then proceeded to the formulation of a hypothesis, that most of the citizens would be able to evacuate if a leak of hazardous gas did happen. Then information found in the research phase of our project was condensed into a set of rules that would be followed by agents in NetLogo. These rules are as follow:

Movement rules followed by people/vehicle agents moving towards exits:

At each step these agents try to move in a direction that takes them closer to the exit. However, there is a possibility that any given step may be taken in a random direction.

- At each time step *t*, for each agent *A,*
    - If $U(0,1) < p_I$, then
        - $\theta = U(0,2\pi)$
    - else
        - $\theta = \theta'$
    - $\boldsymbol{Q}_{t+1} = \boldsymbol{P}_t + (1,\theta)$
    - If no agent *B* exists, such that $D(\boldsymbol{Q}_{t+1}, B) < S(A, B)$, then
        - $\boldsymbol{P}_{t+1} = \boldsymbol{Q}_{t+1}$
    - else
        - $\boldsymbol{P}_{t=1} = \boldsymbol{P}_t$
- where
    - t = current time step;

7 i.e. tornado, hurricane, earthquake, spontaneous eruption of a volcano, etc.

- $U(a, b)$ = uniformly distributed continuous random variable on the semi-closed interval [a, b);
- p_1 = probability of random movement (i.e. a first-approximation modeling of imperfect information);
- $\boldsymbol{P}_t$ = position at time *t*;
- $(1, \theta)$ = vector of length 1 and angle θ
- $\mathrm{E}(\boldsymbol{P})$ = minimum travel distance from point **P** to nearest exit
  - Not necessarily Euclidean or rectilinear distance
  - Any point is considered "forbidden" (agents may not move to or through the point) if and only if $\mathrm{E}(\boldsymbol{P}) = \infty$
- θ '= direction of maximum improvement (decrease) in distance to exit, that is
  - $\mathrm{E}(\boldsymbol{P}_t + (1, \theta')) \leq \mathrm{E}(\boldsymbol{P}_t + (1, \theta)) \forall \theta \epsilon [0, 2\pi)$
- $\boldsymbol{Q}_{t+1}$ = tentative position at time *t* + 1;
- $D(\boldsymbol{P}, B)$ = distance between point **P** and *B*;
- $S(A, B)$ = "personal space" required between agents *A* and *B*; currently, this is a linear function of the sizes of *A* and *B*.

Movement rules followed by parent agents moving toward pickup area:

At each step these agents try to move in a direction closer to the pickup area. However there is a possibility that any given step may be taken in a random direction.

- At each time step *t*, for each agent *A,*
  - If $U(0,1) < p_1$, then
    - $\theta = U(0, 2\pi)$
  - else
    - $\theta = \theta'$
  - $\boldsymbol{Q}_{t+1} = \boldsymbol{P}_t + (1, \theta)$
  - If no agent *B* exists, such that $D(\boldsymbol{Q}_{t+1}, B) < S(A, B)$, then
    - $\boldsymbol{P}_{t+1} = \boldsymbol{Q}_{t+1}$
  - else
    - $\boldsymbol{P}_{t=1} = \boldsymbol{P}_t$
- where
  - t = current time step;

  - $U(a, b)$ = uniformly distributed continuous random variable on the semi-closed interval [a, b);
  - p_1 = probability of random movement (i.e. a first-approximation modeling of imperfect information);
  - $\boldsymbol{P}_t$ = position at time *t*;
  - $(1,\theta)$ = vector of length 1 and angle θ
  - $\mathrm{E}(\boldsymbol{P})$ = minimum travel distance from point **P** to nearest pickup
    - Not necessarily Euclidean or rectilinear distance
    - Any point is considered "forbidden" (agents may not move to or through the point) if and only if $\mathrm{E}(\boldsymbol{P}) = \infty$
  - θ'= direction of maximum improvement (decrease) in distance to exit, that is
    - $\mathrm{E}(\boldsymbol{P}_t+(1,\theta'))\leq\mathrm{E}(\boldsymbol{P}_t+(1,\theta))\,\forall\theta\epsilon[0,2\pi)$
  - $\boldsymbol{Q}_{t+1}$ = tentative position at time $t + 1$;
  - $D(\boldsymbol{P}, B)$ = distance between point **P** and *B*;
  - $S(A, B)$ = "personal space" required between agents *A* and *B*; currently, this is a linear function of the sizes of A and B.

