HIC 2012

CADDIES: a New Framework for Rapid Development of Parallel Cellular Automata Algorithms for Flood Simulation

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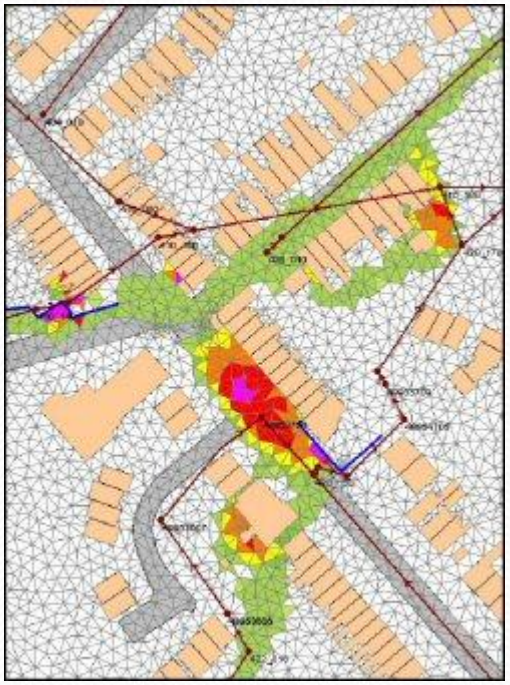
Outline

- Conventional pluvial flood modelling
- CADDIES project
  - Cellular Automata Dual DraInagE Simulation
  - Cellular Automata (CA) modelling alternative
- CA Framework (API)
  - Research tool to allow CA models to be developed
  - Parallelisation (GPU / Cluster / Cloud)
  - CA model performance evaluation

Conventional 1D/2D Pluvial Flood Modelling

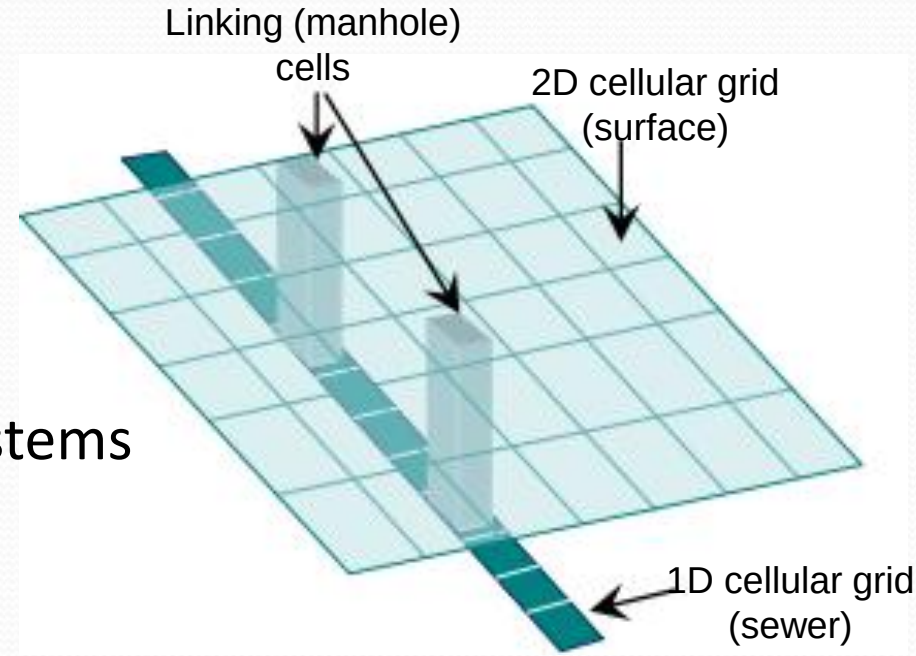
- Hydrodynamic (St Venant equations)
  - Solution is iterative process
  - Urban surface / sewer flow
    - "dual drainage"
  - Full 2D approach
    - computationally intensive (hours run time)
  - Pseudo-2D
    - 1D surface channels + ponds
- Trade-off between speed and accuracy



