Object-oriented tracking of the dynamic behavior of urban heat islands

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Content

Introduction

What is an urban heat island?

1. Temperatures in the urban area are significantly higher than its rural areas
2. It is more obvious during the night than during the day
3. Due to solar radiation and anthropogenic heat
4. Measurable influence on the weather and even regional climate evolution

Related work

1. Consist in correlating thermal intensity from static surface temperature images with environmental indicators (e.g., land cover and social impacts)
2. Use data mining techniques to establish patterns between land covers and temperatures
3. Use machine learning to improve spatial resolution of thermal RS images
4. Consider the dynamic evolution of UHI where UHI are defined from clusters of pixels moving towards object-based analysis

However, RS and conventional GIS data models and analytical tools lack capabilities to adequately handle massive amounts of multidimensional data.

Any good ideas?

Geographical phenomena can be defined as field objects

1. with an internal structure defined by variations of field-related properties
2. within the boundary of the object

Their dynamic is driven by

1. their activities, events and processes
2. can be observed through changes and movements

Processes and events are spatiotemporal objects defined with

1. temporal property (e.g. starting and ending time)
2. thematic property (e.g. temperature of UHI)
3. spatial property describing movement linking to entities involved in the events

Therefore, event-based method defines dynamic behaviors

1. as event properties or relationships
2. with spatiotemporal peoperties which can be queried

Model moving objects

A hierarchical framework where moving objects are described by four different states:

(1) a zone is an area of spatial contiguous cells

meeting a designated threshold in a snapshot

(2) a sequence is a set of zones

meeting a threshold in consecutive snapshots

(3) a process is a set of sequences

where the geographical objects are topologically related

(4) an event is at least one type of process

during a consecutive time interval

Topological relationships between objects define topological transitions between two consecutive time instants.

Research objective

Problematic

Current temporal GIS models particularly for the application of the UHI still limits to the static or preliminary dynamic modeling

Objective

To establish a spatiotemporal model to track dynamic behaviors of UHIs

Conceptual modeling

Field Conceptualization

1. Temperatures can be modeled as a set of two-dimensional fields.
2. UHI is a shape-variable field determined by environmental temperatures.
3. Temperatures are able to warm up, cool down, or remain constant triggering the shape variation of the field.

Object Conceptualization

1. Decreasing of temperatures can make an UHI disappear (inactive).
2. The disappeared UHI may reappear (active) with the increase of temperatures.
3. UHI can change its state between *active* and *inactive* in its *life-cycle*.

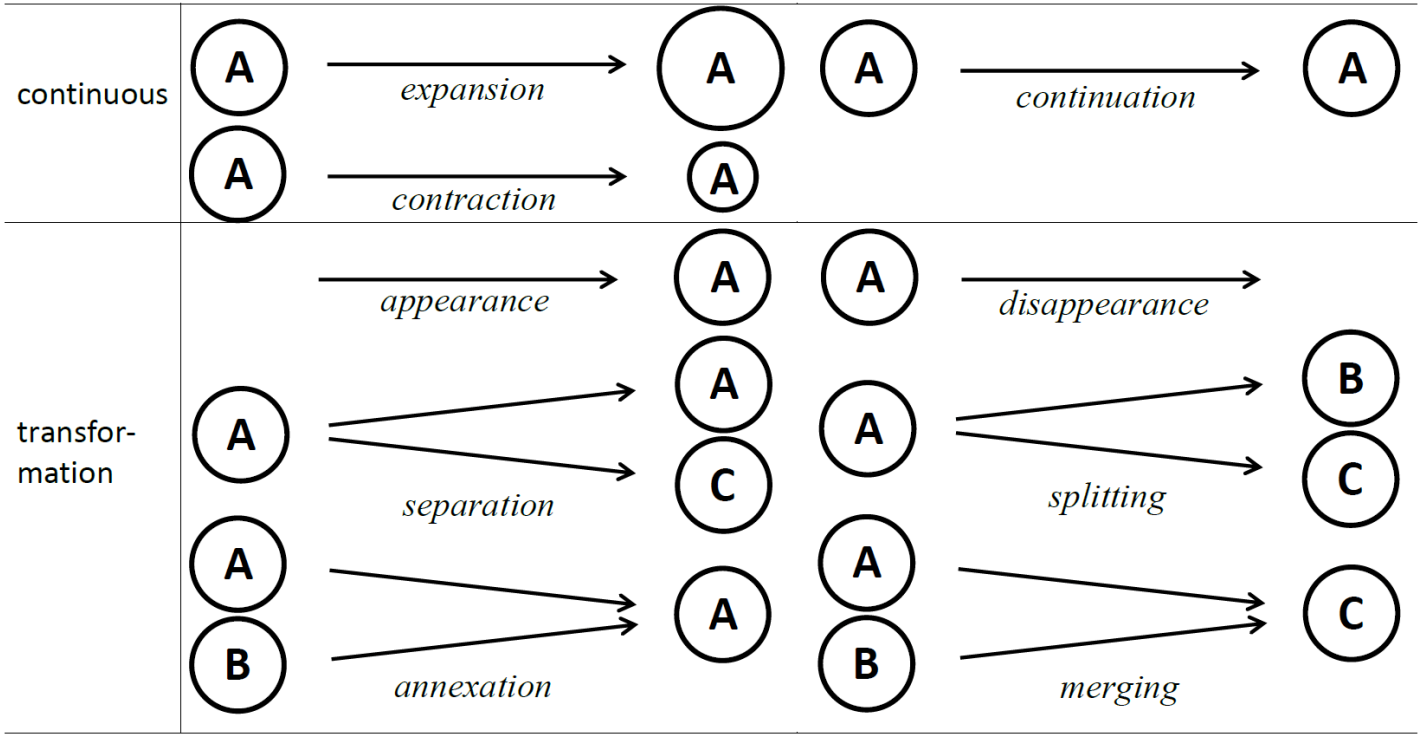
Conceptual modeling

Field-object Conceptualization

An *urban heat island* is a field-object

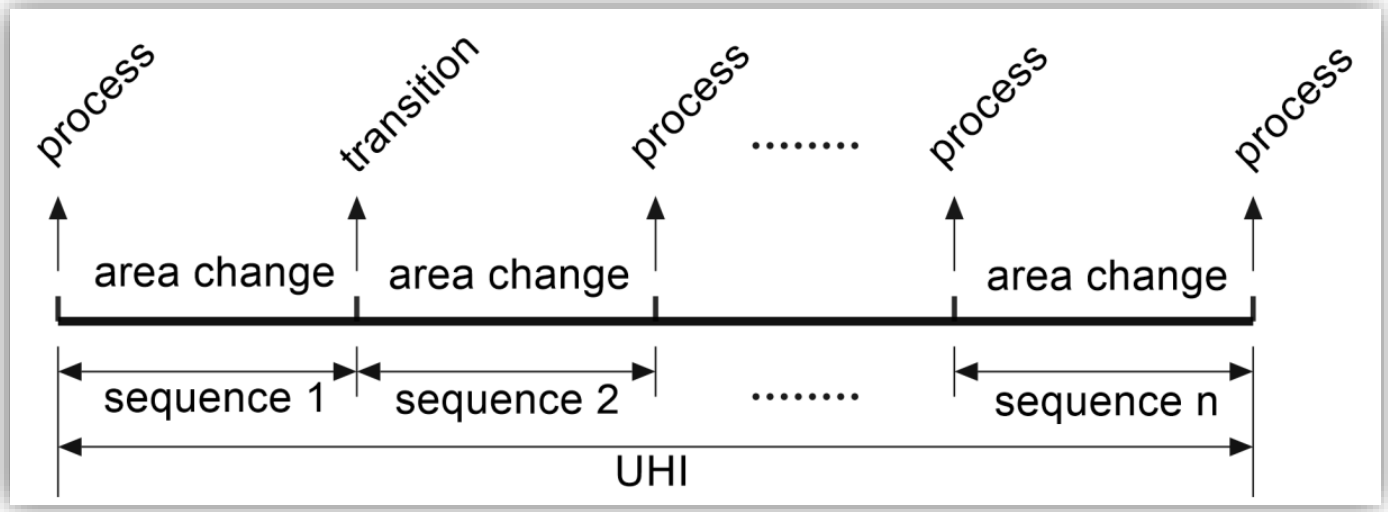
1. its temperatures ≥ referenced rural temperature + a given temperature
2. varying of the thematic property (*temperatures*) changes the spatial property (*shape*)

