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SYSC 5104 Assignment 2 Report

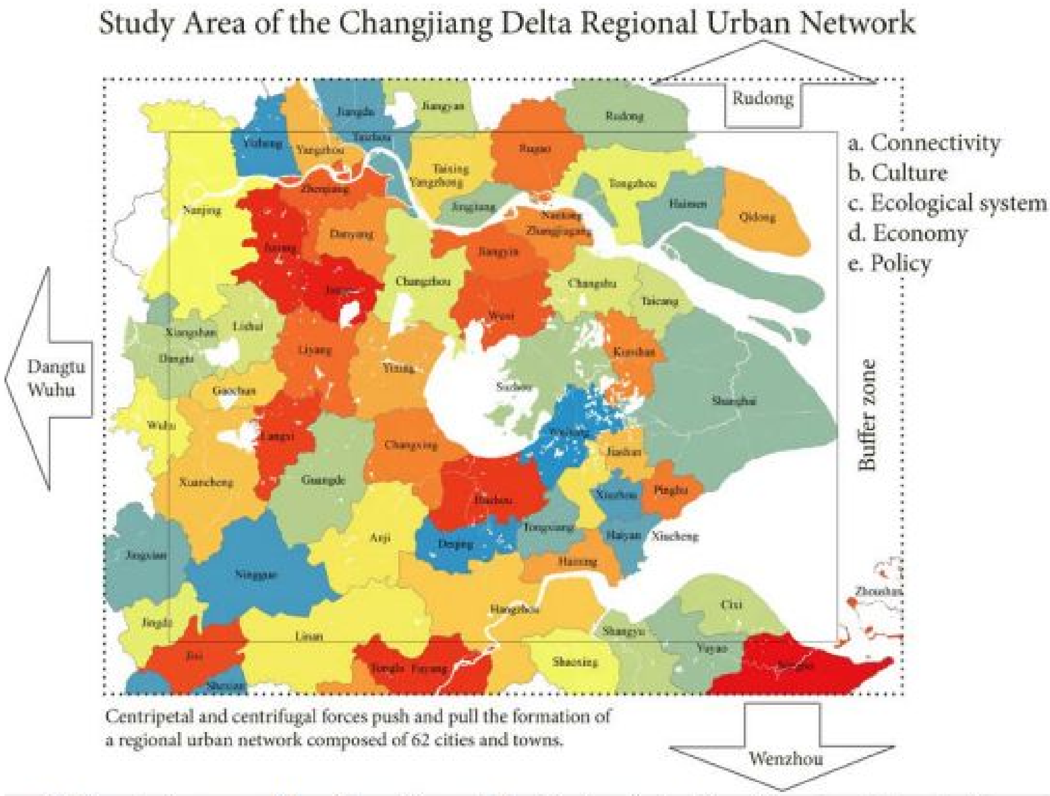
Should big cities grow? Scenario-based cellular automata urban growth modeling and policy application

https://dash.harvard.edu/handle/1/33747421

Introduction

Urban environments can be modelled as networks. Globally, there are diverging views of management and control of environment, land use, scale and arrangement of settlements. These can be assisted by simulation using now-widely available spatial information. This is a case study of the Chanjiang Delta Region in China.
The study area covers 75,900 km^2 of land with 10,200 km^2 of water bodies. There are 16 regional-level cities, 28 county-level cities and 1700 towns.
Four growth scenarios were considered, depending on different growth factors, and are outlined below.

Individual Model Description



Different scenarios for city growth are considered, like

1) Development corridors
2) Corridors with big city growth
3) Ecological system concerns, plus development corridors, and
4) Disaster prevention with development corridors.

The urban growth prediction model (modified with these scenarios) is given below, and is used as the basis for the Cell DEVS models created for this assignment, covering scenarios 1 through 4.

Urban growth prediction model summary

Table 2. Urban growth prediction model.

$$(a)\ G_{total}^{t+1} = \sum G_{spontaneous(i,j)}^{t+1} + G_{spread(i,j)}^{t+1} + G_{edge(i,j)}^{t+1} + G_{road(i,j)}^{t+1} + G_{corridor(i,j)}^{t+1}$$

$$(b)\ G_{total}^{t+1} = \sum G_{spontaneous(i,j)}^{t+1} + G_{spread(i,j)}^{t+1} + G_{edge(i,j)}^{t+1} + G_{road(i,j)}^{t+1} + G_{corridor(i,j)}^{t+1} + G_{city(i,j)}^{t+1}$$

$$(c)\ G_{total}^{t+1} = \sum G_{spontaneous(i,j)}^{t+1} + G_{spread(i,j)}^{t+1} + G_{edge(i,j)}^{t+1} + G_{road(i,j)}^{t+1} + G_{corridor(i,j)}^{t+1} + G_{ecological(i,j)}^{t+1}$$

$$(d)\ G_{total}^{t+1} = \sum G_{spontaneous(i,j)}^{t+1} + G_{spread(i,j)}^{t+1} + G_{edge(i,j)}^{t+1} + G_{road(i,j)}^{t+1} + G_{corridor(i,j)}^{t+1} + G_{disaster(i,j)}^{t+1}$$