Rules for expansion of gas cloud:

This cellular automata (ca) is a first approximation. It doesn't account for wind or dissipation. If cell generates a number less than spread rate and 1 neighbor is in gas state then cell becomes gas.

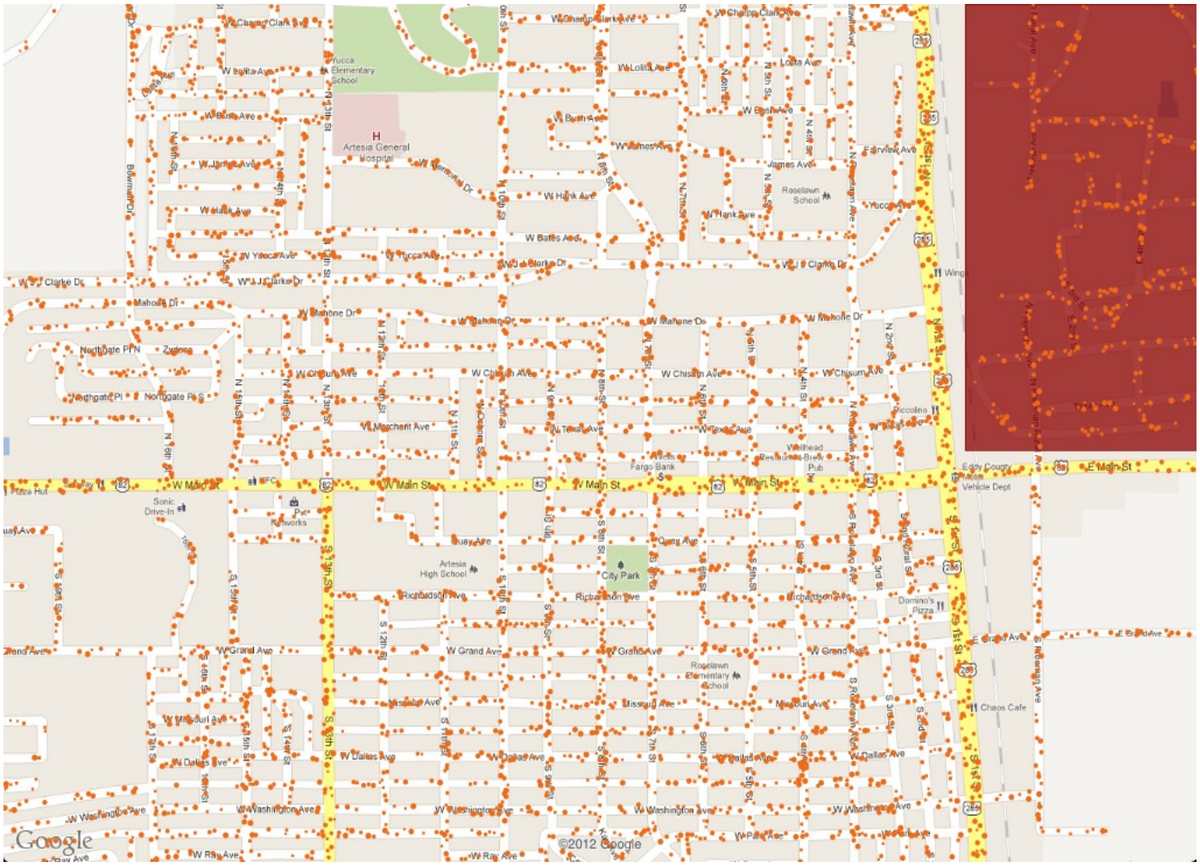
- Each cell is in one of two states:
  - 0 = no gas
  - 1 = gas
- $S_{(ij)t}$ = state of cell (i, j) - i.e. cell at integer coordinates (i, j) - at time .
- $S_{(m,n)t+1}$ =
    - 1, if $S_{(m,n)t} = 1$;
    - 1, if $U(0,1) \leq p_s$ and $\Sigma\Sigma S_{(ij)t} \geq 1$, for $m-1 \leq i \leq m+1, n-1 \leq j \leq n+1$
    - 0, otherwise.
  - where
    - $U(0,1)$ = uniformly distributed continuous random variable on the semi-closed interval [0, 1)
    - P_s = probability of spread (spread rate).

the code for this model may be seen in appendix B. The accuracy of our model cannot be guaranteed, as despite the efforts of a many individuals (teachers, administrators and especially a very dedicated counselor) Navajo Refinery refused to divulge information regarding safety protocols to protect national security. Once verified and validated by comparing the model with the laws the population would follow and showing our model to professionals at the fire and police departments, data was collected by running the model numerous times. The data received from the numerous trials was then used to decided if the majority of Artesia, New Mexico's population could evacuate safely.