CADDIES project

Cellular Automata Dual DraInagE Simulation

- Improve “Dual-Drainage” flood modelling
  - Urban surface / sewer flow
- Cellular Automata
  - Simulate complex physical systems using simple rules
  - Fast computations



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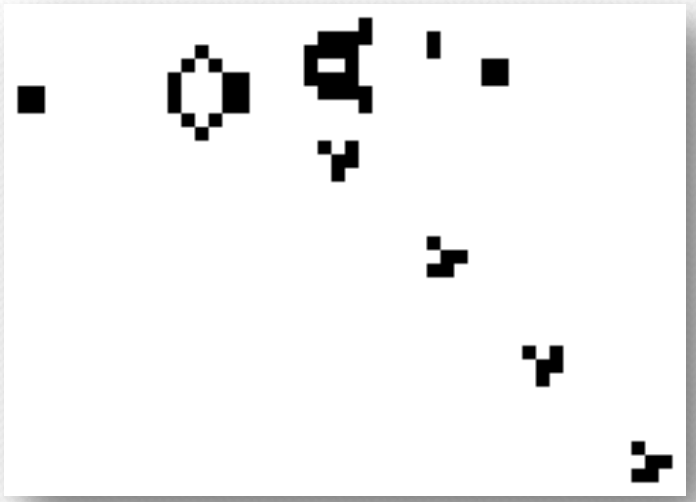
Cellular automata

- Grid of cells
- Each cell has a set of states
- Simple transition rules on each cell
- Use previous state of neighbourhood
- Ideal for parallelisation
- Famous example
  - Game of life (glider gun)

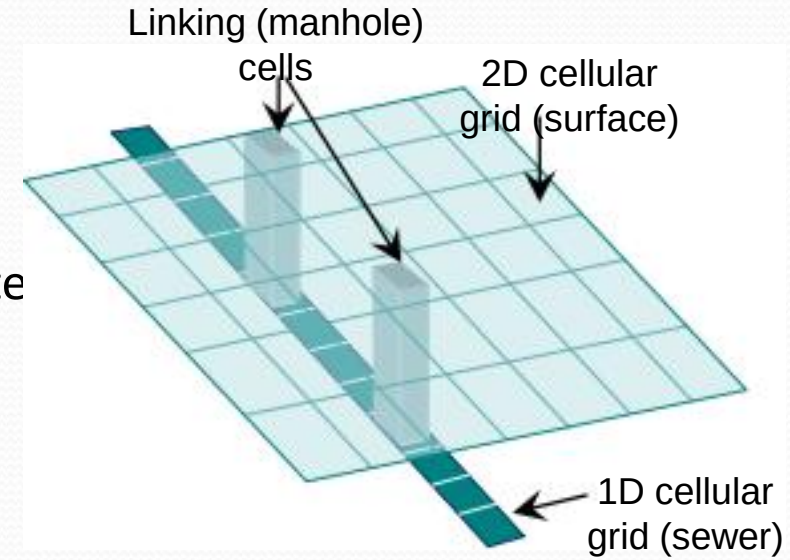


CADDIES Challenges

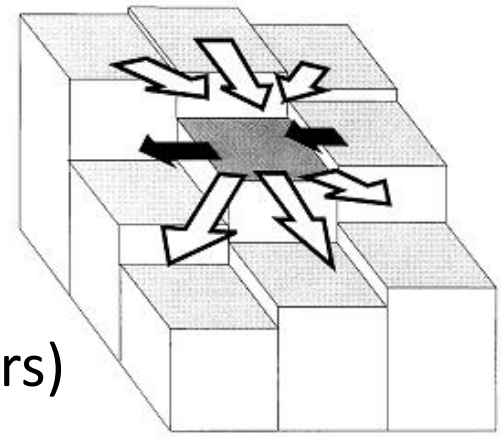
To simulate complex flooding processes

using simple rules... not trivial!