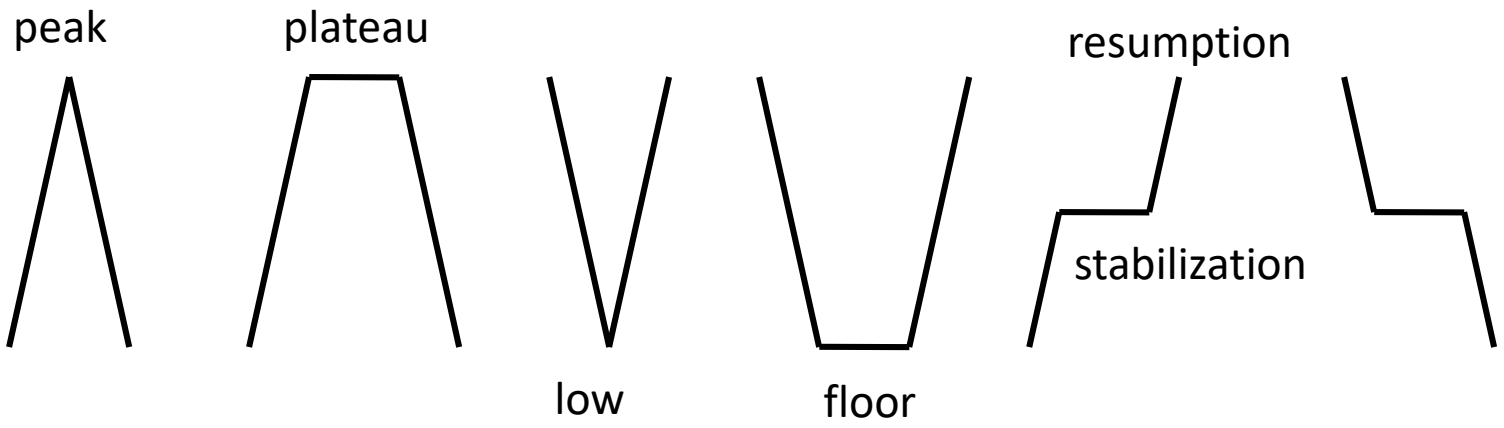
Spatial behaviors



Conceptual modeling

Spatial behaviors

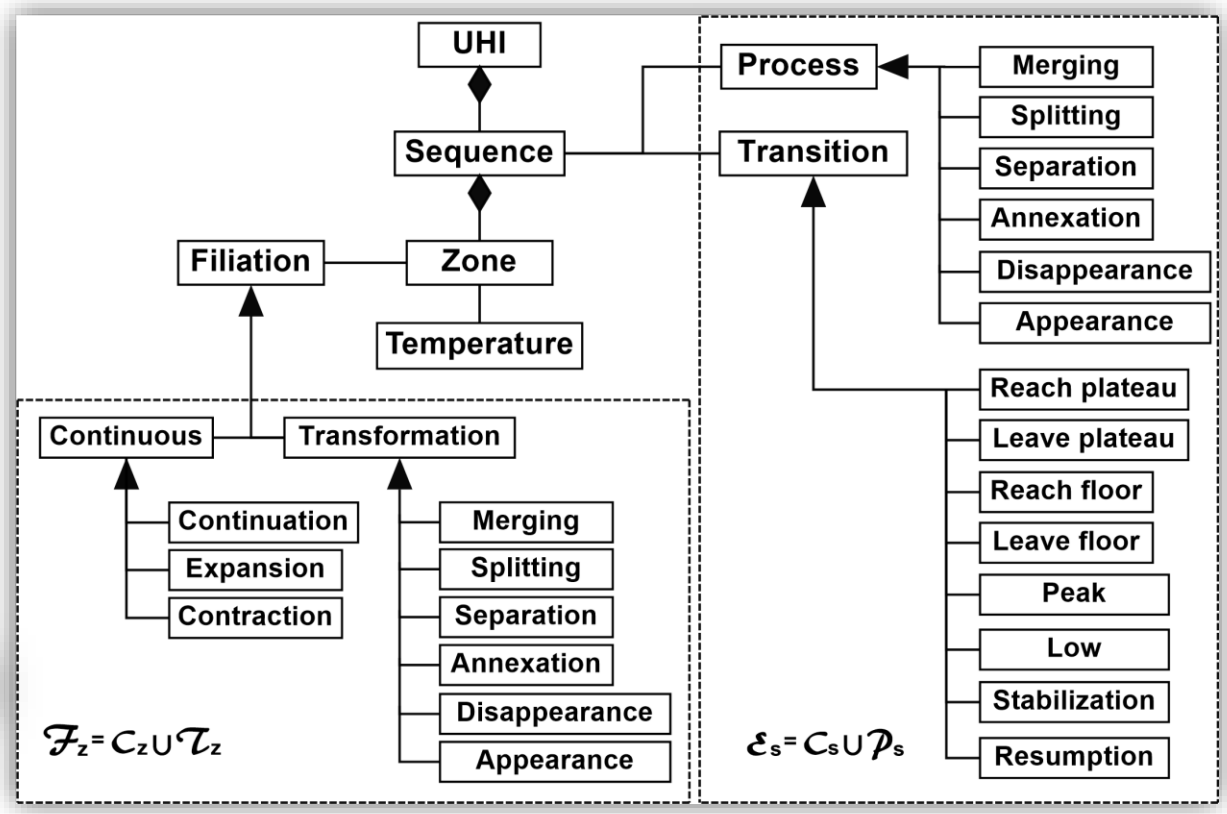




Conceptual modeling

Spatial behaviors

$\mathcal{G}_Z = (\mathcal{Z}, \mathcal{F}_z)$

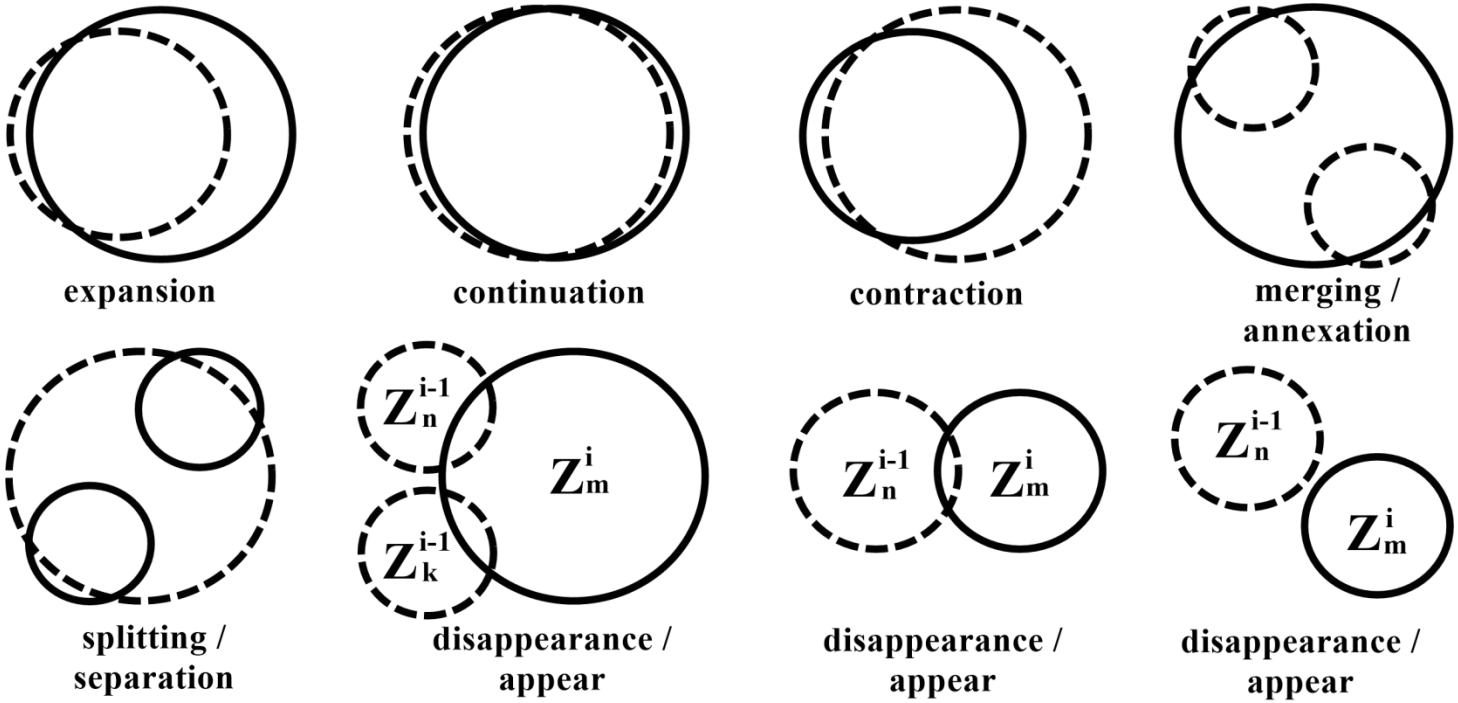


$\mathcal{G}_S = (\mathcal{S}, \mathcal{E}_s)$

Z is the set of all zones and Fz is the set of filiation relationships connecting the zones.
S is the set of sequences and Es is the set of edges marking changes between the sequences.

