# SPATIAL OPTIMIZATION FOR SUSTAINABLE LAND USE PLANNING

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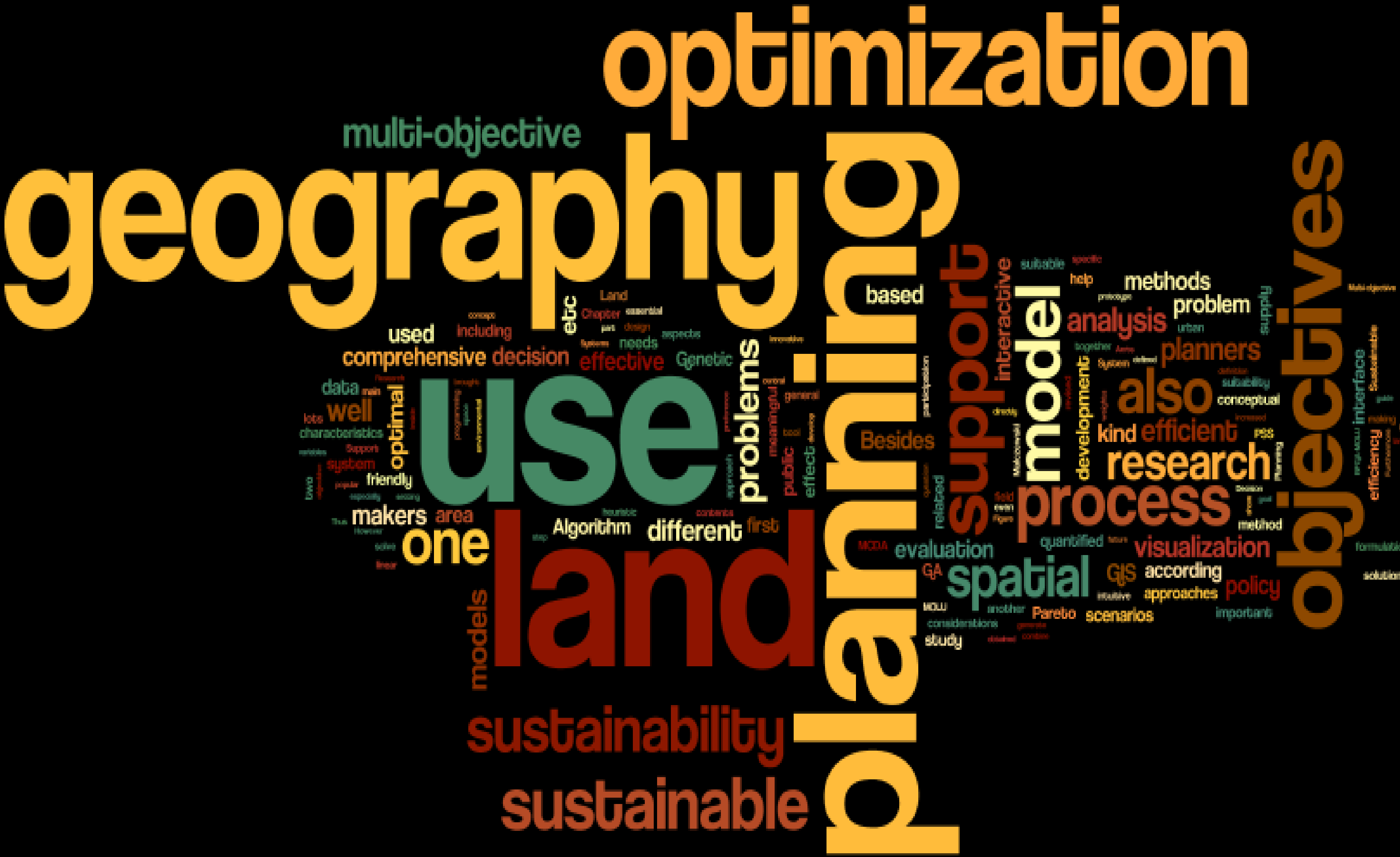
# OUTLINE

- **Background**
- Spatial Optimization (Land Use)
- Case Studies
- Future Work


optimization
multi-objective
geography
planning
objectives
use
land
sustainability
sustainable
support
model
process
research
also
spatial
analysis
planners
problem
methods
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interactive
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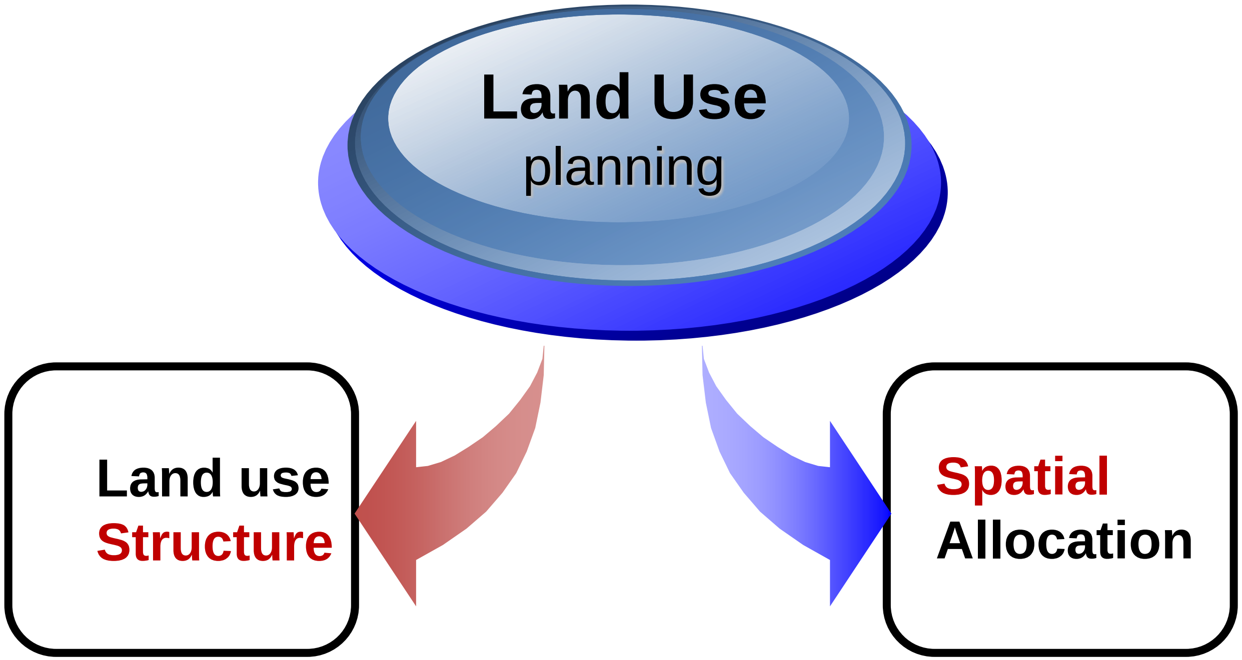
meaningful
study
considerations
another
intuitive
suitability
suitable
supply
help
urban
Land
Chapter