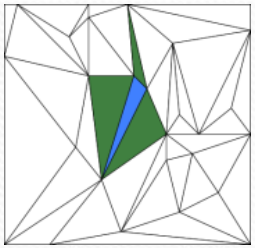
- Grid of cells – each with a "state"
  - e.g. flood depth / flow rate / water volume
- Cell states evolve stepwise
  - simultaneously across whole grid
- New state of each cell
  - only determined by states of immediate neighbours in previous timestep

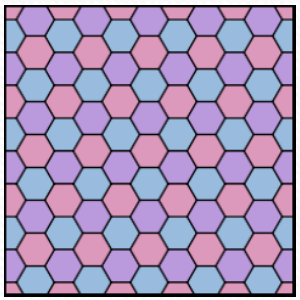


CADDIES Challenges



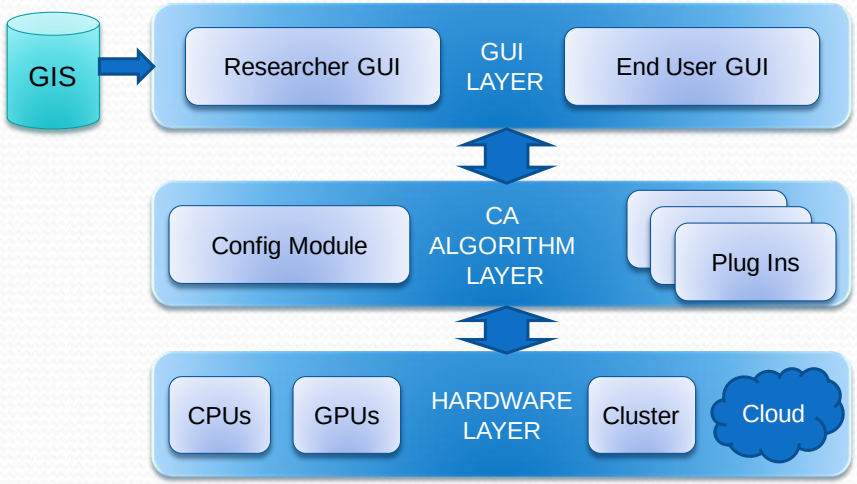
- CA Algorithm is defined by:
  - Transition rules (based on states of neighbours)
    - How many states and which types of value?
    - Which relationships / transition functions?
    - How to handle grid boundary cells?
  - Underlying grid structure
    - Which types of grid structure? (regular / irregular)
    - Cell shapes? (polygon sides)
    - How many cells in the neighbourhood?





CADDIES Framework

- A new flexible software environment (various tools)
  - API (Application Programming Interface)
  - that aims to:
    - Simplify the development/test/analysis of CA algorithms
    - Accelerate CA algorithm using modern hardware
    - Graphically manage the development of CA algorithms



CADDIES CA API

- Standard set of
  - Data structures
  - Variables
  - Methods

```
1  CA_FUNCTION outflow(CA_GRID grid,
2                      CA_EDGEBUFF_REAL_IO OUTF,
3                      CA_CELLBUFF_REAL_I  ELV,
4                      CA_EDGEBUFF_REAL_I  WL) {
5    CA_GRID_INIT(grid);
6    CA_ARRAY_CREATE(grid, CA_REAL, aelv,  caNeighbours+1);
7    CA_ARRAY_CREATE(grid, CA_REAL, aoutf, caEdges+1);
8    CA_INDEX index = caIndex(grid,0);
9    ...
10   caReadCellBuffRealCellArray(grid, ELV, aelv);
11   caReadEdgeBuffRealEdgeArray(grid, ELV, index, aoutf);
```

```
1  #include CA_2D_INCLUDE(outflow)
2
3  int main(...){
4   ...
5   CA::Grid          GRID(ncols,nrows,cellsize);
6   CA::CellBuffReal  ELV(GRID);          // Elevation
7   CA::CellBuffReal  WL(GRID);           // Water Level
8   CA::EdgeBuffReal  OUTF(GRID);         // Outflow
9   CA::Box           area(GRID.box());   // Computational Area
10  ...
11  while(loop) {
12   // Execution of the "outflow" CA transition function
13  CA::Execute::function(area,outflow,GRID,OUTF,ELV,WL);
14   ...
15  }}
```