Where,

G_{total}^{t+1} =Total urban growth prediction, at year t+1
$G_{spontaneous(i,j)}^{t+1}$ = Spontaneous growth, the occurrence of random urbanization of land, at year t+1
$G_{spread(i,j)}^{t+1}$ = Spread growth, the urban spreading of newly urbanized land cell, at year t+1 (pay attention that this excluded the spread growth of existing urbanized land cell)
$G_{edge(i,j)}^{t+1}$ = Edge growth, the further expansion of newly spread urbanized cell, at year t+1
$G_{road(i,j)}^{t+1}$ = Road influenced growth, at year t+1
$G_{corridor(i,j)}^{t+1}$ = Development corridor growth, at year t+1
$G_{city(i,j)}^{t+1}$ = Big cities growth, at year t+1
$G_{ecological(i,j)}^{t+1}$ = Ecological system concerns, at year t+1
$G_{disaster(i,j)}^{t+1}$ = Disaster preventions growth, at year t+1

Scenario 1 (Development Corridor) Specification

CDR = $<X, Y, I, S, \theta, N, d, \boldsymbol{\delta}_{int}, \boldsymbol{\delta}_{ext}, \tau, \lambda, D>$
Where
CDR = Chanjiang Delta Region
X = $\{X_{region}\}$ where
  X_{region} = Region year zero settlement data, e.g road, corridor settlements
Y = $\{ G_{total} \}$ where G_{total} = Total growth of the region
I = $<\eta, \mu, P^x, P^y>$ model's modular interface, where
  η= 8 (neighbourhood size)
  μ= 0 (number of other ports)
  $P^x = \{\}$
  $P^y = \{\}$
S = $\{\{G^t_{total} \in R\}\}$
$\theta = \{G^t_{spontaneous}, G^t_{spread}, G^t_{edge}, G^t_{road}, G^t_{corridor}\}$
  Where
    G^t_{total} = Total urban growth prediction at year t
    $G^t_{spontaneous}$ = Spontaneous growth, the occurrence of random urbanization, at year t
    G^t_{spread} = Spread growth, the urban spreading of newly urbanized land cell, at year t
    G^t_{edge} = Edge growth, the further expansion of newly spread urbanized cell, at year t

G^t_{road} = Road influenced growth, at year t
$G^t_{corridor}$ = Development corridor growth, at year t
G^t_{city} = Big cities growth, at year t
$G^t_{ecological}$ = Ecological system concerns, at year t
$G^t_{disaster}$ = Disaster preventions growth, at year t

N = { [-1,-1], [0,-1], [1,-1], [-1,0], [1,0], [-1,1], [0,1], [1,1] }

$\boldsymbol{\delta}_{int}$ = { }

$\boldsymbol{\delta}_{ext}$ = {

If (X_{road} == 0) passivate
Else if (P_{xy} == [0, 0])
G^t_{road} += X_{road}
}

τ = {

$$G^{t+1}_{total} = \sum G^{t+1}_{spontaneous(t,f)} + G^{t+1}_{spread(t,f)} + G^{t+1}_{edge(t,f)} + G^{t+1}_{road(t,f)} + G^{t+1}_{corridor(t,f)}$$

}

λ = { G^t_{total} }

Scenario 1 Summary

In this scenario, corridor settlement growth was tested, using corridor and road settlement data for year zero, as well as (randomized) town settlement data. Spread and edge growth arounds these settlements was simulated, without regard for ecological, disaster relief and other concerns. The simulation output can be seen in the following subsections.

Cell DEVS Input Data

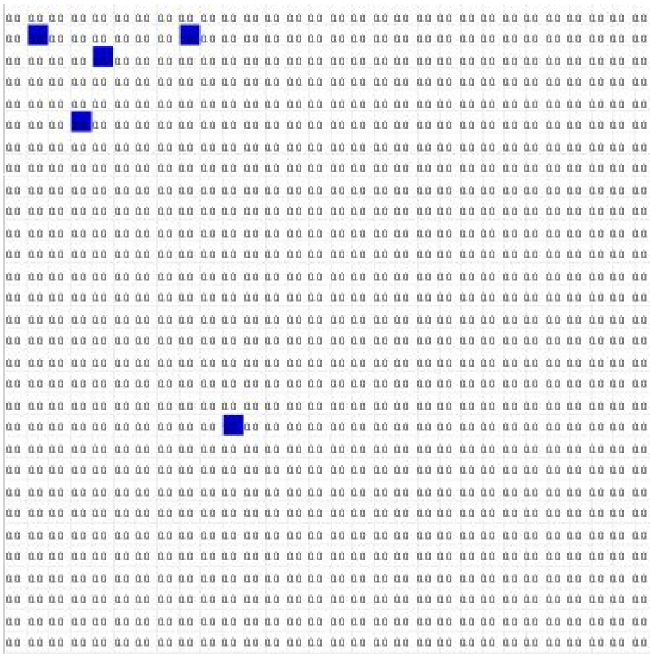
Note that due to memory constraints (Java Heap & Out Of Memory exceptions on CD++ Eclipse), the size of the input data was rarefied for non-primary settlement data. The full data set would be a 3 by 3 by 8 matrix, which would not get processed in a reasonable amount of time, and usually did not even terminate due to the above-mentioned errors.