Logical modeling

Extraction of UHI changes

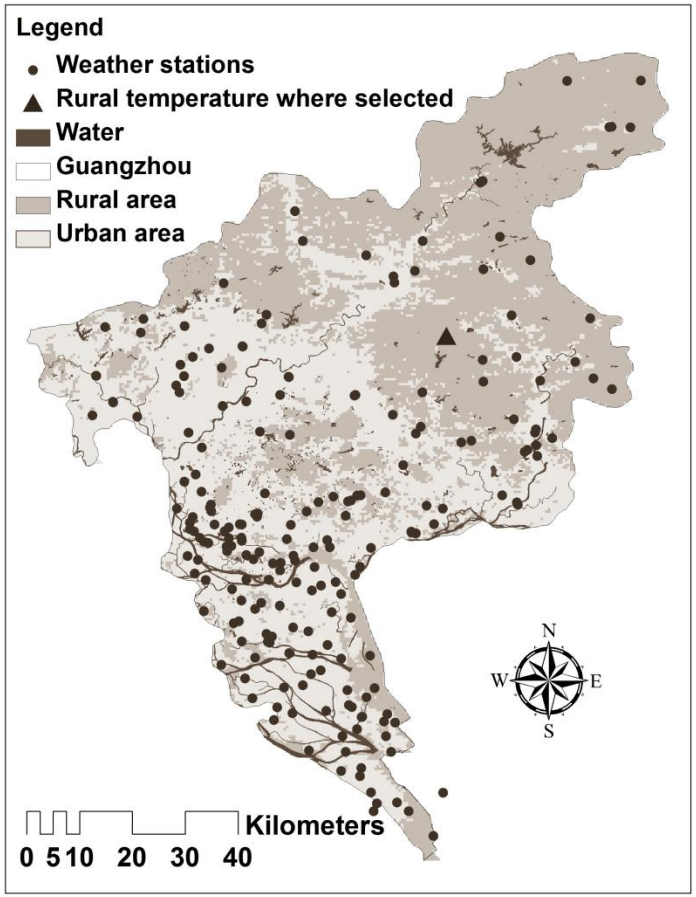


If there is no overlapping area between two consecutive UHI polygons or if the proportion of the overlapping area to either of the two polygons is small, it is reasonable to say that they have no relationship and belong to different UHIs.

On the opposite, they can be considered as belonging to the same object if they overlap on a significant area.

Empirical evaluation

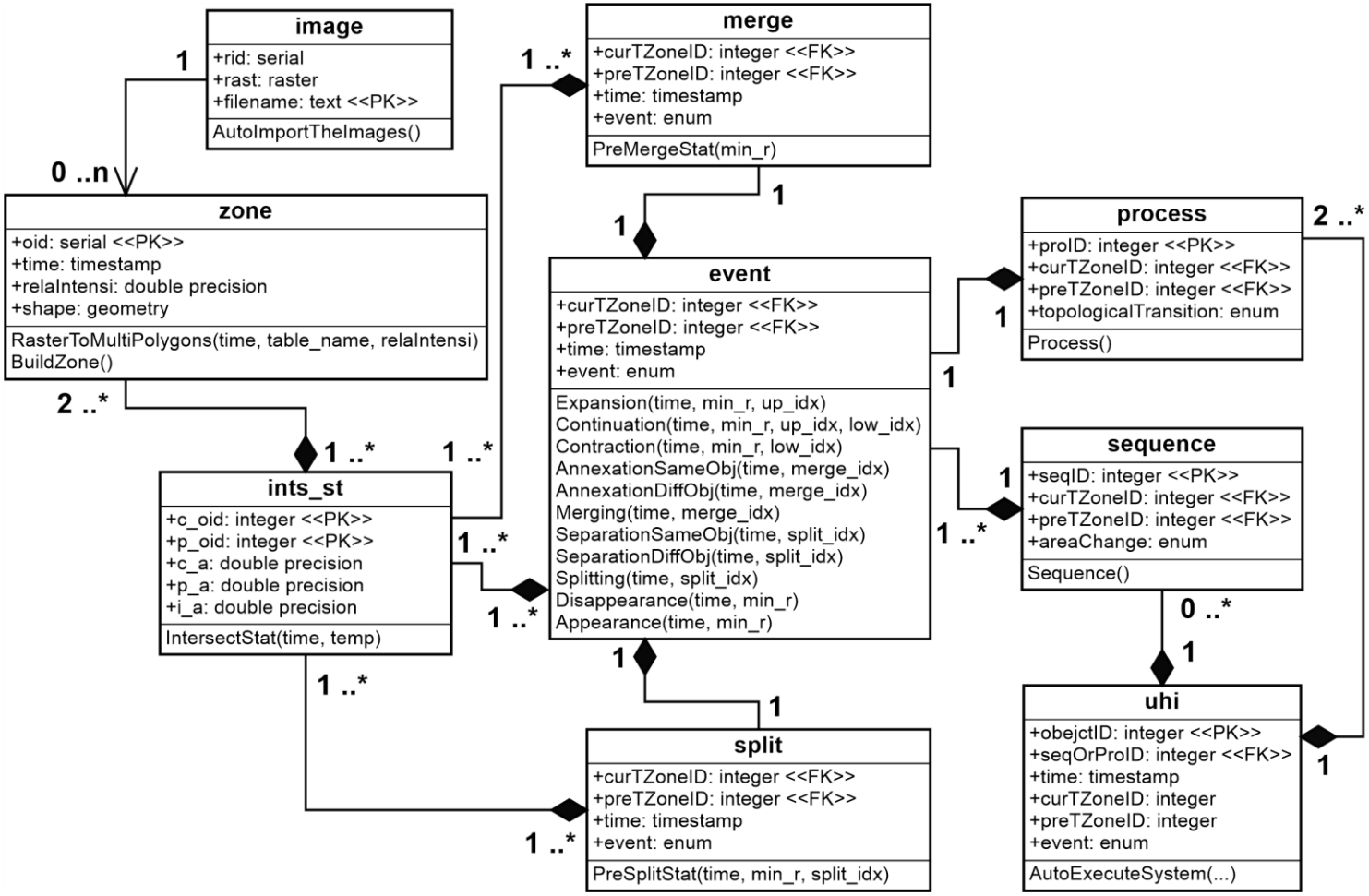
Study area



1. Guangzhou city, China
2. 216 automatic weather stations
3. Hourly updated temperature in each station
4. 31 Jul 2015, 0 am – 6 Aug 2015, 11 pm
5. Generate continuous thermal images using the Kriging interpolation method

Empirical evaluation

System implementation



1. Object-relational database management system (DBMS) PostgreSQL 9.3.4 (to manage test data sets)
2. pgAdmin 1.18.1 (as an administrative and management tool)
3. Experiments are conducted in Windows 8 64-bit with Intel(R) Core(TM) i7-4770 CPU