Results

Data obtained from this model indicates that an emergency evacuation of Artesia, NM would conclude within an average time of 2,244 ticks or 37 minutes 36 seconds, the maximum being 2,349 ticks or 39 minutes 9 seconds. These times are a rough estimate as not all environmental factors are included in the code as of now. Below is an image of our current model at setup the code that for agent movement.

Image of Model at Setup (No Additional Code)



(Red zone indicates position of Navajo Refinery.)

Example 1.1

```
to wiggle [pickup-allowed?]
 right random-float 30
 left random-float 30
 if can-move? 1 and [(not forbidden? or (pickup-allowed? and is-pickup?)) and not is-gas?] of patch-ahead 1 [
   forward 1
   let others other (turtles in-radius 2.5)
   if any? others [
     let my-size size
     ifelse breed = parents [
       if any? others with [(self != [my-child] of myself) and (size + [size] of myself) * personal-space-radius > distance myself ] [
         back 1
```

```
    ]
   ]
   [
    if any? others with [(size + [size] of myself) * personal-space-radius > distance
myself ] [
     back 1
    ]
   ]
  ]
 ]
end
```

(The above code is for agent movement.)

Additional code being written, will account for: movement of gas,

creation of parents and children,

```
hatch-children 1 [
   set my-parent the-parent
   ask my-parent [
    set my-child myself
   ]
   set size (0.5 * [size] of my-parent)
   set color cyan
   set attached? false
   move-to one-of patches with [is-pickup?]
  ]
 ]
end
```

agent death,

```
ask patches [
  set safe? shade-of? pcolor lime
  set forbidden? (pcolor != white and not safe?)
```

```
  set safe-distance ifelse-value (safe?) [0] [inf-distance]
  set is-pickup? (abs (pcolor - blue) < 1)
  set is-gas? false
  set distance-to-pickup ifelse-value (is-pickup?) [0] [inf-distance]
 ]
 ask one-of patches with [pxcor > 825 and pycor > 338] [
  set is-gas? true
  if (not forbidden? and not safe? and not is-pickup?) [
   set pcolor violet
  ]
  set gas-boundary neighbors
  sprout-gas-clouds 1 [
   set color (violet + 1.5)
   set size 1.415
   stamp
   die
  ]
  ask turtles-here [
   set gas-fatalities (gas-fatalities + 1)
   die
  ]
 ]
 import-drawing "what we see SUCCESS!!!.png"
end
```