The structure of the matrix consisted of an initial layer (layer zero) of settlements across the Chianjiang region in 2D, plus higher layers containing corridor settlements, road settlements, spread and edge hotspots, ecological and disaster relief areas, etc. These subsequent layers were then condensed into two layers, providing a 30 by 30 by 3 matrix, which was processed in a reasonable amount of time by CD++.

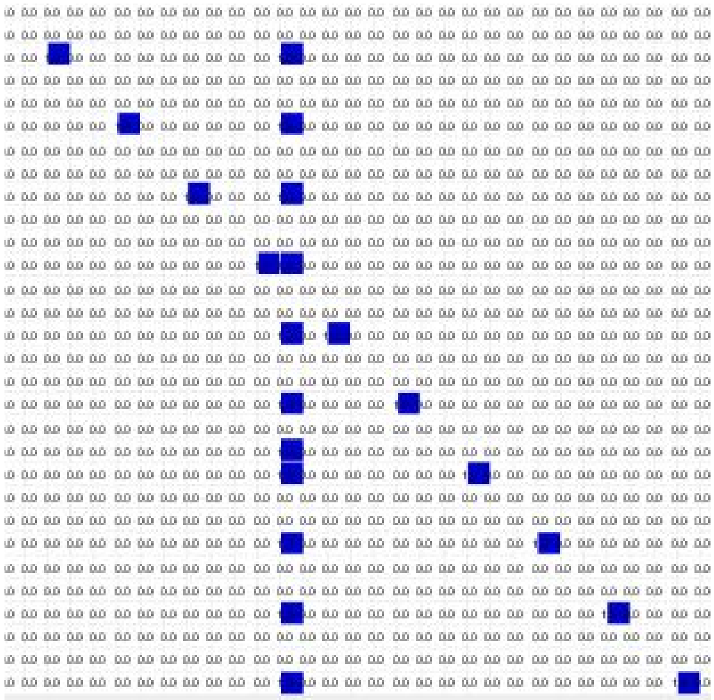
Layers two and three consisted of interleaved rows of settlement influencing data as described earlier such as road, corridor settlements, spread hotspots, etc. They are interleaved in groups of 3, allowing three different datasets per layer. Having three interleaved datasets is important because it allows all the datasets to be accessible from a cell’s neighbours, in higher layers.