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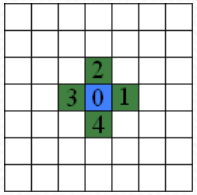
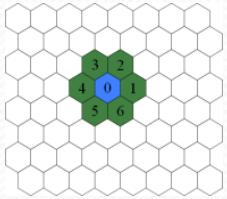
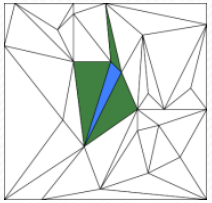
CADDIES CA API Ideas

- The developer need write the CA algorithm only once
- The algorithm will work with different types of grids





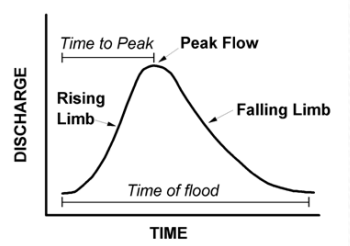


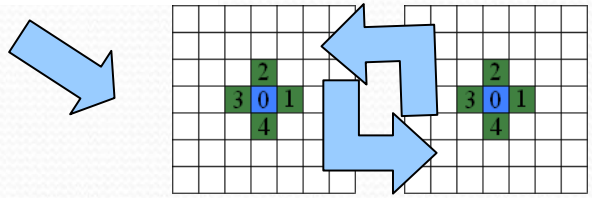
- Automatically accelerate execution using modern hardware (GPU / Cluster / Cloud)