Empirical evaluation

SQL queries

SQL 1 FUNCTION PreMergeStat(min_r)

```
1 SELECT ints_st.c_oid, ints_st.p_oid, ints_st.c_a, ints_st.i_a
2 FROM  (SELECT count(c_oid) AS cnt, c_oid
3        FROM  (SELECT ints_st.c_oid FROM ints_st WHERE ints_st.i_a / ints_st.p_a >= min_r
4               AND p_a > 0) AS cur_g GROUP BY c_oid) AS cnt_cur_g, ints_st
5 WHERE  cnt_cur_g.cnt > 1 AND cnt_cur_g.c_oid = ints_st.c_oid
6 AND    ints_st.p_a > 0 AND ints_st.i_a / ints_st.p_a >= min_r;
```

SQL 2 FUNCTION AnnexationDiffObj(time, merge_idx)

```
1 SELECT time, merge.c_oid, merge.p_oid, annex_diff_obj
2 FROM  (SELECT merge.c_oid, merge.p_oid
3        FROM  (SELECT c_oid, max(i_a) AS max_i_a FROM merge GROUP BY c_oid) AS p_key, merge
4        WHERE  merge.c_oid = p_key.c_oid AND merge.i_a = p_key.max_i_a
5        AND    merge.c_a > 0 AND merge.i_a / merge.c_a >= inh_merge) AS inh_mer_obj, merge
6 WHERE  inh_mer_obj.c_oid = merge.c_oid AND inh_mer_obj.p_oid <> merge.p_oid;
```

SQL 3 FUNCTION Expansion(time, min_r, up_idx)

```
1 SELECT time, ints_st.c_oid, ints_st.p_oid, expansion
2 FROM   ints_st, (SELECT count(c_oid) AS cnt, c_oid FROM ints_st WHERE p_a > 0
3                  AND i_a / p_a >= min_r GROUP BY c_oid) AS maintain_obj
4 WHERE  maintain_obj.cnt = 1
5 AND    ints_st.c_oid = maintain_obj.c_oid AND ints_st.i_a / ints_st.p_a >= min_r
6 AND    ints_st.p_a > 0 AND ints_st.c_a / ints_st.p_a >= up_idx;
```

SQL 4 FUNCTION Appearance(time, min_r)

```
1 SELECT time, potential_oid.c_oid, appearance
2 FROM  (SELECT c_oid FROM ints_st WHERE c_a > 0 GROUP BY c_oid) AS potential_oid
3 LEFT JOIN (SELECT c_oid FROM ints_st WHERE p_a > 0
4            AND i_a / p_a >= min_r GROUP BY c_oid) AS ints_oid
5 ON         potential_oid.c_oid = ints_oid.c_oid
6 LEFT JOIN (SELECT c_oid FROM merge GROUP BY c_oid) AS merged_oid
7 ON         potential_oid.c_oid = merged_oid.c_oid
8 LEFT JOIN (SELECT c_oid FROM split GROUP BY c_oid) AS split_oid
9 ON         potential_oid.c_oid = split_oid.c_oid
10 WHERE ints_oid.c_oid IS NULL AND merged_oid.c_oid IS NULL AND split_oid.c_oid IS NULL;
```

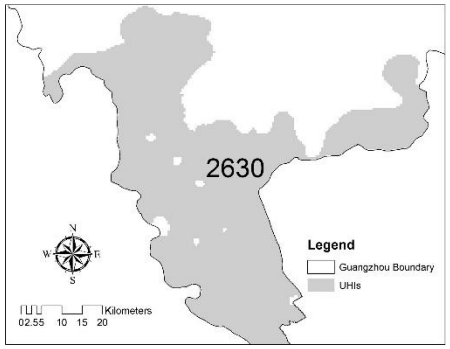
Empirical evaluation

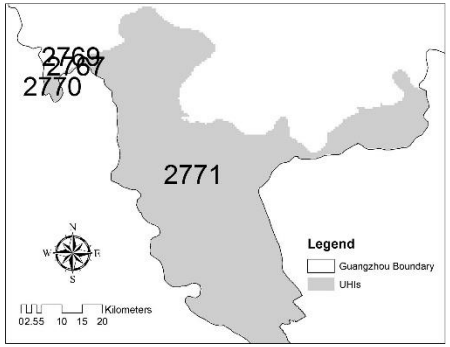
Results

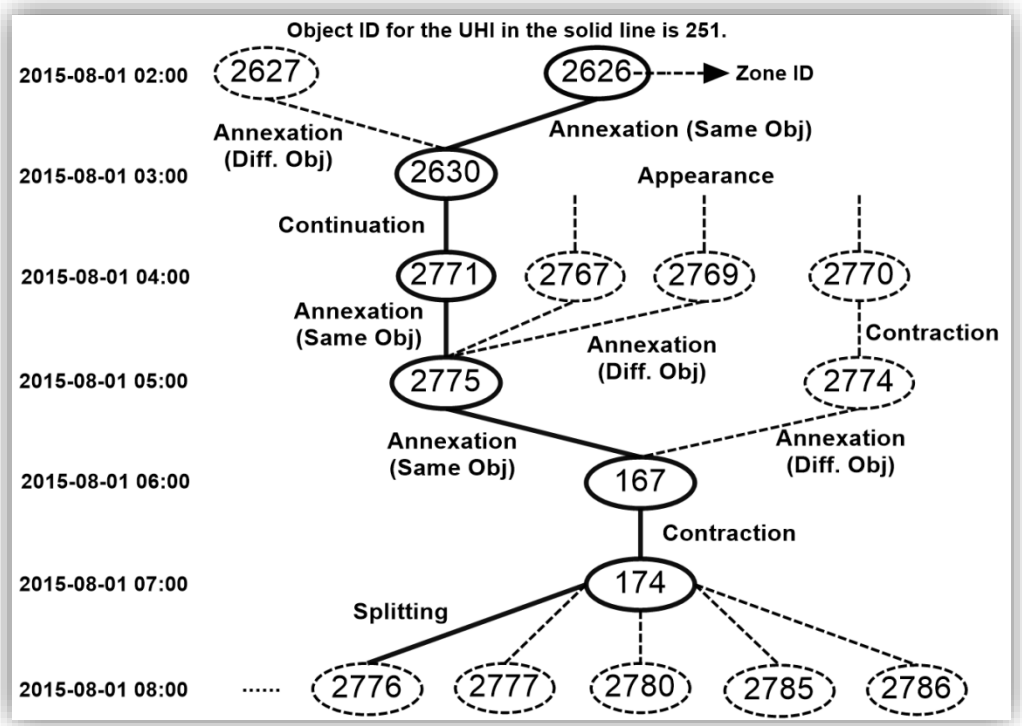
obj_id integer	pro_seq_id integer	t_s timestamp without time zone	c_oid integer	p_oid integer	filiation character varying(13)	transition character varying(13)
251	153	2015-07-31 21:00:01	67	51	annexa s obj	annexa s obj
251	153	2015-07-31 22:00:01	70	67	annexa s obj	annexa s obj
251	174	2015-07-31 23:00:01	74	70	continuation	plateau
251	174	2015-08-01 00:00:01	2765	74	continuation	plateau
251	174	2015-08-01 01:00:01	2694	2765	continuation	plateau
251	190	2015-08-01 02:00:01	2626	2694	contraction	leave plateau
251	196	2015-08-01 03:00:01	2630	2626	annexa s obj	annexa s obj
251	205	2015-08-01 04:00:01	2771	2630	continuation	
251	212	2015-08-01 05:00:01	2775	2771	annexa s obj	annexa s obj
251	212	2015-08-01 06:00:01	167	2775	annexa s obj	annexa s obj
251	220	2015-08-01 07:00:01	174	167	contraction	
251	239	2015-08-01 08:00:01	2785	174	splitting	splitting