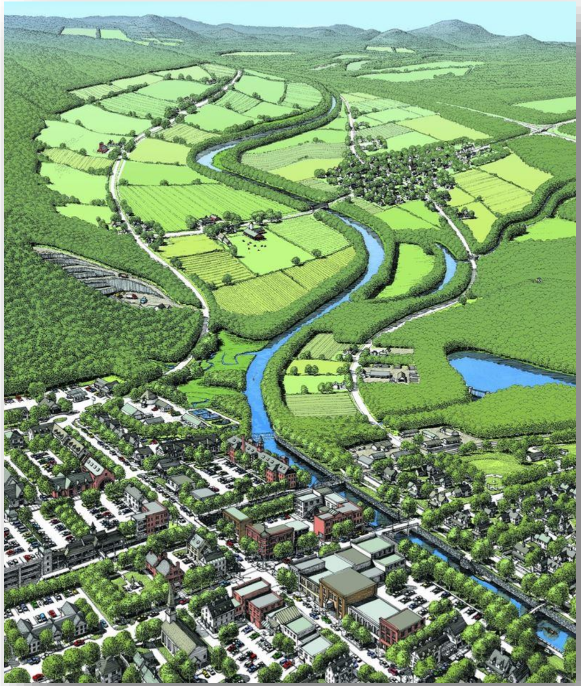
# CONCEPTS

- Land use planning/allocation is a decision-making process that "facilitates the allocation of land to the uses that provide the greatest sustainable benefits" (*L.M. Fletcher-Paul, FAO*).
- It is the systematic assessment of physical, social and economic factors in such a way as to encourage and assist land users in selecting options that increase their productivity, are sustainable and meet the needs of the society.

# CONCEPTS



# CONCEPTS



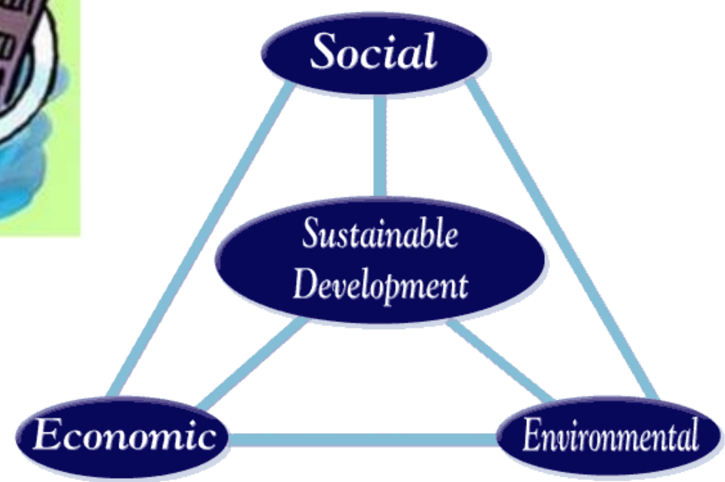
(Source: http://dodsonflinker.com/ and http://www.managenergy.net)

# CONCEPTS

Sustainable development, according to the *World Commission on Environment and Development*, is :

***"development that meets the needs of the present without compromising the ability of future generations to meet their own needs."*** ["Our Common Future", 1987]

# CONCEPTS




(Source: http://www.iseu.by and http://hsc.csu.edu.au/ )

# CONCEPTS

***Multi-objective optimization** is the process of simultaneously optimizing two or more conflicting objectives subject to certain constraints.*

- Economic Gain
- Social Benefit
- Environmental Impact

} **CORE Objectives**

# CONCEPTS

- Spatial Optimization
  - Maximizing or minimizing planning objectives subject to constraints on area, resources, and spatial relationships for a location-related problem.
  - Applications:
    - Zoning (Land use planning, Redistricting etc.)
    - Site selection of facilities
    - Route planning

# CONCEPTS

- Complexity of Spatial Optimization Problems

$$ {}_{100}C_{50} = \frac{100!}{50!\times(100-50)!} > 10^{29} $$

(if a computer can generate 100B solutions/sec, then it takes more than 100M centuries to finish the computation.)