Test Simulations

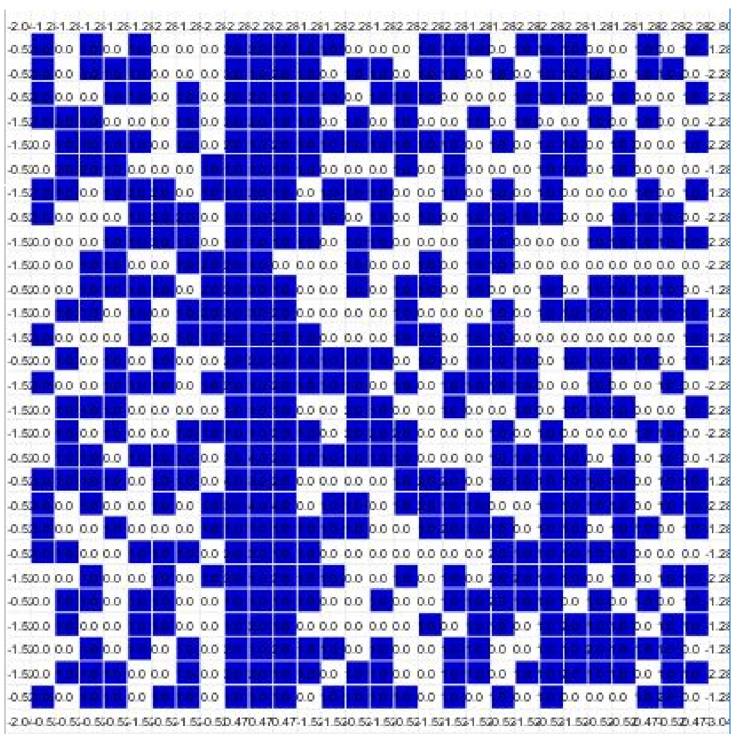
Initial Settlements



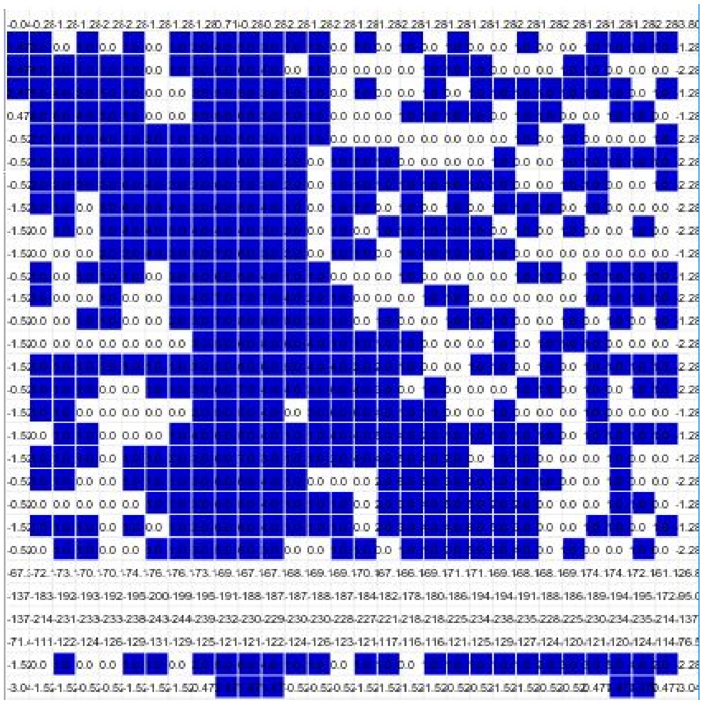
Initial River Locations (Vertical and Diagonal Markers Across Region)



Settlements Around Rivers After Some Years (Vertical and Diagonal Clusters)



Spread Around Edges Of Existing Settlements



Scenario 2 (Corridors with Big City Growth) Specification

$CDR = \langle X, Y, I, S, \theta, N, d, \boldsymbol{\delta}_{int}, \boldsymbol{\delta}_{ext}, \tau, \lambda, D \rangle$

Where

CDR = Chanjiang Delta Region

$X = \{X_{region}\}$ where

X_{region} = Region year zero settlement data, e.g road, corridor settlements

$Y = \{ G_{total} \}$ where G_{total} = Total growth of the region

$I = \langle \eta, \mu, P^x, P^y \rangle$ model’s modular interface, where

$\eta = 8$ (neighbourhood size)

$\mu = 0$ (number of other ports)

$P^x = \{\}$

$P^y = \{\}$

$S = \{\{G^t_{total} \in R\}\}$

$\theta = \{G^t_{spontaneous}, G^t_{spread}, G^t_{edge}, G^t_{road}, G^t_{corridor}, G^t_{city}\}$

Where

G^t_{total} = Total urban growth prediction at year t

$G^t_{spontaneous}$ = Spontaneous growth, the occurrence of random urbanization, at year t

G^t_{spread} = Spread growth, the urban spreading of newly urbanized land cell, at year t

G^t_{edge} = Edge growth, the further expansion of newly spread urbanized cell, at year t
G^t_{road} = Road influenced growth, at year t
$G^t_{corridor}$ = Development corridor growth, at year t
G^t_{city} = Big cities growth, at year t
$G^t_{ecological}$ = Ecological system concerns, at year t
$G^t_{disaster}$ = Disaster preventions growth, at year t
N = { [-1,-1], [0,-1], [1,-1], [-1,0], [1,0], [-1,1], [0,1], [1,1] }
$\boldsymbol{\delta}_{int}$ = { }
$\boldsymbol{\delta}_{ext}$ = { }
τ = {

$$G^{t+1}_{total} = \sum G^{t+1}_{spontaneous(t,f)} + G^{t+1}_{spread(t,f)} + G^{t+1}_{edge(t,f)} + G^{t+1}_{road(t,f)} + G^{t+1}_{corridor(t,f)} + G^{t+1}_{city(t,f)}$$

}
λ = { G^t_{total} }

Scenario 2 Summary

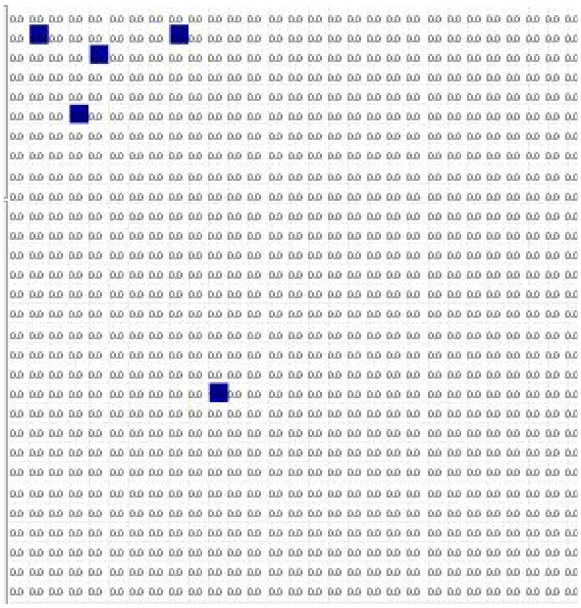
In this scenario, big city settlement growth was tested, using corridor and road settlement data for year zero, as well as (randomized) town settlement data, and of course big city settlement data. Spread and edge growth arounds these settlements was simulated, without regard for ecological, disaster relief and other concerns. The simulation output can be seen in the following subsections.

