An Optimization Approach To Constraint-Based Generalization In A Commodity GIS Framework

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Introduction

- Generalization (Model and Cartographic)
  - Not many generalization tools in commodity GIS
  - Lack of contextual awareness for ones that do exist
  - AGENT project good, but tied to active object database capabilities, not in mainstream GIS
- NMAs and others want contextual generalization in commodity GIS production environment
- Research project at ESRI on an optimization approach to constraint-based generalization
  - Rule-Condition-Constraint-Action paradigm

Optimization

- Generalization as optimization
  - Optimizing both the amount of information to be presented, and the legibility/usability of the final map
  - … while conserving data accuracy, geographic characteristics, and aesthetic quality.

Concepts & History

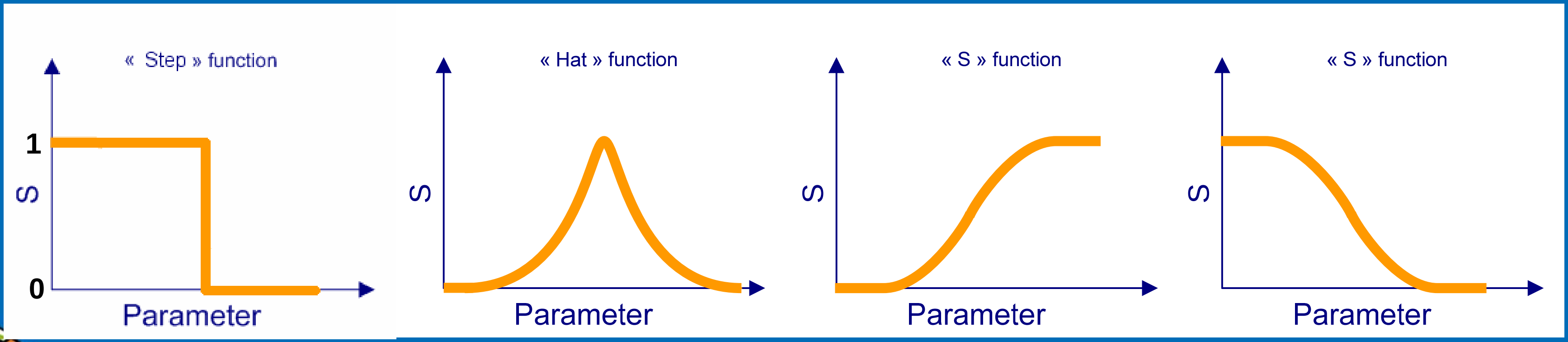
- Constraints
  - Beard 1991, Ruas 1999, AGENT 1999, …
  - Graphical, Structural, Application, Procedural
- Optimization
  - Statistical optimization - Metropolis 1953
  - Simulated Annealing - Kirkpatrick 1983
  - In Generalization - Ware & Jones 1998

Optimizer Prototype - Concepts

- Optimize map (set of data) against a set of rules
- Rule made up of Constraint and Action(s)
  - Constraints define the preferred state
  - Action should improve satisfaction against constraint
- Satisfaction Function for each rule
  - 0 to 1.0 means Unacceptable>Bad>Good>Excellent
- Can have Condition (predicate) for constraint
  - So can apply to subset of features
- Also have Reflex/Trigger actions
  - Good to prohibit invalid states
- Optimizer Kernel
  - Manages plan of actions, backtracks
  - ‘Simulated Annealing’ optimization technique
    - Gradually lower notional ‘temperature’
      - Avoid sticking in local minima (worse in order to get better)

Satisfaction Function

- Function is supplied by every Constraint
  - Can use all of ArcObjects to evaluate satisfaction
  - But often will be simply related to a measurable parameter, such as distance, or area
- Graph of function will vary according to constraint
  - Some will be sudden step, some smooth variation



Different levels of Satisfaction - *S*

Constraint satisfaction for a given feature:

$$0 \le S_c(F_i) \le 1$$

Constraint satisfaction:

$$S_c = \left\langle S_c(F_i) \right\rangle_i = \frac{1}{N_f} \sum_i S_c(F_i)$$

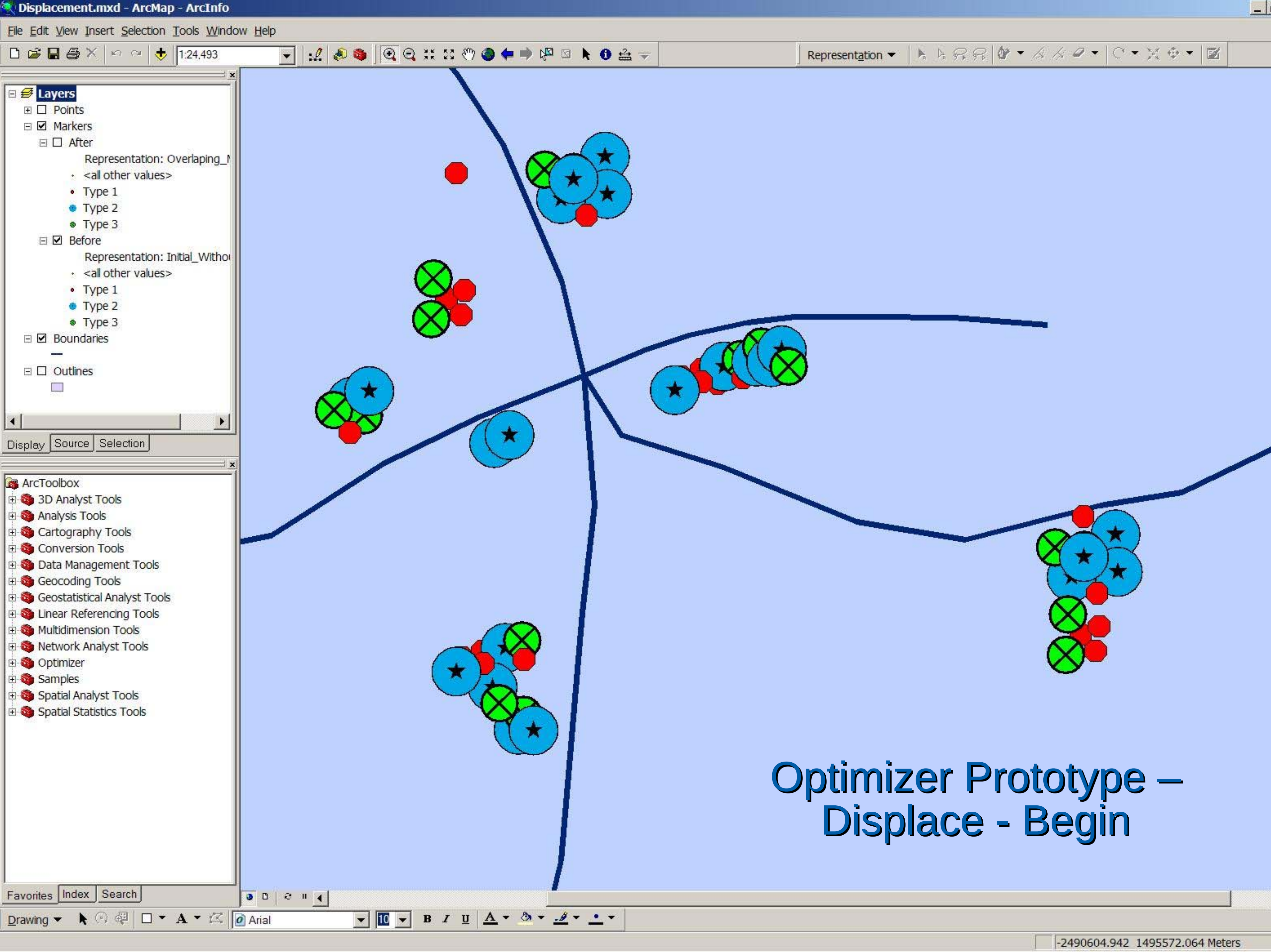
Feature satisfaction:

$$S(F_i) = \left\langle S_c(F_i) \right\rangle_c = \frac{1}{\sum_c w_c} \times \sum_c w_c \, S_c(F_i)$$

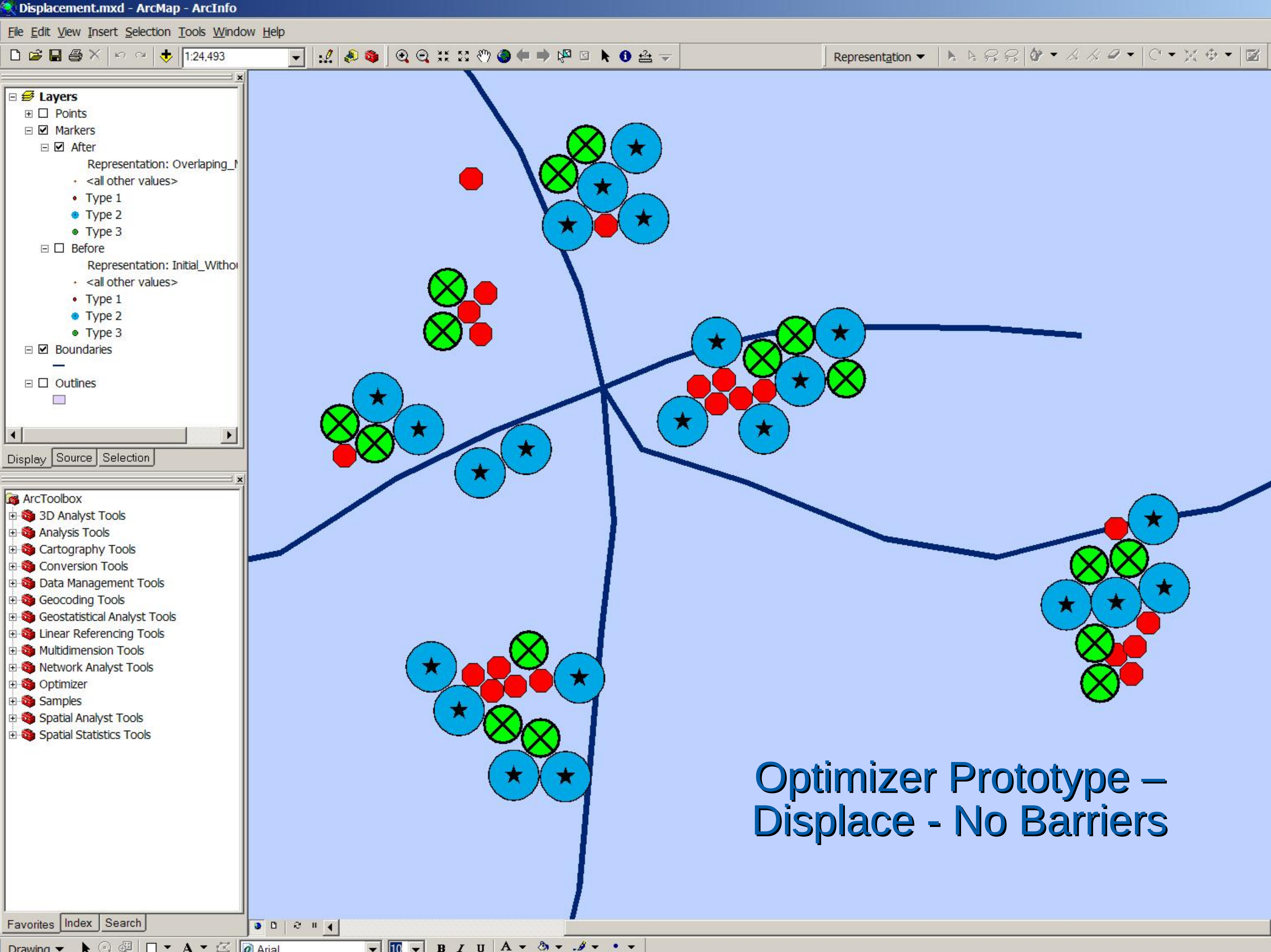
System satisfaction:

$$S = \frac{1}{N_f} \times \frac{1}{\sum_c w_c} \times \sum_c \sum_i w_c \, S_c(F_i) = \left\langle S_c \right\rangle_c = \left\langle S(F_i) \right\rangle_i$$