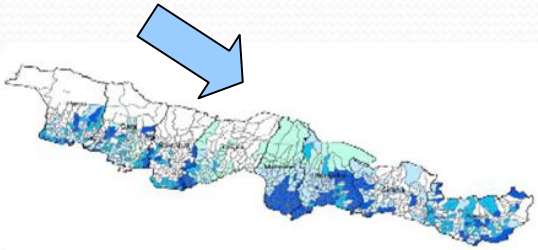


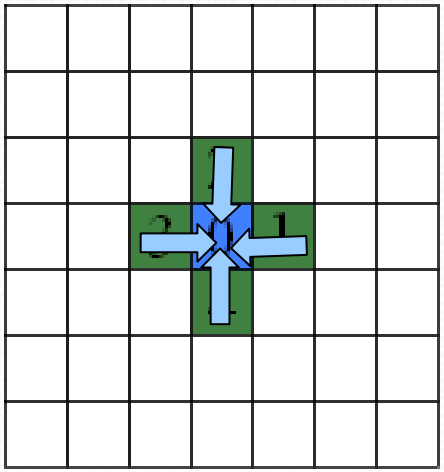
CA ALGORITHM using the API

1. CA Execution
   - Data management
   - Flow control
2. CA Transition Rules
   - Computation in each cell



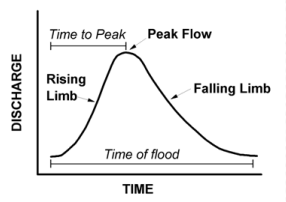


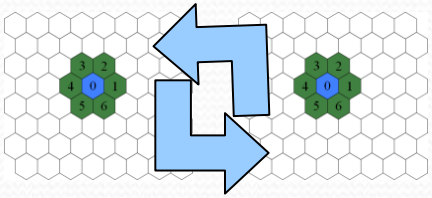


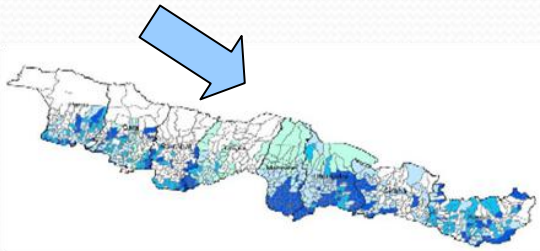


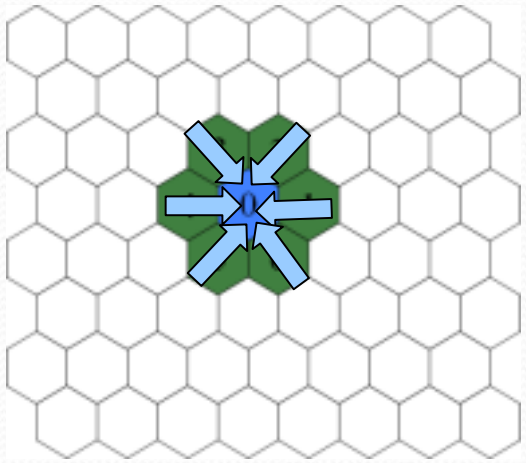
CA ALGORITHM using the API

3. CA options
   - Define Attributes
     - Grid/Cells/Etc.







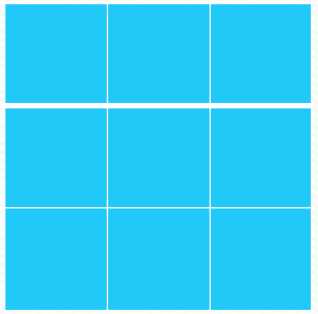


CA API Implementations

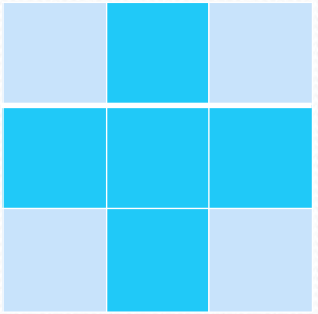
- Different implementations depending on:
  - CA attributes
  - Hardware used
- At the moment three implementations:
  - Sequential CPU / Square / Moore
  - Sequential CPU / Square / von Neumann
  - OpenCL GPU / Square / von Neumann