Cell DEVS Input Data

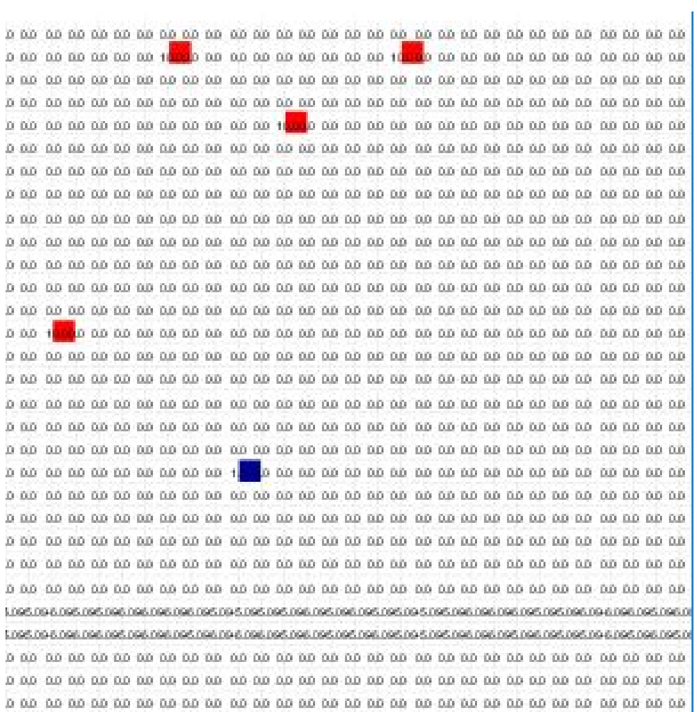
See Scenario 1 for section on Cell DEVS input specification.

Test Simulations

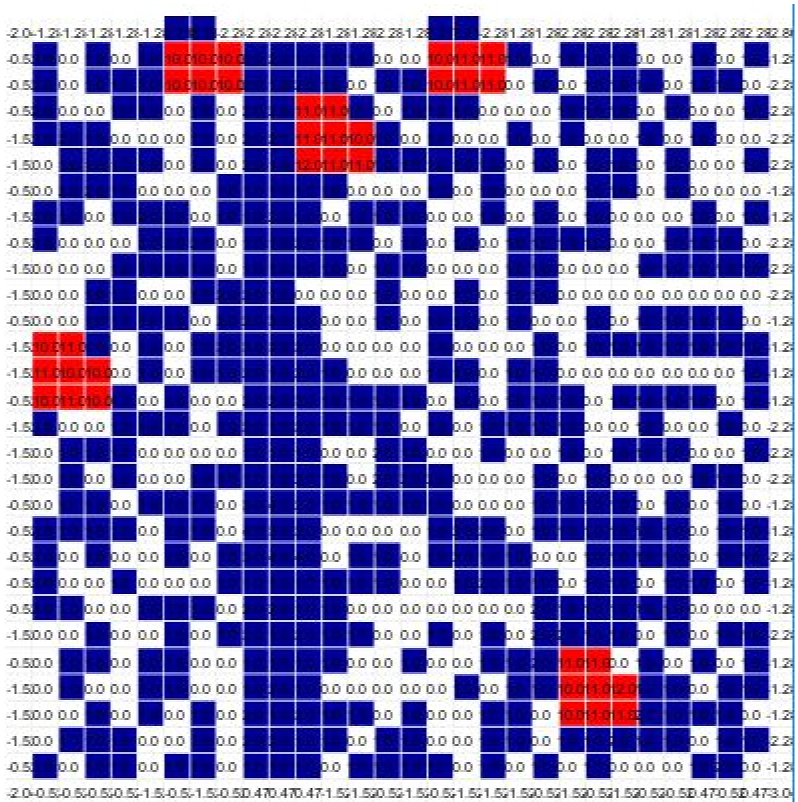
Initial Settlements (River & Corridor Settlement In Scenario 2)



Initial Big City Locations (Red Spots)



Settlements Spread Around Big Cities After Some Years (Red Clusters)