(Source: http://www.nationsencyclopedia.com/)

# RESEARCH QUESTION AND OBJECTIVES

- Research Question
  - **How to achieve sustainable land use planning through the state-of-the-art methods and technologies of spatial optimization and GIS**
- Research Objectives
  - To interpret sustainability on land use planning, and quantify the sustainability objectives and constraints that guide the land use planning
  - To design the land use optimization model to integrate these objectives and constraints
  - To find (an) efficient method(s) to implement the land use optimization model
  - To establish a user-friendly interface to support the sustainable land use planning
  - To explore the integration of High Performance Computing for more efficient and effective land use planning support

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# Objectives and Model Formulation

# OBJECTIVES

- Economic Gain
- Social Equity
- Environmental Impact

**General Objectives**

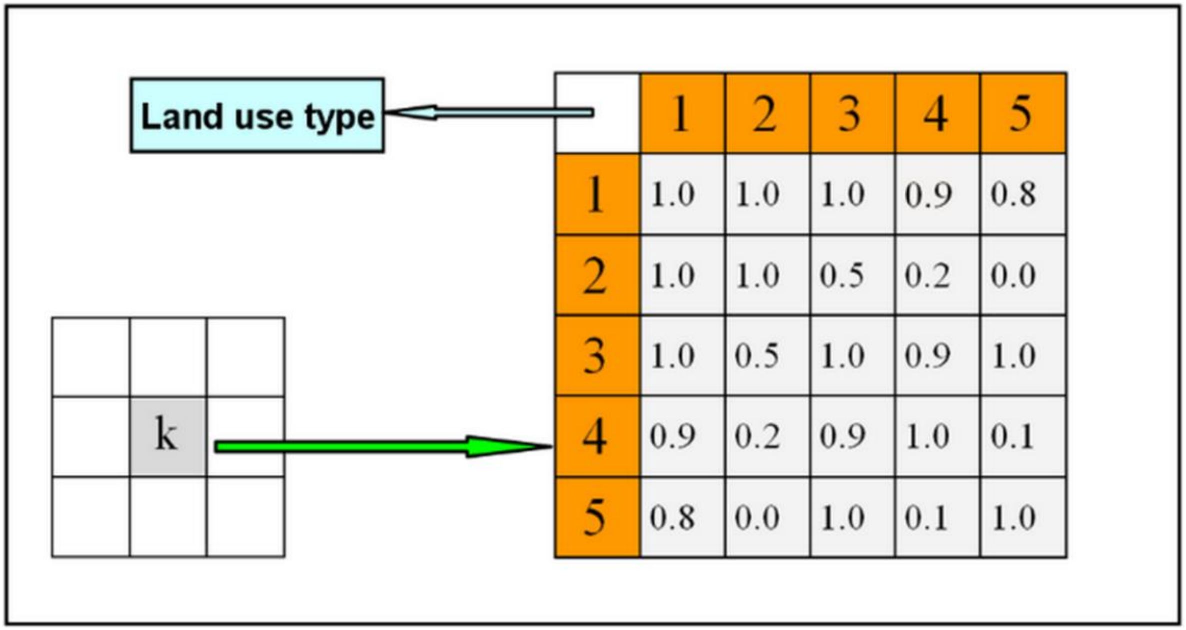
- GDP
- Energy Consumption
- Urban Pattern (Compactness)
- Compatibility
- Ecological Protection
- Environmental Impact
- Accessibility
- Conversion Cost/Defensible Development/Infill development
- More and better located public area
- …

**Specific Objectives**

# CONSTRAINTS

- Conservation Area
- Minimal Need of Residential/Commercial/Industrial Area
- …

# MAXIMIZATION OF COMPATIBILITY




| | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| 1 | 1.0 | 1.0 | 1.0 | 0.9 | 0.8 |
| 2 | 1.0 | 1.0 | 0.5 | 0.2 | 0.0 |
| 3 | 1.0 | 0.5 | 1.0 | 0.9 | 1.0 |
| 4 | 0.9 | 0.2 | 0.9 | 1.0 | 0.1 |
| 5 | 0.8 | 0.0 | 1.0 | 0.1 | 1.0 |

# FORMULATION

Accordingly, for each objective function described above, all these objectives are based on the grid with $N$ rows and $M$ columns, therefore each objective function of them can be understood as the equations as follows:

$$\sum_{k=1}^{K}\sum_{i=1}^{N}\sum_{j=1}^{M} B_{ijk} x_{ijk} \tag{3.1}$$

Where

$\forall k = 1,\ldots,K, i = 1,\ldots,N, j = 1,\ldots,M$

$x_{ijk} \in \{0,1\}$

$\sum_{k=1}^{K} x_{ijk} = 1$

$B$ is the parameter based on each cell for each land use type

# FORMULATION

For weighted sum method, this can be understood as:

Minimize

$$f_{obj} = -\sum_{o=1}^{O}\sum_{k=1}^{K}\sum_{i=1}^{N}\sum_{j=1}^{M} \alpha_o B_{ijk} x_{ijk}$$

Where

$$\forall o = 1,\dots,K, i = 1,\dots,N, j = 1,\dots,M$$

$$x_{ijk} \in \{0,1\}$$

$$\sum_{k=1}^{K} x_{ijk} = 1$$

$B$ is the parameter based on each cell for each land use type

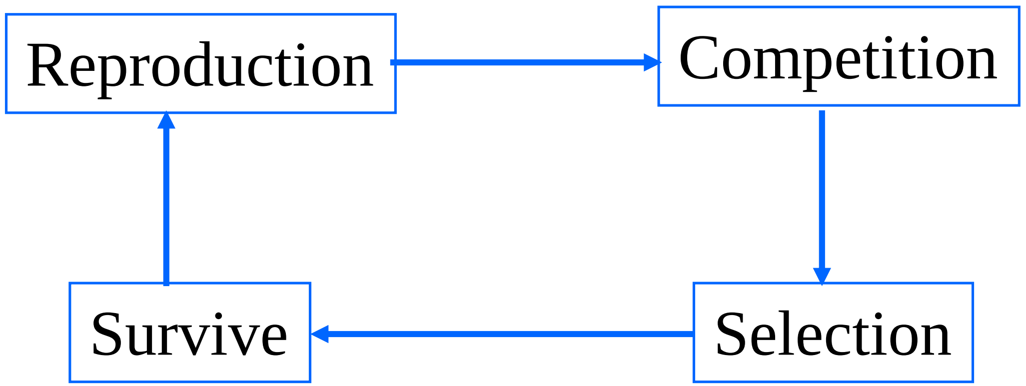
$\alpha_o$ is the **weights** of different objectives

$$f_{obj} = -\sum_{o=1}^{O} \alpha_o \left[ \frac{f_{objo} - I_o}{T_o - I_o} \right]$$

