Cellular approach and accurate large scale environment simulation

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CONTEXT

Needs to understand climate change effects: flood, fire, insect swarms… and evolving environment: sea level, weather patterns, ecosystems.

Fig 1. Harmful Algal Blooms (HABs) [4] are *bound to change* of temperature and water, producing toxic or harmful effects on people, fish, shellfish, marine mammals, and birds.

Fig 2. Brown Planthopper, insect swarms, impact on rice field in Vietnam[3]

Fig 3. India floodings: 1.000.000 people displaced, and deaths >400 reported

Fig 4. California has 149 million dead trees in 2018

Methods:

To monitor changes and mitigate consequences together using sensor networks, aerial pictures, physical modeling and computer simulation.

- Test applications are needed such as Harmful Algal Blooms monitoring.
- Measure from sensor fields, simulate with cellular systems [1], and adjust theoretical model behaviour.
- Elaborate prediction software.

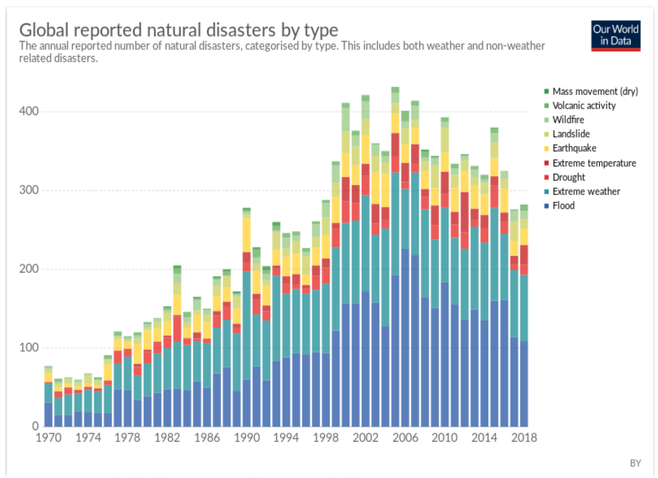

Fig 5. Global reported natural disasters in 1970-2018

Problems:

- Characterization of “complex terrains”: mountains, hills, rivers, shores are disrupting behaviour. Other parameters too : population density, soil composition, people activity.
- Modeling large areas will induce partitioning based on these characteristics.

DATA ANALYSIS

Fig 6. Initial cell system at step t, center is partition data, based on parameters: region, map color, elevation... processed step by step with a management of margin dependencies.

Cellular automata example: rain

Data space is divided into tiles, zone character, elevation,… processed step by step, independently, with a management of margin dependencies.

$$T_i = \frac{nD_i}{\sqrt[3]{h_0^2}\sqrt{(H_i - H_0)/D_i}}$$

$$f_i = \begin{cases} (avg - H_i)\dfrac{t}{T_i}, & t < T_i \\ (avg - H_i), & t >= T_i \end{cases}$$

Eq 1. Propagation time (T_i) and water quantity from central cell to its neighbors (f_i)

n: Manning’s coefficient
h_0: The water depth in central cell
H_i: Neighbor heights
H_0: Height of central cell
D_i: Distance from central cell to each flowing neighbor.
t: time step
avg: the sum of water quantity of cells divide count of its neighbor

Transition Rules:

- The water quantity of each central cell distributed to its neighbors at each time step based on Equation 1, 2.
- A minimization algorithm based principle of a dynamic system has proposed to minimize the height margin of cells [6].

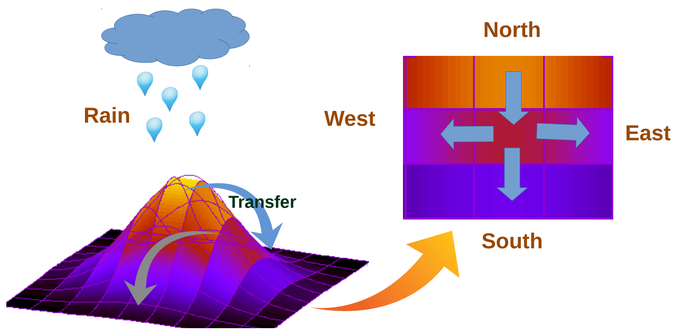

Fig 7. Water flow moved on cell system based on trasition rule during a rain episode (showed by sending water quantity North Cell to Center Cell, and Center Cell to the West, East, and South Cell)