Neighbourhoods

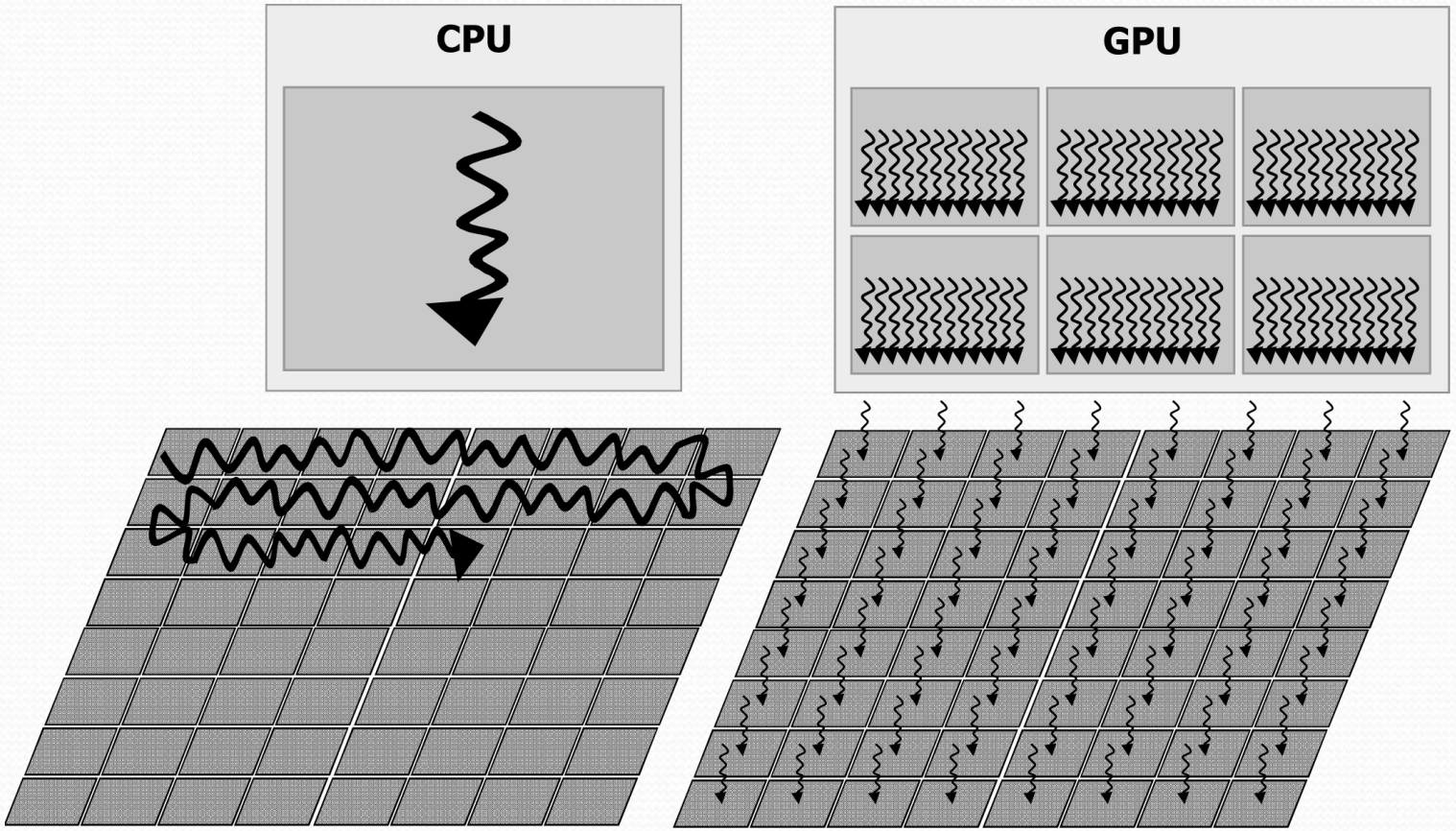
Moore



von Neumann



CPU versus GPU



Game of Life Example

CA Execution

```
#include CA_2d_INCLUDE(gol)

int main(...){
  ...
  CA::Grid          GRID(ncols,nrows,1);
  CA::CellBuffState A(GRID),B(GRID);
  CA::Box           area(GRID.box());
  ...
  while(loop) {
    CA::Execute::function(area,gol,GRID,A,B);
    ...
  }
}
```

CA Transition Rules

```
CA_FUNCTION gol(CA_GRID grid,
                CA_CELLBUFF_STATE_IO a,
                CA_CELLBUFF_STATE_I  b)
{
  CA_GRID_INIT(grid);
  CA_ARRAY_CREATE(grid,CA_STATE,states,caNeighbours+1);
  ...
  caReadCellBuffStateCellArray(grid,b,states);
  for(int i=0;i<=caNeighbours;i++) {
     ...
  }
  caWriteCellBuffState(grid,a,0,states[0]);
}
```