# Artificial Intelligence Integration for Efficient and Effective Implementation of the Model

# GENETIC ALGORITHM

- Base on Darwinian Paradigm
- A robust search and optimization mechanism



# PARETO FRONT BASED ALGORITHMS

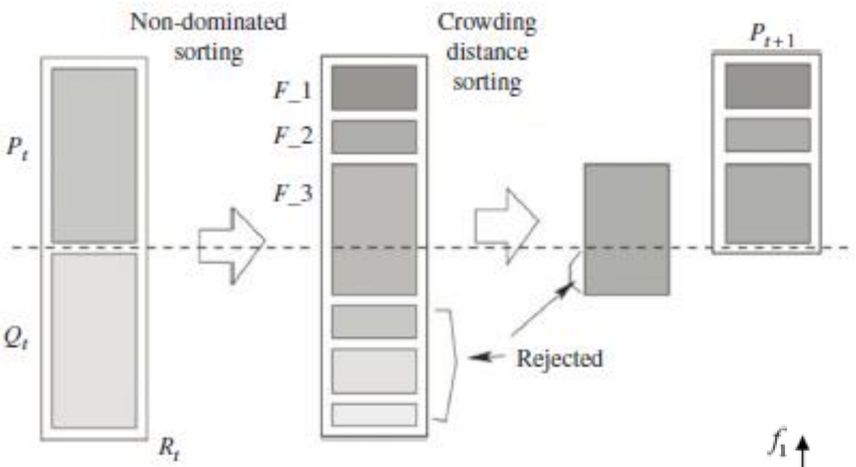



Figure 1. A sketch of NSGA-II (after Deb *et al*. 2002).

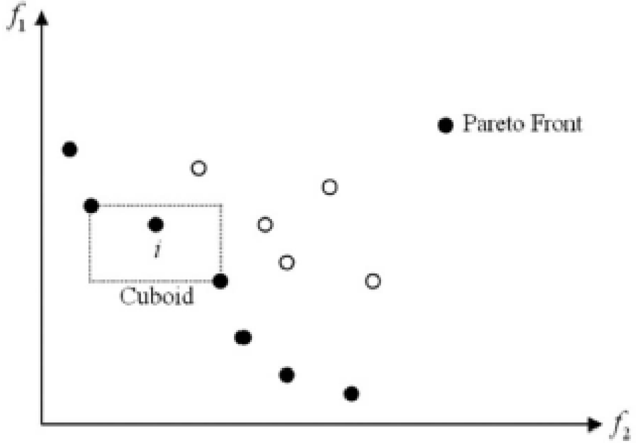



Figure 2. The crowding distance calculation (Deb *et al*. 2002).