SYSTEM MODEL

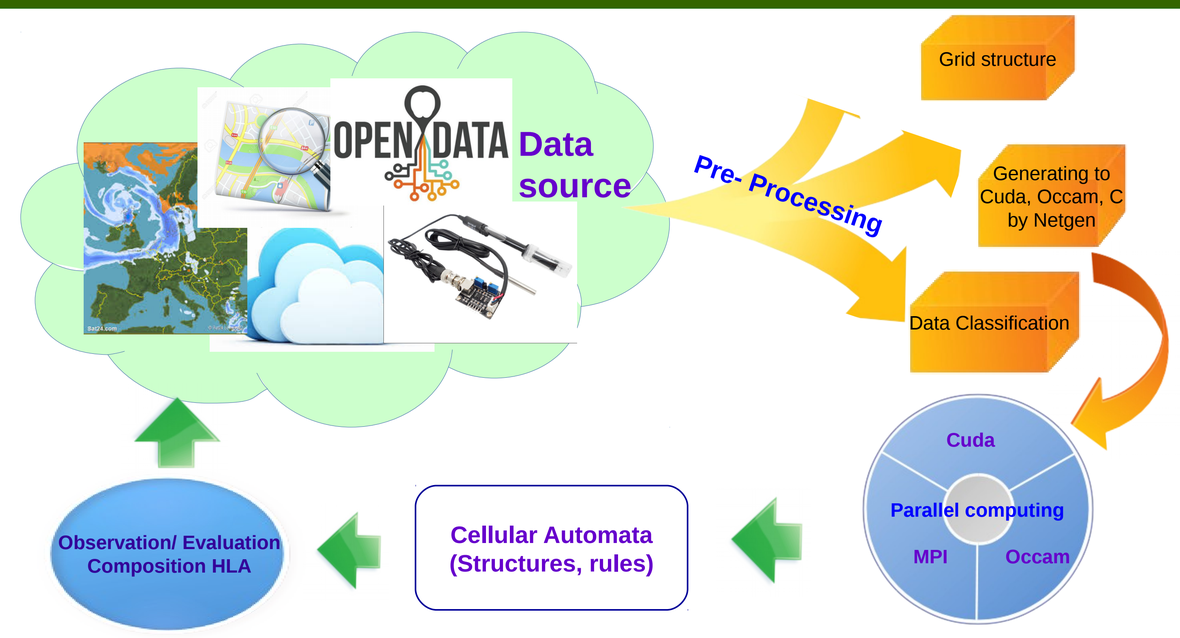

Fig 8. Workflow for simulation system

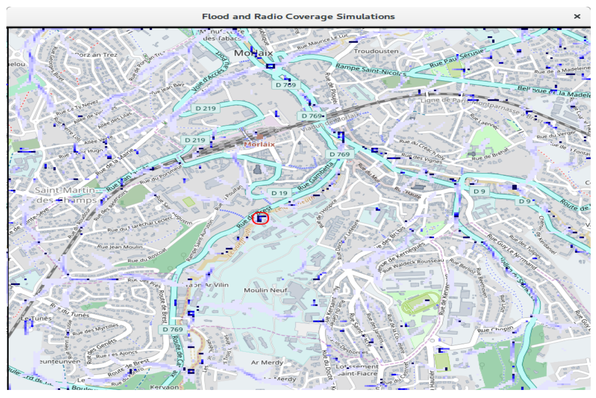

Fig 9. Morlaix (France) Simulation (58275 cells, 3 x 3 km, rainfall: 60cm) by GPUs with thousands of CUDA cores.

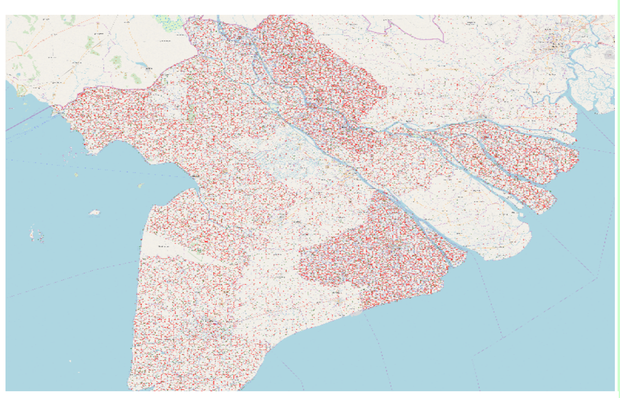

Fig 10. Mekong (Vietnam) Simulation (23.592.960 cells, 76 x 76 m, rainfall: 100cm) by CPU (MPI) with clusters.

Resolution (pixels)	Number of cells	Execution time 820M	GTX 680	GTX 1070
3x3	58725	28.168 (ms)	6.5269 (ms)	1.3373 (ms)
5x5	21060	10.411 (ms)	2.1728 (ms)	518.64 (μs)
10x10	5226	2.5234 (ms)	454.59 (μs)	83.696 (μs)
15x15	2340	1.1155 (ms)	181.48 (μs)	65.916 (μs)
20x20	1287	602.47 (μs)	171.19 (μs)	62.085 (μs)

Tab 1. Execution times for flood simulations which are performed on Linux Ubuntu PCs with Cuda [2].

Number of cells	Resolution	m/cell	10 hours		24 hous	
			Normal	MPI	Normal	MPI
768.432	1024x768	76	9.431s	9.029s	18.284s	19.716s
3.145.728	2048x1536	76	12.150s	30.230s	24.245s	1m
23.592.960	5120x4608	76	7m21s	5m7s	17m9	11m30

Tab 2. Execution times for flood simulations which are performed on Linux Ubuntu PCs with MPI evaluation on 3 nodes.

CHALLENGES/PERSPECTIVES

- Multiple targets computation solution: CPU, GPU, MPI.
- Real world applications.
- Parallel load distribution related to data complexity/requirements.
- Data diversity and Open Data [5] access from cells.
- Integrating of remote detection and ground sensor.
- Modeling of fluid dynamics and computing methods for Biosystems applied to water management and monitoring in system model.

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