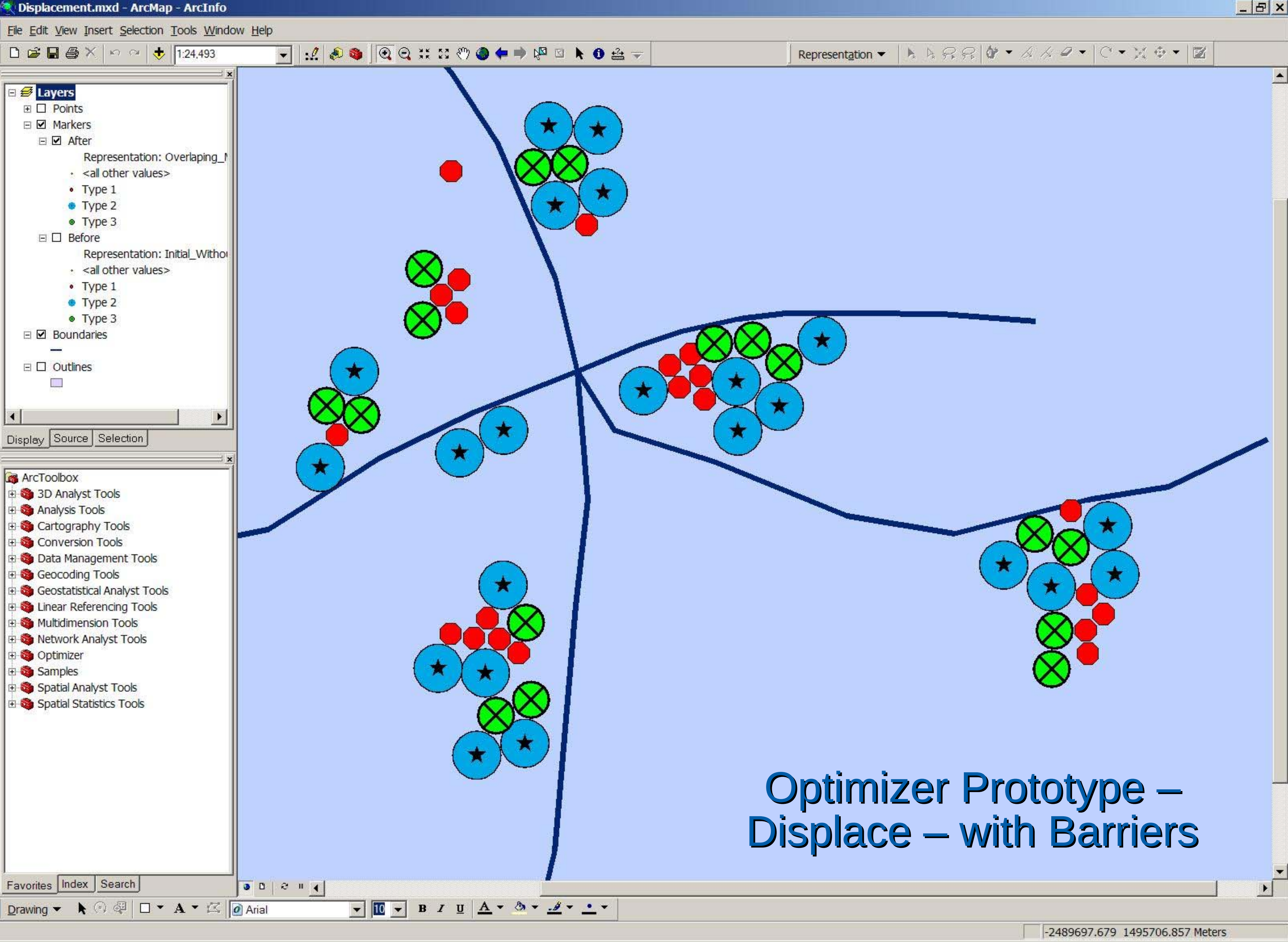
Optimizer Prototype – Displace - Begin

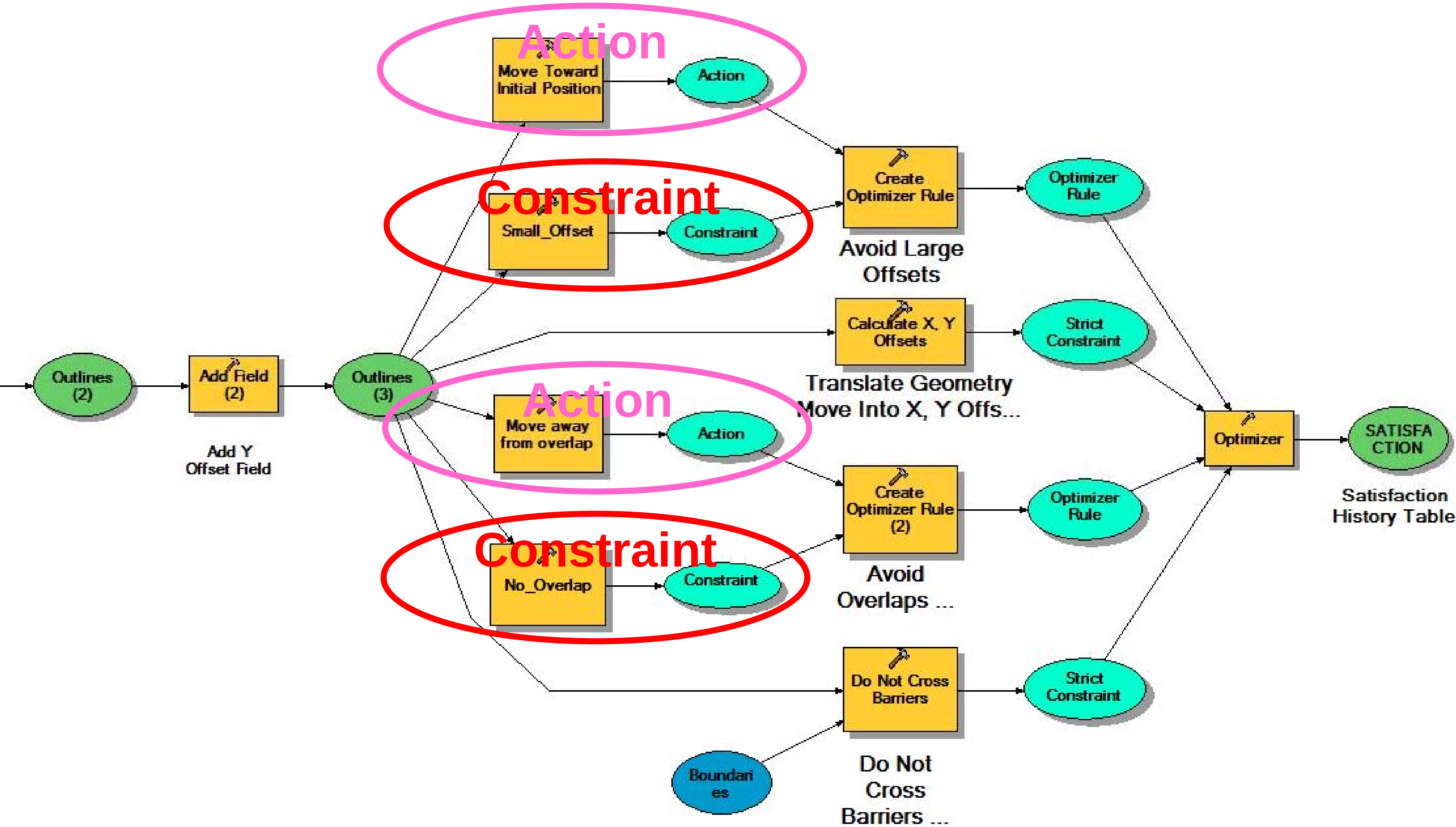


Optimizer Prototype – Displace - No Barriers

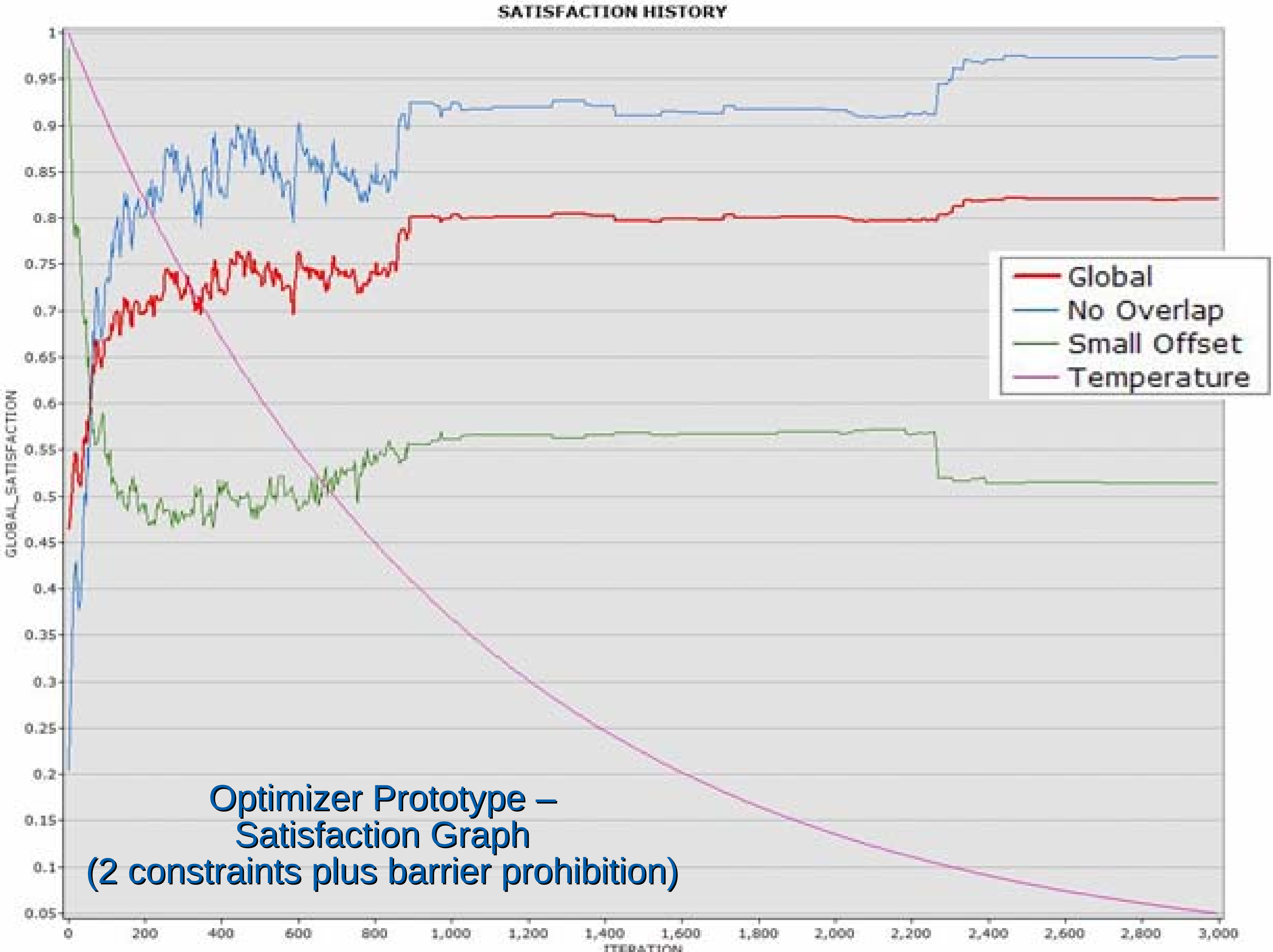


Optimizer Prototype – Displace – with Barriers





Optimizer Prototype – Displacement – GP model with Barriers Prohibition



Optimizer Prototype – Satisfaction Graph (2 constraints plus barrier prohibition)