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# RESEARCH AREA

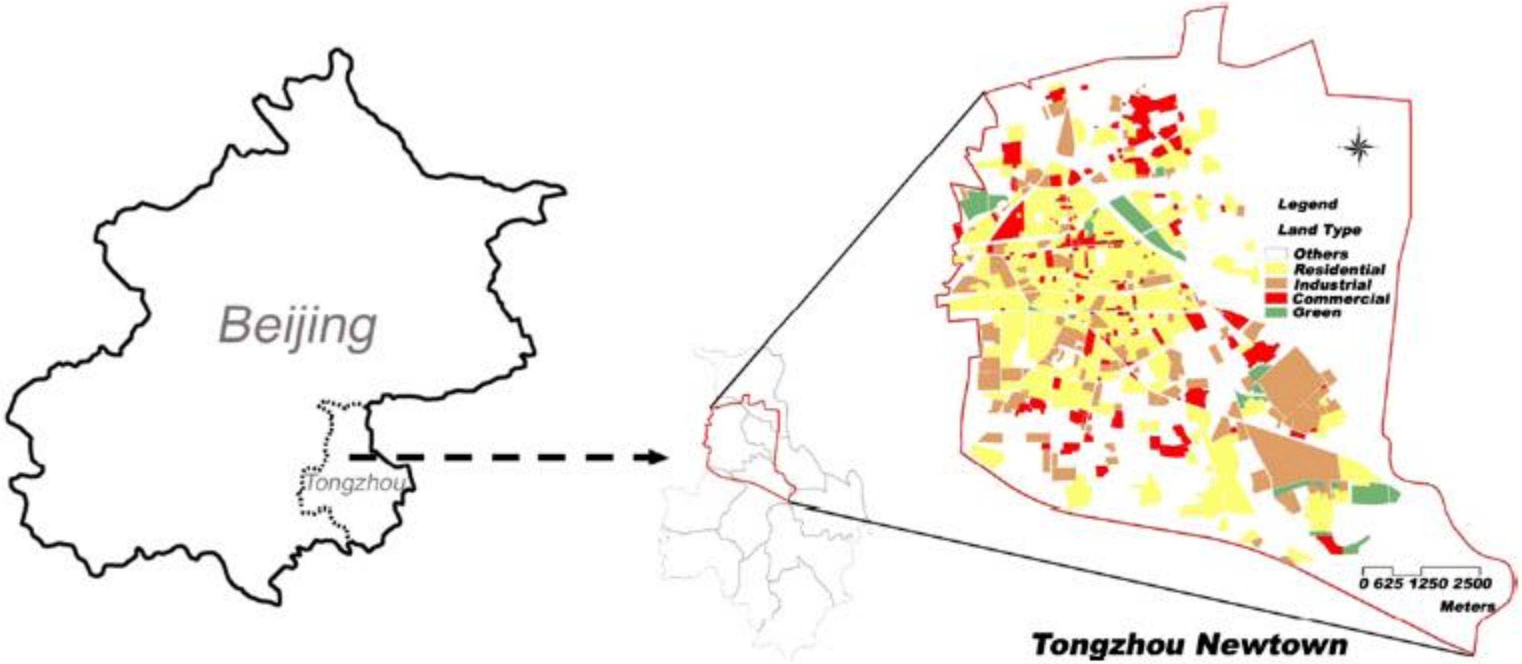



**Fig. 3.** Study area – Tongzhou Newtown (Cao et al., 2011).

# RESEARCH AREA

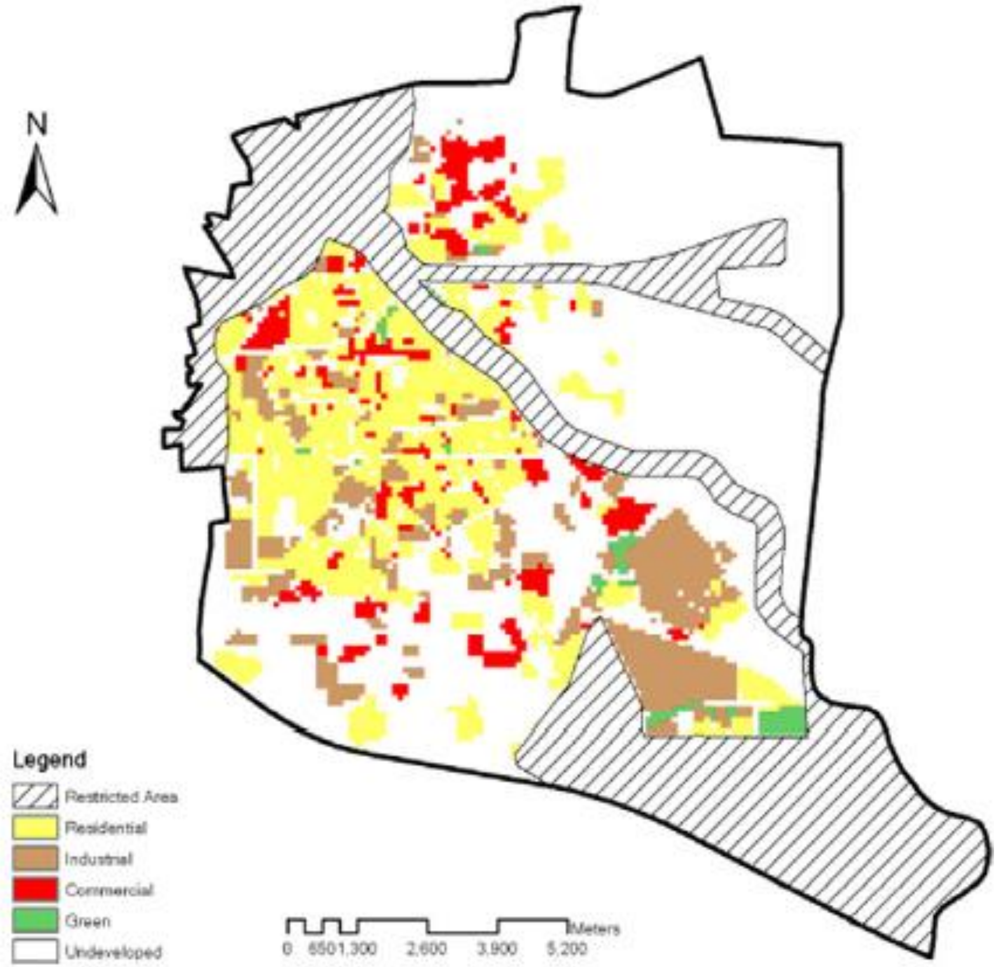



**Fig. 10.** Restricted land (Cao et al., 2011).

# Pareto Front based Land Use Optimization

# OBJECTIVES AND CONSTRAINTS

- Minimization of Conversion
- Maximization of Accessibility
- Maximization of Compatibility

Subject to

- Conservation Area (to exclude the restricted area)
- Minimal Need of Residential Area (low bound of the residential and commercial area)