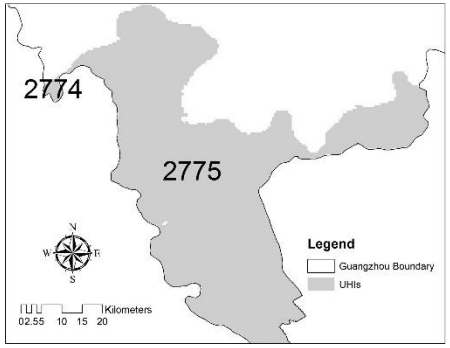
Empirical evaluation

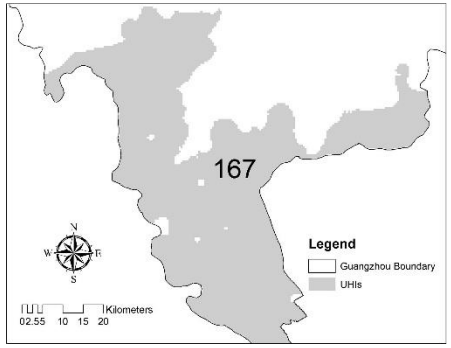
Results

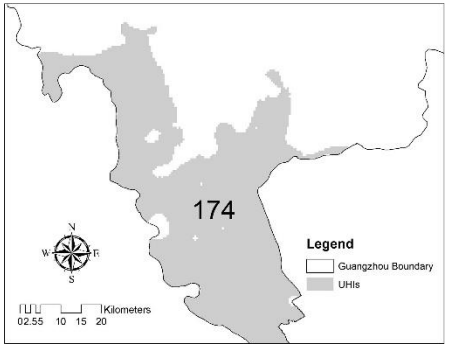


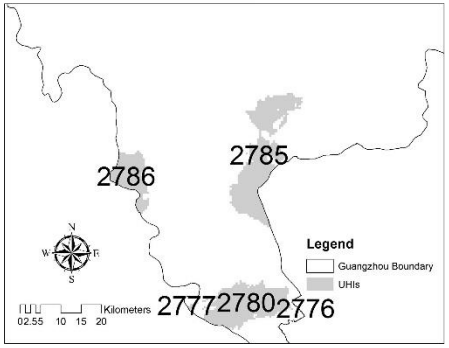




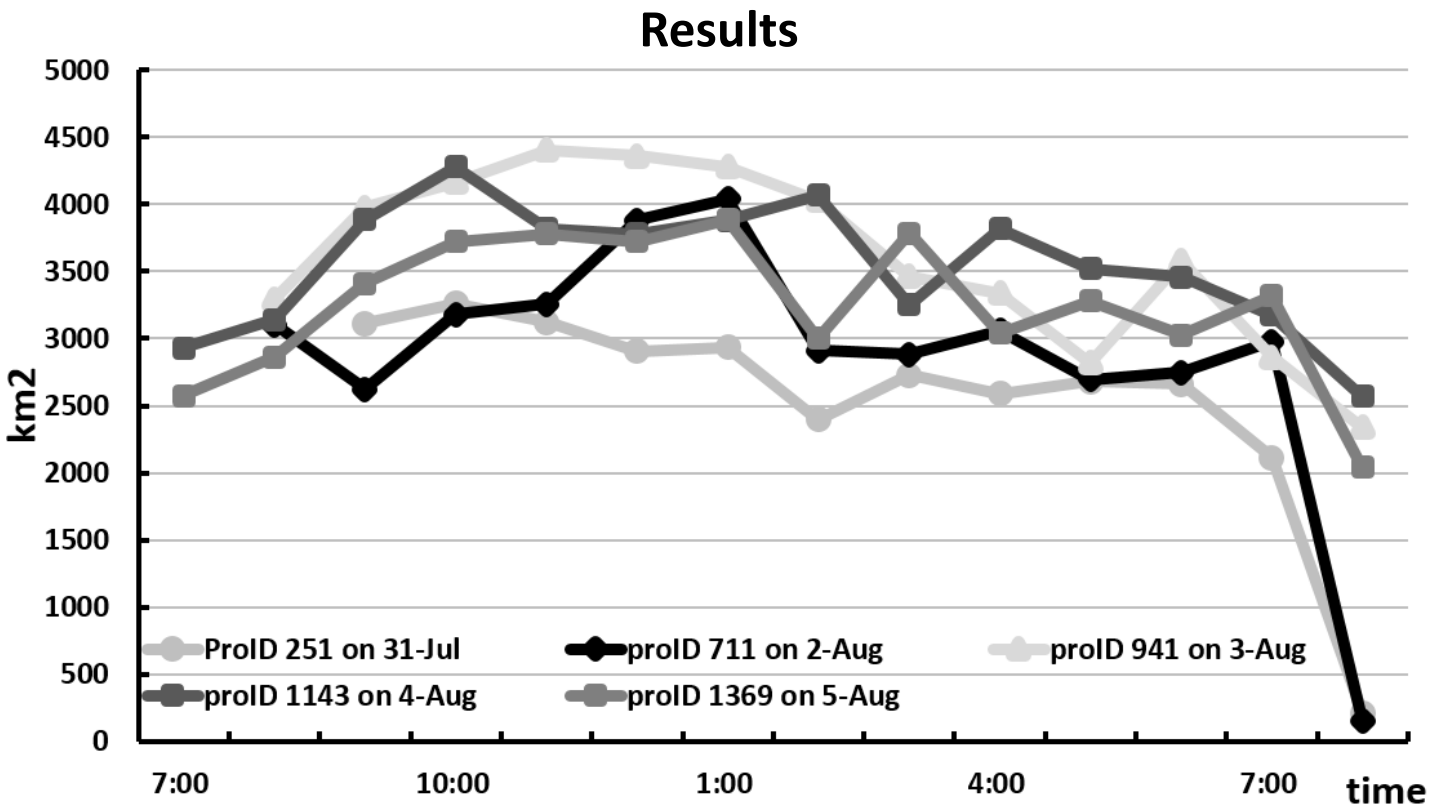








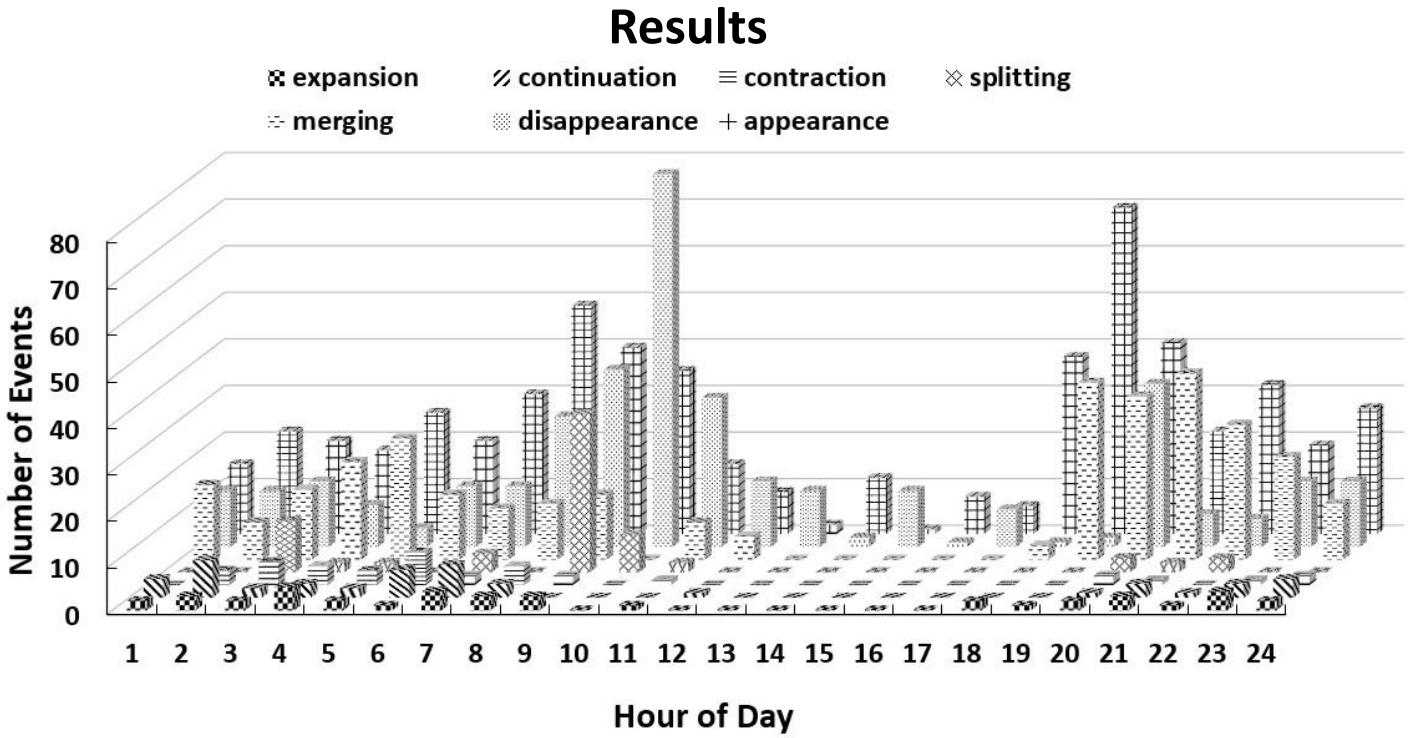
Empirical evaluation



Area tracking of five UHIs in five different days

They locate in the same region, but whether they are the same UHI will be investigated.