Concept proven in DataDraw

Bus route maps - Complex graphic representation

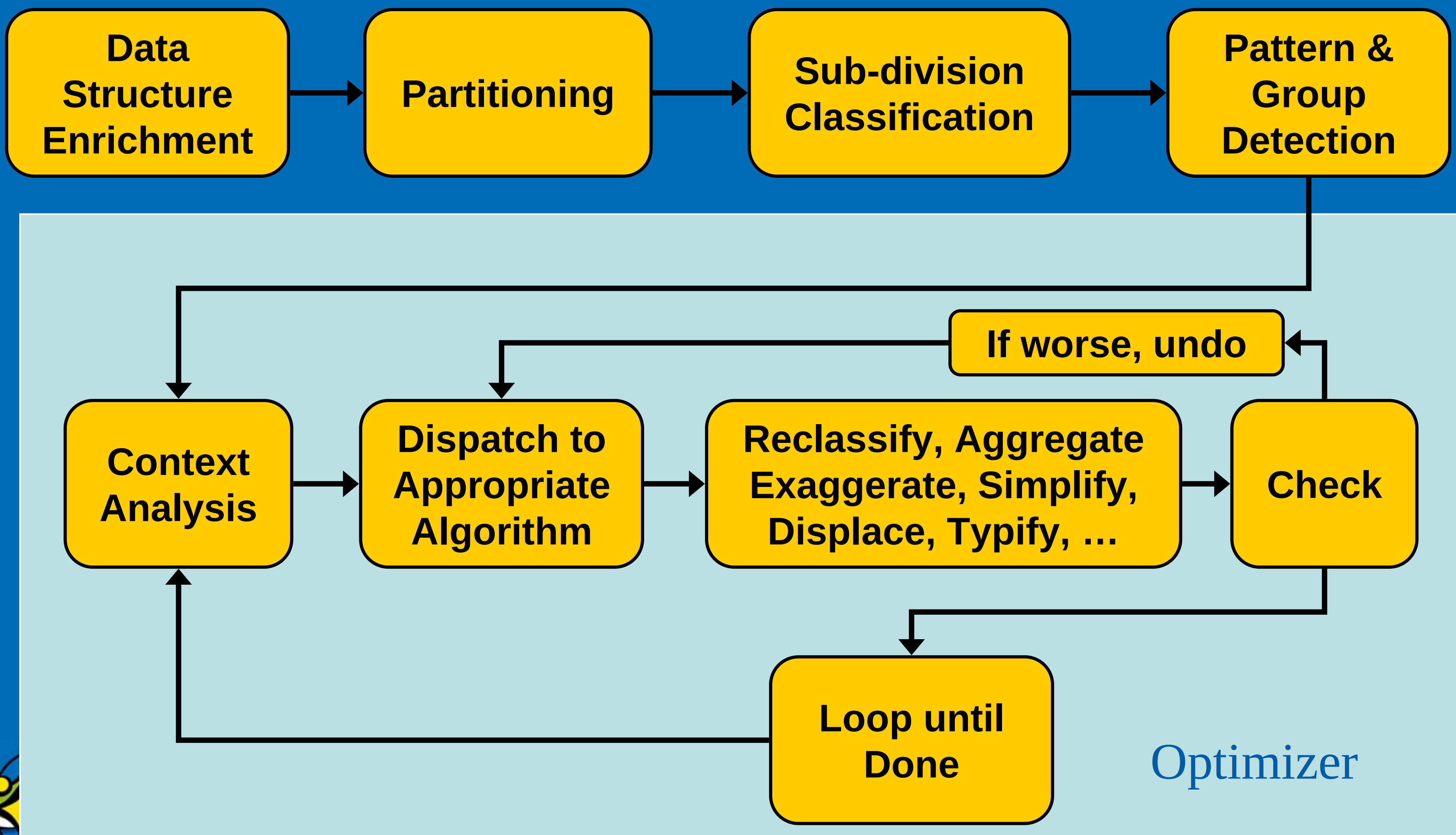
-Rule 1: Minimize change of side and crossings (legibility)

-Rule 2: Graphic continuity

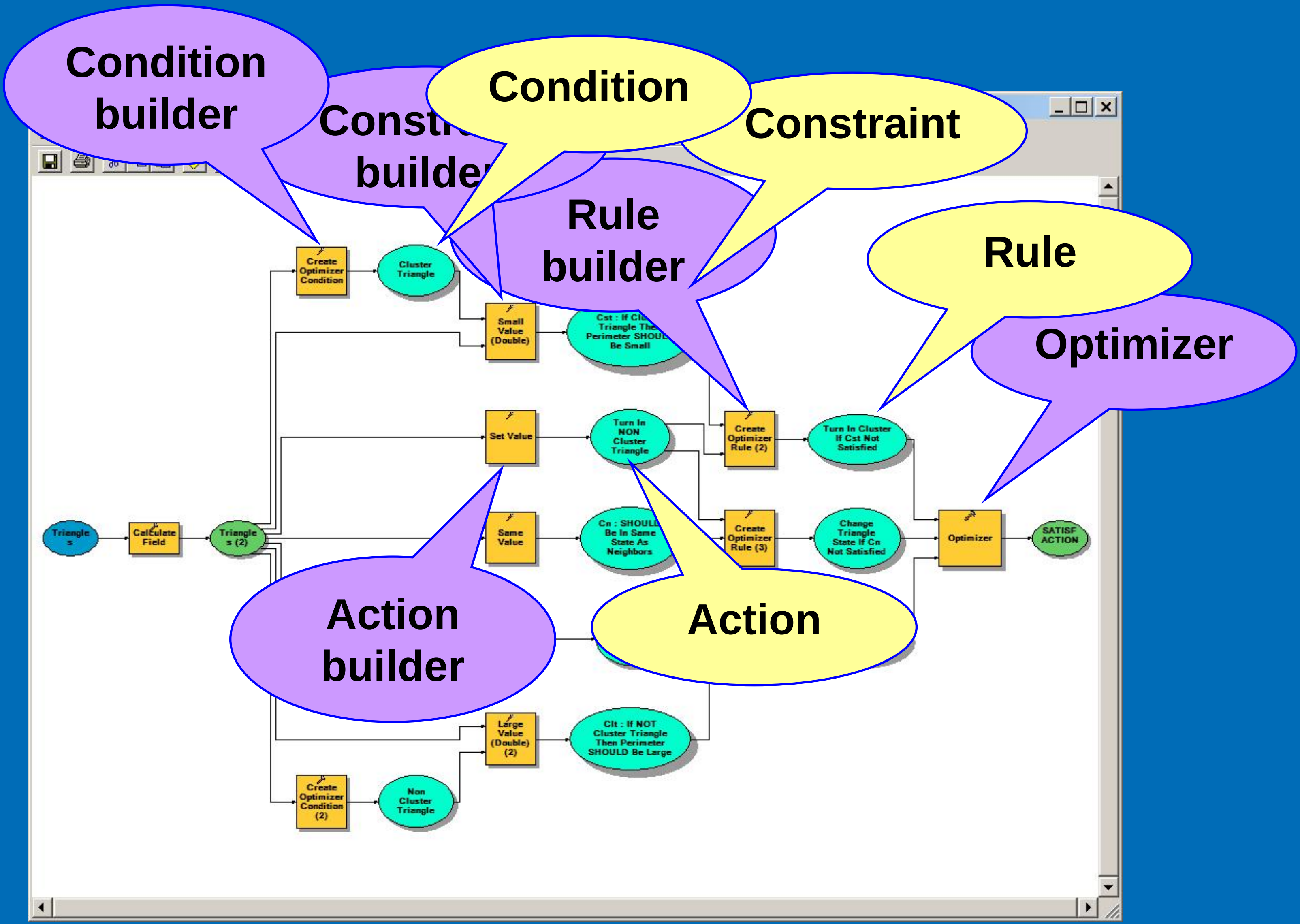
-Rule 3: End and start of routes should be on sides