# RESULT-1

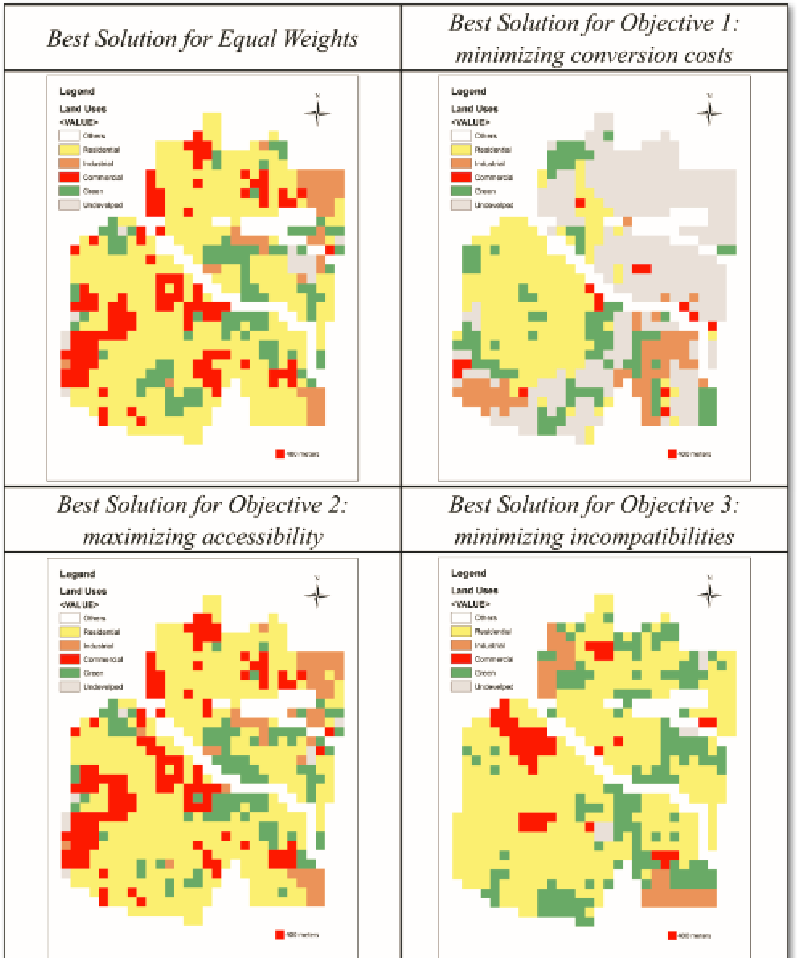



Table 4. Attribute information associated with the four solutions.

| | Equal weights solution | Objective 1 solution | Objective 2 solution | Objective 3 solution |
|---|---|---|---|---|
| Value of Objective 1 | −115 | −418 | −101 | −127 |
| Value of Objective 2 | −53,039 | −27,087 | −53,729 | −48,508 |
| Value of Objective 3 | −2,585 | −2,479 | −2,565 | −2,632 |
| Number of residential cells | 416 | 200 | 412 | 444 |
| Number of industrial cells | 45 | 58 | 50 | 38 |
| Number of commercial cells | 116 | 15 | 124 | 45 |
| Number of green space cells | 97 | 97 | 94 | 153 |
| Number of undeveloped cells | 14 | 318 | 8 | 8 |

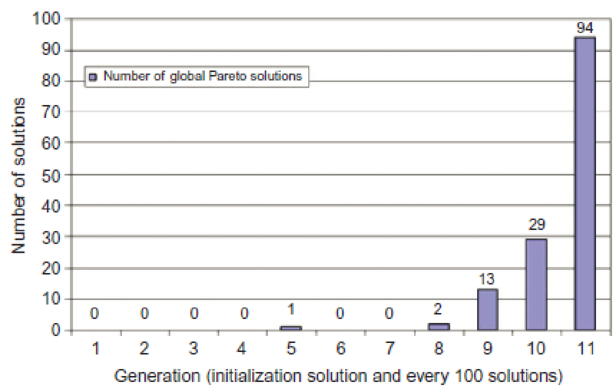
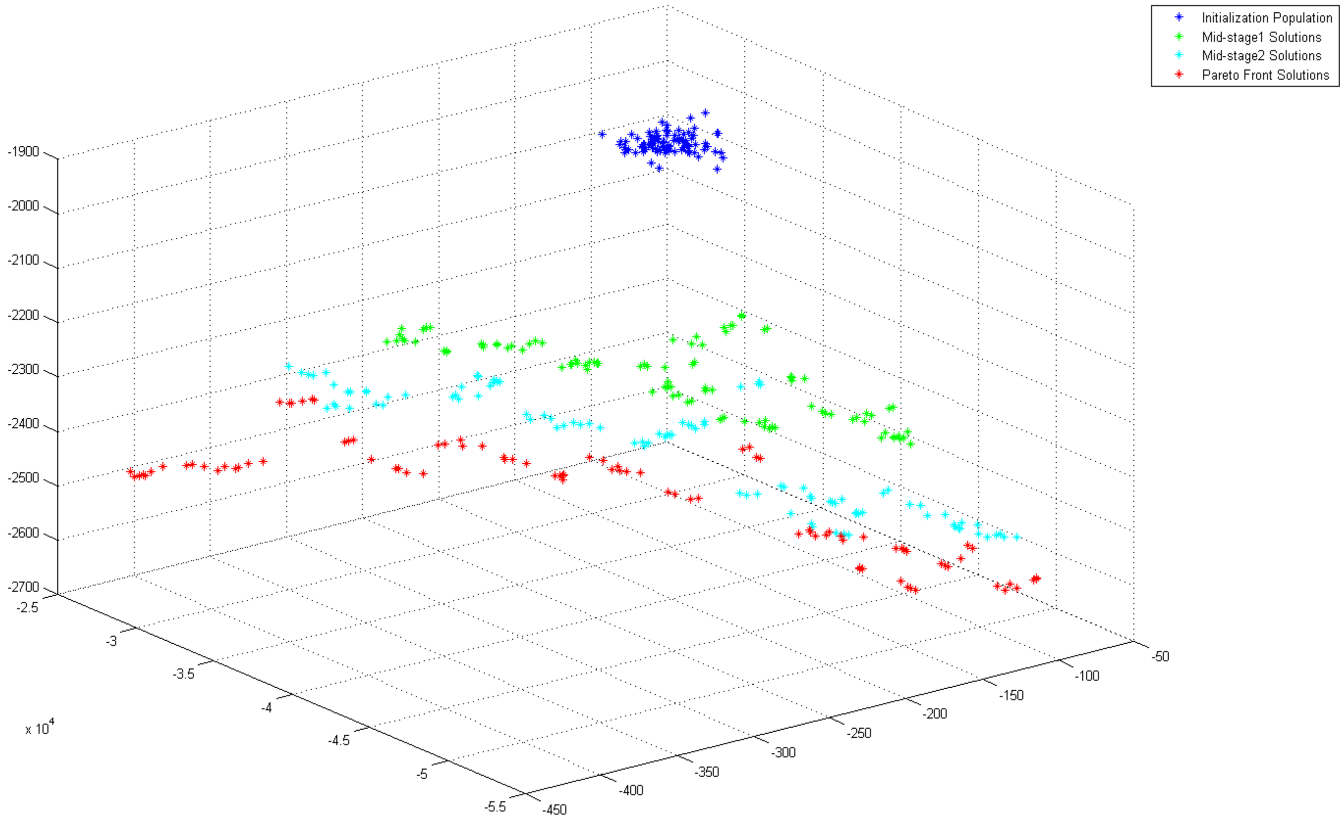