Scenario 3 (Ecological Systems Concerns) Specification

CDR = <X, Y, I, S, θ, N, d, $\boldsymbol{\delta}_{int}$, $\boldsymbol{\delta}_{ext}$, τ, λ, D>
Where
CDR = Chanjiang Delta Region
X = {X_{region}} where
X_{region} = Region year zero settlement data, e.g road, corridor settlements
Y = { G_{total} } where G_{total} = Total growth of the region
I = <η, μ, P^x, P^y> model's modular interface, where
η= 8 (neighbourhood size)
μ= 0 (number of other ports)
P^x = {}
P^y = {}
S = {{$G^t_{total} \in$ R}}
θ = {$G^t_{spontaneous}$, G^t_{spread}, G^t_{edge}, G^t_{road}, $G^t_{corridor}$, $G^t_{ecological}$}
Where
G^t_{total} = Total urban growth prediction at year t
$G^t_{spontaneous}$ = Spontaneous growth, the occurrence of random urbanization, at year t
G^t_{spread} = Spread growth, the urban spreading of newly urbanized land cell, at year t
G^t_{edge} = Edge growth, the further expansion of newly spread urbanized cell, at year t
G^t_{road} = Road influenced growth, at year t
$G^t_{corridor}$ = Development corridor growth, at year t
G^t_{city} = Big cities growth, at year t
$G^t_{ecological}$ = Ecological system concerns, at year t
$G^t_{disaster}$ = Disaster preventions growth, at year t
N = { [-1,-1], [0,-1], [1,-1], [-1,0], [1,0], [-1,1], [0,1], [1,1] }
$\boldsymbol{\delta}_{int}$ = { }
$\boldsymbol{\delta}_{ext}$ = { }
τ = {

$$G^{t+1}_{total} = \sum G^{t+1}_{spontaneous(t,f)} + G^{t+1}_{spread(t,f)} + G^{t+1}_{edge(t,f)} + G^{t+1}_{road(t,f)} + G^{t+1}_{corridor(t,f)} + G^{t+1}_{ecological(t,f)}$$

}
λ = { G^t_{total} }

Scenario 3 Summary

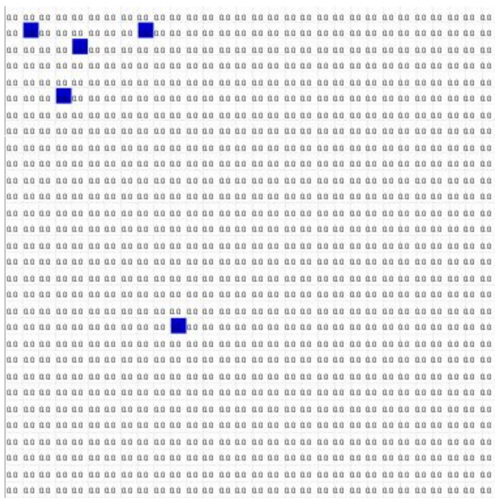
In this scenario, the impact of ecological concerns on growth was tested, using corridor and road settlement data for year zero, as well as (randomized) town settlement data, and of course ecological location data. Spread and edge growth arounds these settlements was simulated, paying attention to ecological factors, but disregarding disaster relief and other concerns. The simulation output can be seen in the following subsections.

Cell DEVS Input Data

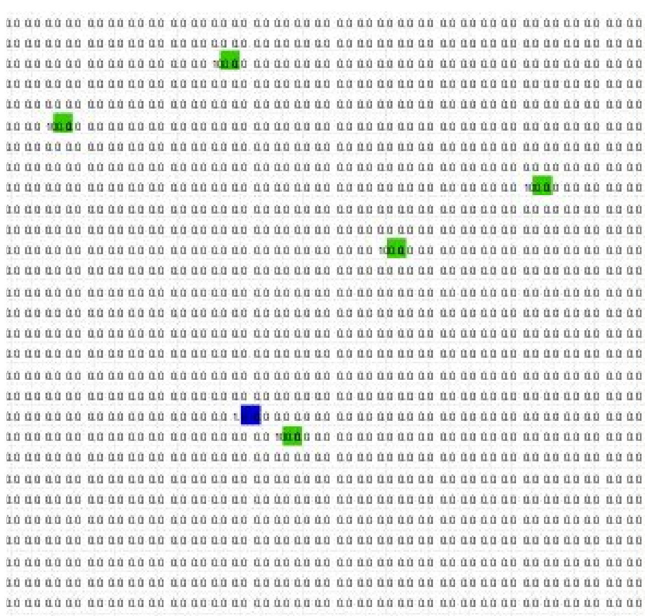
See Scenario 1 for section on Cell DEVS input specification.

Test Simulations

Initial Settlements



Initial Ecological Safe Areas (Green Spots)