-Rule 4: …

Possible Generalization Flow



Optimizer and GP framework



Summary

- Optimization for contextual generalization
  – Looks good approach
- Rule = Constraint+Action(s)
  – Optionally [Condition+] Constraint+Action(s) [+Reflex]
- Prototype implemented as GP tools in a commodity GIS
  – Very extensible
  – Easily use GIS spatial knowledge, tools and data structures, within constraints and actions
  – Fits into automated process models for multi-scale product generation
- Continuing to develop prototype and scenarios
  – And evaluating transition to product

Questions and Comments?

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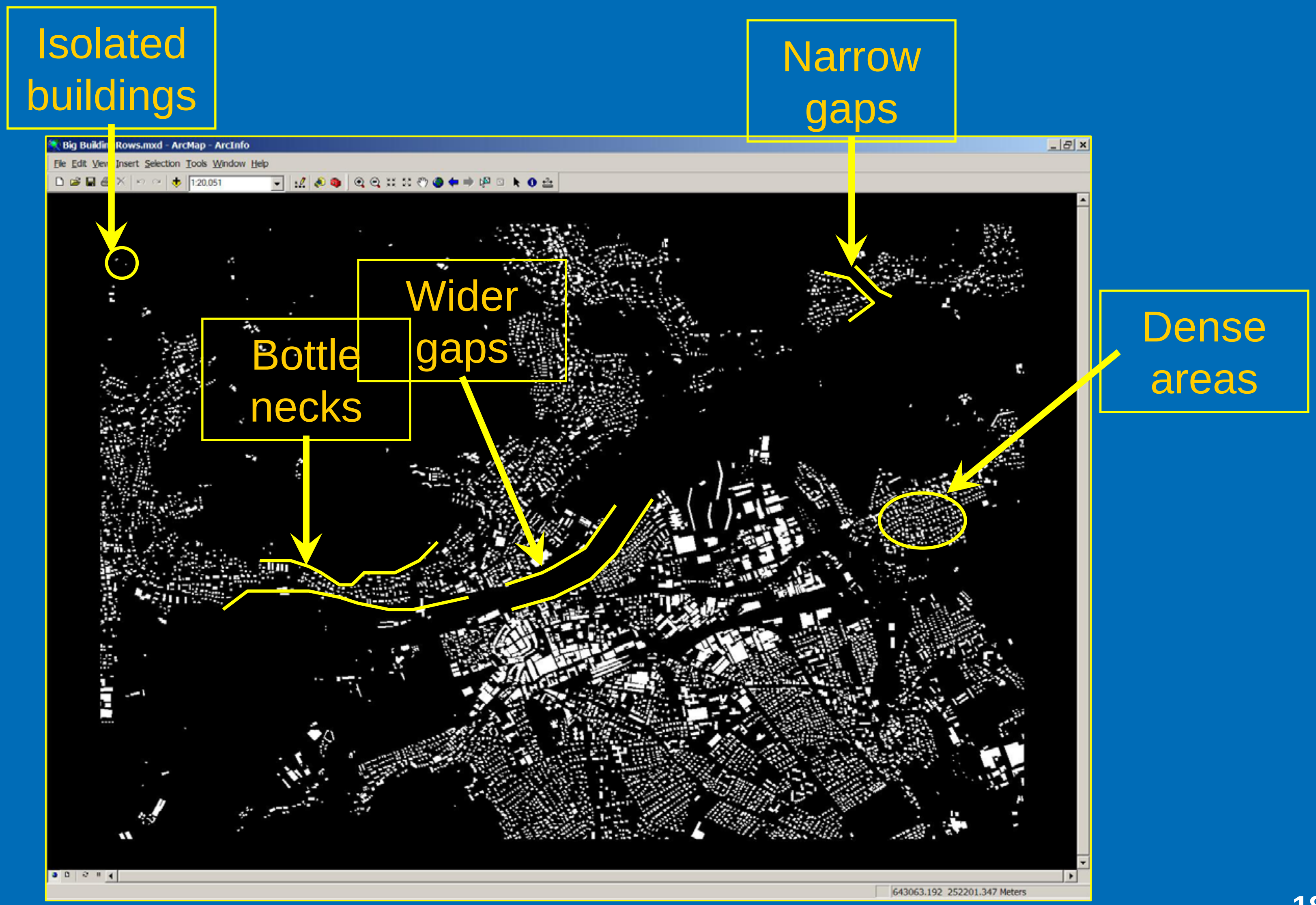
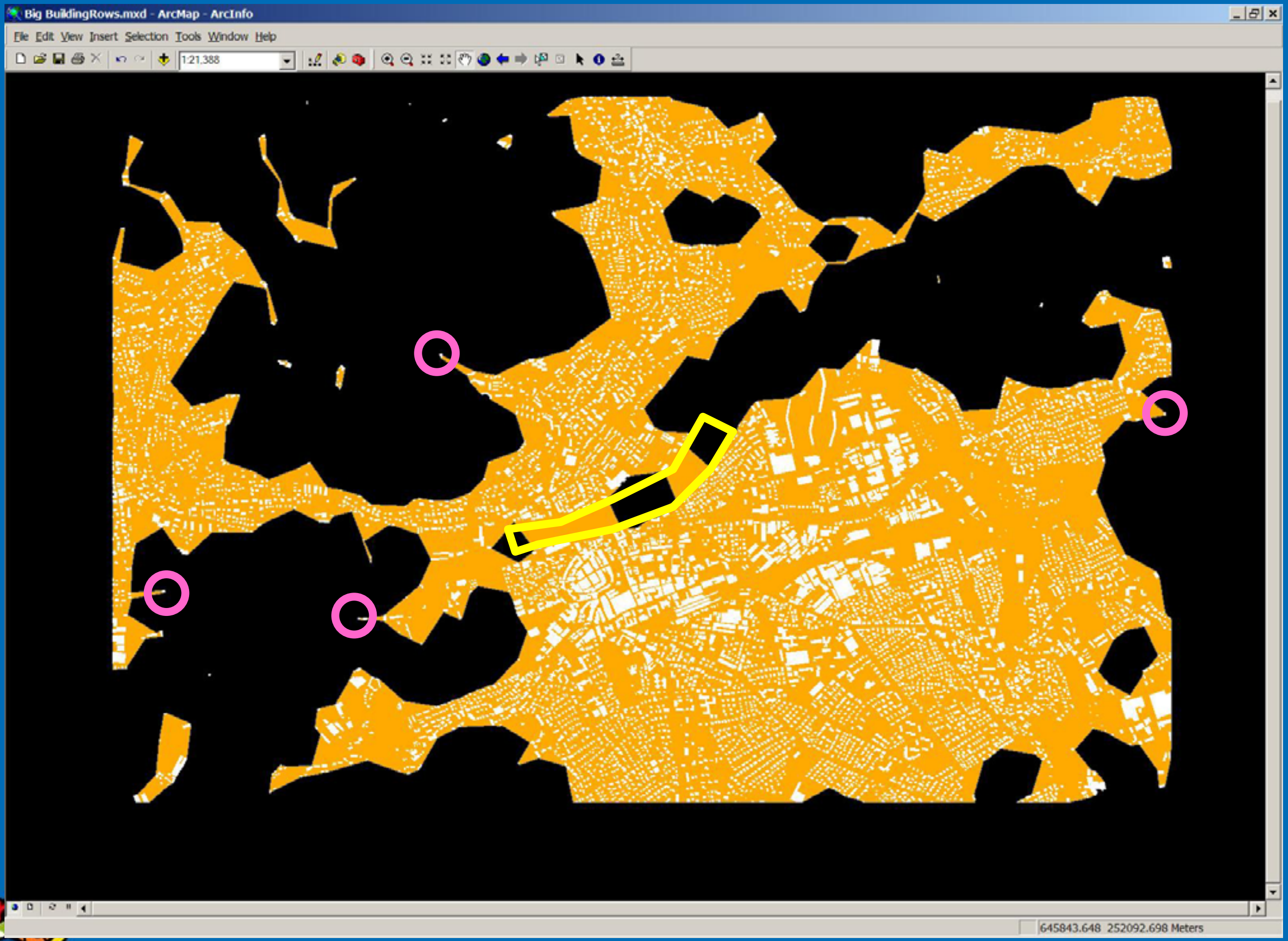
This paper is a forward-looking research document, and the capabilities it describes are evolving prototypes. As such, it should not be interpreted as a commitment by ESRI to provide specific capabilities in future software releases.