school grounds,

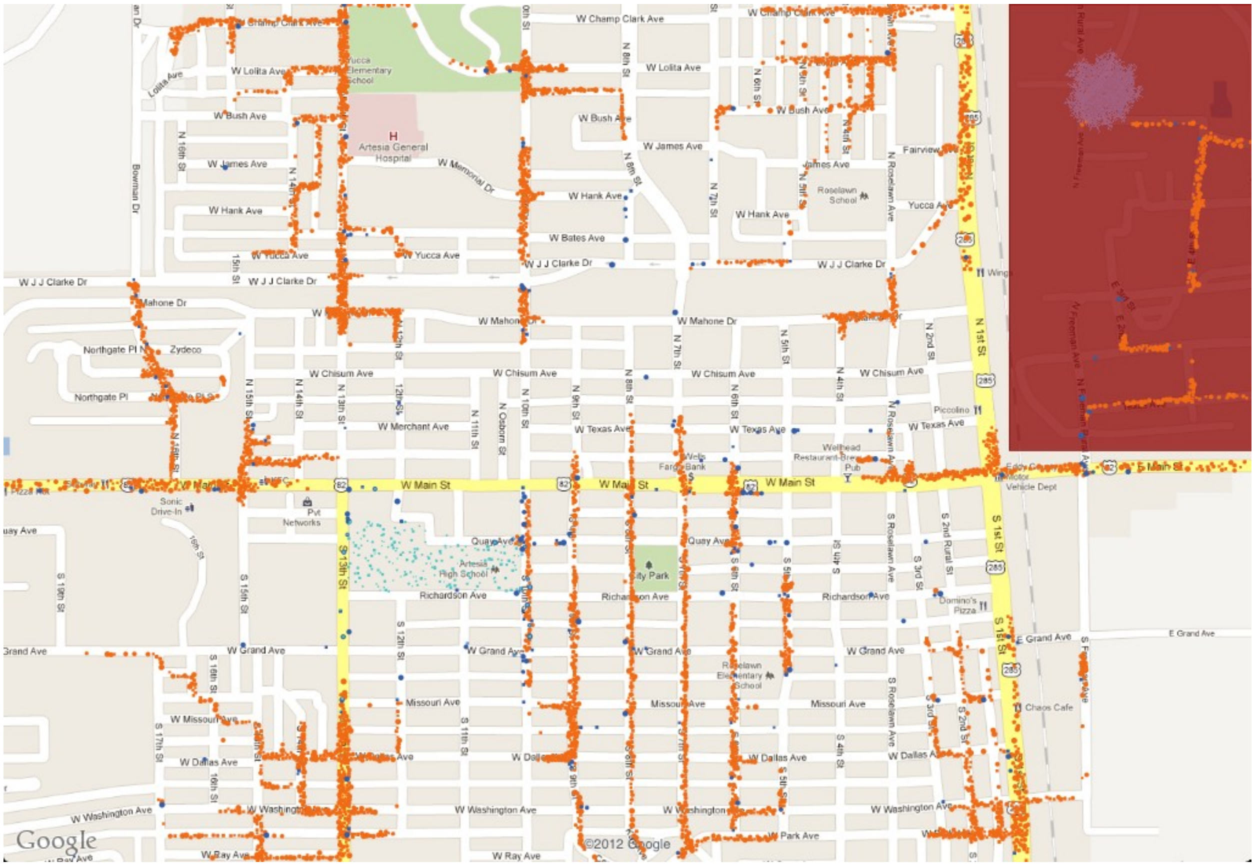
to setup-patches

```
 import-pcolors (word scenario ".png")
 ask patches [
  set safe? shade-of? pcolor lime
  set forbidden? (pcolor != white and not safe?)
```

```
    set safe-distance ifelse-value (safe?) [0] [inf-distance]
    set is-pickup? (abs (pcolor - blue) < 1)
    set is-gas? false
    set distance-to-pickup ifelse-value (is-pickup?) [0] [inf-distance]
  ]
  ask one-of patches with [pxcor > 825 and pycor > 338] [
    set is-gas? true
    if (not forbidden? and not safe? and not is-pickup?) [
      set pcolor violet
    ]
    set gas-boundary neighbors
    sprout-gas-clouds 1 [
      set color (violet + 1.5)
      set size 1.415
      stamp
      die
    ]
    ask turtles-here [
      set gas-fatalities (gas-fatalities + 1)
      die
    ]
  ]
  import-drawing "what we see SUCCESS!!!.png"
end.
```

With this additional coding, we expect to receive a different set of evacuation times. It is also expected that problems of traffic congestion will arise, along with discrepancies between the model and the real world. A discrepancy already noted in our preliminary testing is that children agents whose parents die stay on school grounds until the gas kills them instead of walking to safety. For a complete version of our code view Appendix B.

Model with Additional Code



(This is what our model currently looks like with additional coding. The dark blue represents parents, the cyan or lighter blue, represents children. The orange represents people with no children. The purple on top right shows the gas-boundary. The gas can only be expelled from any point in the red zone. Red zone indicates Navajo.)

Conclusions

Our biggest achievement at this time, is the creation of a model that spans the majority of the town of Artesia, NM. This model encompasses an estimated nineteen square miles. The results of running the model at this time seem to indicate that it is possible to evacuate the town of Artesia under the current guidelines for evacuation provided by, 3.. It is expected that recent, untested additions to the model will result in extended evacuation times and increased deaths.

Any continuation of this subject on our part, will focus a different population mix: age, mobility, ethnicity, percent of population married, number of parents in population, distribution of populace in city/town, size, etc. or will concentrate on a area of interest[8] indicated in the model. Our aim in the former will be to apply the knowledge gained from this project to that of another populace. The aim of the latter will be trying to solve or closer inspect a specific problem that arose in the model.

Acknowledgments

We would like to sincerely thank:

Mr. Randall Gaylor, for keeping us on task and helping us throughout the year.

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Police, Fire Departments and various professionals in Artesia for their cooperation.

Various education professionals involved with the challenge for feedback (librarian, computer lab manager, CAD instructor) and the people who came to observe our peer review.