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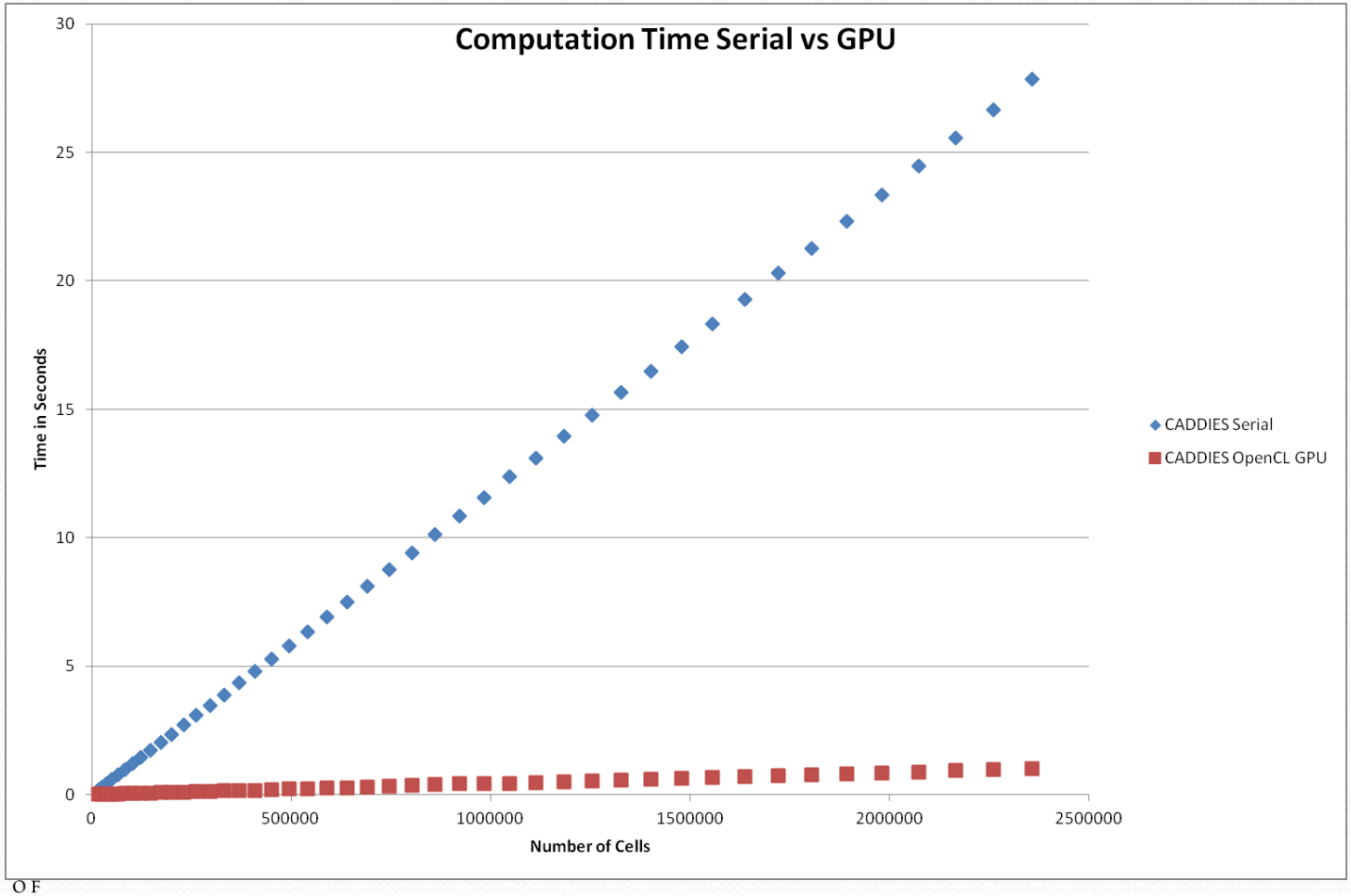
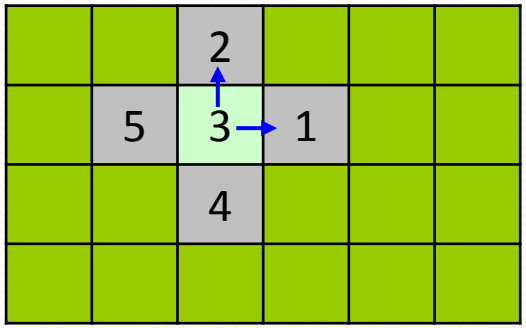
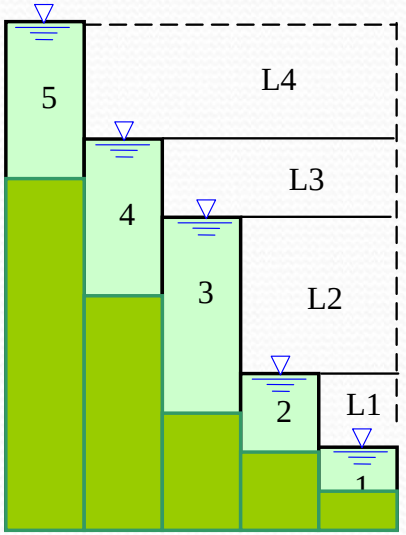
Game of Life Results