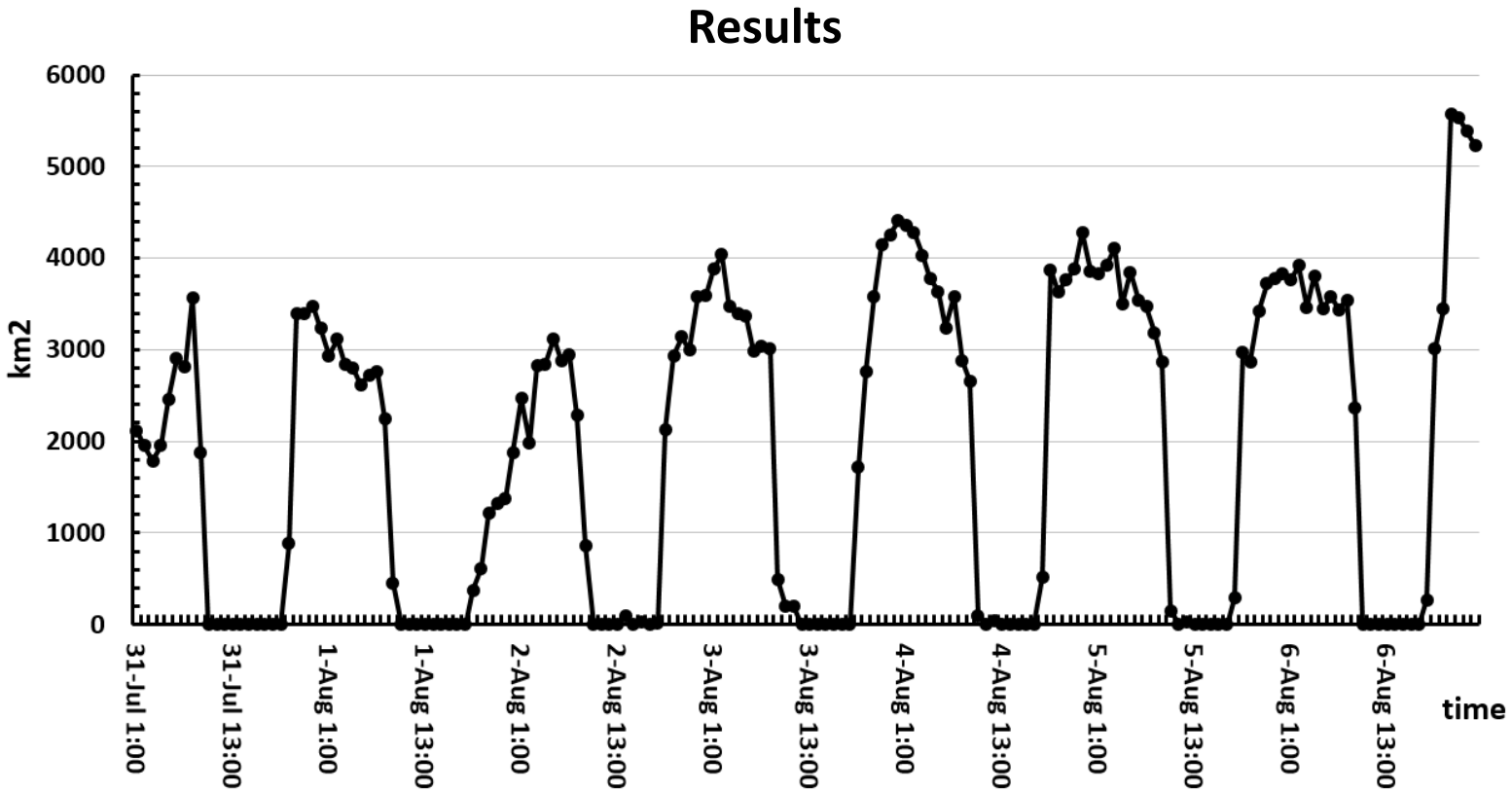
Empirical evaluation



The number of different spatial behaviors accumulated by hour-of-day for seven days

Dynamic behaviors significantly happen during the sun raising and right after the sun set.

Empirical evaluation

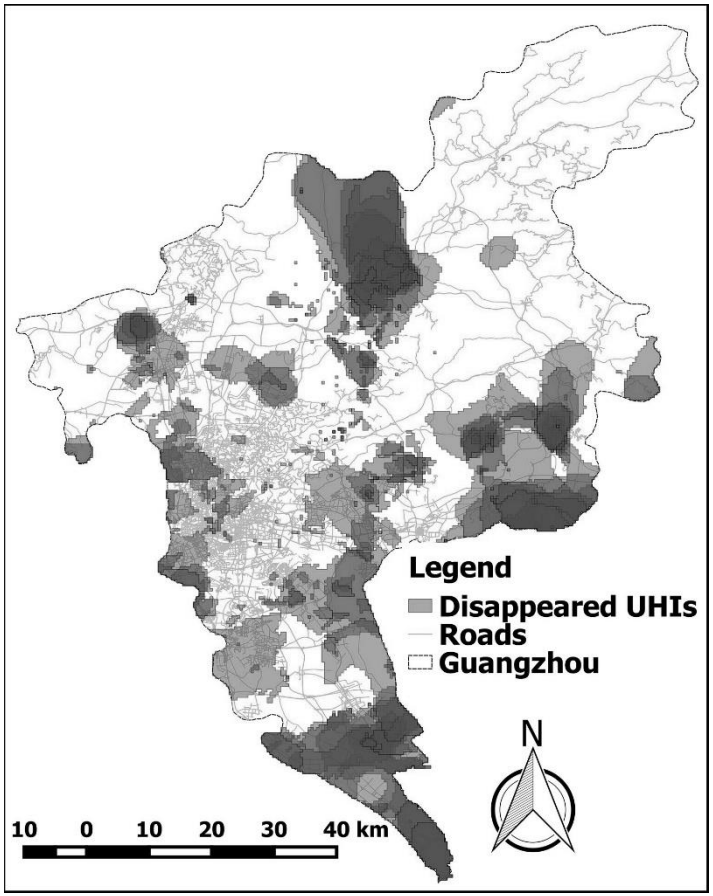


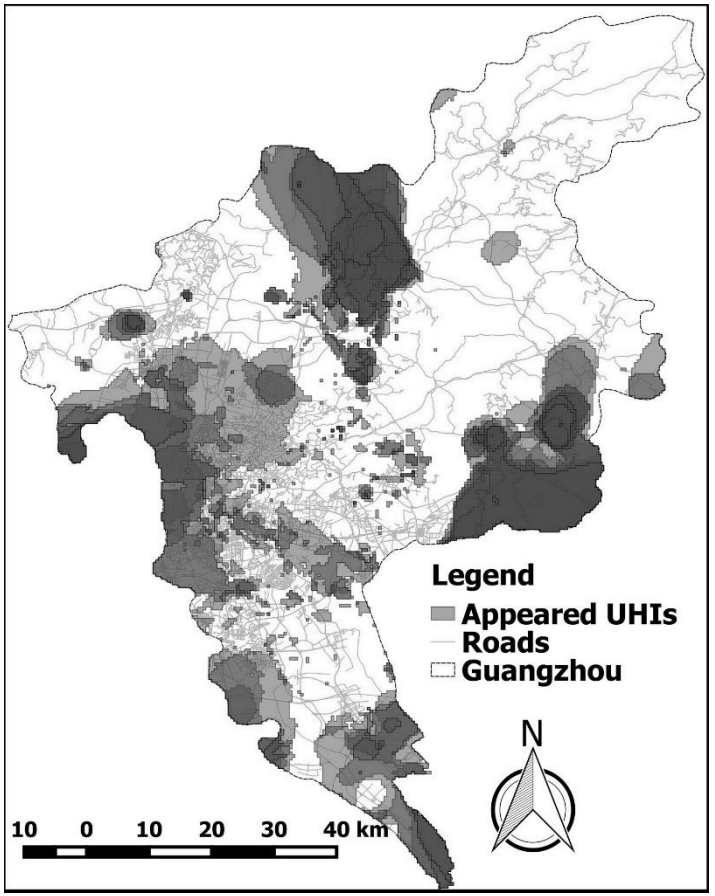
The total area of UHIs during seven days in the whole study area

Description of different scales (e.g. with different given temperatures) are needed since the process is periodic.

