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How to become great Chicago Plumbers

Jiren Mao
Shengwen Wang
Zicheng Li

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Agenda

- Background
- Hypothesis
- Assumption
- Simplified Variables
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- Standard Simulation
- Demo
- Conclusion

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Background

- Why
  - St Patrick's Day
  - Dye Chicago River green
- What
  - Time need to dye the river in different parameters
- How
  - Monte Carlo Simulation

Hypothesis

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01

Different boat speed

02

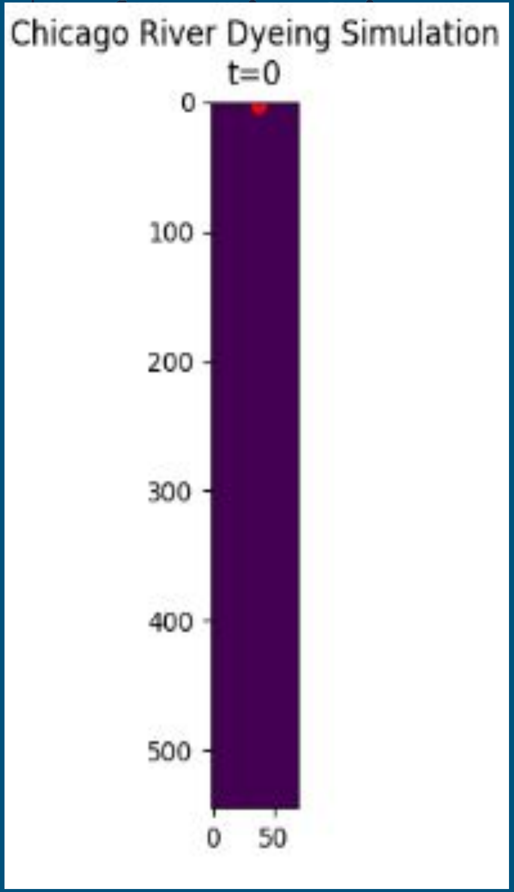
Different dye spreading strategy

03

Different boat movement

Assumptions of River

- River size: Length 545m, Width 70m, Depth 1m
- The water flow affects diffusion process is based on the flow speed and depth (average depth of 7)
- Diffusion effect has boundaries on both ends of the river
    - Extend the river boundary by 1m on each edge and used the concentration at the boundaries.



Assumptions of Boat

- A small boat and a large boat will spread dye in river.
- The boats carries 45 pounds of dye powder in total
- The velocity of the boats is a constant
- Boats behavior:
  - Straight sailing back and forth along the river
  - Zigzag sailing back and forth along the river
  - Randomized sailing (high intention to low concentration areas)

Assumptions of Dye and Dissolving

- Dye powder dissolves into water instantly
- Dye weight / Concentration conversion ratio

Concentration (g/m^3) = Dye weight / 100^3 * 1000

- Least Visible Dye concentration (LVC)

LVC (g/m^3)= Total Dye Weight / (Length * Width * Depth) * 1000

- Dye spreading speed

Speed = mean + white noise

Simplified Variables

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- Treat the depth of river as a constant
- Water flow speed in simulation is defined by:

$$V = \text{mean} + \text{white noise}$$

- Ignore bend of the river
- Ignore disturbance of the boat
- Ignore dye decomposition
- Ignore vertical dimension dissolve effect

Randomize Variables

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- Diffusion effect through time
- Flow effect on diffusion through time
- Dye spreading speed
- Boats behaviour

Concentration simulation-Diffusion

$$\frac{\partial C}{\partial t} + u\frac{\partial C}{\partial x} + \cancel{v\frac{\partial C}{\partial y}} + \cancel{w\frac{\partial C}{\partial z}} = D_x\frac{\partial^2 C}{\partial x^2} + D_y\frac{\partial^2 C}{\partial y^2} + \cancel{D_z\frac{\partial^2 C}{\partial z^2}}$$

Diffusion

$$C_{i,j}^{n+1} = s_x\ C_{i+1,j}^{n} + s_x\ C_{i-1,j}^{n} + s_y\ C_{i,j+1}^{n} + s_y\ C_{i,j-1}^{n} + (1 - 2s_x - 2s_y)\ C_{i,j}^{n}$$

$$\langle \varepsilon_y \rangle = 0.067hu_*.$$

Random variable

$$s_x = \frac{\boxed{D_x}\Delta t}{\Delta x^2}$$

Determine dissovisity scale with velocity:

$$\frac{u}{u_*} = \frac{1}{\kappa} ln\left(\frac{z}{k_s}\right) + 8.5 = \frac{1}{\kappa} ln\left(30\frac{z}{k_s}\right)$$

$$\langle \varepsilon_y \rangle =$$ 9.7 x 10 ^ (-3)

Concentration simulation - Flow effect

$$\frac{\partial C}{\partial t} + u\frac{\partial C}{\partial x} + \cancel{v\frac{\partial C}{\partial y}} + \cancel{w\frac{\partial C}{\partial z}} = D_x\frac{\partial^2 C}{\partial x^2} + D_y\frac{\partial^2 C}{\partial y^2} + \cancel{D_z\frac{\partial^2 C}{\partial z^2}}$$

Flow effect

$$C_{i,j}^{n+1} = \boxed{\left(\frac{C_{i-1,j}^{n} - C_{i+1,j}^{n}}{2\Delta x}\right) \times \Delta t \times \boxed{u_{i,j}^{n}}}$$

Random variable

Velocity: Normal distribution with mean and standard deviation in March on Chicago river

Standard Simulation

- Variable used:
  - 2 boats:
    - Big boat: speed 1.4 m/s, zigzag movement, spread dye with 3m width
    - Small boat: speed 2.8 m/s random movement, spread dye with 1m width
  - 45 pounds of dye
    - Big boat: 5.67 g/s
    - Small boat: 1.89 g/s
  - River size: 70m width X 545m length
- Complete: 95% of the pixels meet visible concentration
- Failure: cannot complete in 2 hours (7200 sec)
- Simulate 100 times
- The average time to dye the river is: <u>57 minutes and 52 seconds</u>

Demo

- Big boat position
- Small boat position
- Dyed area

Conclusion

- H1: Different faster boat speed would dye the river faster
  - Boats speeds B: 2 m/s; S: 4 m/s
  - The average time to dye the river is: 41 minutes and 49 seconds
- H2: Different spreading strategy
  - Increase dye spreading B: 7.5 g/s; S: 2.5 g/s
  - The average time to dye the river is: 1 hour, 31 minutes and 24 seconds
  - Decrease spreading B: 4.5 g/s; Increase spreading S: 2.1 g/s
  - The average time to dye the river is: 1 hour, 34 minutes and 30 seconds
  - There are 9 simulations fail to cover the river with an average 94.00% coverage rate.
- H3: Different boats movement
  - Change the big boat movement to straight sailing
  - The average time to dye the river is: 42 minutes and 36 seconds

Limitation and Future work

- Limitation
  - Ignore turbulence cause by the boat movement
  - Ignore river bend
  - Ignore dye decomposition
- Future work
  - Improve simulation speed: 15 mins for 100 simulation
  - Add to 3D model
  - Custom boat movement style

Thank You

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