Aggregation - Input Dataset



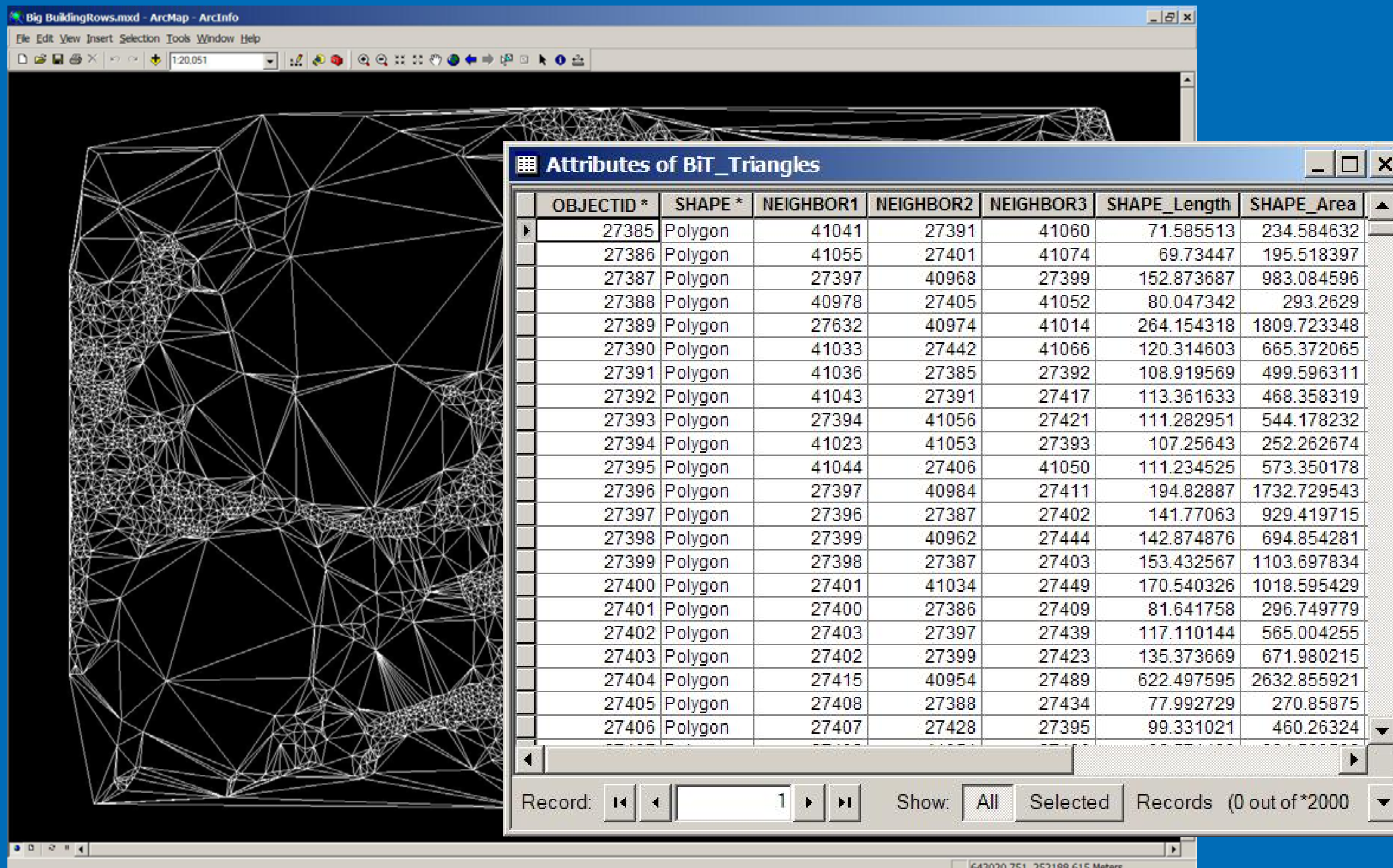
Disadvantages of ‘classical’ Approach



No contextual decision

Strictness of “hard” threshold

Recast Building Centers as Triangles



OBJECTID *	SHAPE *	NEIGHBOR1	NEIGHBOR2	NEIGHBOR3	SHAPE_Length	SHAPE_Area
27385	Polygon	41041	27391	41060	71.585513	234.584632
27386	Polygon	41055	27401	41074	69.73447	195.518397
27387	Polygon	27397	40968	27399	152.873687	983.084596
27388	Polygon	40978	27405	41052	80.047342	293.2629
27389	Polygon	27632	40974	41014	264.154318	1809.723348
27390	Polygon	41033	27442	41066	120.314603	665.372065
27391	Polygon	41036	27385	27392	108.919569	499.596311
27392	Polygon	41043	27391	27417	113.361633	468.358319
27393	Polygon	27394	41056	27421	111.282951	544.178232
27394	Polygon	41023	41053	27393	107.25643	252.262674
27395	Polygon	41044	27406	41050	111.234525	573.350178
27396	Polygon	27397	40984	27411	194.82887	1732.729543
27397	Polygon	27396	27387	27402	141.77063	929.419715