Empirical evaluation

Results





By respectively overlapping disappeared and appeared zones with road networks, preliminary results indicate periodical trend of UHIs are locational fixed.

Discussion and feature work

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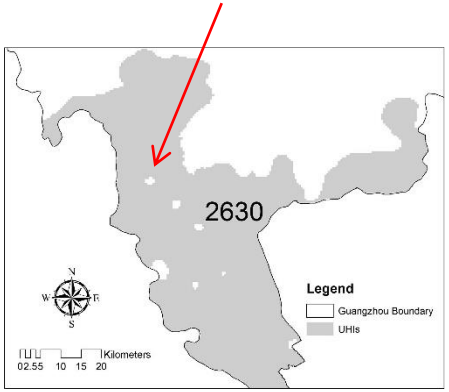
Discussion

1. The built model is specific for tracking spatial behavior of UHIs
2. Only models extent changes of UHI
3. The model can be easily extended for tracking typical moving objects
4. The model requires thermal images with high temporal resolution

Future Work

1. Model the thematic and spatial behaviors simultaneously
2. Model the periodical behaviors of UHIs
3. Model dynamic behavior of the urban heat sinks

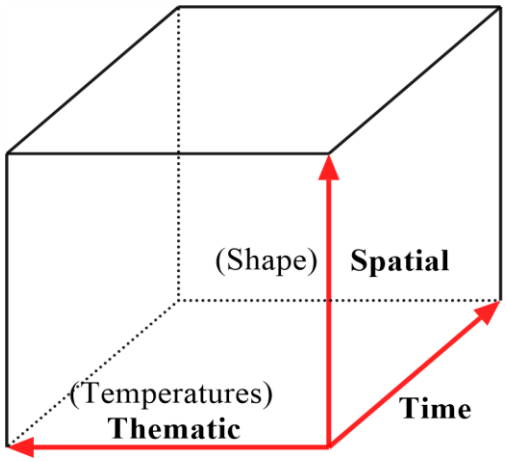


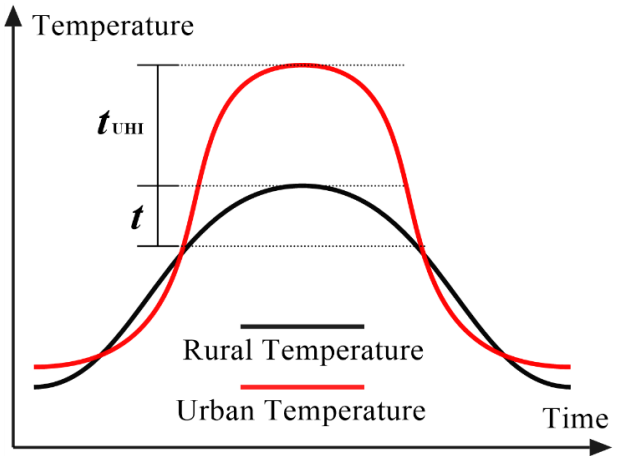
Rui Zhu, Eric Guilbert, Man Sing Wong, 2016. Object-oriented tracking of dynamic behavior of urban heat islands. *International Journal of Geographical Information Science*. (has been accepted)

Field-object Conceptualization

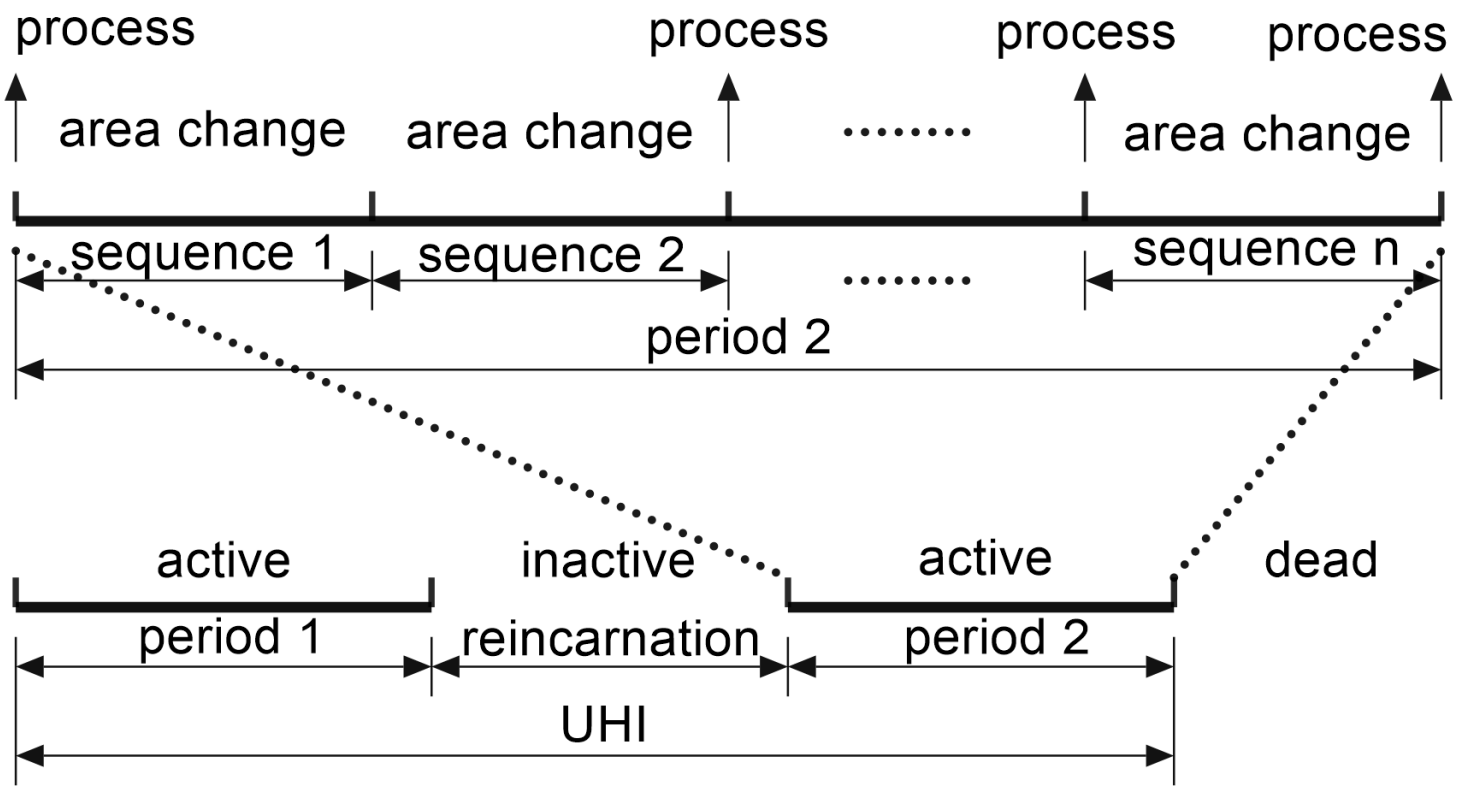
An *urban heat island* is a field-object

1. its temperatures ≥ referenced rural temperature + a given temperature
2. the thematic property (*temperatures*) can change the spatial property (*shape*)
3. changes of spatial property leads to the state transition (*active*, *inactive*, and *dead*)