Figure 14. The number of global Pareto solutions (the number in each column represents the number of the final Pareto Front solutions in each generation).

# RESULT-1



Initialization Population
Mid-stage1 Solutions
Mid-stage2 Solutions
Pareto Front Solutions
-1900
-2000
-2100
-2200
-2300
-2400
-2500
-2600
-2700
-2.5
-3
-3.5
-4
-4.5
-5
-5.5
x 10^4
-450
-400
-350
-300
-250
-200
-150
-100
-50

# High Performance Computing Integrated Land Use Optimization

# RESULT-2

- High Performance Computing Integration

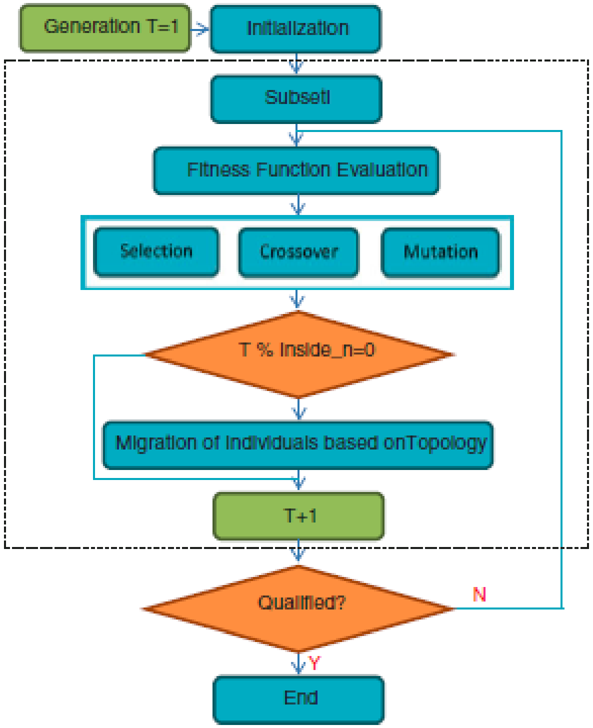



**Fig. 1** Structure of CGPGA

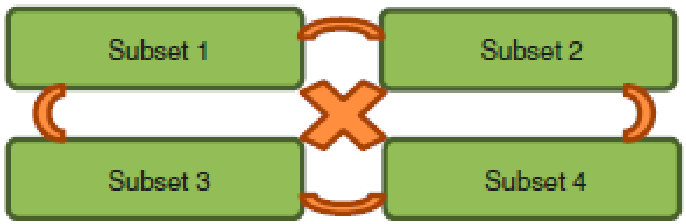



**Fig. 3** Migration paradigm of CGPGA

# RESULT-2

**Table 3** Comparison between the GGA and CGPGA for convergent optimization

| | GGA-1000 | GGA-2000 | CGPGA-2 cores | CGPGA-4 cores |
|---|---|---|---|---|
| Fitness function value | −5.2561 | −5.2827 | −5.2877 | −5.2905 |
| Time consumed (s) | 23201.5 | 46053.3 | 32416.4 | 36302.7 |