Appendix A

$$
\begin{aligned}
\boldsymbol{P} &= \text{point on terrain} \\
d(\boldsymbol{P}) &= \text{distance from } \boldsymbol{P} \text{ to safety} \\
\boldsymbol{G}(\boldsymbol{P}) &= \text{direction of greatest safety from } \boldsymbol{P} \\
p_{\mathrm{I}} &= \text{probability of perect information} \\
\boldsymbol{M} &= \text{direction chosen for movement by an agent at point } \boldsymbol{P} \\
U(0,\ 2\pi) &= \text{unformily distributed continuous random variable on } [0, 2\pi) \\
p(\boldsymbol{M}=\boldsymbol{G}(\boldsymbol{P})) &= p_{\mathrm{I}} \\
p(\boldsymbol{M}=U(0,2\pi)) &= 1 - p_{\mathrm{I}}
\end{aligned}
$$

This equation defines agent movement.

Appendix B

The following the complete code for our model. But the code has not been fully refined.

```
<creates breeds or types of turtles>
        breed [solos solo]
        breed [parents parent]
```

8 Area of interest as defined in this paper shall be an area of high traffic or an area with the greatest possibility of accident

```
    breed [children child]
    breed [gas-clouds gas-cloud]

<keeps track of agent specific variables>
    global's [
      safe-turtles
      inf-distance
      gas-boundary
      gas-fatalities
      escapes
      personal-space-radius
    ]

<tells patches if they are safe to walk, forbidden, and how far the agents are from the exit>
    patches-own [
      safe?
      forbidden?
      safe-distance
      is-pickup?
      is-gas?
      distance-to-pickup
    ]

    parents-own [
      my-child
      picking-up?
    ]

    children-own [
      my-parent
      attached?
```

```
]
```

<sets up the patches and resets the model>

```
to setup
  clear-all
  setup-globals
  setup-patches
  setup-flood-fill
  setup-population
  reset-ticks
end

to setup-globals
  set safe-turtles 0
  set inf-distance 99999
  set personal-space-radius 0.5
end
```

<sets up the different patches such as forbidden, safe, safe distance, as well as sets the different scenario>

```
to setup-patches
  import-pcolors (word scenario ".png")
  ask patches [
    set safe? shade-of? pcolor lime
    set forbidden? (pcolor != white and not safe?)
    set safe-distance ifelse-value (safe?) [0] [inf-distance]
    set is-pickup? (abs (pcolor - blue) < 1)
    set is-gas? false
    set distance-to-pickup ifelse-value (is-pickup?) [0] [inf-distance]
  ]
```

```
  ask one-of patches with [pxcor > 825 and pycor > 338] [
    set is-gas? true
    if (not forbidden? and not safe? and not is-pickup?) [
      set pcolor violet
    ]
    set gas-boundary neighbors
    sprout-gas-clouds 1 [
      set color (violet + 1.5)
      set size 1.415
      stamp
      die
    ]
    ask turtles-here [
      set gas-fatalities (gas-fatalities + 1)
      die
    ]
  ]
  import-drawing "what we see SUCCESS!!!.png"
end


to setup-flood-fill
  let boundary patch-set ([neighbors with [not safe? and not forbidden?]] of (patches
with [safe?]))
  while [any? boundary] [
    ask boundary [
      set safe-distance (min [safe-distance + distance myself] of neighbors)
    ]
    set boundary (patch-set [neighbors with
      [not safe? and not forbidden? and safe-distance >= inf-distance]] of boundary)
  ]
```

<untested code>

```
  set boundary patch-set ([neighbors with [not is-pickup? and not forbidden?]] of
(patches with [is-pickup?]))
  while [any? boundary] [
    ask boundary [
      set distance-to-pickup (min [distance-to-pickup + distance myself] of neighbors)
    ]
    set boundary (patch-set [neighbors with
      [not safe? and not forbidden? and distance-to-pickup >= inf-distance]] of boundary)
  ]
end


to setup-population
  set-default-shape solos "circle"
<untested code>
  set-default-shape parents "circle"
  set-default-shape children "circle"
  set-default-shape children "circle"
  create-solos (total-population * fraction-solos) [
    set size 2 + random-float 3
    set color orange
    setxy random-xcor random-ycor
    while [safe? or forbidden? or is-pickup?
        or any? (other (turtles in-radius 2.5)) with [(size + [size] of myself) * personal-
space-radius > distance myself]] [
      setxy random-xcor random-ycor
    ]
  ]
<untested code>
  create-parents (total-population * (1 - fraction-solos) / 2) [
    let the-parent self
    set size 2 + random-float 3
    set color blue
```

```
  set picking-up? true
  setxy random-xcor random-ycor
  while [safe? or forbidden? or is-pickup?
    or any? (other (turtles in-radius 2.5)) with [(size + [size] of myself) * personal-space-radius > distance myself]] [
   setxy random-xcor random-ycor
  ]
  hatch-children 1 [
   set my-parent the-parent
   ask my-parent [
    set my-child myself
   ]
   set size (0.5 * [size] of my-parent)
   set color cyan
   set attached? false
   move-to one-of patches with [is-pickup?]
  ]
 ]
end
```