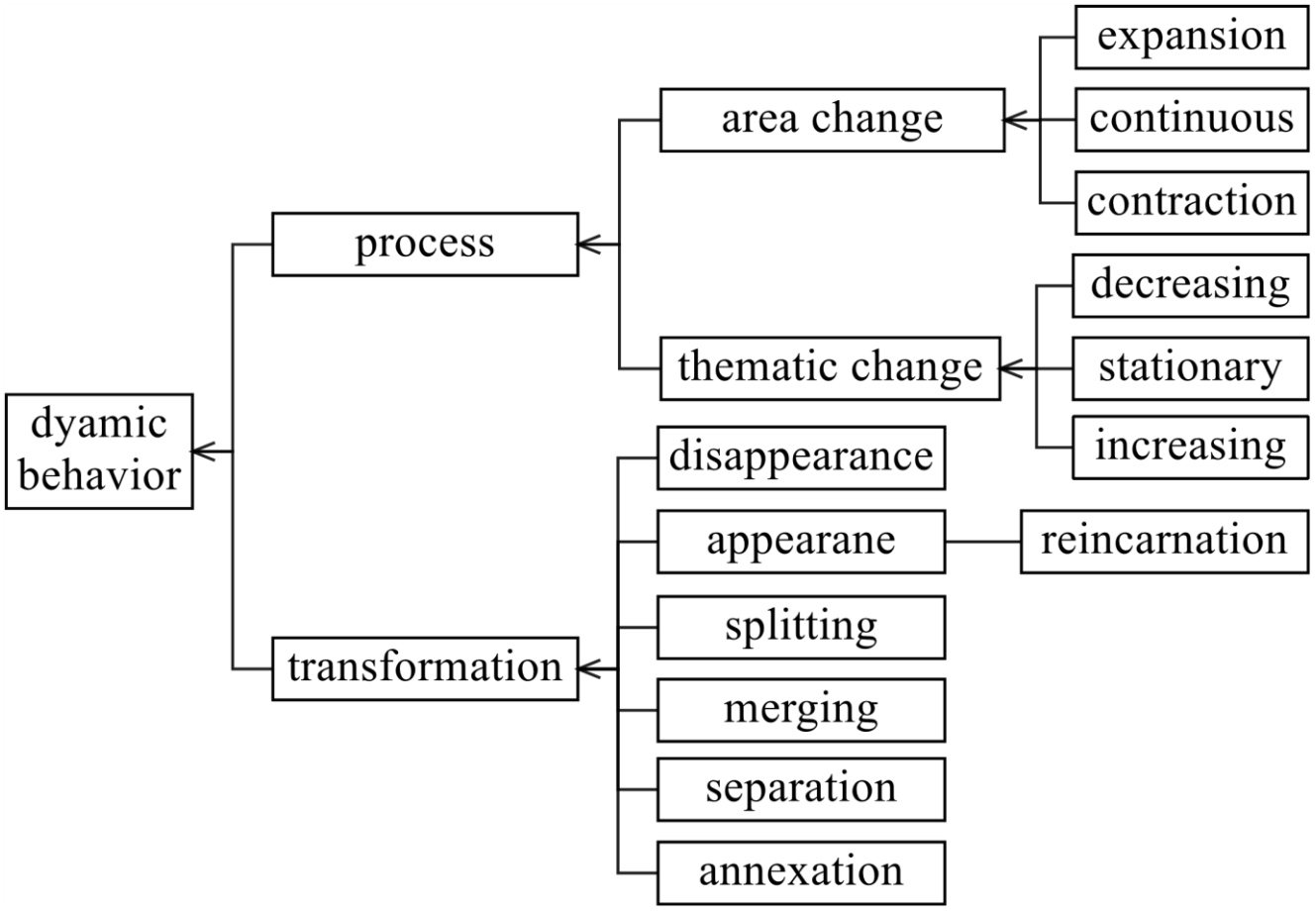




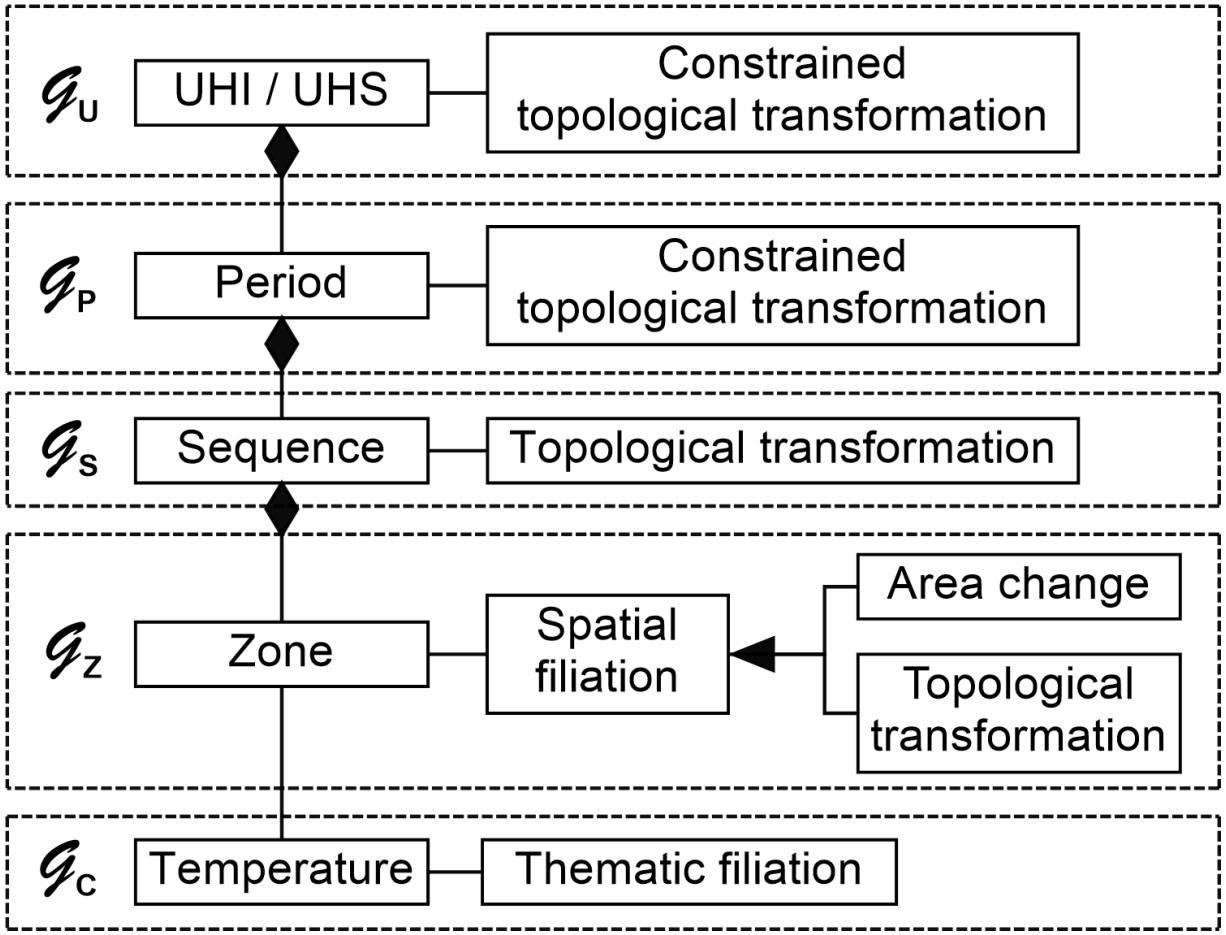
Life period for an UHI



Hierarchical description of dynamic behaviors



Five graphs


$\mathcal{G}_U$
UHI / UHS
Constrained topological transformation
$\mathcal{G}_P$
Period
Constrained topological transformation
$\mathcal{G}_S$
Sequence
Topological transformation
$\mathcal{G}_Z$
Zone
Spatial filiation
Area change
Topological transformation
$\mathcal{G}_C$
Temperature
Thematic filiation

Full research scope for dynamic behaviors of UHIs

1. Dynamic behaviors of anthropogenic heat flux (AHF)

1.1. Heat emission from moving vehicles

1.1.1. be vital to estimate the accurate number of vehicles

1.1.2. use vehicle-counting stations in HK

1.1.3. avoid duplicated counting of vehicles in the same unit (e.g. street)

1.1.4. simulate traffic flows

1.2. Pedestrian mobility

1.2.1. data from HK Census and Statistics Department

1.3. Electricity consumption

2. Thematic and spatial behaviors of (AHF)

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Thank you & any questions?