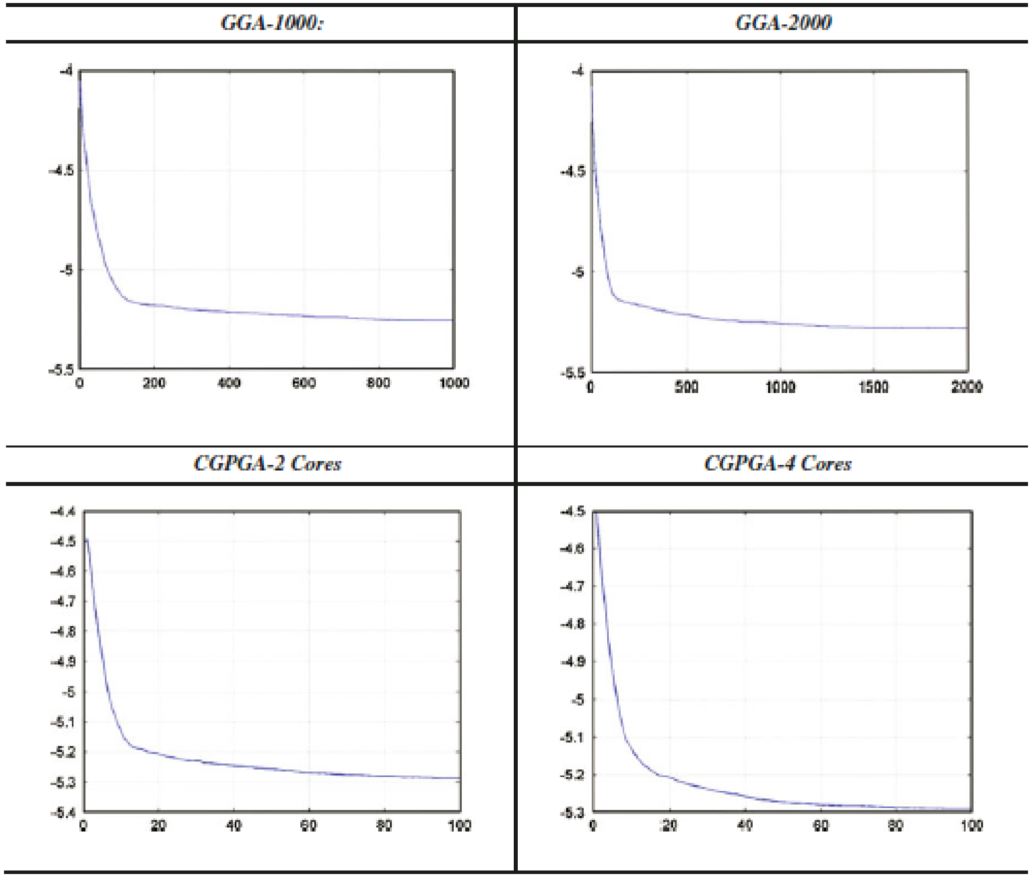



**Fig. 7** Land use allocation optimization convergent curves based on GGA-1000, GGA2000, CGPGA-2 cores, and CGPGA-4 cores

# RESULT-2

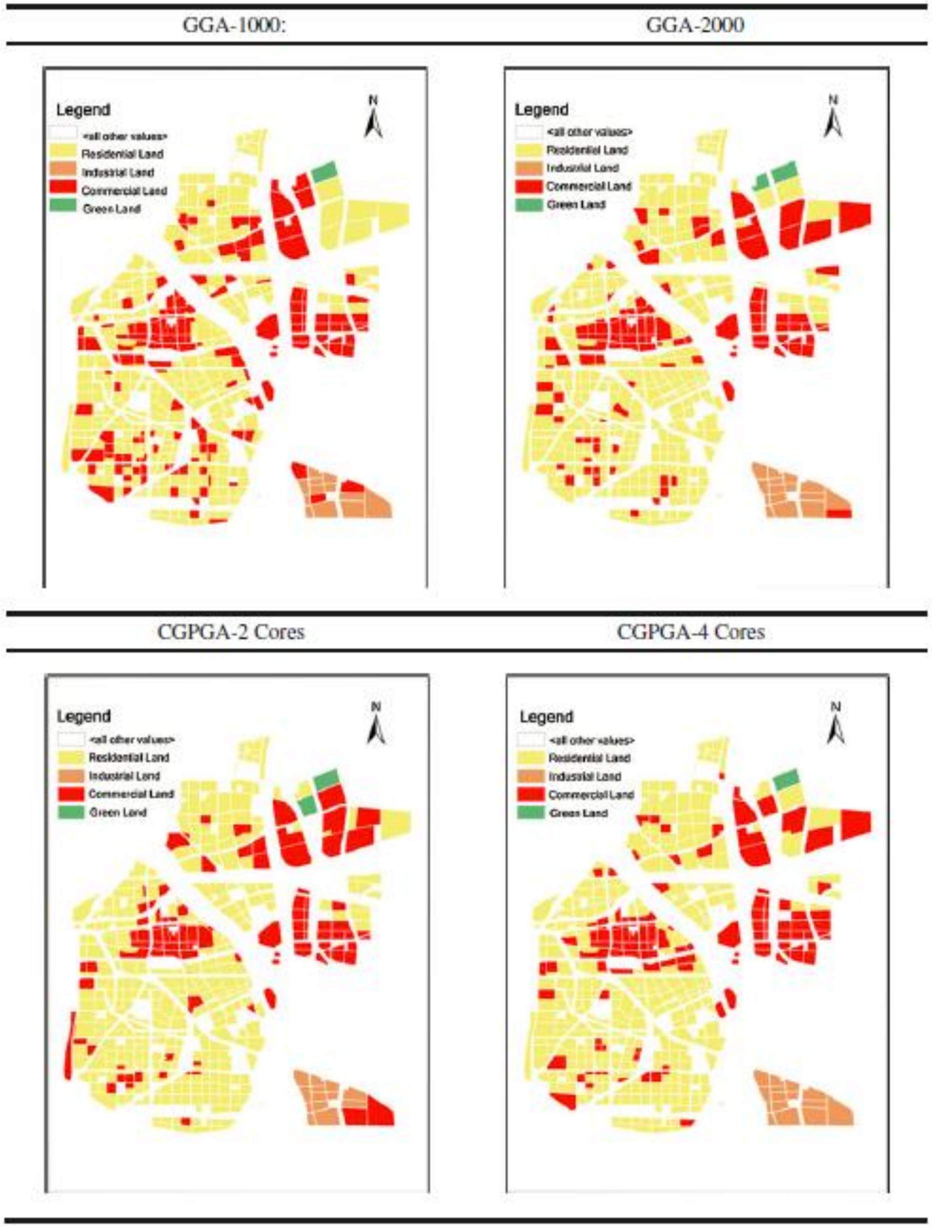



**Fig. 8** Land use allocation optimization results based on GGA-1000, GGA2000, CGPGA-2 cores, and CGPGA-4 cores

# Web based Interactive Land Use Allocation/Planning Support Prototype

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# FUTURE WORK

- Land use (**Temporal**) optimization for sustainable land use planning
- Clusters/Cloud implementation of the parallel computing
- Better user-friendly interface design
- More objectives and/or in-depth interpretation on different objectives
  - Accessibility
  - Compactness
  - Etc.
- Extensions
  - More broad case studies (including Singapore)
  - More studies (such as waste collection, redistricting, service coverage)

# REFERENCE


***Peer Reviewed Journal Articles***

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  - **Richard Church**, Department of Geography, University of California, Santa Barbara, Email: church@geog.ucsb.edu

# THE END!