<starts the model>

```
to go
 if not any? turtles [
  stop
 ]
 ask turtles [
  evacuate
 ]
 ask gas-boundary [
  spread-gas
 ]
```

```
  set gas-boundary (patch-set (gas-boundary with [not is-gas?]) ([neighbors with [not is-gas?]] of gas-boundary with [is-gas?]))
  tick
end
```

<part of these lines are untested>

```
to evacuate
  if is-gas? [
    set gas-fatalities (gas-fatalities + 1)
    if (breed = parents and not picking-up?) [
      ask my-child [
        set gas-fatalities (gas-fatalities + 1)
        die
      ]
    ]
    die
  ]
  if (breed = parents and picking-up? and not is-pickup?) [
    ifelse (random-float 1) < imperfect-information [
      set heading (random-float 360)
    ]
    [
      let destination min-one-of neighbors [distance-to-pickup]
      face destination
    ]
    wiggle true
  ]
  if (breed = solos or (breed = parents and not picking-up?)) [
    if safe? [
      set safe-turtles (safe-turtles + 1)
      if (breed = parents) [
```

```
      ask my-child [
        set safe-turtles (safe-turtles + 1)
        die
      ]
    ]
    die
  ]
  ifelse (random-float 1) < imperfect-information [
    set heading (random-float 360)
  ]
  [
    let destination min-one-of neighbors [safe-distance]
    face destination
  ]
  wiggle false
]
if (breed = children) [
  ifelse attached? and is-agent? my-parent [
    move-to my-parent
    set heading [heading] of my-parent
  ]
  [
    ifelse (is-agent? my-parent and [is-pickup?] of my-parent) [
      ifelse (distance my-parent <= 1) [
        move-to my-parent
        set heading [heading] of my-parent
        set attached? true
        ask my-parent [
          set picking-up? false
        ]
      ]
```

```
        [
          face my-parent
          forward 1
        ]
      ]
      [
        right random-float 30
        left random-float 30
        ifelse (can-move? 1 and [is-pickup?] of patch-ahead 1) [
          forward 1
        ]
        [
          set heading random-float 360
        ]
      ]
    ]
  ]
end
```

<tells the agents how to move about the map>

```
to wiggle [pickup-allowed?]
  right random-float 30
  left random-float 30
  if can-move? 1 and [(not forbidden? or (pickup-allowed? and is-pickup?)) and not is-
gas?] of patch-ahead 1 [
    forward 1
    let others other (turtles in-radius 2.5)
    if any? others [
      let my-size size
      ifelse breed = parents [
```

```
          if any? others with [(self != [my-child] of myself) and (size + [size] of myself) *
personal-space-radius > distance myself ] [
            back 1
          ]
        ]
        [
          if any? others with [(size + [size] of myself) * personal-space-radius > distance
myself ] [
            back 1
          ]
        ]
      ]
    ]
end
```

<our time monitor for the model>

```
to-report elapsed-time
  let hours (floor (ticks / 3600))
  let minutes (floor ((ticks - hours * 3600) / 60))
  let seconds (ticks - (3600 * hours) - (60 * minutes))
  if minutes < 10 [
    set minutes (word "0" minutes)
  ]
  if seconds < 10 [
    set seconds (word "0" seconds)
  ]
  report (word hours ":" minutes ":" seconds)
end

to spread-gas
  if (random-float 1) < gas-spread-rate [
    set is-gas? true
```

```
    sprout-gas-clouds 1 [
      set color (violet + 1.5)
      set size 1.415
      stamp
      die
    ]
    ask turtles-here [
      set gas-fatalities (gas-fatalities + 1)
      die
    ]
  ]
end
```

as stated above, this model has been recently updated, we are still working to refine the model to a more accurate representation of a real world evacuation.

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