CA Flood algorithm Example

- Computes outflow of cell by ranking the water surface elevation





- Presented in detail in HIC 2012 paper:
  - Colleague: Dr. Bidur Ghimire
  - Wednesday 18 July 9.20 - 9.40
  - Topic A5.2

Case Study

- Stockbridge area in Keighley (UK)
- DEM of 2m resolution with 377x269 cells
- Rainfall of 42.3 mm/hr (100 year return)
- Used two CA API implementations
  - Sequential CPU / Square / von Neumann
  - OpenCL GPU / Square / von Neumann
- Used two hardware configurations
- Used physical based UIM model as reference

CA flood algorithm Results

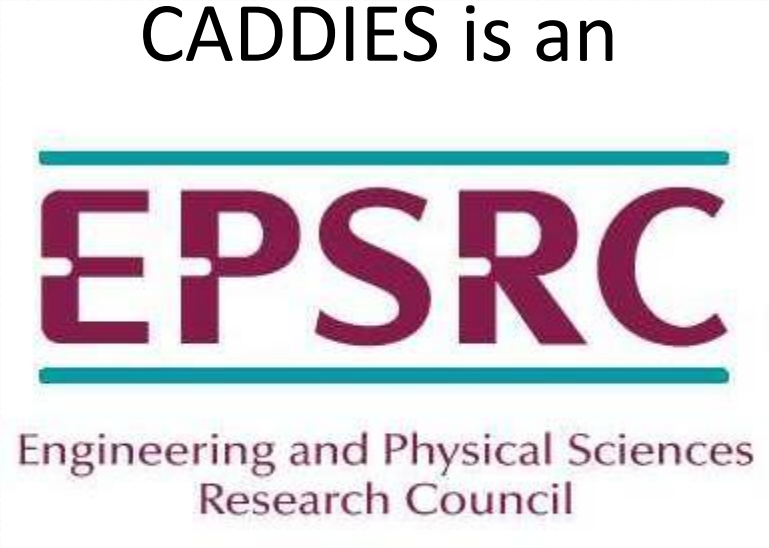
	UIM	Simple Serial			OpenCL			
Model	Time (s)	Time (s)	S_p^{UIM}	RMSE (m)	Time (s)	S_p^{Ser}	S_p^{UIM}	RMSE (m)
1	10371.1	280.9	36.9	0.027	50.8	5.5	204.2	0.027
2	5885.7	161.6	36.4	0.029	44.5	3.6	132.3	0.029

Conclusion

- CA API is part of CADDIES framework
- It possible to simply develop CA algorithms
  - Game of life
  - CA algorithms for pluvial flood modelling
- Automatically accelerate algorithm using modern hardware
- CA flood model with GPU can be an order of magnitude faster than physical models (UIM)

Acknowledgment

CADDIES is an



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Thanks

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