27398	Polygon	27399	40962	27444	142.874876	694.854281
27399	Polygon	27398	27387	27403	153.432567	1103.697834
27400	Polygon	27401	41034	27449	170.540326	1018.595429
27401	Polygon	27400	27386	27409	81.641758	296.749779
27402	Polygon	27403	27397	27439	117.110144	565.004255
27403	Polygon	27402	27399	27423	135.373669	671.980215
27404	Polygon	27415	40954	27489	622.497595	2632.855921
27405	Polygon	27408	27388	27434	77.992729	270.85875
27406	Polygon	27407	27428	27395	99.331021	460.26324

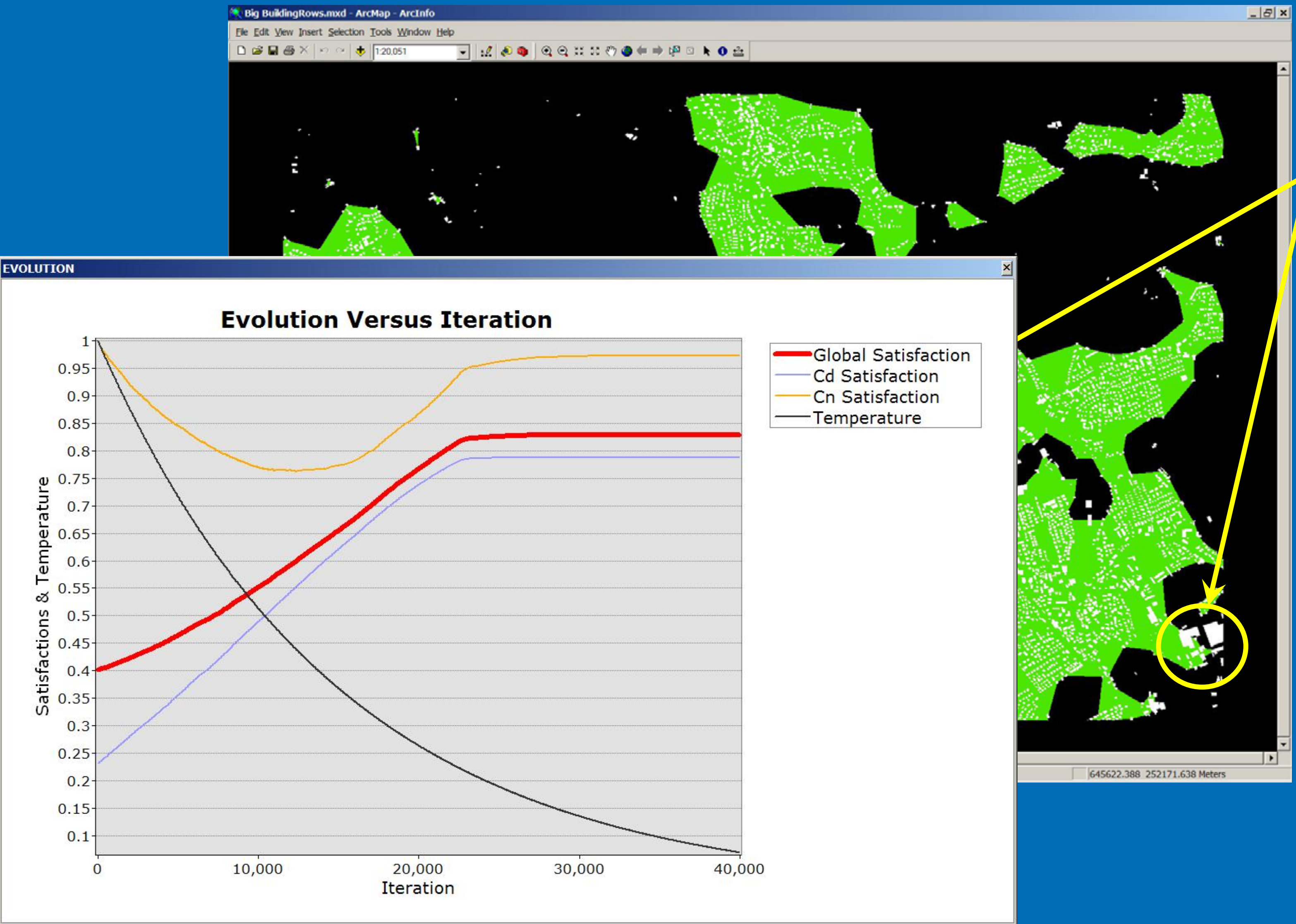
What are the Constraints?

1. “little” triangles prefer to be in clusters - proximity
2. Triangles prefer being like their neighbors - coherence

- Choose the best state for the whole triangle dataset obeying these 2 constraints.

Results of Optimization

Results generally good! Just with 2 simple constraints.



Issues with large buildings.

We could triangulate building corners?

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