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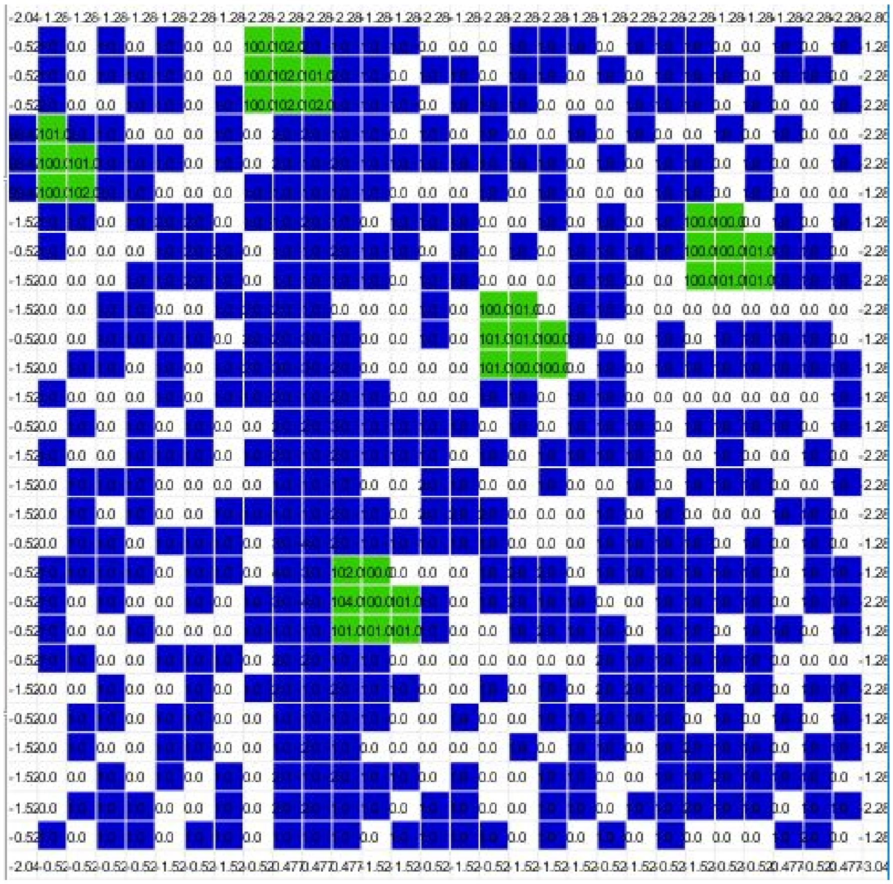
Settlements Around Ecological Safe Areas (Green Clusters)



Scenario 4 (Disaster Prevention) Specification

CDR = <X, Y, I, S, Θ, N, d, $\boldsymbol{\delta}_{int}$, $\boldsymbol{\delta}_{ext}$, τ, λ, D>
Where
CDR = Chanjiang Delta Region
X = {X_{region}} where
X_{region} = Region year zero settlement data, e.g road, corridor settlements
Y = { G_{total} } where G_{total} = Total growth of the region
I = <η, μ, P^x, P^y> model's modular interface, where
η= 8 (neighbourhood size)
μ= 0 (number of other ports)
P^x = {}
P^y = {}
S = {{$G^t_{total} \in$ R}}
Θ = {$G^t_{spontaneous}$, G^t_{spread}, G^t_{edge}, G^t_{road}, $G^t_{corridor}$, $G^t_{disaster}$}
Where
G^t_{total} = Total urban growth prediction at year t
$G^t_{spontaneous}$ = Spontaneous growth, the occurrence of random urbanization, at year t
G^t_{spread} = Spread growth, the urban spreading of newly urbanized land cell, at year t
G^t_{edge} = Edge growth, the further expansion of newly spread urbanized cell, at year t
G^t_{road} = Road influenced growth, at year t
$G^t_{corridor}$ = Development corridor growth, at year t
G^t_{city} = Big cities growth, at year t
$G^t_{ecological}$ = Ecological system concerns, at year t
$G^t_{disaster}$ = Disaster preventions growth, at year t
N = { [-1,-1], [0,-1], [1,-1], [-1,0], [1,0], [-1,1], [0,1], [1,1] }
$\boldsymbol{\delta}_{int}$ = { }
$\boldsymbol{\delta}_{ext}$ = { }
τ = {

$$G^{t+1}_{total} = \sum G^{t+1}_{spontaneous(t,f)} + G^{t+1}_{spread(t,f)} + G^{t+1}_{edge(t,f)} + G^{t+1}_{road(t,f)} + G^{t+1}_{corridor(t,f)} + G^{t+1}_{disaster(t,f)}$$

}
λ = { G^t_{total} }

Scenario 4 Summary

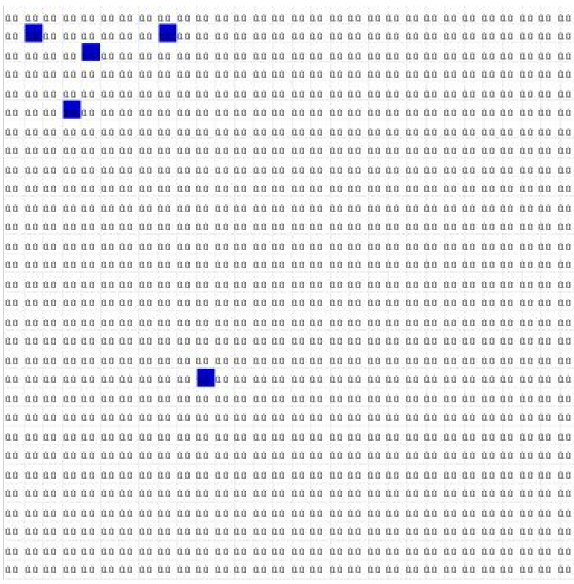
In this scenario, the impact of disaster prevention on growth was tested, using corridor concerns and road settlement data for year zero, as well as (randomized) town settlement data, and of course ecological location data. Spread and edge growth arounds these settlements was simulated, paying attention to disaster prevention settlement information. The simulation output can be seen in the following subsections.

Cell DEVS Input Data

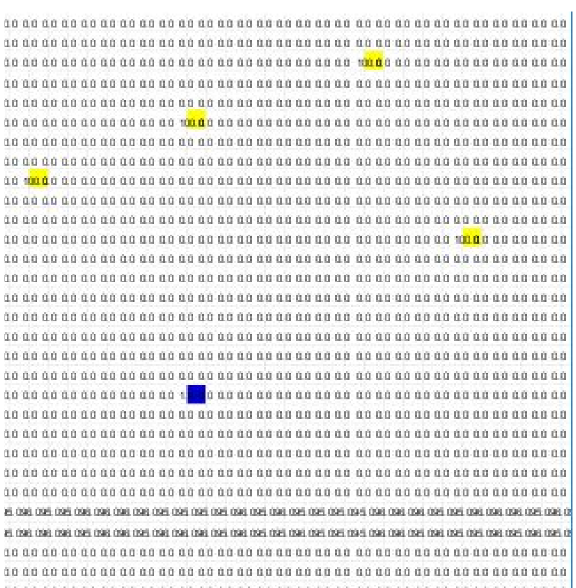
See Scenario 1 for section on Cell DEVS input specification.

Test Simulations

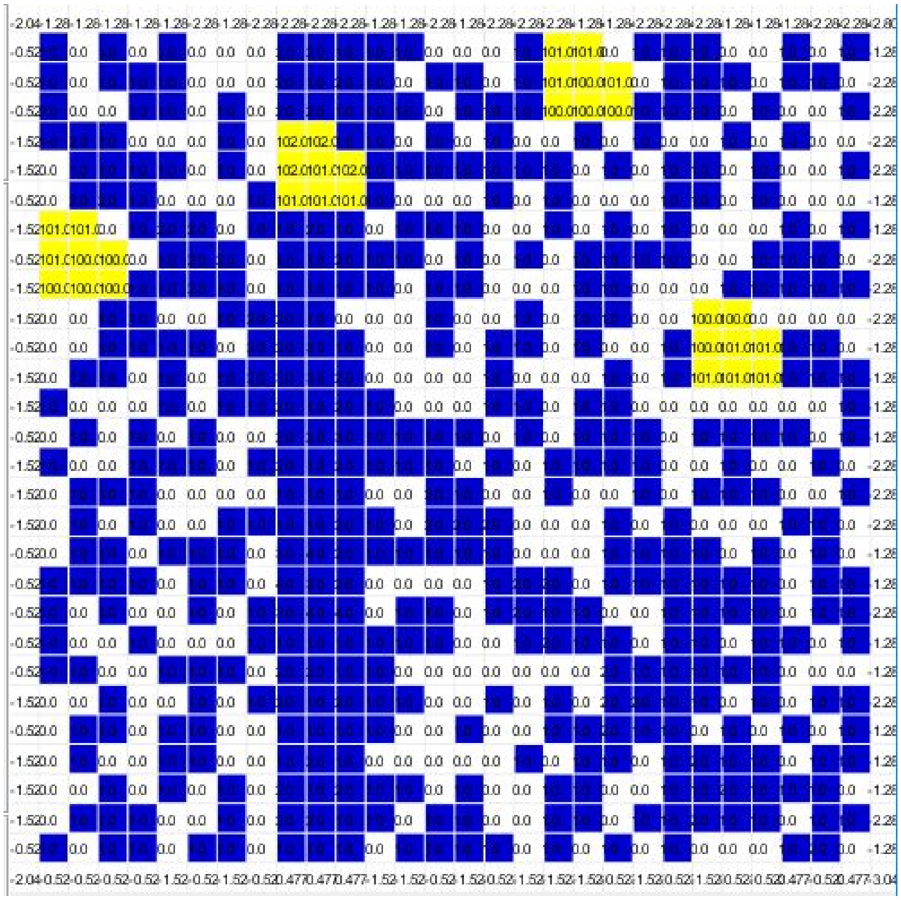
Initial Settlements (Rivers & Corridors Present But Not Shown)



Initial Disaster Safe Sites (Yellow Spots)



Settlements Spread Around Disaster Safe Sites (Yellow Clusters)



Source code, Build and Modelling Instructions

The models were developed and tested using CD++ Builder plugin for Eclipse 3.6.0. All source code for the scenarios are included in the attached zip archive. CD++ Modeller was used for rendering and visualization of the simulation output.

No compilation is needed as per the CD++ Builder manual. To run a simulation for any of the scenarios simply open the scenario model file (***Region.ma***) in Eclipse CD++ Builder and use the simulation run feature, ensuring to set a run duration sufficiently long to generate enough iterations of output. Typically 2 or 3 minutes are enough. If the duration is not set, the simulation will complete early, probably with fewer iterations than desired for visualization.

Palette files and draw files are provided for each scenario in the scenario folders: **scenario1/**, **scenario2/**, etc. A demo video can be found here: http://youtu.be/2bZXbgtI23E